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Post-middle Miocene Geologic History of the Tualatin Basin, Oregon with Hydrogeologic Implications

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<https://doi.org/10.15760/etd.6595>

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POST-MIDDLE MIOCENE GEOLOGIC HISTORY OF THE TUALATIN BASIN
OREGON WITH HYDROGEOLOGIC IMPLICATIONS

by
DOYLE COLEY WILSON

A dissertation submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY
in
ENVIRONMENTAL SCIENCES AND RESOURCES:
GEOLOGY

Portland State University
1997

DISSERTATION APPROVAL

The abstract and dissertation of Doyle Coley Wilson for the Doctor of Philosophy in Environmental Sciences and Resources: Geology were presented January 10, 1997, and accepted by the dissertation committee and the doctoral program.

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An abstract of the dissertation of Doyle Coley Wilson for the Doctor of Philosophy in Environmental Sciences and Resources: Geology presented January 10, 1997.

Title: Post-Middle Miocene Geologic History of the Tualatin Basin, Oregon with Hydrogeologic Implications.

The geologic history and sedimentary fill of the Tualatin Basin after Columbia River Basalt Group (CRBG) emplacement is assessed and related to groundwater characteristics. The 334 m deep HBD-1 core from the Hillsboro Airport, provides the primary information for sediment characterization and is supported by over 2400 well logs and cores, and four seismic lines. The sedimentary section above the 26 m thick paleosol on the CRBG in HBD-1 is divided into two main groups: a 25 m thick section of Missoula flood sediments called the Willamette Silt overlies a 263 m thick fine-grained sequence of fluvial Neogene sediments.

Pollen, diatom and paleomagnetic data support dividing the Neogene sediments 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 the Neogene sediments were primarily derived from local highlands surrounding the Tualatin Valley.

The structure of the top CRBG in the Tualatin Basin exhibits two provinces, a larger northern subbasin with few faults cutting the Neogene sediments above the CRBG and a smaller, more complexly faulted, subbasin south and east of the Beaverton Fault. Neogene sedimentation rates increased ten fold from the late Miocene-Pliocene to the Pleistocene, concomitant with increased basin subsidence. Comparison of Neogene basin evolution among Willamette Valley depositional centers reveals similarities among gravity and seismic reflection characters and subsidence timing between the

Tualatin Basin and the northern Willamette Basin and out of phase with the Portland Basin.

The Tualatin River CRBG nickpoint near the river's mouth has remained essentially unchanged since the Missoula floods filled the basin 12,700 years ago. This has kept the river from cutting back into the valley resulting in the low gradient evident today.

Elevated orthophosphate levels in the upper 140 m of the Neogene sediment section indicate that the sediments are a natural source of phosphorus supplied to groundwater. Groundwater conditions in the lower Neogene sediments promote stabilization of phosphorus as vivianite. The unconfined Willamette Silt aquifer and the underlying confined Neogene aquifers are distinct, separate hydrogeologic units and usually yield less than 40 lpm.

ACKNOWLEDGMENTS

I would like to thank first and foremost my advisor, Dr. Scott Burns, for the great enthusiasm and support of this project. Special thanks also go out to Dr. Marvin Beeson and Dr. Ansel Johnson of the Geology Department for their support and suggestions during the research process. I would also like to thank the other committee members, Dr. Roy Koch and Dr. Shu-Guang Li of the Civil Engineering Department, and Dr. Richard Petersen of the Biology Department for their helpful suggestions and critical review of the manuscript. I would like to express my appreciation to the Oregon Community Foundation and to the Unified Sewerage Agency for their financial grant support.

This project was also supported by specialists and by landowners whose contributions were essential to the success of the project. I would like to thank Richard Verboort PE, the Jannsen Drilling Company, Bert Devlaeminck of Devlaeminck Well Drilling, John and Stan Gaunt of Gaunt and Son Well Drilling, Jeff Haboush Well Drilling, American Well Drilling, Jerry Rodgers of the Washington County Watermaster Office, Ron Jannisen, Bernie Klutche, and Sue D'Agnese of the Oregon Department of Transportation, Ian Madin, Mathew Mabey, and Dan Meier of the Oregon Department of Geology and Mineral Industries, K. C. Cooper of Tri-Met, Jack Meyers and Roy Rogers of Northwest Natural Gas, Dave Morgan, Dennis Lynch, Marshall Gannet, Stewart Rounds, and Lenny Orzol of the United States Geological Survey Water Resources Division Office, and Rick Malin of Parametrix, Inc. for

helping to obtain field data and providing existing data. Landowners in Washington County that gave gracious consent to obtain field sediment samples and gamma log data include Don & Ruth Leisigang, Hilbert Lardy, Richard VanDomelen, Harold Bennett, William Roth, Brett Etzold, Mrs. Rosie Spiering, Glenn Walters Nursery, Joyce Childress, Vernon Duyck, Oregon Garden Products, Inc., West Oregon Nursery, Karban, Inc., Tom Marshall, Dave Carter, Joe Salta, Bill Van Roekel, William Wiabel, Jeff Kennedy, Clarence Ite, Elenor Ritter, Mike Crop, Larry Landauer, Monty Duyck, Gerald VanFleet, Twin Oaks Tavern, Townsend Nursery, Meadowcroft Nursery, Gary Hellwege of Pumpkin Ridge Golf Course, Joan Vanderzanden, Lee Hodges, the Oregon Graduate Institute, and the City of Hillsboro.

Special thanks to the professional who helped with data analysis and pertinent suggestions: Dr. Wesley Jarrell, of the Oregon Graduate Institute, Dr. Cathy Whitlock of the University of Oregon, Cr. Ed Larson and Dr. Alan Lester of the University of Colorado, Dr. Don Charles and Dr. Edward Theroit of the Philadelphia Academy of Natural Sciences, Cr. Roger Neilsen of Oregon State University, Dr. Charles Miller of the University of Montana at Missoula, and graduate students Tom Popowski and Scott Billings of Oregon State University, and Michelle Barnes, Stuart Asbaugh, Ken Walsh, and Bruce Dougan of Portland State University.

I would finally like to express my deep gratitude to my wife, Martha, whose support in this program over the last six years made this effort possible. This work is dedicated to her and our twin sons, Ian and Alex.

TABLE OF CONTENTS

	<u>PAGE</u>
ACKNOWLEDGMENTS	i
LIST OF TABLES	x
LIST OF FIGURES	xii
CHAPTER 1 - INTRODUCTION	1
CHAPTER 2 - THE TUALATIN VALLEY GEOLOGIC SETTING AND PAST WORK.	7
Stratigraphy of the Tualatin Basin.	7
Paleogene Volcanics and Sedimentary Rocks.	7
The Columbia River Basalt Group.	12
Neogene Sediment	14
Boring Lava.	17
Willamette Silt.	19
Portland Hills Silt.	22
Recent Alluvium.	24
Structure of the Tualatin Basin.	24
Geomorphology of the Tualatin Valley	26
CHAPTER 3 - TUALATIN BASIN STRATIGRAPHY AND STRUCTURE . .	30
Methods	33
Types of Subsurface Information for Lithology	33
Sample Cuttings and Core Descriptions	33
Grain Size Analyses and Sand and Clay Characterization	34

PAGE

HBD-1 Synthetic Seismogram	34
Seismic Reflection Data Lines	35
Subsurface Mapping	35
HBD-1 Stratigraphy and Sedimentology	35
General Lithology	37
Willamette Silt	37
Neogene Sediments.	37
Columbia River Basalt Group	49
Lateritic Weathered Zone.	49
Basalt Texture and Age.	49
Sand Unit Distribution	51
Sediment Characterization	54
Sediment Texture	54
Sand Petrology	54
Grain Size Analysis	54
Sand Classification and Composition	56
Accessory Minerals	65
Clay Mineralogy	66
Basin Stratigraphy and Sedimentology	68
Exposures	68
Subsurface Information	88

	<u>PAGE</u>
Core Information	88
Water Well Drill Samples and Logs	91
Gamma Logs	92
ODOT Boring Logs	95
Seismic Stratigraphy	97
Synthetic Seismic Profile from HBD-1 Velocity Data . . .	97
Synthetic Seismograms from DOGAMI Shallow Borings.	100
Seismic Reflection Data Interpretation.	104
Sand Unit Distribution in the Neogene	112
Willamette Silt Isopach and Lithology Distribution	119
Boring Lava extension into the Tualatin Valley.	122
CHAPTER 4 - AGE OF THE NEOGENE SEDIMENTS AND PALEOECOLOGY IN THE TUALATIN - WILLAMETTE VALLEY REGION . . .	126
Methods	126
Palynology.	128
Diatoms	132
Paleomagnetic Analysis of HBD-1 Sediments	132
Radiocarbon Dating	138
Wood Identification and Paleoclimate Implications	140
Geologic Age of the Tualatin Basin Neogene Sediments	140
Paleo-ecology of the Tualatin-Willamette Valley Region	144

	<u>PAGE</u>
CHAPTER 5 - PROVENANCE OF THE NEOGENE SEDIMENTS	146
Methods	146
Heavy Mineral Sand Separations and Point Counts for Provenance Work.	146
Instrumental Neutron Activation Analysis	146
Heavy Minerals: The Augite-Hornblende-Hypersthene Relative Abundances	147
Instrumental Neutron Activation Analysis	162
Neogene Sediment Sources	168
CHAPTER 6 - NEOGENE STRUCTURE OF THE TUALATIN BASIN	171
Subsurface Mapping	171
Seismic Reflection Data	171
Structure Contour Maps.	175
Columbia River Basalt	175
Neogene Sediment Maps	188
Structural Implications	193
CHAPTER 7 - TUALATIN BASIN DEVELOPMENT AND	
REGIONAL SETTING	199
Eocene to Middle Miocene Setting	199
Late Miocene to Recent Sedimentation	203
Helvetia Formation Problem	203
Neogene Sedimentation	205
Ashfall and Lacustrine Sedimentation Events	209

PAGE

Neogene Sedimentation Rates	214
Willamette Silt Deposition	215
Boring Lava Events on the East Side of the Tualatin Basin	217
Tectonic Setting	217
Comparison of the Neogene Geologic Histories Between the Tualatin Basin and the Portland Basin-Willamette Valley Region	218
Willamette Valley South of Salem	221
Northern Willamette Valley	222
Portland Basin	224
Regional Implications	229
CHAPTER 8 - GEOMORPHOLOGY OF THE TUALATIN VALLEY	231
Geomorphology Techniques	231
Hydrology	231
Tualatin River Terrace Mapping.	232
Red Clay Soils Mapping.	232
Tualatin River and Tributary Subbasins	233
Tualatin River Terrace Mapping	252
Residual Soil Mapping	258
Tualatin River Plio-Pleistocene History	262

PAGE

CHAPTER 9 - NEOGENE SEDIMENT HYDROGEOLOGIC PROPERTIES AND GROUNDWATER MAPPING	265
Porosity and Permeability Measurements of HBD-1 Sediments	265
Groundwater Mapping.	268
Groundwater Quality	273
Groundwater Characteristics of Sediments in the Tualatin Basin.	277
Willamette Silt	277
Neogene Sediments	278
Neogene Sediment Groundwater Temperatures	279
Hydrogeologic Model of the Willamette Silt and Neogene Sediments . . .	281
Contrast of Hydrogeologic Units Between the Tualatin and Portland Basin	282
CHAPTER 10 - PHOSPHORUS IN THE WILLAMETTE SILT AND NEOGENE SEDIMENTS	285
Phosphorus Analysis	285
HBD-1 Phosphorus Profile	286
Tualatin Valley Samples	286
Vivianite Occurrence	294
Phosphorus in the Tualatin Basin	295
CHAPTER 11 - SUMMARY AND CONCLUSIONS	299
CHAPTER 12 - FUTURE WORK AND RECOMMENDATIONS	308

	<u>PAGE</u>
REFERENCES.	311
APPENDICES	
A METHODS AND TECHNIQUES.	A1
Sample Cuttings and Core Descriptions	A1
Grain Size Analyses	A1
Heavy Mineral Separations and Point Counts for Provenance	A3
Microprobe Work	A5
Preparation of Clay Minerals and X-ray Diffraction Analysis	A5
Gamma Logging Recordings	A6
Age Dating Techniques	A12
Palynology	A12
Phosphorous Analyses	A12
Seismic Reflection Data Lines	A13
Geomorphologic Techniques	A15
Hydrographic Subbasin Divisions	A15
Stream Ordering and Longitudinal Stream Profiles	A15
B HBD-1 STRATIGRAPHIC DESCRIPTION	
AND GAMMA LOG	B1
C HBD-1 GRAIN SIZE ANALYSIS RESULTS	C1
D XRD CLAY MINERAL TYPES IN HBD-1 SAMPLES	D1
E HEAVY MINERAL ANALYSIS RESULTS	E1
F INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS	F1
G HBD-1 AND DOGAMI SHALLOW BORING VELOCITY	
DATA AND SYNTHETIC SEISMOGRAMS	G1
H TUALATIN VALLEY PHOSPHORUS ANALYSIS RESULTS	H1

LIST OF TABLES

<u>TABLE</u>	<u>PAGE</u>
1 Sand - Silt - Clay Percentages of HBD-1 Sediment Samples . . .	39
2 HBD-1 Sand Intervals and Thicknesses for Sand Layers	
Over 0.5' Thick	40
3 Grain Size Distribution for HBD-1, Recent Stream, and Selected	
Boring Sands.	57
4 Sand Mineral Composition for HBD-1 and Other Borings in the	
Tualatin Valley	61
5 Semiquantitative Relative Clay Mineral Percentages from HBD-1	
Silts and Clays	66
6 HBD-1 Pollen Species Abundances with Comparison to Pollen	
Identified at Monroe, Oregon.	129
7 HBD-1 Paleogenetic Inclinations and Intensities at Various	
Temperatures of Neogene Silts and Clays	134
8 Augite-Hornblende-Hypersthene Realtive Ratios for HBD-1,	
Recent Stream, and Selected Borings in the Tualatin	
and Portland Basins.	153
9 Major element chemistry of altered HBD-1 Sands.	160
10 INAA chemistry for HBD-1 Neogene Sediments	163
11 INAA Major and Trace Element Values of Columbia River Basalt	
Samples from the HBD-1 Boring at the Hillsboro Airport	
and Their Assigned Flow Unit	202

<u>TABLE</u>	<u>PAGE</u>
12	HBD-1 and MTD-1 Estimated Sediment Thickness Based on Age and Corresponding Sedimentation Rates 228
13	Tualatin Valley Watershed 3rd Order or Greater Subbasin Characteristics 235
14	Tualatin Valley Watershed Stream Orders and Average Stream Lengths per Stream Order for 3rd Order and Higher Streams 239
15	HBD-1 Porosity and Permeability Measurements from Sands and Finer-Grained Sediments 266
16	Calculated Hydraulic Conductivities and Transmissivities from Permeability Measurements of HBD-1 Sands and Fine-Grained Sediments 269
17	Weighted Mean Horizontal and Vertical Hydraulic Conductivities for Four Heterogeneous, Anisotropic Sediment Layers in HBD-1. 281
18	Orthophosphorus Levels for Sediments from HBD-1 and other Borings in the Tualatin Valley 287

LIST OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
1	Location Map of the Tualatin Valley and Associated Physiographic Features	2
2	Tectonic Setting of the Tualatin Valley	3
3	Schematic model for the depositional style of the Neogene sediments and Willamette Silt in the Tualatin Basin.....	6
4	Generalized Stratigraphic Relationships from Past Work in and around the Tualatin Basin.....	8
5	Location Map of Surface Eocene-aged Volcanic Complexes.....	9
6	Location Map of Exposed Paleogene Marine to Nonmarine Sedimentary Rocks.....	11
7	Location Map of Exposed Middle Miocene Columbia River Basalt Group (CRBG) Basalts and Associated Lateritic Soils.....	13
8	Location Map of Exposed Neogene-age Sediments in the Portland Hills Region.....	15
9	Location Map of Exposed Plio-Pleistocene Boring Lava along the Tualatin Mountains - Portland Hills Region.....	18
10	Location Map of Upper Pleistocene Willamette Silt.....	20
11	Location Map of Exposed Pleistocene Portland Hills Silt.....	23
12	Location Map of Major Recognized Structural Features in the Tualatin Valley that have Influenced Neogene Basin Development.....	25
13	Location map of HBD-1 at the Hillsboro Regional Airport and MTD-1 at the Portland International Airport.....	31
14	Generalized Stratigraphic Section of HBD-1 Core Boring Drilled at the Hillsboro Regional Airport.....	32
15	Location of the HBD-1 Core Boring at the Hillsboro Regional Airport.....	36
16	HBD-1 Core Sample of the Willamette Silt From a Depth of 35' (10.7 m).....	38
17	HBD-1 Core Sample of a Neogene Sand From a Depth of 683' (208.2 m).....	42
18	HBD-1 Core Sample of a Gravelly, Very Poorly Sorted Neogene Sand From a Depth of 693.5' (211.4 m).....	42
19	HBD-1 Core Sample of a Low-Angle, Cross-Bedded, Fine to Medium Neogene Sand From a Depth of 141' (43 m).....	44
20	HBD-1 Core Sample of Either Root or Burrow Structures in a Clayey, Silty, Fine Grained Neogene Sand From a Depth of 693' (211.2 m).....	44
21	A 6 mm Powdery, Oxidized Vivianite Nodule in a Clayey Silt From Sample HBD-1 848' (258 m).....	45
22	Vivianite Crystals in Vugs Surrounded by Clayey Silt From a Depth of 491' (150 m) in HBD-1.....	45

FIGURE		PAGE
23	Diatomaceous, Laminated Silty Clay From at Depth of 721' (219.8 m) in HBD-1.....	46
24	Moderately Endurated, Silica Cemented, Cross-Bedded Neogene Sandstone From a Depth of 761.5' to 762' (232 m) in HBD-1.....	46
25	Red-Brown, Clayey, Silty, Very Fine Grained Sand and Gray-Brown, Clayey Silt Units Below the Conglomerate Layer.....	48
26	Columbia River Basalt Lateritic Soil From a Depth of 946' (288.3 m) in HBD-1.....	48
27	Weathered Columbia River Basalt From a Depth of 1002' (305.4 m) in HBD-1.....	49
28	Percent Sand Beds of the Total Neogene Sediment Section in the HBD-1 Core Test.....	52
29	Clay Drape Overlying Clayey, Silty, Very Fine to Fine Grained Sand From a Depth of 412' (125.6 m) in HBD-1...	53
30	Sediment Classification of HBD-1 Samples Based on Sand-Silt-Clay Ratios.....	55
31	Photomicrograph of #120 Mesh Sand Grains from HBD-1 484' (147.5 m).....	59
32	Photomicrograph of #120 Mesh Sand Grains Under Cross-Nicols from HBD-1 141' (43 m).....	63
33	Ternary Plot of Mono- & Poly -Crystalline Quartz, Feldspar, and Unstable Lithic Fragments from HBD-1 and Other Borings in the Tualatin Valley, Depicting Sand Classification.....	64
34	Willamette Silt Cutbank Exposures (labeled) Along the Tualatin River South of Hillsboro, Oregon in NE1/4 of Sec. 21, T1S R2W.....	69
35	COSTCO Construction Exposure of Willamette Silt and Underlying Neogene Sediments in Tigard, Oregon, SW1/4 of Sec. 36, T1S R1W.....	70
36	Willamette Silt exposure along the southeast bank of the Tualatin River in the NE1/4 of Sec. 21, T1S R2W.....	71
37	Willamette Silt Exposure with a Two Foot (0.8 m) Thick, 17 foot (5 m) Wide Channel of Clayey Silt and Cobble-Sized Basalt Clasts Between Flood Silt Layers.....	71
38	Willamette Silt and Neogene Sediment Exposure at the Temporary COSTCO Construction Site in Tigard, Oregon, SW1/4 of Sec. 36, T1S R1W.....	73
39	Interlayered Clayey, Silty, Very Fine Grained Sands and Clayey Silts in the Neogene Sediments at the COSTCO Construction Exposure in Tigard, Oregon.....	73

FIGURE		PAGE
40	Partially Indurated Iron Oxide Stained, Gravelly, Clayey Silt Zone in the Neogene Sediment Section of the COSTCO Construction Site in Tigard, Oregon.....	74
41	Iron Oxide Staining and Chemical Fronts in the Neogene Sediments Incorrectly Give the Appearance of Steeply Dipping Strata at the COSTCO Construction Site.....	74
42	A 2" (5 cm) Silt to Very Fine Sand Dike in the Neogene (NEO) Sediments and into the Overlying Willamette Silt (WS) at the COSTCO Construction Site.....	75
43	Close up of the Silt/Sand Dike Shown in Figure 51 Depicting the Dike Shape Change from Narrow and Nearly Linear to Wide and Irregular as it Enters the Willamette Silt from the Underlying Neogene Sediments.....	77
44	Schematic Geologic Cross-Section Below Sylvan Depicting the Tri-Met Westside Light-Rail Tunnel Alignment.....	78
45	Contact Between Stratified and Massive Neogene Sediments in the Westbound Tri-Met Light-Rail Tunnel Along Hwy 26 Approximately 4000' (1220 m) from the West Portal.....	79
46	Ripples and Subparallel Layering of the Stratified Neogene Sediments in the Tri-Met Light-Rail Tunnel Along Hwy 26.....	79
47	Microfaults in the Stratified Neogene Unit in the Westbound Tri-Met Light-Rail Tunnel Along Hwy 26.....	81
48	Sharp Contact Between Gravelly, Stratified, Stream Sediments and Underlying Red-Brown, Massive, Clayey Silt in the Eastbound Tri-Met Light-Rail Tunnel, Approximately 4000' (1220 m) from the West Portal.....	82
49	Contact Between the Neogene Stratified Sediments and an Overlying 960,000 Year Old Boring Lava Flow.....	83
50	Schematic Geologic Cross-Section in the Eastbound Tunnel of the Tri-Met Westside Light-Rail Tunnel Alignment Exhibiting a Shear Zone that may Correlate with the Oatfield Fault Mapped on the Lake Oswego and Portland Quadrangles..	84
51	Overturned Dark Red-Brown, Clayey Silt on top of Younger Light Red-Brown, Clayey Silt in the Shear Zone (Oatfield Fault ?) of the Eastbound Tunnel in the Tri-Met Westside Light-Rail Tunnel Alignment Underneath Sylvan.....	86
52	Vertical Gravel Layer in Neogene Red-Brown Silty Clay to Clayey Silt Approximately 3300' (1005 m) from the West Portal of the Eastbound Tri-Met Tunnel.....	87

FIGURE		PAGE
53	Location Map of Subsurface Borings from Which Sediment Samples, Gamma Logs, and Geologic Boring Descriptions Were Utilized for this Study.....	89
54	Thinly Bedded Nature of the Neogene Silts and Sands in BVD-6 from 50' to 55' (15.2-16.8 m) Below the Surface.....	90
55	Thin Ash Lens in the Lower Part of the Willamette Silt in LOD-3 Drilled at the Hwy 217 and Interstate 5 Intersection.....	90
56	Stratigraphic and Gamma Log section of the Childress Water Well Drilled in the NW 1/4 of Sec. 18, T1S R2W South of Hillsboro, Oregon.....	93
57	Stratigraphic and Gamma Log Section of the Itel Water Well Drilled in the SW 1/4 of Sec. 11, T2S R2W South of Scholls, Oregon.....	94
58	ODOT Test Boring Log of the Hwy 26 Bridge over the Burlington Northern Railroad One Mile (1.6 km) West of North Plains.....	96
59	Synthetic Seismogram of HBD-1 with Stratigraphy Exhibiting Horizon Correlations from Seismic Reflection Line Data.....	98
60	Primary Velocity Profile for HBD-1 Taken from a Velocity Survey Run by DOGAMI for a Regional Seismic Hazards Program	99
61	HBD-1 Synthetic Seismogram Tie with the Nearest Seismic Reflection Line Data Approximately 5800' (1768 m) Southwest of the Drill Site.....	101
62	Synthetic Seismogram of BVD-5 with Stratigraphy.....	102
63	Location Map of Four Proprietary Seismic Reflection Data Lines in the Tualatin Valley.....	105
64	East-West Seismic Reflection Line Displaying HBD-1 Tie and General Nature of the Post-CRBG (Red Horizon) Sediment Package Near the Center of the Tualatin Basin.....	106
65	East-West Seismic Reflection Line Illustrating the General Reflection Character of the Neogene Sediment Section.....	107
66	North-South Seismic Reflection Line in the Eastern Part of the Tualatin Valley Showing Neogene Geometries as the Section Thins Towards the North.....	109
67	North-South Seismic Reflection Line in the Western Part of the Tualatin Valley Illustrating the Same General Geometries of the Neogene Section as in Figure 72. Indicating the Continuity of Basin Formation in the Northern Part of the Tualatin Basin.....	110
68	East-West Seismic Reflection Line Exhibiting how the Neogene Section Thins Towards the West End of the Tualatin Basin.	111

FIGURE		PAGE
69	Neogene Sediment Isopach Map Below the Willamette Silt in the Tualatin Basin, Oregon.....	113
70	Sand Unit Percent Map of the Top 100' (30.5 m) of the Neogene Section Below the Willamette Silt or Boring Lava Contact in the Tualatin Basin, Oregon.....	115
71	Sand Unit Percent Map of the Neogene Sediment Section 100' to 500' (30.5-152.4 m) Below the Top of the Neogene Section in the Tualatin Basin, Oregon.....	116
72	Sand Unit Percent Map of the Neogene Sediment Section Greater than 500' (152.4 m) Below the Top of the Neogene Section in the Tualatin Basin, Oregon.....	117
73	Willamette Silt Isopach Map in the Tualatin Basin, Oregon.....	120
74	Lithofacies Map of the Missoula Catastrophic Flood Deposits at the West End of Lake Oswego and Westward into the Tualatin Valley.....	121
75	Boring Lava Structure Contour Map Along the Tualatin Mountains and Portland Hills on the East Margin of the Tualatin Valley, Oregon.....	123
76	Boring Lava Isopach Map Along the Tualatin Mountains and the Portland Hills Along the Eastern Margin of the Tualatin Valley, Oregon.	124
77	Photomicrograph of diatom <i>Aulacosira canadensis</i> in a Lacustrine Silty Clay from HBD-1 724' (220.7 m).....	133
78	Photomicrograph of Diatom <i>Pliocaenicus</i> in a Lacustrine Silty Clay from HBD-1 724' (220.7 m).....	133
79	Inclinations and Intensities for Natural Remnant Magnetization Analysis of HBD-1 Neogene Core Samples.....	136
80	Inclinations and Intensities of 250°C Thermal Demagnetized HBD-1 Neogene Core Samples.....	137
81	Inclinations and Intensities of 350°C Thermal Demagnetized HBD-1 Neogene Core Samples.....	138
82	Location Map and Stratigraphic Column for the Gillenwater Water Well #1 in the NE1/4 of Sec. 21, T1S R2W, south of Hillsboro, Oregon.....	139
83	Location Map of the M. Duyck Water Well in the NE1/4 of Sec. 8, T1N R3W, in Roy, Oregon.....	141
84	Generalized HBD-1 Stratigraphic Column Indicating Interpreted Ages from Palynological, Diatom, and Paleomagnetic Data.....	142
85	Location Map of Boring and Stream Samples Used for Heavy Mineral Provenance Determination of the Neogene Sediments in the Tualatin Basin and in the Portland Area....	148

FIGURE		PAGE
86	Augite-Hornblende-Hypersthene Relative Ratio Ternary Diagram for Sands from Borings in the Portland Basin and Northern Willamette Valley.....	150
87	Augite-Hornblende-Hypersthene Relative Ratio Ternary Diagram of Recent Stream Sediments in the Tualatin Valley and Columbia River.....	152
88	Augite-Hornblende-Hypersthene Relative Ratio Ternary Diagram for Water Well and ODOT Core Samples in the Tualatin Valley.....	154
89	Augite-Hornblende-Hypersthene Relative Ratio Ternary Diagram of HBD-1 Sands.....	155
90	Location Map of Shallow DOGAMI Borings Illustrating the Differences in Hypersthene levels.....	158
91	Photomicrograph of an Altered Hornblende Mineral Grain from HBD-1 836'.....	161
92	INAA Chemistry Comparisons Between HBD-1, MTD-1, and DOGAMI Shallow Borings in the Tualatin Valley for Fe vs Na (A) and Sc vs Cr (B).....	164
93	INAA Chemistry Comparisons Between HBD-1, MTD-1, and DOGAMI Shallow Borings in the Tualatin Valley for Th vs Cr (A) and Na vs La/Sm (B).....	165
94	Iron (A) and Sodium (B) Depth Trend Comparisons Between HBD-1 MTD-1.....	167
95	Ternary Plot of Mono- & Poly- Crystalline Quartz, Feldspar, Lithic Fragments (A) and Monocrystalline Quartz, Feldspar, and Total Lithic Fragments, Including Polycrystalline Quartz (B), from HBD-1 and Other Borings in the Tualatin Valley.....	170
96	Computer Generated Structure Contour Map of the Green Seismic Horizon Developed from Shot Point Time-Depth Interpretations.....	172
97	Computer Generated Structure Contour Map with Faults Added of the Red Seismic Horizon Developed from Shot Point Time-Depth Interpretations.....	173
98	Top of the CRBG Laterite Structure Contour Map for the Tualatin Basin, Oregon.....	176
99	Top of Weathered Basalt Structure Contour Map of the CRBG in the Tualatin Basin, Oregon.....	177
100	Section A - A' East-West Across the Main Northern Portion of the Tualatin Basin.....	179
101	Location Map with Elevations of the CRBG or Total Depths of Water Wells Drilled Beyond the Neogene Sediments in the Northwest Portion of the Hillsboro Quadrangle.....	181

FIGURE		PAGE
102	Possible Geologic Models Explaining the Missing CRBG in Sec. 7, T1N R2W of the Hillsboro Quadrangle.....	182
103	Section B-B' North-South Across the Western Portion of the Tualatin Basin, Oregon Displaying a Thick Neogene Sediment Sequence Overlying CRBG North of Forest Grove.....	184
104	Section C-C' North-South Across the Eastern Margin of the Tualatin Basin, Oregon, Demonstrating the Faulted Nature of this Portion of the Basin.....	186
105	Section D-D' East-West Section Across the Southern Portion of the Tualatin Basin, Oregon Illustrating the Faulted and Folded CRBG and the Effect on Neogene Sediment Distribution.....	187
106	CRBG Top Weathered Zone Isopach Map in the Tualatin Basin, Oregon.....	189
107	Top Neogene Sediment Structure Contour Map in the Tualatin Basin, Oregon.....	190
108	Section D - D' North-South Across the Central Part of the Tualatin Basin, Oregon.....	191
109	Faults at the Level of the CRBG in the Northeastern Portion of the Tualatin Basin and Over the Tualatin Mountains - Portland Hills Area.....	194
110	Synclinal Axis of the Tualatin Basin Prior to Uplift of the Cooper-Bull Mountain Structures.....	198
111	Isostatic Residual Gravity and Aeromagnetic Data Anomalies for the Northern Willamette Valley Region.....	200
112	Location of Borings Containing Examined Neogene Sediments in the Northeastern Portion of the Tualatin Basin, Oregon.....	207
113	Schematic Model of Pleistocene Sediment Depositional Styles in the Northeastern Part of the Tualatin Valley.....	208
114	Cross-Section of ODOT Hwy 219 Borings Representing Interrelationships Between the Willamette Silt and Tualatin River Sediments.....	210
115	Possible Paths for Missoula Flood Waters into and out of the Tualatin Valley During the Episodic Events Between 12,700 and 15,300 Years b. p.....	216
116	Tectonic Forearc Basin Model of the Tualatin Basin.....	219
117	Outlines and Basin Centers for the Tualatin, Portland, and Northern Willamette Basins.....	220
118	Willamette Valley Depositional Basin Activity Status for the Pleistocene Epoch Indicating Relative Subsidence and Uplift Among the Basins.....	230

FIGURE		PAGE
119	Tualatin Valley Watershed With 3rd Order or Higher Stream Subbasins.....	234
120	Stream Order vs. the Log of the Number of Streams per Order (A) and the Stream Order vs. the Log of the Average Stream Lengths per Order (B) for Drainages in the Tualatin Valley Watershed.....	238
121	Drainage Areas for Primary Subbasins in the Tualatin Valley Given as Percent of Total Watershed Area for Third Order or Higher Streams.....	241
122	Surface Geology Map Around the Tualatin Valley Watershed.....	242
123	Longitudinal Profile of the Tualatin River from the Confluence with the Willamette River to the source in the Coast Range.....	244
124	Cross-section of ODOT borings at the Weiss Bridge showing the CRBG near the surface at river level.....	245
125	Longitudinal Profiles of East Fork Dairy Creek (A) and Gales Creek (B) Exhibiting Steadily Increasing Gradients.....	247
126	Longitudinal Profiles of Scoggins Creek (A) and Fanno Creek (B) Displaying Rounded Profiles.....	248
127	Longitudinal Profiles of West Fork Dairy Creek (A) and Rock Creek (B) Displaying a Steep Upstream Section and a Flat Downstream Reach.....	249
128	Longitudinal Profiles of McKay Creek (A) and Chicken Creek (B) Displaying Flat Downstream Gradients and Steep Upstream Profiles.....	250
129	Longitudinal Profiles of Beaverton Creek (A) and McFee Creek (B) Illustrating Flatten Lower Reaches and Steep Upstream Gradients.....	251
130	Longitudinal Profiles with Labeled Nick Points of Representative Willamette River Tributaries in the Willamette Valley.....	253
131	Tualatin River Terrace Map Displaying Geomorphic Surfaces from the Floodplain to the Lower Foothills of the Surrounding Region in the Tualatin Valley, Oregon.....	255
132	Residual Red Soils Minimum Elevation Map and General Locations of Erratics (X) above 225' (68.6 m) Recorded by Allison (1935).....	260
133	Water Flow Relationships Between the Tualatin and Willamette Rivers During Plio-Pleistocene time.....	263
134	HBD-1 Sediment Air Porosity and Permeability Trends with Depth.....	267
135	Potentiometric Surface Map Developed from Initial Static Water Levels of Water Wells Tapping Groundwater from the CRBG in the Tualatin Valley.....	270

FIGURE		PAGE
136	Water Wells in the Tualatin Valley Tapping CRBG Aquifers that Contain Either High Iron Oxide Content, Saline Water, and/or Have Artesian Flow.....	272
137	Potentiometric Surface Map Developed from Initial Static Water Levels of Water Wells Pumping Neogene Aquifers in the Tualatin Valley.....	274
138	Water Wells in the Tualatin Valley Pumping Neogene Sediment Aquifers that Contain Either High Iron Oxide Content, Saline Water, and/or Artesian Flow.....	275
139	Formation Temperature Curve with Depth in HBD-1.....	280
140	Comparison of Hydrogeologic Units Recognized in HBD-1 and MTD-1.....	283
141	Orthophosphate Concentration Depth Trend in the HBD-1 Boring at the Hillsboro Airport.....	288
142	Sample Locations for Tualatin Valley Phosphate Analyses.....	289
143	Orthophosphate Concentrations from ODOT (A) and Tri-Met (B) Core Samples Along the Westside Light-rail Alignment in the Northeastern Portion of the Tualatin Valley.....	290
144	Orthophosphate Concentrations of DOGAMI Core Samples Along the Hwy 217 and I-5 Corridor (A) and from Water Wells in the Hillsboro Area (B).....	291
145	Orthophosphate Concentrations from the VanDomelen Water Well South of Hillsboro (A) and from Two Western Tualatin Valley Water Wells, One in Forest Grove and the Other in Roy (B).....	292
A1	Gamma Response Difference Between a Cased Section and an Uncased Section of a Water Well Located in the CRBG	A8
A2	Gamma Response Variations Due to Type of Casing Material	A9
A3	Gamma Response in Sediments from a Water Well With a 12' Diameter Steel Casing	A10
A4	Gamma spike in an unfinished water well	A11
A5	Depth-Time Correlation Between Water Well Horizon Picks and Seismic Reflection Horizons Based on RMS Velocity-Time Grids Generated by the Seismic Reflection Data	A14
D1	An Example of X-Ray Diffraction Peaks from Sample HBD-1 249' Used to Identify Clay Mineral Types.....	D3
G1	Primary Wave Velocity/Depth Profile and Synthetic Seismogram for DOGAMI Boring BVD-2.....	G5
G2	Primary Wave Velocity/Depth Profile and Synthetic Seismogram for DOGAMI Boring BVD-3.....	G6

<u>FIGURE</u>		<u>PAGE</u>
G3	Primary Wave Velocity/Depth Profile and Synthetic Seismogram for DOGAMI Boring BVD-4.....	G7
G4	Primary Wave Velocity/Depth Profile for DOGAMI Boring BVD-5.....	G8
G5	Primary Wave Velocity/Depth Profile and Synthetic Seismogram for DOGAMI Boring BVD-6.....	G9

CHAPTER 1 - INTRODUCTION

The Tualatin Basin, located in Washington County, Oregon, 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. The basin occurs as a partially isolated western extension of the Willamette Valley forearc regional low west of the Cascade Range volcanic arc complex (Figure 2). Approximately 14,000' (~4300 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; and Schlicker and Deacon, 1967). As much as 1000' (~300 m) of middle Miocene Columbia River basalt and up to 1500' (460 m) of overlying Neogene continental sediments blanket the marine sediments. A thin capping of Late Pleistocene catastrophic flood silts covers the Tualatin Valley to elevations of approximately 250' (76 m).

The Tualatin River is the major waterway that drains the Tualatin Valley, emptying into the Willamette River to the southeast. Major tributaries of the Tualatin River include Gales Creek, Dairy Creek, McKay Creek, Rock Creek, and Fanno Creek. Elevations range from approximately 1100' (335 m) in the surrounding highlands to an average of 175' (53 m) on the valley floor. The elevation at the Tualatin River's confluence with the Willamette River is approximately 55' (16.8 m) above mean sea level. The region's climate is temperate with an average annual rainfall varying from 60 inches (152 cm) per year near the Coast Range to 30 in (76 cm) per year at the east side of the valley (Green, 1982).

Washington County nearly encompasses the Tualatin River Watershed and is incorporated into the Portland metropolitan area, which is currently one of the fastest

Figure 1: Location map of the Tualatin Valley and associated physiographic features. The northwest - southeast oriented valley is essentially surrounded by highlands.

Figure 2: Tectonic setting of the Tualatin Valley. The valley is located at the northern Oregon portion of the Willamette-Puget Sound Lowland and is considered part of the fore-arc region relative to the Cascade Range magmatic arc (modified from Baldwin, 1981).

growing regions in the country. The Tualatin River system has historically been negatively impacted by agricultural practices, forest logging, residential development, and industry. The large expected growth of the Washington County area over the next few decades will undoubtedly further environmental degradation of the region. Past surface and groundwater pollution and the potential for more in the future have resulted in the initiation of a variety of environmental research to help identify solutions to clean the system (McHugh, 1967; Swift, 1971; Carter, 1975; Stewart Rounds, 1993, personal comm.). Hydrologists modeling the river dynamics need to understand the groundwater dynamics of the near subsurface, which is not currently well known, to accurately model the river system. Accurate groundwater modeling can only be achieved by understanding the geologic constitution of the subsurface sediments underlying the Tualatin River and its tributaries and the geomorphology of the Tualatin Valley.

The purpose of this study is to elucidate the post-Columbia River basalt Neogene (late Miocene to Holocene) history of the Tualatin Valley and relate the sedimentary and structural conditions to groundwater dynamics. The entire geologic model generated in this study should enhance the understanding of the regional geologic patterns in northwest Oregon.

The Neogene stratigraphy and surface geomorphology in the Tualatin Basin has only been subjected to peripheral studies and has not been examined in detail. Research presented in this report addresses surficial mapping in conjunction with geomorphological properties of the watershed and subsurface investigations that define the placement and structural disturbance of the Neogene sediments. The geomorphic properties, including river profiles and terrace distribution, are utilized to characterize the Tualatin River drainage system and delineate any recent structural influence around the valley. The subsurface work includes delineation of the lithologic constitution,

origin, distribution, and diagenesis of the Neogene sediments. The presented results should provide a solid geologic foundation for future hydrogeologic, geotechnical, and soil science studies in the Tualatin Valley.

Geologic Model for the Neogene Tualatin Basin

The following is an encapsulated geologic model of Neogene sedimentation and structural events in the Tualatin Basin to orient the reader for the subsequent discussion. The Neogene fluvial/lacustrine sediment package overlies the broad synclinal surface of the Middle Miocene Columbia River Basalt Group in the Tualatin Basin and may attain a thickness up to 1400' (430 m) (Figure 3). The locally derived late Miocene to Pleistocene sediments are primarily composed of silt and clay units with interbedded, discontinuous sand bodies. Two recognized, widespread lacustrine units are present in the middle of the sequence. A unit of Missoula flood deposits up to 120' (37 m) thick in the middle of the basin overlies the fluvial sediments. The basin is structurally bound on the northeast and southwest sides by right lateral shear fault zones. Two structural styles subdivide the basin into a northern deep downwarp with minor faulting and a smaller, faulted region to the south consisting of a series of shallow depressions interrupted by uplifted CRBG blocks.

Details of the composition and dynamics of the basin along with appendices are presented in this volume. Water well data and stratigraphic descriptions of selected borings with gamma ray logs are presented in a separate well data repository volume found in the Portland State University Geology Department.

SCHEMATIC MODEL OF TUALATIN BASIN NEOGENE SEDIMENTATION

Figure 3: Schematic geologic model of Neogene sediment deposition overlying the CRBG. The fluvial/lacustrine clastics were primarily derived from the surrounding highlands, particularly the Coast Range, to the basin in equilibrium with basin subsidence

CHAPTER 2 - THE TUALATIN VALLEY GEOLOGIC SETTING AND PREVIOUS WORK

Geologic studies around the Portland region have primarily considered structural tectonics and stratigraphic relationships involved in the evolution of the region since Eocene time. Many of the studies that have concentrated on the Portland Basin and the Tualatin Mountains/Portland Hills have also included references to the Tualatin Basin. A composite summary is presented below of the interpreted stratigraphy and structure of the Tualatin Basin.

Stratigraphy of the Tualatin Basin

Paleogene Volcanics and Sedimentary Rocks

The Cenozoic sediments within the valley have not been scrutinized in the past; however, the general stratigraphic relationships in the Tualatin and Portland Basins have been fairly well established (Figure 4). Lower to middle Eocene ocean-floor basalt, equivalent to the Siletz Volcanic series, is thought to be the basement of the deep Tualatin Basin and is exposed in the Coast Range Mountains (Wells et al., 1994). The younger middle to upper Eocene Tillamook Volcanic series overlie the older volcanic rocks in the Coast Range and may also extend into the Tualatin Basin (Figure 5; Hart and Newcomb, 1965; Schlicker and Deacon, 1967). Recent field mapping of the Tillamook Volcanic series in highlands west of Gales Creek indicates that most of this group is younger than the Eocene Yamhill Formation (Wells et al., 1994). Field investigations in the Tillamook Highlands on the west side of the Coast Range indicate three mappable units of the Tillamook Volcanic series: a lower section of pillow basalts, a middle section of volcanoclastic siltstones and sandstones, basaltic tuff, and pillow basalts, and an upper interval consisting of subaerial basalt (Snively et al., 1970).

	Trimble 1963	Hart & Newcomb 1965	Schlicker & Deacon 1967	Newton 1969	Madin 1990	This Report	
Holocene		Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	
Pleistocene	Willamette Silt		Lacustrine Dep.		Willamette Silt	PHS	Willamette Silt
	Loess		Silt / PHS				
	Boring Lava	Boring Lava	Boring Lava	Boring Lava	Boring Lava	Boring Lava	
Pliocene	Troutdale	Troutdale	Troutdale	Troutdale	Sandy River Mudstone	Neogene	
	Sandy River Mudstone		Helvetia		Equivalent		
U. Miocene							
Middle Miocene	Columbia River Basalt	Columbia River Basalt	Columbia River Basalt	Columbia River Basalt	Columbia River Basalt	Columbia River Basalt	
L. Miocene	Scappoose	Oligocene & Miocene Sediments Undiff.	Oligocene Sediments Undiff.	Scappoose		Scappoose	
Oligocene				Pittsburg Bluff		Pittsburg Bluff	
U. Eocene			Spencer	Keasey		Keasey	
				Cowlitz		Spencer/Cowlitz	
Middle to Lower Eocene				Eocene Volcanics & Sediments Undiff.		Eocene Volcanics & Sediments Undiff.	Tillamook
						Yamhill	
						Siletz equivalent	

Figure 4: Generalized stratigraphic relationships from past work in and around the Tualatin Basin. The stratigraphic section used in this report reflects new data interpretations from the Boring Lava, the Neogene sediments, and the Paleogene sediments and volcanic packages.

Figure 5: Location map of surface Eocene-aged volcanic complexes including the lower Eocene Siletz Volcanics-equivalent and the middle - upper Eocene Tillamook Volcanic series. A separate volcanic unit, known as the Waverly basalt, is exposed on the eastern margin of the Tualatin Valley (modified from Schlicker and Deacon, 1967 and Wells et al., 1994).

There are only two known well penetrations of Eocene volcanics in the subsurface of the Tualatin Basin. Texaco's Cooper Mountain wildcat well encountered siltstones interbedded with volcanics (Newton, 1969). The mudlog of Northwest Natural Gas' Van Dyke exploration well near Gaston, Oregon (Sec. 26 T1S R4W) indicates that drilling ended at the top of a basalt unit some 3400 feet (1036 m) below the surface.

The middle to upper Eocene Waverly Heights basalt, found around the southeast end of the Portland Hills in the Lake Oswego Quadrangle, consists of subaerial basalt flows chemically similar to the Tillamook Volcanic series (Beeson et al., 1989a) and marine sediments (Beeson et al., 1989b). Geochemical studies of the sedimentary material indicate that this unit is part of an oceanic island that docked to western Oregon during the Eocene.

Marine Paleogene (Eocene to lower Miocene) sedimentary rocks overlie the Siletz Volcanic series equivalents and crop out along the western and southwestern edges of the valley (Figure 6; Schlicker and Deacon, 1967; Yeats et al., 1991; Van Atta and Thoms, 1993; and Wells et al., 1994). The units consist of siltstones and sandstones of the middle Eocene Yamhill Formation; volcanoclastic sandstones and conglomerates of the Eocene Cowlitz Formation (Timmons, 1981); tuffaceous mudstones, siltstones, and sandstones of the Eocene Spencer Formation (Van Atta and Thoms, 1993); claystones and mudstones of the upper Eocene Keasey Formation; sandstones of the Oligocene Pittsburg Bluff Formation; and fluvial/estuarine fossiliferous sandstones and tuffaceous shales of the Oligocene to lower Miocene Scappoose Formation (Baldwin, 1981; Van Atta and Kelty, 1981; and Yeats et al., 1991). The Cowlitz and Spencer Formations are the same age. Sediments around and south of Henry Hagg Lake are known as the Spencer Formation and sediments in and north of the West Fork of Dairy Creek are called the Cowlitz Formation (Ray Wells, 1996, personal comm.). The Scappoose

Figure 6: Location map of exposed Paleogene marine to nonmarine sedimentary rocks. Most outcrops are in the Coast Range with a few in the Tualatin Mountains and on the southwest side of the Chehalem Mountains (modified from Schlicker and Deacon, 1967).

Formation also occurs near the surface in a very restricted area around Bonny Slope (Sec.26 and 27, T1N, R1W) on the northeast side of the basin (Nazy, 1987).

The Paleogene sequence is up to 14,000' (4270 m) thick as interpreted from proprietary seismic reflection lines through the basin (Jack Meyer, 1992, personal comm.). An industry generated gravity map of the Portland metropolitan area depicts a very deep gravity low in the basin supporting the notion of the thick column of sedimentary rocks (Popowski, 1996). Petroleum exploration wildcat tests on the Tualatin Mountains, Cooper Mountain and just south of Gaston, Oregon penetrated several thousand meters of these units. A few water wells in the Tualatin Valley also penetrated the top of the marine sediment section after drilling through the Columbia River Basalt Group.

Geochemistry from several of these formations in the Mist, Oregon area suggests a changing provenance over time from almost exclusively continental derivation in the Cowlitz Formation to a mixed continental and western Cascadian influence for the Pittsburg Bluff Formation (Kadri et al., 1983).

The Columbia River Basalt Group

The middle Miocene Columbia River Basalt Group (CRBG) unconformably covers the Paleogene sediments and volcanics. This unit composes the majority of the surrounding highlands and Cooper, Bull, and Sexton Mountains within the Tualatin Valley (Figure 7). Basalt flows of the CRBG originated from fissures in northeastern Oregon and southeastern Washington. Individual flows from the younger reverse and normal polarity (R_2 and N_2) eruptions of the Grande Ronde Basalt entered the Tualatin Basin through the Sherwood Trough beginning with the Wapshilla Ridge unit (Beeson et al., 1989a). The Grande Ronde units have been noted in deep water wells in the center of the Tualatin Basin. The Frenchman Springs Member of the Wanapum Basalt

Figure 7: Location map of exposed middle Miocene Columbia River Basalt Group (CRBG) basalts and associated lateritic soils. This unit almost encircles the Tualatin Valley (modified from Schlicker and Deacon, 1967).

has been mapped in the highlands bordering the southern margin of the basin (Al-Eisa, 1980, Beeson and Tolan, 1984; Beeson et al., 1985; and Beeson et al., 1989b) and is present in the center of the basin (Marvin Beeson, 1993, personal comm.). Flows of the Ginkgo and Sand Hollow units in the Frenchman Springs Member of the Wanapum Basalt (15.3 Ma) traveled to the east margin of the basin and were diverted by the Portland Hills structure (Beeson et al., 1989a). The CRBG is as much as 1000' (305 m) thick under the Tualatin Valley with separate flows as thin as 20 feet (6m) (Schlicker and Deacon, 1967). The sequence has undergone structural deformation in the surrounding highlands and is faulted in the subsurface (Madin, 1990). Structure contour maps representing the top of the CRBG have been developed using water well data (Hart and Newcomb, 1965; Schlicker and Deacon, 1967, Hammond et al., 1974; and Madin, 1990).

Hart and Newcomb (1965) focused on the water resources of the CRBG in the Tualatin Valley as a hydrogeologic unit separate from the overlying Valley Fill unit. The southern extent of the Tualatin Valley was further considered as part of a groundwater study in the Newberg, Oregon area (Frank and Collins, 1978).

Neogene Sediment Section

Nonmarine clays, silts, and sands 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 1500' (~460 m) in the central part of the basin under Hillsboro, Oregon (Hart and Newcomb, 1965; Schlicker and Deacon, 1967; and Madin, 1990). Hart and Newcomb (1965) report sediments of the Troutdale Formation occur in synclines of CRBG in the Portland Hills and into the Tualatin Valley (Figure 8). Outcrops are limited to an area north of Tigard, Oregon and north and west of the Six Corners area near Sherwood (Schlicker and Deacon, 1967).

Figure 8: Location of exposed Neogene-aged sediments in the Portland Hills region (modified from Beeson et al., 1989b and Beeson et al., 1991).

The age and lithologic distribution of these sediments has not been firmly established. Lowry and Baldwin (1952) and Trimble (1963) only briefly referred to the Tualatin Valley Neogene sediments as lacustrine and possible equivalents to the Troutdale Formation and Sandy River Mudstone of the Portland Basin. Hart and Newcomb (1965) suggested that the lower portion of the section along the northeastern margin of the basin is lacustrine and equivalent in age to the alluvial fan deposits of the Troutdale Formation in the east Portland Basin. Schlicker and Deacon (1967) suggest a fluvial-lacustrine origin and an early Pliocene age for this formation. The section is predominantly composed of clays and silts, with lesser amounts of fine sand and gravel. Subsurface drill cuttings indicate the granular material is dominantly quartzo-micaceous (Madin, 1990). Some of the sand bodies are extensive; however, they are not necessarily basinwide (Schlicker and Deacon, 1967). The sediments are characterized as being moderately to highly plastic and firm to dense, with some brittle clays sporting slickensides. An erosional surface which truncates the top of this section was identified and is partly preserved at the base of the Boring Lava along the Portland Hills (Hart and Newcomb, 1965).

Schlicker and Deacon (1967) distinguished a basal, laterized unit overlying the CRBG along most edges of the valley as the Helvetia Formation. Outcrops of the section are at least 25 feet (~8 m) thick and exhibit reddish to light brown clayey silt and sandy silt with some pebbly silty sand. Water well information indicates that the section may be 75' (23 m) thick in the subsurface. The Helvetia Formation is overlain by catastrophic flood deposits of the Willamette Silt and loess upland silts (Portland Hills Silt) along the valley edges. Schlicker and Deacon (1967) assigned the Helvetia Formation to an early Pliocene age and equivalent to the earliest Troutdale Formation based on its stratigraphic position in water well borings and to exotic minerals and rock

fragments present in the strata. Angular quartz, muscovite, feldspars, pyroxene, amphiboles, magnetite, other heavy minerals and occasional diatoms compose the sediment.

Madin (1990) has lumped the Helvetia and Troutdale Formations in the Tualatin Valley as an equivalent to the Sandy River Mudstone. These sediments more closely resemble the Sandy River Mudstone than the coarser gravels of the Troutdale Formation in the Portland Basin. The Sandy River Mudstone is time equivalent to the lower Troutdale Formation in the Portland Basin (Tolan and Beeson, 1984; Bet and Rosner, 1993).

Boring Lava

The gray, pilotaxitic to diktytactic, olivine-bearing, Plio-Pleistocene Boring Lava is exposed around local volcanic centers in the Portland Hills (Figure 9; Trimble, 1963; and Schlicker and Deacon, 1967). The Boring Lava stratigraphically lies between the Troutdale - Sandy River Mudstone equivalent and the overlying Willamette Silt or Portland Silt, depending on the elevation of occurrence. The volcanic activity may be associated with structural lineaments along the east edges of the Portland Basin (Blakely et al. 1995). Proprietary seismic reflection data suggest that Boring Lava domes poke up through the CRBG and into the overlying Neogene sediment package in the eastern parts of the Tualatin Basin (Popowski, 1996). A Boring flow under Catlin Gable School in the Linnton Quadrangle trends southwest for almost 2.5 miles (4 km) to Cedar Hills and contains some of the oldest known lava tubes in the state (Allen, 1974).

Radiocarbon dates from charred wood in sediments above the Boring Lava are older than 43.7 ka suggesting that the flows are older than this date (Hammond, 1975).

Recent work indicates that the Boring Lava flows of the Tualatin Mountains near

Figure 9: Location map of exposed Plio-Pleistocene Boring Lava along the Tualatin Mountains - Portland Hills region (modified from Beeson et al., 1989b, Madin, 1990, and Beeson et al., 1991).

Sylvan are between 0.26 Ma and 1.0 Ma, while the flows around Oregon City are up to 2.4 Ma (Conrey et al., 1996). Madin (1990) has mapped the subsurface extent of the Boring Lava into the Tualatin Valley.

Willamette Silt

The upper section of the Neogene valley fill is up to approximately 120' (37 m) thick (Madin, 1990) and occurs as an extensive surficial deposit throughout the valley plain (Figure 10). This unit, sometimes called the Willamette Silt (Schlicker and Deacon, 1967), consists of dominant medium brown, micaceous, clayey to sandy silt (lacustrine deposits of Schlicker and Deacon, 1967), with sands and gravels in the east end of the valley near Lake Oswego. The lithological facies changes may be examined on the Lake Oswego geologic map (Beeson et al., 1989b). The sediments are interpreted as catastrophic flood deposits from recurring jokulhlaups of glacial Lake Missoula in Montana during the late Pleistocene between 12,700 and 15,300 years ago (Schlicker and Deacon, 1967; Allison, 1978a; Waitt, 1985; Beeson et al., 1989b; Madin, 1990; McDowell, 1991; and Reckendorf, 1992). Occasional ice-rafted erratics of metamorphic and plutonic rocks not originating in western Oregon are found in the sediments. McDowell (1991) indicates that there possibly was an earlier phase of flooding around 35,000 years ago. Mullineaux et al., (1978) document the age of the last flood cycle at 13,080 years ago based on radiocarbon dating of peat from the Portland delta.

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 Tualatin Valley (Waitt, 1996). They entered the southeastern part of the Tualatin Valley from the Lake Oswego gap, Tualatin River-Willamette River

Figure 10: Location map of exposed upper Pleistocene Willamette Silt. The silt, derived from the catastrophic Missoula floods, covers the floor of the Tualatin Valley to approximately 250' (76 m) above mean sea level (modified from Schlicker and Deacon, 1967).

confluence, and possibly the Rock Creek or Tonquin scabland area south of Onion Flat where extensive channeling or scouring is noted (Allison, 1978a). The floods were strong enough to scour the preexisting divide at Rock Creek (presently only 150' (46 m) in elevation) between the Tualatin and Willamette valleys (Allison, 1978b). Allison speculated that only one major flood entered the Tualatin Valley; however, road cuts of flood gravels and silts near Lake Grove, Oregon, exhibit at least five rhythmite sequences (Scott Burns, 1995, personal comm.).

The Willamette Silt has been named the Willamette Formation in the southern Willamette Valley and has been subdivided, from oldest to youngest, into the Wyatt Member, the Irish Bend Member, the Malpass Member and the Greenback Member (Balster and Parsons, 1969). Roberts (1984) modified this stratigraphic nomenclature for the northern Willamette Valley with two intertonguing lower units, the Irish Bend Member and the River Bend Member, and a single overlying unit, the Greenback Member. Glassman and Kling (1980) presented evidence for a glacial origin of the Irish Bend and Greenback Members from the study of surface morphologies of grains with scanning electron microscopy.

Several geomorphic surfaces have been attached to the above mentioned members in the Willamette Valley region, including the Winkle surface and the Ingram surface along the Tualatin River within the Tualatin Valley (Reckendorf, 1992). The sand fractions of the flood deposits in the Lake Oswego area form terraces on the north and south edges of the valley, and they exhibit channeling from later events (Allison, 1978b).

An unpublished report by Squier Associates, Inc. (1993) focuses on the flood deposits and uppermost part of the underlying sediments in their geotechnical survey for

the westside light rail project in Beaverton. They were able to distinguish between the similar silt deposits of each unit by the differences in the standard penetration rates and overall clay content. The less cohesive overlying flood deposits have lower blow count rates, generally ranging from 5 to 20 blows per 1.5' (0.46 m). Twenty-five to 45 blows per 1.5' (0.46 m) are required to drive the SPT core barrel into the underlying, greater cohesive, Neogene sediments. Schlicker and Deacon (1967) presented several examples of this phenomenon from structural stability test borings located throughout the Tualatin Valley.

Portland Hills Silt

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 (Figure 11; Lentz, 1981). The unit may be as thick as 100 feet (30 m) on the Portland Hills. Schlicker and Deacon (1967) used the term Upland Silt for these deposits. The eolian silt was arbitrarily mapped down to the 250' (76 m) elevation, below which are catastrophic flood deposits of the Willamette Silt (Schlicker and Deacon, 1967; Madin, 1990). Allison (1935) has mapped erratic boulders from the flood deposits as high as 400' (122 m) in the adjacent Willamette Valley and up to 300' (91.4 m) above sea level in the Tualatin Valley area. The two units are almost impossible to distinguish in the field on a lithologic basis. The micaceous Portland Hills Silt consists of almost 80% silt and 16% clay, has an uniform massive texture, and contains 35% quartz, 36% feldspar, and 15% clay minerals (Lentz, 1981). Augite, hornblende, hypersthene, magnetite, and other heavy minerals along with diatoms have been reported in the deposits (Schlicker and Deacon, 1967). John Lawes is currently determining the geochemical signature of the Portland Hills Silt through INAA for his Master of Science thesis at Portland State University.

Figure 11: Location map of exposed Pleistocene Portland Hills Silt. These silts are loesses that mantle the surrounding highlands above elevation 250' (76 m) and are thickest in the Tualatin Mountains - Portland Hills region (modified from Schlicker and Deacon, 1967).

Recent Alluvium

Quaternary alluvium exists along the main stem and tributaries of the Tualatin River. Hart and Newcomb (1965) divide the alluvium into older and younger units. The older units form river terraces, which are topographically higher than the younger alluvium within the waterways. The Recent alluvium may be up to 30' (10 m) thick and consists predominantly of silty clay, clayey silt, and fine sand (Schlicker and Deacon, 1967). Local peat and organic clays occur where the water table exists near the surface most of the year.

Structure of the Tualatin Basin

The Tualatin Basin is an extensional forearc depression, which offshoots northwest from the north-south Willamette Valley (Figure 2). Previous work has described the basin as a broad syncline surrounded by a faulted anticline of the Tualatin Mountains and Portland Hills to the north, the Parrett Mountain-Chehalem Mountains monocline to the south, and a faulted monocline of the Coast Range to the west. (Trimble, 1963; Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Frank and Collins, 1978; Al-Eisa, 1980; and Brodersen, 1995). The east side of the Tualatin Valley contains a composite of uplifted CRBG and older basalt units with Boring Lava constructional vents interspersed (Beeson et al., 1989b, 1991). Cooper and Bull Mountains within the valley are also described as faulted anticlines.

Recent work has recognized the Portland Hills Fault Zone that demarcates the boundary between the Tualatin Mountains/Portland Hills and the western margin of the Portland Basin to the northeast, (Figure 12) as part of a major right-lateral structural lineament across the Willamette Valley to the Clackamas River drainage (Balsillie and

Figure 12: Location map of the major recognized structural features in the Tualatin Valley that have influenced the Neogene basin development (modified from Yeats et al., 1991).

Benson, 1971; Perttu, 1981; Beeson et al., 1985; Beeson et al., 1989a; Madin, 1990; Yeats et al., 1991; Yelin and Patton, 1991; and Blakely et al., 1995). This zone consists of three named faults in the Tualatin Mountains/Portland Hills area; the Portland Hills Fault along the northeast border of the highlands, the Oatfield Fault along the southwest part of the Tualatin Mountains, and the East Bank Fault on the northeast side of the Willamette River. Vertical displacement along the Portland Hills Fault is estimated to be several hundred feet, down to the northeast in the Portland Basin (Madin, 1990) and may be the result of reverse movement as evidenced by the studies of the 1982 to 1985 earthquake swarms (Yelin, 1992) and of a high resolution aeromagnetic survey (Blakely et al., 1995). Seismicity in the Portland area indicates that the Portland Hills fault is still active (Yelin and Patton, 1991). The Portland Hills Fault Zone may extend southeast to the Bend, Oregon area as part of the Brothers Fault Zone (Beeson, 1990).

The Oatfield Fault trends parallel to the Portland Hills Fault on the southwest side of the Tualatin Mountains and into the Lake Oswego Quadrangle where it cuts Eocene oceanic crust of the Waverly Heights basalt at the surface (Beeson et al., 1989; and Blakely et al., 1995). The corresponding locations of the aeromagnetic lineation together with a 1991 earthquake swarm of $M \leq 3.5$ studied by Yelin (1992), indicate that the Oatfield Fault is active expressing reverse and strike-slip movement (Blakely et al., 1995).

The northeast trending Sherwood fault bounds the southeast part of the basin and has down to the northwest displacement (Yeats et al., 1991). The Gales Creek and Newberg faults lie just to the west and southwest part of the basin and the Chehalem Mountains (Al-Eisa, 1980; and Yeats et al., 1991). These two faults are part of the en echelon Gales Creek-Newberg-Mt. Angel fault zone that forms a parallel dextral shear couple with the Portland Hills-Clackamas River fault zone (Werner et al., 1992).

Recent field mapping of the highlands in the Gales Creek and Gaston Quadrangles revealed highly inclined strata of the Paleogene volcanic and sedimentary rocks suggesting that the adjacent Gales Creek Fault zone has played a major role in the deformation of this portion of the northern Coast Range (Ray Wells, 1996, personal comm.).

Yeats et al. (1991) have mapped the Helvetia Fault that trends northwest and is subparallel to the Tualatin Mountains. This fault and the northeast trending Beaverton fault, running from the northwest side of Cooper Mountain to the Portland Hills, have been interpreted from proprietary seismic reflection data and water well descriptions within the basin (Popowski, 1996). All of these faults displace portions of the CRBG. A recently published aeromagnetic map exhibits linear features in the basin, especially near the Cooper Mountain area (Snyder et al., 1993).

The top of the CRBG has been mapped as an irregular surface through the basin, which may be caused by structural and/or erosional activity (Madin, 1990; and Yeats et al., 1991). Madin (1990) mapped several faults in the CRBG based on water well stratigraphy bordering the Tualatin Mountains along the northeast border of the Tualatin Valley and around Cooper and Bull Mountains in the southeastern part of the valley. The CRBG has been gently folded as part of the Yakima fold belt east of the Portland area (Beeson et al., 1989a; and Reidel et al., 1989). There is evidence from proprietary seismic data that the overlying Neogene sediment package is slightly downwarped. Balsillie and Benson (1971) mapped phantom CRBG flow surfaces using joint columns in the Portland Hills. This technique indicated that the CRBG flows covered gently sloped surfaces where the Portland Hills are today, suggesting that the current topographic relief was not present at deposition of these flows. Much deformation

occurred after CRBG emplacement during the late Miocene to Recent interval; however, the Portland Hills fault generated enough relief in mid-Miocene time to detour some flows of CRBG (Beeson et al., 1989a; Beeson and Tolan, 1990). The recent 1993 earthquake in Scotts Mill, Oregon and 1990 tremblers near Woodburn, Oregon occurred along the south end of the Gales Creek-Mt. Angel fault trend (Werner et al., 1990), demonstrating that this system is also active.

Parrett Mountain along the extreme southeast edge of the Tualatin Valley contains three main fault trends, north-south, northeast, and east-west (Brodersen, 1995). A northwest oriented fault southeast of Parrett Mountain may have lateral movement. The north-south and northeast fault trends have been mapped with normal displacement, including the Sherwood Fault (Schlicker and Deacon, 1967). The east-west mapped fault in the area is most likely high angle reverse to thrust fault, indicating that both extensional and compressional stresses have affected Parrett Mountain (Brodersen, 1995).

Geomorphology of the Tualatin Valley

The geomorphology of the Tualatin Valley has predominantly focused on the hydrological watershed drainage system of the Tualatin River and associated tributaries. The river gradient and phosphate levels of the Tualatin River have been of particular recent interest due to the potentially devastating effects of summer algal blooms in the lower reaches of the river (Swift, 1971; Carter, 1975; and Stewart Rounds, 1993, personal comm.).

Schlicker and Deacon (1967) examined landslide features, soil features next to modern stream channels, and soil development within and around the valley in

conjunction with construction stability. Slope failure is generally restricted to the steeper slopes of the highlands, especially around the Chehalem and Tualatin Mountains where the Portland Hills Silt overlies the Paleogene sediments. Streambank erosion of the upper Tualatin River has been assessed between Gaston and Cherry Grove in Patton Valley (Soil and Water Conservation District, 1983).

Published studies including geomorphic surfaces and associated soils in the Tualatin Valley have primarily concentrated on the Willamette Valley (Balster and Parsons, 1968; Gelderman and Parsons, 1972; Glassman and Kling, 1980; Glassman et al., 1980; Parsons et al., 1970; Glenn, 1965; and Reckendorf, 1973 and 1992). Parsons (1969) directly studied the geomorphology of the Lake Oswego area and inferred that the Tualatin River mouth locality changed during the formation of the Champoege surface prior to 12 ka. The Winkle geomorphic surface occurs along the Tualatin River floodplain above the river's nick point, while the Ingram surface is present from the nick point to the confluence with the Willamette River. Reckendorf (1992) states that the Tualatin River did not develop the younger Ingram surface above the nick point due to sediment deposition from annual flooding. The flooding has also enhanced Chehalis soil formation on the Winkle surface (Parsons, 1969). Parsons describes the Tualatin River as being part of a hanging valley above the nick point. Winkle surfaces also include ponded areas such as Jackson Bottom south of Hillsboro and Onion Flat north of Sherwood, Oregon (Reckendorf, 1992). The age of the Winkle surface is roughly between 11 and 12 ka as determined by radiocarbon dated organic matter from the city of Tualatin (11.3 ka, Reckendorf, 1992) and from peat taken the Onion Flat (12.24 ka $\pm$ 330 years, Glenn, 1965).

CHAPTER 3 - TUALATIN BASIN STRATIGRAPHY

The Oregon Department of Geology and Minerals Industries (DOGAMI) cored the 1095' (330m) deep Hillsboro Deep Test #1 (referred to in this report as HBD-1) at the Hillsboro Regional airport (NW1/4 Sec.28, T1N, R2W) in 1993 as part regional seismic hazards study (Figure 13). HBD-1 penetrates the entire "Valley Fill" section (Hart and Newcomb, 1965; Schlicker and Deacon, 1967) near the center of the Tualatin Basin and bottoms in the Columbia River Basalt Group (CRBG)(Figure 14). The Valley Fill in this report is divided into two units: 1) the bulk of the section overlying the CRBG is referred to as "Neogene sediments"; 2) overlying the Neogene sediments are catastrophic Missoula flood deposits known as the Willamette Silt (Schlicker and Deacon, 1967). The HBD-1 core is considered the main reference for the Neogene sediments, from which correlations are made to other parts of the basin. Most of the analytical work on the Neogene sediments in this study comes from this cored unit.

Over 2400 water wells and other borings along with geophysical data were used in the Tualatin Valley to develop an interpretation of the basin's Neogene stratigraphic and structural relationships.

Three borings drilled in the Portland and Northern Willamette Basins, including DOGAMI's Mount Tabor Deep Test (MTD-1) at the Portland International Airport (SW1/4 Sec.6, T1N, R2E), cut through the Troutdale Formation to the top of the CRBG (Figure 14). These borings are used to compare sediment types and depositional styles between the Portland, Northern Willamette, and Tualatin Basins.

Figure 13: Location map of HBD-1 at the Hillsboro Regional Airport and MTD-1 at the Portland International Airport. Both core tests were drilled in 1993 by the Oregon Department of Geology and Minerals Industries (DOGAMI) as part of a seismic hazards study of the Portland metropolitan area.

Figure 14: Generalized stratigraphic section of HBD-1 core boring drilled at the Hillsboro Regional Airport. Clayey silt is the dominant lithology in the Neogene sediments. About 100' (30.5 m) of weathered basalt and laterite overlies fresher basalt in the CRBG.

Methods

A brief description of the methods used to characterize the Neogene sediments and the basin stratigraphy is summarized below and expanded in Appendix A of the appendices volume of this report.

Types of Subsurface Information for Lithology

The nature of the Neogene sediments in the Tualatin Basin was delineated from DOGAMI, ODOT, and proprietary cores, drill cuttings from water wells and other borings, gamma logs of borings, lithology logs from water wells and other borings, and seismic reflection data. Approximately 2400 water wells were located and used in this study to make geologic and hydrogeologic interpretations. Copies of the water well logs were obtained from the Watermaster of Washington County in Hillsboro, Oregon and the Oregon Water Resources Department in Salem, Oregon.

Sample Cuttings and Core Descriptions

Descriptions from cores and drill cuttings from exploration bore holes and water wells form the basis of the lithologic characterization of the Willamette Silt and the Neogene sediments. Most of the Neogene sediment section consists of clay and silt mixtures. Determination of the prominent lithology as silty clay or clayey silt was accomplished by examining the sample under a binocular microscope and noting the type of texture in the sample. The "silty clay" samples have a smooth texture infrequently interrupted by silt and very fine sand grains. The "clayey silt" samples exhibit a grainy texture indicative of silt and very fine to fine sand grains. The binocular microscope was also used to distinguish sand units. Interpretations were based on sample texture in which sand grains dominated in the sample.

Grain Size Analyses and Sand and Clay Characterization

Thirty nine samples from HBD-1 (21 sands, 6 silts, and 12 clays) and three sand cores from various Tualatin Valley borings were subjected to standard grain size analysis to characterize the Willamette Silt and the Neogene sediments. Grain size boundaries used in this study are: gravel-sand at 2.0 mm (#10 sieve size), sand-silt at 0.063 mm (#230 sieve size) and silt-clay at 0.002 mm. Details of the procedures are given in Appendix A.

Minerals from 17 stained, Neogene sand grain mounts (14 from HBD-1 and three from core borings in the Tualatin Valley) were identified and point counted for comparative abundances to classify the sands according to Folk (1968).

The clay mineral identification of ten HBD-1 clay and silt units is based on semi-quantitative interpretations of x-ray diffraction characteristic signatures from the coarse clay fraction ($<0.2 \mu\text{m}$) of the samples. Clay mineral identification was done by comparing diffraction peaks on the recordings with standard diffraction patterns from the United States Geological Survey (Chen, 1977). Semi-quantitative analysis to roughly determine relative percentages of clay species was accomplished using the triangle area comparison method of Mann and Fischer (1982).

HBD-1 Synthetic Seismogram

DOGAMI recorded down hole p-wave and s-wave velocities at six foot (two meter) intervals in HBD-1 from the Columbia River basalt at 1095' (333 m) to the surface. HBD-1 is the only boring in the Tualatin Valley with seismic velocities that can be used to correlate Neogene sediment horizons to existing seismic reflection data. The primary wave profile was used in this study to calculate reflection coefficients and generate a synthetic seismogram of HBD-1 to help correlate reflection horizons to and from

seismic reflection data lines that were shot in the Tualatin Valley in 1984. The computer program used is a shareware program from Computer Oriented Geological Society (COGS) obtained from Northwest Natural Gas Company of Portland, Oregon (Jack Meyer, 1995, personal comm.). The process to calculate synthetic seismograms is outlined in Coffeen (1978).

Seismic Reflection Data Lines

Geometries and textures of reflection horizon data were used to interpret depositional styles and suggest modes of structural development, thus providing a good representation of the history of basin fill. Four proprietary seismic reflection data lines shot in the Tualatin Valley in 1984 were obtained from the current owner of the data, Geophysical Pursuit of Houston, Texas. The seismic lines are excellent representative cross-sections of the basin that provide information about the depositional and structural styles in the Neogene sediments.

Subsurface Mapping

Subsurface structure contour and isopach maps were constructed by hand from over 2400 boring and water well stratigraphic descriptions and gamma logs, then digitized into the Rockworks mapping program by Rockware Inc., based in Golden, Colorado, and overlain onto a basemap created with the Rockworks program.

HBD-1 Stratigraphy and Sedimentology

HBD-1, located at the north end of the Hillsboro Regional airport (Figure 15), encountered 945 feet (288m) of fluvial and lacustrine sediment overlying one hundred feet (30.5m) of lateritic soil and weathered basalt of the Columbia River Basalt Group (CRBG). Black, unweathered basalt underlies the weathered zone from 1030' (314m) to a drilled total depth of 1095' (334 m). Figure 13 illustrates an abbreviated form of the

stratigraphic column of HBD-1. A detailed stratigraphic column and the complete lithologic description of the HBD-1 core is found in Appendix B.

General Lithology

Willamette Silt

The Willamette Silt at the site of HBD-1 primarily consists of massive, micaceous, clayey, very fine sandy silt (Figure 16) with scattered layers of silty clay, and some dispersed organic woody material near the base from 75' (23m) to 80' (24m). The formation color changes at 20' (6m) from an oxidizing medium yellow-brown to a reducing blue-gray. The color becomes mottled with blue-gray and light brown in the basal five feet (1.5 m) of the unit. Crude laminations occur in thin sandy stringers at 66' - 67' (20 m) and gravel up to 4-5 mm is scattered about in the basal silt at 80' (24 m).

Neogene Sediments

The underlying Neogene sedimentary material extends from 82' (25m) to 945' (288m) in HBD-1 and consists of at least 20% sand units, 48% silt units and 32% clay units by thickness, although the silt and clay fractions are significant in all lithologies (Table 1). Approximately 10% of the cored section (~90', 27.4 m) was not recovered below 70' (21 m), making the above lithology percentages a minimum for the section. Sand units occur as thin beds ranging from millimeter thick stringers to 12' (3.7 m) thick layers, averaging 3.0' (1m) thick when considering sand layers greater than 0.5' (0.15 m) thick (Table 2). The sands are generally loose to slightly compacted, subangular to rounded, poorly to moderately sorted, clayey, silty, very fine to fine grained, although scattered layers of medium grained to gravelly sands are present (Figures 17 and 18).

Figure 16: HBD-1 core sample of the Willamette Silt from a depth of 35' (10.7 m).
The massive nature of the silt is the predominant texture of this unit.

Table 1: Sand -Silt -Clay content of selected HBD-1 and other boring sediments from the Tualatin Valley.

DEPTH feet (meters)	Lithology	Total Sand %	Total Silt %	Total Clay %
34' (10.4 m)	Silt	0.7	60.2	39.1
73' (22.3 m)	Silt	1.5	59.0	39.5
90' (27.4 m)	Silt	14.1	62.5	23.4
141' (43 m)	Sand	43.7	38.3	18.0
162' (49.4 m)	Silt	8.9	57.8	33.2
166' (50.6 m)	Clay	4.3	32.8	63.0
226' (68.9 m)	Silt	40.5	43.7	15.8
249' (75.9 m)	Clay	0.2	42.0	57.8
300' (91.4 m)	Sand	41.0	40.0	19.0
385' (117.3 m)	Sand	61.7	13.3	25.0
420' (128 m)	Silt	26.1	33.5	40.4
448' (136.6 m)	Sand	43.8	32.3	24.0
484' (147.5 m)	Sand	76.0	21.0	3.0
499' (152.1 m)	Clay	7.5	37.4	55.2
537' (163.7 m)	Sand	59.0	31.9	9.1
565' (172.2 m)	Silt	17.7	57.8	24.6
579' (176.5 m)	Silt	0.3	62.1	37.6
609' 8" (185.8 m)	Sand	53.9	40.9	5.2
632' (192.6 m)	Silt	0.3	85.4	14.4
640' (195.1 m)	Silt	25.9	61.7	12.4
677' (206.3 m)	Clay	4.3	45.3	50.4
683' (208.2 m)	Silt	18.7	44.3	37.0
693' (211.1 m)	Sand	50.4	28.2	21.3
714' (217.6 m)	Sand	61.1	25.0	13.9
734' (223.7 m)	Sand	63.5	25.3	11.2
769' (234.4 m)	Clay	0.0	31.2	68.8
777' (236.8 m)	Clay	2.5	38.9	58.7
833' (253.9 m)	Silt	0.1	54.3	45.6
836' (254.8 m)	Silt	9.4	55.8	34.9
846' (257.9 m)	Silt	20.2	63.3	16.6
877' (267.3 m)	Sand	49.3	36.1	14.6
898' (273.7 m)	Silt	24.1	43.6	32.3
926' (282.2 m)	Clay	1.0	49.2	49.7
929' (283.2 m)	Silt	32.3	51.5	16.2
932' (284.1 m)	Silt	35.9	42.4	21.7
939' (286.2 m)	Clay	0.4	32.1	67.5
EB-1 55' (16.8 m)	Sand	58.9	29.9	11.2
TRB-1 56' (17.1 m)	Sand	71.8	18.2	10.0
BVD-6 55' (16.8 m)	Sand	67.4	20.5	12.2

Table 2: HBD-1 Neogene sand intervals and thicknesses in sand layers one half foot (0.15 m) thick or greater.

<u>TOP OF INTERVAL</u>	<u>THICKNESS</u>	<u>SAND GRAIN SIZE DESCRIPTION</u>
feet (meters)	feet (meters)	
93' (28.3 m)	1' (0.3 m)	SILTY, V. FINE
96' (29.3 m)	13' (4 m)	SILTY, V. FINE
115.5' (35.2 m)	0.5' (0.15 m)	V. FINE TO COARSE
134' (40.8 m)	2.3' (0.7 m)	FINE TO MEDIUM
137' (41.8 m)	1.5' (0.5 m)	FINE TO MEDIUM
140' (42.7 m)	7' (2.1 m)	FINE TO COARSE
148' (45.1 m)	1' (0.3)	V. FINE
157' (47.9 m)	5' (1.5 m)	SILTY, V. FINE TO MEDIUM
167' (50.9 m)	1' (0.3 m)	V. FINE TO FINE
181' (55.2 m)	4' (1.2 m)	V. FINE TO FINE
185' (56.4 m)	1' (0.3 m)	CLAYEY, SILTY, V. FINE TO MEDIUM
188' (57.3 m)	0.5' (0.15 m)	V. FINE
212' (64.6 m)	0.5' (0.15 m)	CLAYEY, SILTY, V. FINE
224' (68.3 m)	5' (1.5 m)	FINE
257' (78.3 m)	5' (1.5 m)	SILTY, V. FINE TO FINE
262' (79.9 m)	2' (0.6 m)	V. FINE TO GRAVELLY
267' (81.4 m)	1' (0.3 m)	CLAYEY, SILTY, V. FINE
298' (90.8 m)	2' (0.6 m)	FINE TO MEDIUM
302.5' (92.2 m)	0.5' (0.15 m)	CLAYEY, SILTY, V. FINE TO V. COARSE
325' (99.1 m)	1' (0.3 m)	SILTY, V. FINE TO FINE
328' (100 m)	2.5' (0.8 m)	V. FINE TO FINE
335.5' (102.3 m)	1.5' (0.5 m)	CLAYEY, SILTY, V. FINE
346' (105.5 m)	2' (0.6 m)	CLAYEY, SILTY, V. FINE TO MEDIUM
380' (115.8 m)	2' (0.6 m)	V. CLAYEY, SILTY, V. FINE TO FINE
382' (116.4 m)	2' (0.6 m)	AS ABOVE WITH GRAVEL
385' (117.3 m)	3' (0.9 m)	SILTY, V. FINE
388.7' (118.5 m)	1.3' (0.4 m)	CLAYEY, SILTY, V. FINE
394' (120.1 m)	3' (0.9 m)	CLAYEY, SILTY, V. FINE TO FINE
398' (121.3 m)	1' (0.3 m)	FINE TO MEDIUM (SL. CLAYEY)
407' (124 m)	4' (1.2 m)	V. FINE TO FINE
411' (125.3 m)	3' (0.9 m)	MEDIUM
414' (126.2 m)	1' (0.3 m)	MEDIUM TO GRAVELLY
437' (133.2 m)	3' (0.9 m)	FINE
440' (134.1 m)	3' (0.9 m)	MEDIUM
443' (135 m)	2' (0.6 m)	COARSE TO GRAVEL
445' (135.6 m)	4' (1.2 m)	FINE TO MEDIUM
455' (138.7 m)	1' (0.3 m)	CLAYEY, SILTY, V. FINE TO FINE
464' (141.4 m)	1' (0.3 m)	CLAYEY, V. FINE TO FINE

Table 2 continued.

<u>TOP OF INTERVAL</u>		<u>THICKNESS</u>	<u>SAND GRAIN SIZE DESCRIPTION</u>
feet (meters)		feet (meters)	
476'	(145.1 m)	4'	(1.2 m) SILTY, V. FINE TO FINE
480'	(146.3 m)	4'	(1.2 m) FINE TO MEDIUM
484'	(147.5 m)	4'	(1.2 m) FINE TO COARSE
517'	(157.6 m)	5'	(1.5 m) CLAYEY, SILTY, V. FINE TO MEDIUM
522'	(159.1 m)	1'	(0.3 m) V. FINE TO V. COARSE
527.5'	(160.8 m)	4'	(1.2 m) V. FINE TO FINE
535'	(163.1 m)	2.5'	(0.8 m) V. FINE TO V. COARSE
539'	(164.3 m)	5'	(1.5 m) CLAYEY, SILTY, V. FINE TO FINE
548'	(167 m)	1'	(0.3 m) CLAYEY, FINE TO MEDIUM
563'	(171.6 m)	1'	(0.3 m) V. FINE TO FINE
565'	(172.2 m)	1'	(0.3 m) MEDIUM TO GRAVELLY
607.5'	(185.2 m)	2.5'	(0.8 m) CLAYEY, MEDIUM TO GRAVELLY
633'	(192.9 m)	1'	(0.3 m) CLAYEY, SILTY, V. FINE TO FINE
639'	(194.8 m)	1.5'	(0.5 m) V. FINE
653'	(199 m)	3'	(0.9 m) CLAYEY, V. FINE TO FINE
656'	(199.9 m)	2'	(0.6 m) MEDIUM
681'	(207.6 m)	3.5'	(1.1 m) CLAYEY, FINE TO MEDIUM
692.7'	(211.1 m)	1.3'	(0.4 m) FINE TO GRAVELLY
711.3'	(216.8 m)	1.2'	(0.4 m) CLAYEY, V. FINE TO FINE
714.5'	(217.8 m)	0.7'	(0.2 m) CLAYEY, V. FINE TO FINE
730.3'	(222.6 m)	1.2'	(0.4 m) V. FINE TO FINE
731.5'	(223 m)	4.5'	(1.4 m) MEDIUM TO SL. GRAVELLY
751.4'	(229 m)	1.6'	(0.5 m) CLAYEY, SILTY, V. FINE
760.3'	(231.7 m)	1.2'	(0.4 m) FINE TO MEDIUM - CEMENTED
796.5'	(242.8 m)	2.5'	(0.8 m) CLAYEY, SILTY, V. FINE TO FINE
808.5'	(246.4 m)	2.5'	(0.8 m) CLAYEY, V. FINE TO FINE
848.5'	(258.6 m)	0.9'	(0.3 m) SILTY, V. FINE TO COARSE
873'	(266.1 m)	0.3'	(0.1 m) CLAYEY, V. FINE TO FINE
873.3'	(266.1 m)	1.7'	(0.5 m) MEDIUM
875'	(266.7 m)	1'	(0.3 m) MEDIUM TO GRAVELLY
877'	(267.3 m)	2.2'	(0.7 m) CLAYEY, SILTY, V. FINE TO FINE
897'	(273.4 m)	1.2'	(0.4 m) CLAYEY, SILTY, V. FINE TO FINE
927'	(282.5 m)	2.7'	(0.8 m) CLAYEY, V. FINE TO FINE
930.6'	(283.6 m)	5.4'	(1.6 m) CLAYEY, SILTY, V. FINE
TOTAL THICKNESS		73.2' (52.8 m)	Boxed intervals indicate fining upward sequences within the sand units.
AVE. THICKNESS		3' (0.9 m)	
SD		2.9' (0.9 m)	
% OF SEDIMENT		20.3	

CLAY - 269' (82 m) OR 31.5% OF THE SEDIMENTS

SILT - 412.8' (125.8 m) OR 48.2% OF THE SEDIMENTS

(Silt includes apprx. 49' of unrecovered core in top 70'.)

APPROX. 90' NOT RECOVERED BELOW 70' DEPTH

TOTAL CORE RECOVERY APPROX. 85.2%

Figure 17: HBD-1 core sample of a Neogene sediment sand from a depth of 683' (208.2 m). This silty, clayey, very fine sand is typical of most sands in the Neogene sediment section.

The sand constituents include lithic fragments (mostly weathered basaltic grains), plagioclase and potassium feldspars, quartz, micas, and a variety of heavy minerals. Some form of mica is almost ubiquitous throughout the Neogene sediments.

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. Very fine sand grains are present in most of the silts and a few of the clays. 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- to non- 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 microlaminations, low angle cross-laminations, and possible burrow structures (Figures 19 and 20). Wood debris is present in small amounts throughout the section; however, a one inch thick plug of wood was cored at 522' (159 m). The coloration of the sediments ranges from blue gray to various shades of gray and/or brown which may be dependent on post depositional subsurface conditions. The section from approximately 500' (152 m) down to 890' (271 m) is peppered with the iron phosphate mineral, vivianite. The mineral dominantly occurs as a microcrystalline powder in small nodules; however, there are two known depths (499' (152 m) and 663' (201.5 m)) in which crystals up to a millimeter in length line fracture surfaces (Figures 21 and 22).

A diatomaceous zone from 715' (218 m) to 734' (224 m) consists mostly of a blue gray, micaceous, silty clay (Figure 23) containing the iron phosphate mineral, vivianite. A thin very fine to fine sand stringer occurs at 716' (218 m) and a two feet thick, low

Figure 19: HBD-1 core sample of a low-angle, cross-bedded, fine to medium Neogene sediment sand from a depth of 141' (43 m). Iron oxide staining parallels the cross laminations.

Figure 20: HBD-1 core sample of either root or burrow structures in a clayey, silty, fine grained Neogene sediment sand from a depth of 693' (211.2m).

Figure 21: A 6 mm powdery, oxidized vivianite nodule in a clayey silt from sample HBD-1 848' (258 m). These powdery nodules are common below 500' (152 m) in this boring.

Figure 22: Vivianite crystals in vugs surrounded by clayey silt from a depth of 491' (150 m) in HBD-1. The crystalline cavity is approximately 7 mm across.

Figure 23: Diatomaceous, laminated silty clay from a depth of 721' (219.8 m) in HBD-1. Freshly exposed samples exhibit gray-brown coloration with alternating gray-green laminae.

Figure 24: Moderately indurated, silica cemented, cross-bedded Neogene sandstone from a depth of 761.5' to 762' (232 m) in HBD-1.

density claystone of alternating brown and green-gray laminations is present at 725'-727' (221-221.5 m). Diatoms also occur in less abundance in a very fine sand from 730' (222.5 m) to 734' (224 m). Aulacosira canadensis is the predominant species present in the section (Edward Theriot, 1995, written comm.). No other units in the entire section have been recognized as containing diatoms. The interval between 715'-730' (218-222.5 m) is interpreted as a lacustrine deposit bounded above and below by fluvial sediments.

A green-gray, well indurated, silicified, 6 inch thick mudstone, encountered at 760' (231.5 m), is underlain by eight feet (2.5 m) of somewhat less indurated, friable siltstone, and very fine sandstone (Figure 24). The mudstone and underlying siltstone containing highly contorted laminae, rippled claystone lenses, cross-bedding, and organic debris are indicative of active stream conditions.

The section underlying the silicified zone down to the lateritic soil of the Columbia River basalt is essentially similar to most of the Neogene sediments above the silicified zone, but with fewer sand units. There is a unique one foot (30.5 cm) thick conglomeratic layer at 930' (283.5 m) consisting of rounded, highly weathered, red-brown basalt gravel in a white, siliceous cement (Figure 25). Red-brown, clayey, silty, very fine sand extends almost six feet (1.8 m) below the conglomerate. Three feet (1 m) of medium brown, cross-laminated, clayey silt (936' - 939' (285 - 286 m)) and five feet (1.7 m) of brown-gray, silty clay with red-brown clay clasts and 1mm diameter weathered basalt nodules (939' - 944' (286 - 288 m)) underlie the sand. This zone has a sharp lower boundary at 945' (288 m) with the lateritic weathered zone of the CRBG.

Figure 25: Red-brown, clayey, silty, very fine grained sand and gray-brown, clayey silt units below the conglomerate layer. The boxed section ranges in depth from 929' (283.1 m) at the upper left to 939' (286.2 m) at the lower right.

Figure 26: Columbia River basalt lateritic soil from a depth of 946' (288.3 m) in HBD-1. The soil is characterized by a deep red-brown hue and by highly weathered basalt nodules approximately 4 to 5 mm across.

Columbia River Basalt Group

Lateritic Weathered Zone

The underlying red-brown lateritic weathered zone of the CRB is 85' (26 m) thick and consists of lateritic soil from 945' (288 m) to 1010' (308 m) composed of rounded, highly weathered, pisolitic basalt nodules and more irregularly shaped, gravel sized weathered basalt in a clay matrix (Figure 26). The color of the clay matrix becomes highly variegated (red, ochre, light blue gray, yellow, and gray brown) at 954' (291 m) and shifts to medium gray, ochre, and red brown at 961' (293 m). Highly weathered basalt zones gradually become more common with depth (Figure 27). 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 1010' (308 m) and continues to 1030' (314 m).

Basalt Texture and Age

Black, hard, fine-grained basalt underlies the weathered basalt at 1030' (314 m) and continues downward to total depth of the test hole. The rock is extremely difficult to core. The average core rate in this boring was about 1.5 inches per hour. Elemental signatures from XRF data on samples of this basalt suggest that the unit is part of the Frenchman's 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, 1993, personal comm.). Beeson et al. (1985) describe the Frenchman Springs Member as having a characteristic plagioclase-phyric texture and is chemically distinctive from the surrounding basalt units. The estimated age of the Frenchman's Springs Member is approximately 15 million years before present (Beeson et al., 1989a).

Figure 27: Weathered Columbia River basalt from a depth of 1002' (305.4 m) in HBD-1. The black areas consist of less altered basaltic material.

Sand Unit Distribution

The Neogene sediments can roughly be divided into upper and lower units based on the percentage of sand present. Almost 62% of the cumulative sand unit thicknesses in HBD-1 is in the top 488' (149 m) of the Neogene section with 24% of the total thickness of sand units occurring from 91' (28 m) to 189' (58 m) (Figure 28). The 400' (122m) to 500' (152.5m) interval contains sand beds up to 12' (3.7m) thick arranged in three distinct fining upward sequences (Table 2). Seven to ten sand fining upward sequences are recognized in the upper unit. More units may be interpreted as fining upward when considering an upward trending sand-silt-clay sequence. They are scattered throughout this interval and range from 8' to 29' (2.4 - 8.8 m) thick from basal sand to clay top (Table 2). The bottom sands in most sequences are predominated by medium sand mixed with fine sand, silt, and clay. Some of the basal sands have associated gravel, mostly in the form of weathered, basaltic rock fragments. Thin clay drapes are present on top of some fining upward sand units (Figure 29). The color of the sands is generally blue-gray reflecting reducing conditions; however, light brown to dusky brown coloration can range from a fraction to the entire sand.

Only 46' (14.6m) of cumulative sand units (26% of the total sand) exist below 600' (183m) with beds up to 6' (1.8m) thick, averaging 2' - 3' (< 1m) thick. Four sand to clay fining upward sequences 4' to 17' (1- 6 m) thick are widely spaced apart in this interval (Table 2). 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.

Figure 28: Percent sand beds of the total Neogene sediment section in the HBD-1 core test. Sand units are much more common in the upper 500' to 600' (152-183 m) of the section than below.

Figure 29: Clay drape overlying clayey, silty, very fine to fine grained sand from a depth of 412' (125.6 m) in HBD-1.

Sediment Characterization

Sediment Texture

The sediments of the Neogene section and Willamette Silt are poorly sorted and range from silty sands to muds (Figure 30) as classified by Folk (1968). Each of the sediment types contains a wide mix of grain sizes. Silt and clay are present in all samples, while very fine sand is present in all but the finest clays. The sand units contain significant quantities of silt and clay (Table 1), while the silt units contain up to 11% very fine sand and 8% fine sand along with up to 33% clay fraction (Appendix C). The clay units analyzed contain from 0% to 7.5% very fine sand and as much as 50% silt. No investigated sample contains more than 69% clay, so many of the clays and silts plot in the mud region of the ternary diagram (Figure 30).

The Pleistocene Portland Hills Silt, which forms a veneer over the CRBG in the Portland Hills, Tualatin Mountains, and part of the Chehalem Mountain region, plots in the silt region on the ternary diagram in Figure 30 (Lentz, 1977). The average sand, silt, and clay content of the Portland Hills Silt are 4.9%, 77.2%, and 18.9%, respectively (Lentz, 1977). The eolian nature of the sediment may be responsible for the uniform silt composition, as opposed to the fluvial nature of the Neogene sediments.

Sand Petrology

Grain Size Analysis

The sand samples of the Neogene section are micaceous, subangular to subround, loose to moderately compacted, moderately to poorly sorted, medium to v. fine grained, lithic arenites, containing significant quantities of silt and clay (Table 1). Several sands contain gravel and/or wood debris. They plot in the silty sand, muddy sand, sandy silt,

Figure 30: Sediment classification of HBD-1 samples based on sand-silt-clay ratios. Silt is present in virtually all samples and all sands fall into the silty or muddy sand categories. Portland Hills Silt region is from Lentz (1977) and classification scheme is after Folk (1968).

and sandy mud regions of Folk's (1968) sediment size classification and nomenclature ternary diagram (Figure 30). The average percentages of sand, silt, and clay in the sand unit samples are 54.9% (SD=11.5%), 30.4% (SD=9.0%), and 14.7% (SD=6.3%), respectively.

Table 3 summarizes sample statistical size parameters calculated from Folk's (1968) graphic methods. The mean grain size (M_z) from each of the sand samples ranges from 2.6 ϕ to 5.5 ϕ , reflecting the silt levels in the sediments. The graphic standard deviation (σ_i) indicates that the samples are poor ($\sigma_i = 1.6$) to very poorly sorted ($\sigma_i = 3.7$). The consistent presence of silt and clay in the sands is displayed in the dominantly "strongly fine-skewed" curve values averaging 0.4 SK_i (Table 3). Only one measured sand unit, HBD-1 610', falls in the "near-symmetrical" range.

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 (Figure 31). Sedimentary rock fragments in the form of polyquartz grains were the only other lithic type noted in the samples. The lithic fraction ranges between 27% and 79%, averaging 49% of the total sand (Table 4).

Plagioclase is the dominant group in the feldspar family, ranging from 7% to 34% and averaging 21% of the total sand. K-feldspar is a minor constituent averaging 3% and ranges from 0% to 6%. No attempt was made to subdivide the plagioclase types based on the An - Ab ratio.

The total sand sample range for quartz is 8% to 27%, averaging 14%. Monoquartz grains, at an average of 76% of total quartz, dominate over polyquartz fragments. The

Table 3: Grain size distribution for HBD-1 , recent streams, and selected boring sands. Statistical data given on next page.

<u>Depth</u>	<u>Sand%</u>	<u>Silt%</u>	<u>Clay%</u>
141' (43 m)	43.7	38.3	18.0
226' (68.9 m)	40.5	43.7	15.8
300' (91.4 m)	41.0	40.0	19.0
385' (117.3 m)	61.7	13.3	25.0
448' (136.6 m)	43.8	32.3	24.0
484' (147.5 m)	76.0	21.0	3.0
537' (163.7 m)	59.0	31.9	9.1
610' (185.9 m)	53.9	40.9	5.2
693' (211.1 m)	50.4	28.2	21.3
714' (217.6 m)	61.1	25.0	13.9
734' (223.7 m)	63.5	25.3	11.2
877' (267.3 m)	49.3	36.1	14.6
932' (284.1 m)	35.9	42.4	21.7
TRB-1 55' (16.8 m)	71.8	18.2	10.1
BVD-6 55' (16.8 m)	67.4	20.5	12.2
EB-1 56' (17.1 m)	58.9	29.9	11.2
AVG	54.9	30.4	14.7
STD	11.5	9.0	6.3
VAR	133.4	81.9	39.1

Recent Stream Sediments

	<u>Total Sand %</u>
WFDC	84.5
Tualatin River	94.4
EFDC	93.6
McFee Cr.	22.6
Gales Cr.	87.4
McKay Cr.	46.4
Rock Cr.	10.6
AVG	62.8

Tualatin Valley Sands

	<u>Total Sand%</u>
EB-1(55')	58.9
TRB-1 (56')	71.8
BVD-6 (55')	67.4
Leis. (338')	98.3
Scholl (85-90')	73.4
AVG	73.9

Table: 3 continued.

Depth	Graphical Mean	Graphical SD	Graph. Skewness	Phi size for the given cumulative percentages				
	phi size	phi size	SKi	5%	16%	50%	84%	95%
141' (43 m)	5.0	3.0	0.4	1.5	2.3	4.2	8.6	11
226' (68.9 m)	4.9	2.7	0.5	2.0	2.6	4.2	8.0	11
300' (91.4 m)	5.5	3.3	0.4	1.2	2.3	4.6	9.7	11
385' (117.3 m)	4.7	3.3	0.7	1.3	2.0	3.0	9.2	11
448' (136.6 m)	5.5	3.7	0.4	1.2	1.7	4.4	10.5	11
484' (147.5 m)	2.6	1.6	0.4	0.5	1.2	2.1	4.5	5.6
537' (163.7 m)	3.7	2.7	0.3	0.3	1.4	3.4	6.4	9.9
610' (185.9 m)	3.0	2.4	-0.1	-0.3	0.6	3.4	5.0	8
693' (211.1 m)	5.2	3.3	0.4	1.1	2.1	4.0	9.4	11
714' (217.6 m)	4.0	2.9	0.6	1.2	1.6	3.0	7.4	11
734' (223.7 m)	3.7	2.7	0.6	1.2	1.8	2.9	6.5	11
877' (267.3 m)	4.8	2.6	0.5	2.2	2.6	4.0	7.7	11
932' (284.1 m)	5.1	2.9	0.3	1.4	2.6	4.6	8.3	11
TRB-1 55' (16.8 m)	3.7	2.2	0.7	2.1	2.3	3.1	5.7	11
BVD-6 55' (16.8 m)	3.2	2.6	0.5	0.9	1.3	2.6	5.8	11
EB-1 56' (17.1 m)	3.5	2.2	0.3	1.4	2.1	3.4	5.0	11
	4.3	2.8	0.4					
	AVE.	AVE.	AVE.

Figure 31: Photomicrograph of #120 mesh sand grains from HBD-1 484' (147.5 m). The sand is dominated by basaltic lithic fragments (dark brown) with subordinate amounts of plagioclase (red stained) and potassium (yellow-green) feldspars and quartz (clear). 10x objective

Table 4: Sand mineral composition for HBD-1 and other boring samples in the Tualatin Valley.
Sands are dominated by lithic basalt fragments and plagioclase feldspar.

Sample	Total Count	Plagioclase %	K-feldspar %	Qm %*	Qp %*	Lithic Fragment %
141' (43 m) #120	500	22.2	5.8	12.4	2.8	46.4
226' (68.9 m) #230	540	34.1	2.8	13.1	1.7	39.4
226' (68.9 m) #120	520	30.6	2.7	4.4	3.3	52.3
300' (91.4 m) #120	542	21.0	6.5	11.4	2.6	54.6
385' (117.3 m) #120	518	27.2	5.2	14.3	5.8	39.8
484' (136.6 m) #120	516	8.5	6.0	13.0	4.8	59.3
537" (163.7 m) #120	548	21.9	5.7	10.4	3.1	48.5
610' (185.9 m) #230	518	7.3	1.4	2.5	1.4	78.8
683' (208.2 m) #230	530	12.8	0.0	26.2	2.1	53.6
734' (223.7 m) #120	557	25.5	5.6	21.4	5.9	37.7
846' (257.9 m) #120	529	11.9	1.1	7.8	2.8	70.9
877' (267.3 m) #120	557	18.0	2.2	13.3	4.3	56.6
877' (267.3 m) #230	520	24.8	2.1	17.3	3.8	45.8
929' (283.2 m) #230	540	23.0	1.3	27.4	1.7	41.5
TRB-1 55' (16.8 m) #120	548	20.1	1.1	14.6	0.7	40.5
BVD-6 60' (18.3 m) #120	532	25.2	1.1	8.3	3.0	43.4
Leisigang 338' (103 m) #120	576	20.5	6.6	22.6	4.7	26.9
	Average	20.9	3.4	14.1	3.2	49.2
	SD	7.1	2.2	6.8	1.5	12.3

* Qm = Monocrystalline Quartz

Qp = Polycrystalline Quartz

Table 4 continued

Sample	Total QuarfTotal Lithic Fragement					
	Mica %	Opagues %	Heavies %	Qm+Qp %	Qp+L %	Q/(F+L) %
141' (43 m)	4.2	4.6	2.0	0.0	0.0	0.2
226' (68.9 m)	3.7	3.1	3.0	0.0	0.0	0.2
226' (68.9 m)	5.2	0.8	0.8	0.0	0.0	0.1
300' (91.4 m)	1.7	2.4	0.0	0.0	0.0	0.1
385' (117.3 m)	4.1	3.5	0.4	0.0	0.0	0.2
484' (136.6 m)	4.1	3.9	0.4	0.0	0.0	0.2
537" (163.7 m)	4.9	4.6	0.9	0.0	0.0	0.1
610' (185.9 m)	2.3	6.6	0.8	0.0	0.0	0.0
683' (208.2 m)	0.4	4.7	0.9	0.0	0.0	0.4
734' (223.7 m)	2.9	1.1	0.2	0.0	0.0	0.3
846' (257.9 m)	2.8	0.8	2.3	0.0	0.0	0.1
877' (267.3 m)	3.6	2.2	0.5	0.0	0.0	0.2
877' (267.3 m)	1.7	4.8	1.7	0.0	0.0	0.2
929' (283.2 m)	1.7	3.5	1.1	0.0	0.0	0.4
TRB-1 55' (16.8 m)	0.7	3.8	16.2	0.0	0.0	0.2
BVD-6 60' (18.3 m)	5.8	2.6	10.9	0.0	0.0	0.1
Leisigang 338' (103 m)	1.2	6.4	11.1	0.0	0.0	0.4
Average	3.0	3.5	1.1	0.0	0.0	0.2
SD	1.6	1.7	4.6	0.0	0.0	0.1
For HBD-1 Samples						

polyquartz grains average 3% of the total sample and are considered as sedimentary rock fragments. Most of the monoquartz grains exhibited smooth extinction and clear, unfractured surfaces (Figure 32).

The Neogene sediment sands plot in the feldspathic litharenite to litharenite regions (Figure 33) according to Folk's classification (Folk, 1968). The quartz to total feldspar ratios usually fall between 1:1 and 1:2, and plagioclase is always dominant over K-feldspar, which is consistent with other fore-arc sand compositions of the circum-Pacific region (Dickinson, 1982). Northern Coast Range Paleogene marine sands of the Spencer, Cowlitz, Keasey, and Scappoose Formations (Al-Azzaby, 1980; Cunderla, 1986; Van Atta, 1971; Timmons, 1981; and Ketrenos, 1986) range from dominantly arkose and lithic arkose to litharenite (Figure 33). All of these formations are found in the current Tualatin Valley watershed and may have contributed sediments to the Neogene section in the Tualatin Valley. The differences in classification between the Paleogene and Neogene sediments may be the contribution of CRBG and Tillamook Volcanic Series rock fragments to the Neogene sediment package.

The Neogene sands are texturally immature as they contain more than 5% clay matrix, exhibit poor to very poor sorting, and include angular grain shapes (Folk, 1968). Sand maturity is also gauged by the ratio of quartz to the sum of feldspar and lithic fragments ($Q/(F+L)$) in the sand (Pettijohn, 1975). Quartz is usually the end product of a mature sand, hence the higher the $Q/(F+L)$ ratio, the more mature is the sand (Folk, 1968). The sands in the Neogene sediments have a mean maturity index of 0.21 (Table 4), indicating they are very immature sands as prescribed by Pettijohn (1975). Sandstones of the Cowlitz Formation and lower Keasey Formation have a mean maturity index of 0.83, while sandstones of the uppermost Pittsburg Bluff Formation

Figure 32: Photomicrograph of #120 mesh sand grains under cross-nicols from HBD-1 141' (43 m). White, smooth grains are quartz. Polycrystalline quartz grains occur just right of center in the photo. The dark brown grains are basaltic lithic fragments. 10x objective

and the Scappoose Formation have maturity indices average 0.26 and 0.58, respectively (Van Atta, 1980). The case of the latter two is influenced by abundant volcanic glass in the sandstones. Glass was not noted in the Neogene sands. The immature nature of the sands suggests they accumulated in a lower energy environment free from turbulent current action that could cause winnowing and sorting of the sands (Folk, 1968). Floodplain or small, low gradient stream deposition may be suitable depositional environments in the case of the HBD-1 sands.

Accessory Minerals

The HBD-1 sand samples average 3% each of mica and opaque minerals, and 1% heavy minerals (Table 4). Mica minerals are ubiquitous throughout the entire Neogene sediment section in the Tualatin Valley. The size distribution of mica ranges from coarse sand to silt. Microscopic observations during this study have recognized clear to yellow muscovite and brown to green biotite throughout the Neogene sequence. Rocks of the Spencer Formation contain mica values up to 11% (Van Atta, 1980). Micas are common throughout the Paleogene sediments (Cunderla, 1986; Van Atta and Thoms, 1993; and Van Atta, 1971). The three samples from TRB-1 55', BVD-6 60', and Leisigang well 338' display high levels of heavy minerals. Augite is the main heavy mineral in TRB-1 and BVD-6, and hornblende is dominant in the Leisigang sample.

Opaque minerals and rock fragments were included in the point counts for only two of the HBD-1 samples (Appendix E). Opaque minerals were prominent in most of the samples, but were deemed not essential in determining provenance of the sands. The more common minerals present in the samples include augite, clinozoisite, epidote, garnet, hornblende, and zircon. Minor to trace amounts of actinolite, diopside, enstatite, hypersthene, kyanite, and several unidentifiable silicate minerals are present in the Neogene sediments and from Recent stream sediments.

Clay Mineralogy

Neogene clay and silt sediments from HBD-1 contain variable amounts of smectite, kaolinite and illite clay (Table 5). Smectite is the dominant clay mineral in most samples analyzed, ranging up to 90% relative abundance of the clay minerals. The tendency of the clays to swell when wet supports the presence of smectite. The preponderance of smectite is indicative of a volcanic influence; however, Caldwell (1993) and Cunderla (1986) 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 note becomes important when considering provenance of the sediments.

Table 5: Semiquantitative relative clay mineral percentages from HBD-1 silts and clays. Smectite or kaolinite may dominate the sediments.

<u>Depth</u>	<u>Lithology</u>	<u>Smectite</u>	<u>Kaolinite</u>	<u>Illite</u>
34' (10.4 m)	Silt	50	30	20
166' (50.6 m)	Clay	90	10	0
249' (75.9 m)	Clay	70	20	10
313' (95.4 m)	Clay	80	5	15
352' (107.3 m)	Clay	90	10	0
545' (166.1 m)	Silt	10	50	40
710' (216.4 m)	Clay	30	60	10
769' (234.4 m)	Clay	90	5	5
859' (261.8 m)	Clay	90	10	0
910' (277.4 m)	Clay	75	20	5
942' (287.1 m)	Clay	0	90	10

Kaolinite dominated the clay fraction in 27% of the samples tested and may reach significant percentages, composing 90% of the clay minerals in the clayey silt at 942'

(287 m) in HBD-1. This sample lies within the 930' (283 m) to 945' (288 m) red brown to gray brown clayey silt to silty clay zone that overlies 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% relative abundance in most samples, although the clayey silt at 545' (166 m) roughly contains 40% illite.

The clay fraction of a Willamette Silt sample collected 34' (10 m) downhole in HBD-1 contains 50% smectite, 30% kaolinite and 20% illite/micas. These values can be compared with two older alluvium clay samples (Willamette Silt) collected from water well cuttings in the Dallas-Monmouth area (Caldwell, 1993). A brown clay collected at a depth of 14' (4.3 m) consisted of 29% smectite, 26% vermiculite, 18% each of kaolinite and illite, and 7% expandable mixed layered (kaolinite/smectite) clays in the clay fraction. A blue clay and silt sampled between depths of 54' (16.5 m) and 77' (23.5 m) was composed of 73% smectite, 14% kaolinite, 10% expandable mixed layered clays, and 3% illite.

The HBD-1 clay mineral samples were extracted from clay and silt units that exhibit different textural properties concerning their density and plasticity (Appendix D). 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

Exposures

Outcrops of the upper Neogene sediment section are almost nonexistent due to the incompetent nature of the sediments to form gentle slopes and to the almost complete cover by the Willamette Silt in the lowlands and the Portland Hills Silt in the uplands. Both silt deposits form extensive soil horizons, and the region's soggy climate leads to heavy vegetation cover almost everywhere. Outcrops of any sedimentary material are restricted to river cuts in the Tualatin River channel and to excavations during roadway and building construction. The surrounding highlands usually exhibit only cliff-forming basalt outcrops of either the Boring Lava or CRBG.

Two Willamette Silt exposures were investigated during this study: a short series of cutbank exposures along the Tualatin River in Sec. 21, T1S R2W, approximately two miles (3.2 km) south of Hillsboro, Oregon (Figure 34), and a temporary construction exposure for a Price- COSTCO outlet on the south side of U.S Hwy 99W, just east of Oregon State Hwy 217, in Sec. 36, T1S R1W in Tigard, Oregon (Figure 35). The Tualatin River exposures consist of 5 to 10 feet (2-3 m) tall cutbanks composed of uniform moderate yellow brown, micaceous, very fine sandy, clayey silt (Figure 36). One exposure just above river mile 35 (10.7 km) lies on the south side of an almost 180 degree meander in which the south flowing river turns to the north. This cutbank is approximately 10' (3 m) tall and contains a debris channel two feet thick (0.8 m) at its thickest point and about 17 feet (5 m) wide (Figure 37). The channel fill consists of basalt cobbles in a muddy matrix. The channel is only exposed during Tualatin River low water stages. The existence of the scour and fill sequence suggests a break in the silt deposits and supports the notion that there were multiple late Pleistocene catastrophic flood events into the Tualatin Valley. The river turns south again almost a

Figure 34: Willamette Silt cutbank exposures (labeled) along the Tualatin River south of Hillsboro, Oregon in NE1/4 of Sec. 21, T1S R2W.

Figure 35: COSTCO construction exposure of Willamette SILT and underlying Neogene sediments in Tigard, Oregon, SW1/4 of Sec. 36, T1S R1W.

Figure 36: Willamette Silt exposure along the southeast bank of the Tualatin River in the NE1/4 of Sec. 21, T1S R2W.

Figure 37: Willamette Silt exposure with a two feet (0.8 m) thick, 17 feet (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.

quarter mile (0.4 km) below river mile 35 (Figure 34). The 30' (9 m) high, vegetated, west cutbank slope at the turn has an approximately 50' (15 m) wide talus cover of basalt cobbles and clayey silt; however, there is no distinctive channel or outcrop. The two areas containing basalt cobbles roughly line up with Cooper Mountain to the southeast, although the small basalt hills to the southwest are also possible sources of the basalt cobbles.

The temporary construction exposure just off Hwy 99W in Tigard, Oregon consisted of a 15-20 feet (4.6-6.1 m) thick section of light yellow brown, massive, Willamette Silt overlying approximately 20'-25' (6-7.6 m) of interbedded clay, silt, and very fine sand of the upper most Neogene (Figure 38). The Willamette Silt exhibits little structure within the unit. Occasional shallow channel-like scours are apparent at the contact with the Neogene. The Neogene sediments display a colorful and complex depositional style typical of fluvial environments (Figure 39) and a post depositional feature of interest, vertical silt dikes. Much of the section contains iron oxide staining and banding. Several sand lenses containing basaltic gravel are partially indurated and heavily stained with iron oxides (Figure 40). Individual layers or laminae in the Neogene section pinch out in a short distance, and none are continuous across the 300' (91 m) long exposure. Thin, fining upward sequences of sand to silty clay occur at the exposure. The Neogene unit lies horizontal to subhorizontal, although a pebble zone in the middle of the Neogene exposure demonstrates a slight apparent dip to the northeast (Figure 41). This area of the exposure may contain a low-angle reverse fault (Ian Madin, 1996, personal comm.)

Vertical to steeply dipping sandy silt dikes approximately one to two inches (up to 5 cm) in width shoot through the Neogene sediments and extend into the overlying Willamette Silt (Figure 42). The dikes generally trend north - south and

Figure 38: Willamette Silt and Neogene sediment exposure at the temporary COSTCO construction site in Tigard, Oregon, SW1/4 of Sec. 36, T1S R1W. The buff colored, massive Willamette Silt (WS) noticeably contrasts with the underlying iron oxide stained, laminated, Neogene (NEO) silts and sands.

Figure 39: Interlayered clayey, silty, very fine-grained sands and clayey silts in the Neogene sediments at the COSTCO construction exposure in Tigard, Oregon. Most individual beds do not extend laterally over any great distance. The pencil is almost 5.75" (14.6 cm) long.

Figure 40: Partially indurated iron oxide stained, gravelly, clayey silt zone in the Neogene sediment section of the COSTCO construction site in Tigard, Oregon. The bottom of the 5.75' (14.6 cm) long pencil lies next to a possible low-angle reverse fault.

Figure 41: Iron oxide staining and chemical fronts in the Neogene sediments incorrectly give the appearance of steeply dipping strata at the COSTCO construction site. A pebble zone represented by the dark brown lenses at the lower left of the photo may occur next to a low angle reverse fault (Madin, 1996, personal comm.).

Figure 42: A 2" (5 cm) silt to very fine sand dike in the Neogene (NEO) sediments and into the overlying Willamette Silt (WS) at the COSTCO construction site.

contain micaceous, massive, clayey silt. The dikes traverse irregular upward paths and most likely follow fracture zones as there is no apparent displacement of sediment units on either side of the dikes. The top of one dike that extends into the Willamette Silt expands into an irregular shape several inches across suggesting the flood silt was still water saturated and unable to confine the sandy silt dike as did the underlying Neogene sediments (Figure 43). The dikes probably result from liquification of an underlying sandy silt unit during ground shaking sometime after deposition of the catastrophic flood silts. This indicates that this part of the Tualatin Valley was seismically active 12,000 to 15,000 years before present.

Other series of Neogene sediment exposures were created during the construction phase of the Tri-Met westside light-rail tunnel system through Sylvan Hill in the Tualatin Mountain -Portland Hills region. These sediments occur west of the summit at Sylvan at elevations from approximately 400' to 600' (122-182 m) and overlay lava flows of the Frenchman Springs Member of the Wanapum CRBG (Figure 44). There are two main sections of exposed Neogene sediments. The main occurrence of Neogene sediments in the tunnel system extends from 3800' to 4200' (1158-1280 m) from the west tunnel portal. The sediments in this zone were exposed in both tunnels and consist of two distinctive facies, a stratified unit unconformably overlying a massive unit. The exposure of the underlying massive unit is approximately 10' to 15' (3-4.6 m) thick. The sediments consist of yellow brown to light gray, micaceous, clayey silts that represent loess deposits (Figure 45). Orange to red-brown iron oxides stand out as leisigang bands or as medium to coarse sand-sized concretionary nodules.

The boundary between the two units follows an irregular (Figure 45), concave geometry suggesting that the overlying stratified sediments are part of a channel cut and fill deposit. The stratified sediments are dominantly yellow brown, micaceous, clayey

Figure 43: Close up of the silt/sand dike shown in Figure 42 depicting the dike shape change from narrow and nearly linear to wide and irregular as it enters the Willamette Silt from the underlying Neogene sediments.

Figure 44: Schematic geologic cross-section below Sylvan depicting the Tri-Met westside light-rail tunnel alignment. Boring Lava and Pleistocene loess deposits on the west side of the section give way to CRBG lava flows towards the east. Neogene sediments (TQps) are sandwiched between the Boring Lava and CRBG. (Modified from an unpublished 1993 Squier Associates contract report to Tri-Met).

Figure 45: Contact between stratified and massive Neogene sediments in the westbound Tri-Met light-rail tunnel along Hwy 26 approximately 4000' (1220 m) from the west portal. The gray-brown massive unit is composed of clayey silt with scattered iron oxide concentrations. The water-laid stratified unit contains clayey, sandy silts with occasional interbedded gravelly sand layers.

Figure 46: Ripples and subparallel layering of the stratified Neogene sediments in the Tri-Met light-rail tunnel along Hwy 26. Cross-bedding and disturbed laminae are also present in this section.

silts with subordinate clayey, silty, sand and gravelly sand layers. These deposits may be the result of reworking of the underlying massive sediments with intermixed basaltic material from the CRBG. Most of the larger clasts in the stratified sediments are weathered CRBG. Sedimentary structures exhibited are subparallel, thin layered, small scale fining upward sequences, some with gravelly bases, small scale plane cross-bedding, and ripple marks (Figure 46). Normal microfaults are present in the sediments near middle of the exposure interval (Figure 47), and the contact of the two units is displaced a few feet upward to the east between two successive exposures separated by three feet (1 m) of shotcrete.

The eastbound tunnel contains red-brown, micaceous, clayey silts in the massive unit. These red-brown silts are unconformably overlain by a poorly sorted, silty, gravelly, sand that represents the base of the stratified unit (Figure 48).

The Neogene sediments in the Tri-Met tunnel are bounded at the top by a magnetically reversed, 960,000 year old Boring Lava flow (Conrey et al., 1996; Figure 49). The units surrounding the Neogene sediments bracket its time span between 12 and 0.96 million years b. p. The most likely time interval for the loess deposition is between 2.6 and 0.96 million years b. p., corresponding to glaciated episodes of the Pleistocene Epoch (Easterbrook, 1993).

The other exposure of Neogene sediments in the tunnel occurs around 3300' (1005 m) from the west tunnel portal in a fault zone in which CRBG underlying the sediments is locally thrust eastward over younger sediments and a 960,000 years b. p. paleomagnetically reversed Boring Lava flow. Vertical and subhorizontal slickensides in this faulted section also indicate shear components. The Neogene sediments and the CRBG are overturned at an approximate angle of 130° to normal orientation over a distance of 30' (9 m) west of the fault (Figure 50). The section begins to turn back to

Figure 47: Microfaults in the stratified Neogene sediments in the westbound Tri-Met ligh-rail tunnel along Hwy 26. The faults are normal with displacements of only a few centimeters. The primary fault associated with the microfaults is to the left of the photo and is covered with shotcrete. The schematic diagram below the photo displays the position of the microfaults.

Figure 48: Sharp contact between gravelly, stratified, stream sediments and underlying red-brown, massive, clayey silt in the eastbound Tri-Met light-rail tunnel, approximately 4000' (1220 m) from the west portal.

Figure 49: Contact between the Neogene stratified sediments and an overlying 960,000 year old Boring Lava flow. The top of the stratified section contains gravelly sand beds. Coarse pyroclastic debris comprises the base of the Boring Lava flow. The large gray cobble in the upper right is shotcrete.

Figure 50: Schematic geologic cross-section in the eastbound tunnel of the Tri-Met westside light-rail tunnel alignment exhibiting a shear zone that may correlate with the Oatfield Fault mapped on the Lake Oswego and Portland Quadrangles (Beeson et al., 1989b, 1991). The CRBG and overlying Neogene sediments have been thrust over younger loess sediments (Qphs) and are locally overturned. Subhorizontal slickensides in the sediments indicate possible lateral movement along the fault. Interpretation developed from field notes by Ray Wells, USGS.

normal stratigraphic orientation about 20' (6 m) westward before shotcrete covers the exposure. An 860,000 year old, magnetically normal, Boring Lava flow is present west of this fault zone.

A yellow brown, five feet (1.5 m) thick debris flow of clayey silt containing rounded, cobble and boulder sized, highly weathered CRBG clasts overlies the CRBG. A two to three feet (0.6-0.9 m) thick, gray-brown, micaceous, clayey silt layer with very coarse sand to gravel sized, highly weathered basalt clasts at the base overlies the debris flow. A seven feet (2.1 m) thick debris flow with a similar appearance as the first debris flow overlies the clayey silt bed. Two red-brown, micaceous, clayey silt strata lie above the second debris flow. The contact between the two units is irregular (Figure 51). The stratigraphically younger clayey silt has a brighter red-brown hue and contains light gray, subangular to rounded, gravel sized highly weathered CRBG clasts near the top of the two feet (0.6 m) thick bed. Medium to very coarse sand sized white clasts of volcanic material occur in distinct layers in the mostly massive character of the youngest red-brown clayey silt layer (Figure 52). The exposed thickness of this unit is approximately 20' (6 m).

The observed overturned stratigraphy in the fault zone may result from either compressional forces influencing the development of the Tualatin Mountains - Portland Hills structure or from local rotation and compression of blocks within a larger shear structure. The fault zone is on trend with the Oatfield Fault mapped by Beeson and Madin in the Portland and Lake Oswego Quadrangles (Beeson et al., 1989b, 1990) and may be the same feature as a lineament that appears on recently shot aeromagnetic survey maps (Blakely et al., 1995).

Figure 51: Overturned dark red-brown, clayey silt on top of younger light red-brown, clayey silt in the shear zone (Oatfield Fault ?) of the eastbound tunnel in the Tri-Met westside light-rail tunnel alignment underneath Sylvan.

Figure 52: Vertical gravel layer in Neogene sediment red-brown silty clay to clayey silt approximately 3300' (1005 m) from the west portal of the eastbound Tri-Met tunnel. The Neogene unit is part of an overturned section above the CRBG in a sheared, locally thrust zone, possibly the Oatfield Fault.

Subsurface Information

Core Information

Core samples available for this study were in two forms: 1) three to four and one half inch (7.4-11 cm) diameter, continuous wireline and auger cores from DOGAMI and ODOT; and 2) 1.5 feet long by 1.5 inch (3.7 cm) diameter, standard penetration test (SPT) cores from ODOT, Tri-Met, and private consulting firms. Most of the cores are from the eastern margin of the Tualatin Valley, with the exception of HBD-1 (Figure 53). Stratigraphic sections of selected cored borings are illustrated in Appendix C.

Several shallow DOGAMI cores drilled along Hwy 217 in the eastern part of the Tualatin Valley demonstrated the fluvial nature of the Neogene sediments underlying the Missoula flood deposits. DOGAMI boring BVD-6, located in Tualatin City Park (Sec. 13, T2S R1W), cored through 37' (11.3 m) of sand, gravel, and cobbles of Missoula flood deposits before entering bright blue gray, Neogene, fining upward sequences of sand, silt, and clay with occasional ash laminae (Figure 54). Thin ash lenses were also found in LOD-3 at a depth of 22' (6.7 m) (Figure 55) and in BVD-4 91.4' (27.9 m) below the surface. The LOD-3 boring penetrated 30' (10 m) of Missoula flood sands, 10' (3 m) of Boring Lava, and 160' (48.8 m) of Neogene sediments. BVD-3 at the Washington Square Mall along Hwy 217 (Sec. 6 T1S R1W) encountered the Columbia River Basalt at a depth of 30' (10 m). DOGAMI borings north (BVD-2 and LOD-1) and south (BVD-4 and BVD-5) of BVD-3 did not enter the CRBG, indicating that the BVD-3 site is overlying a basalt high.

DOGAMI drilled one deep test at the Portland International Airport (Sec. 6 T1N R2E) to a total depth of 1523' (464 m) (Figure 13). This boring, known as MTD-1, is used to represent typical Portland Basin stratigraphy and to compare with sediments in

Figure 53: Location map of subsurface borings from which sediment samples, gamma logs, and geologic boring descriptions were utilized for this study.

Figure 54: Thinly bedded nature of the Neogene sediment silts and sands in BVD-6 from 50' to 55' (15.2-16.8 m) below the surface. The blue-gray coloration of the sediment indicates reducing conditions exist in this portion of the Neogene section. Top of the core is up.

Figure 55: Thin ash lens in the lower part of the Willamette Silt in LOD-3 drilled at the Hwy 217 and Interstate 5 intersection. The ash lens signifies that more than one Missoula flood cycle deposited sediment in this area.

the Tualatin Basin. Most of the boring was drilled with a mud rotary drill bit, although sections of the Troutdale Formation were wireline cored. The top 830' (253 m) of the boring predominantly consists of gravels and sands of Columbia River alluvium and the upper Troutdale Formation followed by approximately 500' (152 m) of silt and clay in the lower Troutdale Formation (Sandy River Mudstone Member). The top laterite of the CRBG occurs at 1338' (407.8 m) in the boring, while black, hard basalt is present at 1436' (437.6 m). Several black, hyaloclastite sands similar to those described by Tolan and Beeson (1984) and Swanson (1986) were recovered in the cores between 400' (122 m) and 800' (244 m). The complete stratigraphic column for MDT-1 is presented in Appendix C.

Water Well Drill Samples and Logs

Subsurface and groundwater information was extracted from over 2400 water wells on the valley floor and the foothills of the surrounding highlands. Drill cuttings were obtained and examined from 27 water wells drilled mostly in the western two-thirds of the Tualatin Valley (Figure 53). The penetrations varied in depth from 100' (30.5 m) to over 1000' (305 m) with sample intervals usually 10' (3 m) or so. Fifteen wells traversed the entire Neogene section and into the CRBG. Stratigraphic columns of selected wells are presented in Appendix C. The samples from these wells assisted in various analyses of the Neogene sands and provided an opportunity to visually distinguish the Willamette Silt from the underlying Neogene silts and clays. The Willamette Silt samples usually exhibit a loose, grainy texture under a binocular microscope as clay coated very fine sand and coarse silt grains tend to stand out in a muddy matrix. A more compact clay matrix in the Neogene silts and clays tends to hide more of the very fine sand and silt grains.

Several Northwest Natural Gas borings for gas line corrosion protection drilled around the Tualatin Valley were also available for determining lithology variations with depth. These borings were drilled and logged by a contract drilling company to depths of 400' (122 m) or less. The lithologic descriptions on the driller's logs are of the same quality as most water well driller's logs.

Gamma Logs

Gamma log profiles from 54 water wells and DOGAMI borings from around the Tualatin Valley (Figure 53) were generated in this study and used as guideposts to map the extent and thickness of the Willamette Silt and the depth to the Columbia River Basalt lateritic weathered zone. Four older water well gamma profiles presented by Hart and Newcomb (1956) were also incorporated in this study. Distinguishing sands from clays proved impossible due to the high silt content in most sediments in the Tualatin Basin. Examination of the gamma logs revealed relatively little response and no correlatable patterns within the Neogene section. The Willamette Silt is slightly more radioactive than the underlying Neogene sediment section presumably due to the continental granitic material present in the flood silts. This difference yields a slightly higher gamma response in most of the wells encountering both sections (Figure 56). Gamma logs from water wells in the southern part of the Tualatin Valley do not exhibit a noticeable corresponding rise in radiation from the Neogene to the Willamette Silt. The Itel water well (Sec. 11 T2S R2W) gamma log profile exemplifies this style (Figure 57).

The gamma log response of the CRBG is consistently lower than the overlying Neogene sediments, making the contact between the units readily apparent. This gamma response change is interpreted as the top of the CRBG in wells that are not accompanied with samples or full descriptions.

Figure 56: Stratigraphic and gamma log section of the Childress water well drilled in the NW 1/4 of Sec. 18, T1S R2W south of Hillsboro, Oregon. The gamma response increase in intensity at approximately 100' (30.5 m) is interpreted as the Neogene sediment - Willamette Silt boundary, which is coincident with an upward lithology change from clay to silt.

Figure 57: Stratigraphic and gamma log section of the ITEL water well drilled in the SW1/4 of Sec. 11, T2S R2W south of Scholls, Oregon. The gamma response increases from the CRBG to the overlying Neogene sediment section. There is no clear indication from the gamma log of the boundary between the Neogene sediments and the overlying Willamette Silt.

Two gamma logs, the previously described MTD-1 and a water well drilled to 1500' (457 m) at Meadowcroft Farms, south of Oregon City (Sec. 35, T3S R2E), were obtained from the Portland Basin and Northern Willamette Valley to compare the gamma signatures with the Tualatin Valley logs. The MTD-1 gamma log response is more active than any Tualatin Valley gamma logs (Appendix C). The upper Troutdale Formation contains sharp response peaks and dramatic low radioactivity areas corresponding to the hyaloclastite sand intervals. The gamma response also displays a marked increase at 840' (256 m) from the upper Troutdale to the Sandy River Mudstone Member of the lower Troutdale. The Meadowcroft Farms well started in Boring Lava and penetrated a lengthy interval of sediments before encountering CRBG at approximately 1300' (396 m) (Appendix C). The sediments become progressively more tuffaceous with depth, an observation not seen in the Tualatin Valley sediments. Both borings were gamma logged to 970' (296 m), the full extent of gamma line. Gamma log profiles along with known lithologies from selected penetrations are presented in Appendix C.

ODOT Boring Logs

The Oregon Department of Transportation retains boring logs of several tests from bridge construction sites around the Tualatin Valley (Figure 53). The ODOT logs are available in many areas where there are no samples or gamma log information. These logs provide lithologic information and blow count data from standard penetration tests. The blow count data supply information about the ground resistance to hammer blows on 1" (2.54cm) diameter and 1.5' (0.46 m) long split spoon cores. This process is most commonly used during hollow stem auger drilling projects. Blow counts sharply rise somewhere within the top 100' (30.5 m) in many areas around the Tualatin Valley, and this rise is interpreted to be the top of the Neogene sediments (Figure 58). This blow

Figure 58: ODOT test boring log of the Hwy 26 bridge over the Burlington Northern railroad one mile west of North Plains, Oregon. The number of blow counts per 1.5' (0.46 m) increases at 32' (9.8 m) and is interpreted as the boundary between the Willamette Silt and the underlying Neogene sediments.

count technique proved useful in establishing the Willamette Silt - Neogene contact in areas devoid of other information.

Seismic Stratigraphy

Synthetic Seismic Profile from HBD-1 Velocity Data

The COGS generated synthetic seismogram of HBD-1 (Figure 59) reflects the primary wave velocity data obtained in the boring by DOGAMI (Appendix H). Reflection coefficient calculations from the COGS program reveal where velocity contrasts in the sediment column affect the final synthetic seismic profile. Velocity changes between the two meter measured intervals are usually within 500 ft./sec. (152 m/sec.) with the exception of several units below 615' (187 m) (Figure 60). The most significant changes in primary wave velocity include: 1) where the boring encountered the hard, siliceous zone at 760' (231.6 m), 2) at 820' (250 m), 3) where the bottom of the Neogene section meets the top of the CRBG lateritic soil zone at 944' (288 m), 4) only four feet above the first weathered basalt unit at 957' (292 m), and 5) in the 1026' - 1029' (312.7-313.6 m) interval at the top of the hard, black basalt. The velocity jumps at these depths are on the order of 1000 to 2000 ft./sec. (304-609 m./sec.) or greater. The smallest velocity change from the above is approximately 1000 ft./sec. (312 m./sec.) and occurs in a 24 foot (7.3 m) thick clay unit at 820' (250 m). The velocity jump at the top of the hard basalt is greater than 7500 ft./sec. (2286 m./sec.) and probably corresponds to the correlated "red" horizon (discussed below) noted on the seismic reflection lines shot in the Tualatin Valley.

A frequency filter between 10-50 Hz was chosen to display the seismogram as the reflection wavelets best matched in amplitude to those of the seismic reflection line. The HBD-1 synthetic seismogram reflection horizons correlate well with the nearest

Figure 59: Synthetic seismogram of HBD-1 with stratigraphy exhibiting horizon correlations from seismic reflection line data. The green and orange horizons roughly correspond to velocity changes in HBD-1 at 584' to 597' (187-182 m; 0.24-0.25 sec.) and 760' to 830' (231.6-250 m; 0.285-0.31 sec.), respectively. The red horizon occurs within the CRBG at 0.38 sec (1033', 314.9 m).

Figure 60: Primary velocity profile for HBD-1 taken from a velocity survey run by DOGAMI for a regional seismic hazards program. The high velocity kick at the bottom is unweathered, hard CRBG underlying lateritic soil and weathered basalt.

seismic reflection shot point data approximately 5800' (1768 m) southwest of the drill site (Figure 61). A "green" horizon (labeled G on the seismic lines) between 0.26 and 0.28 seconds at the closest shot point on the seismic reflection data corresponds to 0.24 and 0.25 seconds on the seismogram. The depth conversion of this horizon in HBD-1 is 584' to 597' (178-182 m). The lithology in this section is silty clay that displays a noticeable radioactive low response on the gamma log (Appendix B). An "orange" horizon (labeled O on the seismic lines) just below the green horizon between 0.31 and 0.33 seconds on the seismic reflection line is interpreted between 0.285 and 0.31 seconds on the seismogram. The HBD-1 time level correlates with the 760' to 830' (231.6-250 m) interval in HBD-1. This interval is mostly composed of silt and clay and lies between the high velocity, hard siliceous layer at 760' (231.6 m) and the velocity contrast in the clay layer at 820' (250 m). The "red" horizon (labeled R on the seismic lines) at the closest shot point on the seismic reflection data is approximately at 0.42 seconds, while on the seismogram the horizon is located at 0.38 seconds. The three marked horizons are shallower on the synthetic seismogram because the HBD-1 location is somewhat further away from the center of the Tualatin Basin than the reflection lines.

Synthetic Seismograms from DOGAMI Shallow Borings

The DOGAMI BVD shallow borings along Hwy 217 and Interstate 5 were also surveyed for primary and shear velocities (Figure 53 and Appendix G). These borings are east of all the seismic reflection line coverage in the Tualatin Valley; however, synthetic seismograms were developed to determine whether the Willamette Silt - Neogene boundary can be seen in velocity contrasts (Figure 62 and Appendix H). Increased compactness of the Neogene sediments from the overlying Willamette Silt

Figure 61: HBD-1 synthetic seismogram tie with the nearest seismic reflection line data approximately 5800' (1768 m) southwest of the drill site. The seismic line location is also basinward of HBD-1 and the annotated seismic horizons are consistently deeper on the line than at the boring, yet the spacing between horizons is also consistent. (Data courtesy of Geophysical Pursuit).

Figure 62: Synthetic seismogram of BVD-5 with stratigraphy. The velocity increase at 59' (18 m; 0.042 sec.) may indicate the Willamette Silt - Neogene sediment contact. The boundary is correlated with the base of the first pronounced deflected wavelet.

should lead to higher densities and greater velocities, just as the number of blow counts increase at this boundary during standard penetration tests. Velocity profiles and the corresponding seismograms for BVD-2, BVD-4, BVD-5, and BVD-6 suggest a loose correlation between a velocity jump in the sediments along with wavelet development from reflection coefficients and the Willamette Silt - Neogene boundary (Figure 61 and Appendix H).

BVD-5 sediment velocities begin to increase at 46' (14 m) and continue to increase to 66' (20 m), taking a sizable jump at 59' (18 m) from 5174 ft./sec. to 7566 ft./sec. The corresponding generated seismogram for BVD-5 displays a well developed wavelet in this interval (Figure 62). The gamma log profile of this boring rises above 59' (18 m) indicating the Willamette Silt - Neogene boundary.

Comparison of well developed wavelets and interpreted formation boundary depths in BVD-2, BVD-4, and BVD-6 are less precise, yet are within 10' (3 m) of each other (Appendix H). BVD-3 is a special case in which 33' (10 m) of Willamette Silt directly overlies CRBG. The velocities rise from 3100 ft./sec. to 25,500 ft./sec., producing a significant wavelet at this interface (Appendix H).

Wavelets may not always form across the Willamette Silt - Neogene sediment boundary. The seismogram for HBD-1 does not display a pronounced wavelet at this boundary (Figure 59) as there are no increases in velocity across the boundary at 82' (25 m) in the HBD-1 boring. Silt is the dominant lithology across this boundary so there no corresponding velocity increases related to lithology changes.

Seismic Reflection Data Interpretation

Four proprietary seismic reflection profiles cover a representative portion of the Tualatin Valley (Figure 63). Three of the lines run north-south and the fourth line extends east-west intersecting the other three lines.

Three seismic reflection horizons were correlated throughout the line coverage in the Tualatin Valley (Figure 64). A "red" horizon at the top of the Columbia River Basalt Group is the lowest continuous horizon mapped. The "red" horizon actually approximates the top of the hard basalt rock at the base of the lateritic weathering zone as indicated from the HBD-1 seismogram. Most of the velocities of the lateritic soil zone in HBD-1 are not significantly higher than the overlying sediments (Appendix H).

A prominent pair of continuous reflectors were annotated near the middle of the Neogene section, one labeled "green" and the underlying labeled "orange" (Figure 64). Fluvial systems do not usually display continuous horizons on seismic reflection data as the stream derived sand bodies tend to have shoestring geometries with wedge shaped overbank deposits (Sangree and Widmier, 1977; Pettijohn, 1975). Lacustrine sediments may be continuous over a large area if the sediment lithology is consistent. The lacustrine diatomaceous unit in HBD-1 consists of laminated clay and lies just above the stratigraphic level of the "orange" horizon, 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.

The "green" and "orange" horizons demarcate contrasting seismic characters in the Neogene section (Figure 65). The section above the "green" horizon is noisy and discontinuous suggestive of mixed fluvial lithologies that have different velocities (Sangree and Widmier, 1977). The section between the "orange" and "red" horizons is relatively quiet reflecting more continuity in lithologies. The Neogene in the HBD-1

Figure 63: Location map of four proprietary seismic reflection data lines in the Tualatin Valley.

WEST

Figure 64: East-west seismic reflection line displaying HBD-1 tie and the post-CRBG (red horizon) sediment package near the center of the Tualatin Basin. The structure at the east side of the line may represent a reactivated paleostructure or a Boring Lava related intrusion. The Ray-Maling water well in Hillsboro penetrated the Neogene sediments and the CRBG near the center of the Basin. Also note the continuous green and orange horizon section throughout this and other profiles. These reflectors may represent basin-wide lacustrine environment (see Figure 65 of Geophysical Pursuit).

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Also note the continuity of the green
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custrine environments. (Data courtesy

WEST

EAST

Figure 65: East-west seismic reflection line illustrating the general reflection character of the Neogene sediment section. The red to orange horizon unit above the CRBG is seismically quiet, indicating a more uniform lithology sequence. The section above the green horizon is a bit more noisy, which is indicative of differential lithologies. (Data courtesy of Geophysical Pursuit).

core contains a greater proportion of sand, silt, and clay in the upper 600' (183 m) and a more consistent silt and clay section below this point to the weathered basalt at 1010' (308 m). The lower quiet zone then would include the lateritic weathered zone of the CRBG, which in HBD-1 is approximately 85' (26 m) thick. The seismic data may allow projecting to other parts of the Tualatin Valley.

The top one to one and one-half seconds on the seismic lines is clear of reflection data so that the top 300 feet (91 m) or so of the valley fill is not represented. The Willamette Silt - Neogene contact cannot be mapped with this tool as it is less than 150 feet (46 m) in depth.

The "red" horizon also exhibits an undulating surface with reflection interruptions not clearly associated with faulting (Figure 64). These breaks may represent either intermingling of basalt flow lobes around the preexisting topography, velocity contrasts set up by differential weathering between flow chilled, glassy surfaces and their more crystallized interiors due to the initial cooling processes of the basalt, or to discontinuous lateral interflow sediment deposition or differential soil formation rates.

The section between the "green" and "red" horizons thins toward the edges of the northern and western valley boundaries (Figures 66, 67, and 68). A few faint reflections between the "green" and "red" horizons pinch out at the basin edges in a manner similar to onlapping, although the data are not sufficiently clear to make a definite interpretation. The seismic data quality is also insufficient to clearly determine whether any reflections are truncated below the "green" - "orange" horizon package to establish the presence of any unconformities. The section above the "green" horizon must also thin towards the basin edges as the "green" horizon gently slopes upward from the center of the basin and eventually feathers out. The overall geometry of the Neogene

SOUTH

Seconds

Beaverton Fault

Figure 66: North-south seismic reflection line in the eastern part of the basin showing Neogene sediment geometries as the section thins north. The red to orange section quickly thins; however, the section dips toward the basin center indicating syndepositional subsidence. (Data courtesy of Geophysical Pursuit).

NORTH

Seconds

G = Green Horizon
O = Orange Horizon
R = Red Horizon

the eastern part of the Tualatin Valley
as the section thins towards the
ly thins; however, the entire Neogene
indicating syndeposition with continued
ical Pursuit).

SOUTH

G = Green Horizon
O = Orange Horizon
R = Red Horizon

Figure 67: North-south seismic reflection line in the western part of the T illustrating the same general geometries of the Neogene sediments as Figure 66, indicating the continuity of basin formation in the north of the Tualatin Basin. Gaps in the seismic data near the top of the section are probably due to surface features that obstructed data gathering during field survey. (Data courtesy of Geophysical Pursuit).

NORTH

Seconds

0.1

0.2

0.3

Seconds

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

1.1

1.2

1.3

1.4

1.5

1.6

ection line in the western part of the Tualatin Valley
eral geometries of the Neogene sediments as in
continuity of basin formation in the northern part
aps in the seismic data near the top of the line are
eatures that obstructed data gathering during the
sy of Geophysical Pursuit).

Figure 68: East-west seismic reflection line exhibiting how the Neogene section thins towards the west end of the Tualatin Basin. The red to green horizon interval thins dramatically in comparison to the section above the green horizon. (Data courtesy of Geophysical Pursuit).

sediments observed on the seismic reflection data is indicative of a syndepositional sequence with continued basin subsidence.

Accurately mapping stratigraphic horizons within the Neogene sediments away from the four available seismic reflection lines is unattainable due to incomplete sediment descriptions from water well borings. Cores from other borings, with exception of HBD-1, are only from the upper most Neogene sediments, and drill cutting samples from water wells do not contain indicator lithologies. The three known lateral limits of the "orange" and "green" horizons traced on the seismic reflection lines are marked on Figure 69. All three "orange" and "green" horizon pinch outs occur approximately at the 400' to 500' (122-152 m) isopach lines of the Neogene sediment isopach map, indicating uniform depositional limits of the main basin to the north and west edges. Sediments older than the "orange" horizon also pinch out progressively closer to the basin center with age as indicated by seismic data (Figure 67). This trend leads to the conclusion that the main depositional basin has become larger with time.

Sand Unit Distribution in the Neogene

The distribution of the sand units in the Neogene sediments may help identify major groundwater pathways. Most groundwater taken from the Neogene section is from sand units that contain lower percentages of pore plugging silt and clay. The fluvial sand bodies are highly discontinuous and well spacing is not densely spaced enough to directly map sand bodies around the basin. An alternate approach assigns sand unit percentages to depth intervals taken largely from water well lithology descriptions and subordinately on sample data. The Neogene sediment section was divided into three depth intervals, <100' (30 m) , 100' to 500' (30-152 m), and greater than 500' (152 m)

NEOGENE SEDIMENT ISOPACH MAP

TUALTIN VALLEY OREGON

ENT ISOPACH MAP

Y OREGON

Figure 69: Neogene sediment isopach map below the Willamette Silt in the Tualatin Basin, Oregon. The present thickness distribution reveals a S-shaped basin axis trend from northwest to southeast north of the Beaverton Fault. The basin is broken into narrow linear basins wrapping around the Cooper - Bull Mountain uplift south of the Beaverton Fault.

below the top of the Neogene sediment package. These three intervals are selected using the following criteria: 1) Most penetrations in the valley enter the top 100' (30.5 m) of the Neogene sediments; therefore, this interval would have good data control. 2) The 100' to 500' (30-152 m) interval in the HBD-1 core contains the highest sand unit percentage of the entire Neogene sediment sequence in this boring. 3) The interval from 500' to the top of the CRBG contains the lowest sand unit percentage in the HBD-1 core.

The mapped percentages are intended to illustrate gross sand depositional trends where most sandy stream sedimentation took place (Figures 70, 71, and 72). Accuracy of these percentages is probably low as water well drillers usually estimate sand thicknesses from cuttings and cannot identify thin sands.

The sand distribution of the top 100' (30.5 m) below the Willamette Silt - Neogene sediment contact illustrates linear depositional trends following the modern Dairy Creek and McKay Creek drainages in the Forest Grove Quadrangle, Fanno Creek in the Beaverton Quadrangle, and the Tualatin River in the Laurelwood and Hillsboro Quadrangles (Figure 70). Another linear sand trend not directly associated with a modern stream is located in the middle of Hillsboro. A higher sand unit percentage trend underlies the Beaverton Creek drainage in the southeast part of the Hillsboro and southwest part of the Linnton Quadrangles. The ten and fifteen percentage contours typically outline sand unit trends with local sand unit concentrations up to 50%. The upper Neogene sediments outside of these sand trends are devoid of detectable sand bodies. The sand trends indicate that several of the modern drainages have not appreciably changed since late Pleistocene.

Sand trends in the 100'-500' (30.5-152 m) below the top of the Neogene sediment interval are much more tenuous primarily due to the paucity of data points in the deeper

SCALE 6 MI (9.7 KM)

CONTOUR INTERVAL - 10%

THE
GENE

Figure 70: Sand unit percent map of the top 100' (30.5 m) of the Neogene sediments below the Willamette Silt or Boring Lava contact in the Tualatin Basin, Oregon. The gross sand depositional trends displayed dominantly follow present drainages of the Tualatin River and its major tributaries. Sand layers may compose as much as 50% of the sequence in the central part of the basin.

SAND PERCENT MAP OF

THE NEOGENE SEDIMENT SECTION

100'-500' BELOW THE TOP NEOGENE

Fig

ION
EOGENE

Figure 71: Sand unit percent map of the Neogene sediment section 100' to 500' (30.5-152.4 m) below the top of the Neogene section in the Tualatin Basin, Oregon. Most sand bodies identified from water well logs occur in the central portion of the basin.

Figure 72: Sand unit percent map of the Neogene sediment section greater than 500' (152.4 m) below the top of the Neogene section in the Tualatin Basin, Oregon. Sand bodies generally compose 10% or less of the lower Neogene section and occur north of the basin center.

parts of the basin and secondarily due to the invoked thicker depth interval (Figure 71). Sand unit percentages from many wells that partially penetrate into this interval were calculated on a weighted basis. The region of sand deposition follows an area north of the deepest parts of the top CRBG structural surface in the Forest Grove and Hillsboro Quadrangles (Figure 71). A second broad region of higher sand content crosses the top CRBG synclinal axis and is centered over Aloha, Oregon. Elevated sand percentages are also found over the CRBG troughs winding around the Cooper - Bull Mountain structure. The lack of deep penetrations into the Neogene near the center of the basin probably skews the apparent sand distribution to the north. Most sand unit percentages are 15% or less with a few wells containing 30% or more sand units. The HBD-1 boring contains 24% sand units in this interval. The overall sand unit percentages in this depth interval are close to or a little lower than those in the overlying top 100' (30 m), indicating that depositional style did not radically change during most of the Pleistocene.

Few wells penetrate the deepest Neogene section (>500' (152 m) below top Neogene), and they all occur north and west of the Beaverton Fault in the main basin (Figure 72). No definite sand trends are identifiable, although known elevated sand unit levels are confined to an area north of the deepest top CRBG structural surface. The calculated sand unit percentages in this interval are usually less than 15%, such as 13% sand units in the HBD-1 boring. The lower sand unit percentages in this interval could reflect a difference in depositional style from the overlying intervals with more dominant clay and silt sedimentation during this period.

Willamette Silt Isopach and Lithology Distribution

The Willamette Silt deposits are primarily silt and clay sized away from the Lake Oswego fan complex in the southeastern part of the Tualatin Basin. The deposits are thickest along the paleofloodplains of the present Tualatin River and most of the associated tributaries (Figure 73). The average maximum thickness of the Willamette Silt is just over 100' (30.5 m) in these drainages. The unit reaches 120' (36.6 m) thick in a small area of Sec. 6 T1S R2W in Hillsboro. The deposits thin toward the basin edges with the exception of the northeastern third of the valley. The isopach map includes the Portland Hills Silt above the 250' (76.2 m) elevation contour in the Tualatin Mountains and on Cooper and Bull Mountains. These silts may reach as much as 100' (30.5 m) thick in the Tualatin Mountains- Portland Hills area near Sylvan.

The catastrophic flood deposits contain gravels in a fan configuration in the southeastern part of the valley on the west side of Lake Oswego (Figure 74). The fan complex represents the deceleration of flood waters after passage through the Lake Oswego gap during each flood episode, resulting in rapid coarse particle deposition (Allison, 1978). Subsurface well control depicts the lateral decrease in grain size away from the gravel package. Sediments around the gravel fan deposit are dominantly sand, variably decreasing in gravel content further away from Lake Oswego. Gravel and sand are also concentrated in a small area near the mouth of the Tualatin River. There is no indication of a sand halo around the gravels. Silt and clay strata in the distal parts of the sandy sediments may exist either as a continuous section over or under the sand bodies, or interbedded between sand layers. Sand tongues follow lowlands of the top Neogene structure to the west and northwest, filling the ancient floodplains of the Tualatin River

WILLAMETTE SILT ISOPACH

OF THE TUALTIN VALLEY OREGON

WILLAMETTE SILT ISOPACH MAP
OF THE TUALATIN VALLEY OREGON

Figure 73: Willamette Silt isopach map in the Tualatin Basin, Oregon. The thickest sections closely follow the present Tualatin River, the west and east forks of Dairy Creek, McKay Creek, Rock Creek, and a portion of Fanno Creek. The contours on the map in T1N R1W north of Hwy 26 in the northeast portion of the basin extend above the 250' (76 m) elevation to include the Portland Hills Silt.

Figure 74: Lithofacies map of the Missoula catastrophic flood deposits at the west end of Lake Oswego and westward into the Tualatin Valley. A proximal fan gravel facies extends west and progressively grades to dominantly sand, sand-silt mix, and finally to all silt-clay. The sand facies occur farthest from the proximal facies up the drainages of the Tualatin River and Fanno Creek.

and Fanno Creek. An outer zone of flood sediments containing less than 50% sand units surrounds the dominant sand zone and gradually fines to silts and clays that make up most of the Willamette Silt in the Tualatin Valley.

Boring Lava Extension into the Tualatin Valley

Boring Lava flows from vents in the Tualatin Mountains - West Hills region of the Linnton, Beaverton, and Lake Oswego Quadrangles extend southwest onto the Neogene sediments in the eastern end of the Tualatin Valley. These flows are covered by Portland Hills Silt above the 250' (76.2 m) elevation and the Willamette Silt below this level. Uppermost Neogene sediments may also overlie a Boring flow in Section 20, T1N R1W. The strike trend of the Boring Lava into the Tualatin Valley is approximately N 35° W and extends from Section 18 T1N R1W, southeastward to Section 6 T1S R1E (Figure 75). Boring Lava flow distribution along this trend is discontinuous south of Section 12 T1S R1W, where various vents form small flow fields. The subsurface flow thicknesses of the northwestern Boring Lava field as measured from well logs varies from less than 20' (6.1 m) to over 300' (90 m). A particularly extensive, thick sequence of Boring Lava occurs in Sections 34 and 35 in T1N R1W, and Sections 1 and 2 in T1S R1W (Figure 76). The flows in Sections 34 and 35 are interpreted as originating from the Cornell Mountain vents, and those in Sections 1 and 2 erupted from younger vents of Barnes Road (Barnes, 1995). Extreme changes in thickness may occur over lateral intervals as short as a third of a mile (one-half km).

A Boring Lava flow in Sections 16, 17, and 20 in T1N R1W extends down slope from the Cornell vent field of Barnes (1995) to the southwest for approximately two miles (3.2 km; Figure 75). The lava flow filled in a low-lying drainage path and has

Figure 75: Top Boring Lava structure contour map along the Tualatin Mountains and Portland Hills on the east margin of the Tualatin Valley, Oregon. The western extent of the Boring Lava dominantly overlies, but may interfinger with the Neogene sediment section.

Figure 76: Boring Lava isopach map along the Tualatin Mountains and the Portland Hills along the eastern margin of the Tualatin Valley, Oregon. The thickest portions of the Boring Lava are close to vents and where flows filled stream drainages such as the lobe adjacent to Bronson Creek in TIN R1W.

created an inverted surface topography with as much as 100' (30 m) of relief above Bronson Creek. Three recent water wells for the Claremont Golf Course in Section 20 and 29 define a flow thickness of at least 87' (26.5 m) and mark the southeast flow margin (Figure 76). A well drilled in Section 29 on the north side of Bronson Creek did not encounter any Boring Lava, only Neogene sediments and CRBG below Willamette Silt. Older water wells southwest of the Claremont wells did not encounter Boring Lava.

Flows in the eastern Tualatin Mountains - Portland Hills area have been examined for their age and composition (Barnes, 1995; Conrey et al., 1996). The flows erupted from vents in the Sylvan Hill area are 0.86 Ma, which are overlain by 0.26 Ma flows from the Barnes Road vents (Conrey et al., 1996; Barnes, 1995). Boring Lava from the Cornell vents north and west of Sylvan has been dated at 0.96 Ma.

The southeastern flow field on the isopach map (Figure 76) is associated with vents such as Mount Sylvania in the western part of the Lake Oswego Quadrangle (Beeson et al., 1989). The subsurface extension of this field is as much as 150' (46 m) thick and its area is only approximate because of limited well coverage.

CHAPTER 4 - AGE OF THE NEOGENE SEDIMENTS AND PALEOECOLOGY IN THE TUALATIN - WILLAMETTE VALLEY REGION

The age of the Neogene sediments was suspected to be equivalent to the Troutdale Formation or the Sandy River Mudstone Member (Schlicker and Deacon, 1967; and Madin, 1990), yet no previous analytical work has been performed to determine their age. Determining the age distribution of the Neogene sediments provides a stratigraphic foundation to understand the structural evolution of the Tualatin Basin and a comparison of stratigraphic sequences to other depositional basins in the Willamette Valley region. Several methods of determining the age of the sediments are employed in this study, including the identification of pollen and diatoms, radiocarbon dating wood fragments, and paleomagnetic analysis of the sediments.

Methods

Seventeen HBD-1 core samples of silty clay were sent to Dr. Cathy Whitlock of the Geography Department at the University of Oregon for palynological examination. The identification of pollen species is useful for interpreting the age of the sediments and for indicating the paleoecology of the region.

Two samples from HBD-1 containing diatoms were sent to the Philadelphia Academy of Science for identification purposes. Standard procedures were used to separate the diatoms from the bulk sample (Edward Theriot, 1995, written comm.). The diatoms were microscopically studied and interpretations were made after a literature search revealed precedences of the identified species in the samples. The resultant report provides the basis for diatom interpretations in this study.

One wood sample collected at a depth of 95 feet (29 m) during the drilling of Gillenwater water well #1 south of Hillsboro was sent to Beta Analytic Inc. for

radiocarbon age dating. The purpose was to help ascertain the minimum age of the top of the Neogene package underlying the flood deposits of the Willamette Silt. The sample was prepared and analyzed using a slow decay method (Beta Analytical Inc., Sample number 67014, 1993, written comm.).

Forty Neogene sediment silt and clay samples taken at twenty foot (6 meter) intervals from HBD-1 were shipped to Dr. Ed Larson and Dr. Alan Lester of the University of Colorado to perform a paleomagnetic analysis in the hopes of finding magnetic field reversals that correlate to established time periods. The magnetometer determines the polarity of the Earth's magnetic field when the sediment was deposited and the results produce a paleomagnetic profile of the sediment section in the Tualatin Valley Neogene section. Inclination is the only feasible orientation that can be measured in these sediments since the horizontal orientation is unknown. The samples were heated after the initial readings, first to 250°C and then to 350°C to clean the samples with weak magnetic overprinting.

Two samples of wood drilled up from a water well boring with a cable tool in Roy, Oregon were shipped in glycol alcohol treated water filled plastic containers for identification to Dr. Charles Miller of the University of Montana at Missoula. One sample collected from a depth of 251' (76.5 m) consisted of a small branch about 1/4 inch in diameter. The other sample taken from a depth of 350' (106.7 m) was a piece of a larger branch or trunk. Thin slices of the wood were microscopically examined for their cell structure to identify the tree species.

Palynology

The Neogene sediments in HBD-1 may be subdivided based upon age dates from pollen and diatoms. The clay samples, collected between 250' (76 m) and 940' (286.5 m), were all blue-gray or brown-gray indicating reducing conditions which are needed for pollen preservation. Four of the eleven samples contained palynomorphs of sufficient preservation to be identified: 612' (186.5 m), 649' (198 m), 850' (259 m), and 922' (281 m) (Table 6). The samples at 612' (186.5 m) and 649' (198 m) are dominated by the tree families Picea (spruce), Abies (fir), and Pinus (pine) with subordinate amounts of Cupressaceae (cypress), Alnus (alder), Quercus (oak), Salix (willow), Tsuga heterophylla (western hemlock), Pterocarya, Rhus (sumac), Ulmus (elm), and Fagus (beech) (Table 6). The small amount of Pterocarya present may be from older material as it is currently restricted to Asia (Cathy Whitlock, 1994, written comm.). 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.

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.

Samples analyzed at 850' (259 m) and 922' (281 m) exhibit a different suite of palynomorphs. Cupressaceae constitutes the greatest proportion of the assemblage (44.6%) at the 850' (259 m) level, while Pinus (19%), Alnus (7.4%), Salix (5%), and Abies (2.1%) make up most of the rest of the sample. The sample at 922' (281 m) consists of the above constituents but has a higher percentage of spruce, fir, and pine mixed in the sediment (Table 6). The important families present in these samples are

Table 6: HBD-1 pollen species abundances with comparison to pollen identified at the Monroe, Oregon locality (from Roberts and Whitehead, 1984).

Tree and Shrub <u>Genus</u>	HBD-1 Depths				Monroe, Oregon <u>Pollen Range</u>
	612' 186.5 m	649' 197.8 m	850' 259.1 m	922' 281 m	
<i>Abies</i>	8.8%	12.0%	2.1%	6.5%	10-15%
<i>Acer macrophyllum</i>	0.0%	0.0%	0.5%	0.0%	n/a
<i>Alnus</i>	1.0%	1.3%	7.4%	3.4%	10-20%
<i>Betula</i>	0.0%	0.0%	0.0%	0.3%	0.9-3.3%
<i>Carya</i>	0.0%	0.0%	0.3%	0.0%	< 1%
Cupressaceae	1.3%	1.3%	44.6%	0.3%	10.00%
Ericaceae	0.0%	0.0%	0.0%	0.6%	0.3-3.2%
<i>Fagus</i>	0.0%	0.3%	1.1%	0.0%	0.3-2.6%
<i>Fraxinus</i>	0.0%	0.5%	0.3%	0.0%	1.8-3.3%
<i>Ilex</i>	0.0%	0.0%	0.0%	0.1%	0.3-5.6%
<i>Juglans</i>	0.0%	0.0%	1.1%	0.0%	0.30%
<i>Liquidambar</i>	0.0%	0.0%	0.3%	0.3%	0.8-2.4%
<i>Nyssa</i>	0.0%	0.0%	0.3%	0.0%	0.50%
<i>Picea</i>	27.0%	42.3%	1.1%	10.1%	4-20%
<i>Pinus</i>	37.3%	22.9%	19.0%	38.6%	1.2-22%
<i>Pseudotsuga</i>	0.3%	0.3%	0.3%	0.6%	0.8-2.4%
<i>Pterocarya</i>	0.0%	0.5%	0.3%	0.3%	1.00%
<i>Quercus</i>	0.0%	1.1%	1.1%	0.0%	2.8-26%
<i>Rhus</i>	0.0%	0.3%	0.3%	0.0%	n/a
Rosaceae	0.0%	0.0%	0.5%	0.0%	0.50%
<i>Salix</i>	0.7%	0.8%	5.0%	0.0%	0.60%
Taxodiaceae-Taxaceae	0.0%	0.0%	0.3%	0.0%	n/a
<i>Tilia</i>	0.0%	0.0%	0.0%	1.7%	0.5-1.0%
Triporate	0.0%	0.0%	0.0%	1.1%	n/a
<i>Tsuga heterophylla</i>	0.0%	0.5%	0.8%	3.1%	0.3-2.8%
<i>Tsuga mertensiana</i>	0.3%	0.0%	0.0%	0.0%	n/a
<i>Ulmus/Zelkova</i>	0.0%	0.3%	0.5%	0.3%	0.8-1.6%

Table 6 continued

Herbs and Pteridophytes	612'	649'	850'	922'	Monroe, Oregon Pollen Ranges
	186.5 m	197.8 m	259.1 m	281 m	
Artemisia	0.0%	1.1%	0.8%	0.0%	2.80%
Asteraceae	1.0%	0.0%	0.0%	0.0%	n/a
Botrychium	0.0%	0.0%	0.3%	0.0%	n/a
Cruciferae	0.0%	0.0%	0.3%	0.0%	n/a
Cyperaceae	2.9%	5.3%	0.3%	0.6%	n/a
Dryopteris - type	0.7%	0.0%	0.0%	0.0%	n/a
Liliaceae	0.0%	0.0%	0.3%	0.0%	n/a
Monolete spores	0.0%	0.3%	0.0%	0.0%	0.8-9.8%
Poaceae	6.5%	6.4%	2.1%	0.0%	n/a
Pteridium - type	3.3%	0.0%	0.0%	0.0%	n/a
Trilete spores	0.0%	0.0%	0.8%	0.0%	n/a
Tubuliflorae	0.0%	1.1%	0.3%	0.0%	1.1-3.2%
Urtica - type	0.3%	0.0%	0.0%	0.0%	n/a
Other					
Myriophyllum - type	0.0%	0.0%	0.5%	0.0%	0.6-0.8%
<i>Osmunda</i>	0.0%	0.0%	0.0%	1.4%	3.3-5.6%
Potamogeton	0.0%	0.8%	0.0%	0.0%	n/a
Sagittaria	0.3%	0.0%	0.3%	0.3%	0.8-1.2%
Indeterminate	4.6%	0.0%	2.6%	13.8%	n/a
Unknown	1.3%	1.9%	6.3%	0.3%	n/a
Pre-Miocene	1.3%	2.0%	n/a	16.3%	n/a

Italicized genus are no longer extant in the Pacific Northwest.

Carya (hickory), Cupressaceae, Fagus, Ilex (holly), Juglans (walnut), Liquidamber (sweetgum), Nyssa-type (tupelo), Pterocarya, 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.

The floral collection from the deeper two samples in HBD-1 is also described from other known localities in the Willamette Valley, including northwest of Monroe, Oregon (Roberts and Whitehead, 1984) and just east of Corvallis, Oregon (Scott Billings, 1996, written comm.). Pollen was collected from a 105 foot (32 m) thick lacustrine silty clay, cored near Monroe, that is sandwiched between overlying Pleistocene high terrace gravels and the underlying Eocene Spencer Formation (Roberts and Whitehead, 1984). Abies, Alnus, Cupressaceae, Gramineae, Picea, Pinus, and Quercus occur in significant quantities, while Carya, Cedrus, Fagus, Liquidamber, Nyssa, Platanus, Pterocarya, Ulmus, and several other currently exotic species to the Pacific Northwest are present in trace amounts (Table 6). A late Miocene to early Pliocene age is interpreted for this clay. These species also have been reported from late Miocene sediments in the foothills around the Willamette - Puget lowland region (Wolfe, 1969).

Pliocene flora have been described from the Troutdale Formation in the eastern Portland Basin area (Wolfe, 1969). The broad-leaf species Pterocarya, Ulmus, Platanus (sycamore), and Aesculus (buckeye) are represented in the Pliocene sediments but are not found in nearby early Pleistocene strata.

Diatoms

A diatomaceous zone extends from 715' (218 m) to 734' (224 m) and consists of low density laminated mudstone, underlain by a clayey, silty, very fine to fine sand layer. Two samples (724'; 220.7 m; 730'; 222.5 m) that were examined at the Philadelphia Academy of Natural Science contained identical assemblages with low diversity although the diatoms were not well preserved (Edward Theriot, 1995, written comm.). The upper sample was slightly better preserved than the lower sample. The prominent diatom, Aulacosira canadensis (Figure 77), 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 of Washington state (Van Landingham, 1991). The species ranges from early Miocene to Recent. Rare specimens of the centric genus Pliocaenicus (Figure 78) indicates the sediments are Pliocene to Pleistocene (Edward Theriot, 1994, written comm.). This genus is global in its Pliocene range. Rare fragments of the benthic Rhopalodia and Melosira genera and the general 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.

Paleomagnetic Analysis of HBD-1 Sediments

Magnetic inclinations recorded for the Neogene sediments in HBD-1 include natural remnant magnetization (NRM) and two levels of thermal demagnetization, 250°C and 350°C (Table 7). The NRM sediment profile is dominantly normal with spurious reversals throughout the section (Figure 79). An interval of reversed inclinations below 490' (149.4 m) is revealed from the 250°C and 350°C thermal demagnetization readings (Figures 80 and 81). Three successive samples at 493' (150.3 m), 511' (155.8 m), and

Figure 77: Photomicrograph of diatom *Aulacosira canadensis* in a lacustrine silty clay from HBD-1 724' (220.7 m). This open water diatom dominates the identified diatom assemblage. 10x objective

Figure 78: Photomicrograph of diatom *Pliocaenicus* in a lacustrine silty clay from HBD-1, 724' (220.7 m). This species indicates a late Pliocene to early Pleistocene age for the sediment. 10x objective

Table 7: HBD-1 paleomagnetic inclinations and intensities at various temperatures of Neogene silts and clays.

<u>Depth</u>	<u>Initial</u> <u>NRM Inc.</u>	<u>NRM</u> <u>Intensities</u>	<u>250 deg. C</u> <u>Inclinations</u>	<u>250 deg</u> <u>Intensities</u>	<u>350 deg. C</u> <u>Inclinations</u>	<u>350 deg</u> <u>Intensities</u>
35' (10.7 m)	49	2.30E-03	71	5.60E-03	77.4	3.70E-04
55' (16.8 m)	-32	6.10E-04	35	5.20E-05	67	3.90E-05
75' (22.9 m)	48	1.90E-05	37	1.00E-05	57	8.00E-06
95.5' (29.1 m)	61	2.00E-05	82	4.10E-06	68	1.10E-05
109.25' (33.3 m)	84	3.20E-05	-69	1.30E-05	-22	5.20E-06
129.7' (39.5 m)	-30	4.20E-06	-13		58	7.00E-06
156' (47.5 m)	69	2.00E-04	60	1.60E-05	76	4.80E-05
176' (53.6 m)	60	3.00E-05	59	4.40E-06	35	1.30E-05
195' (59.4 m)	-6	1.80E-04	-33	4.40E-05	-25	3.20E-05
219' (66.8 m)	55	5.80E-04	56	9.40E-05	79	8.10E-05
242' (73.8 m)	79	1.20E-04	32	6.82E-06	10	1.20E-05
270.5' (82.4 m)	67	1.80E-05	56	2.30E-06	22	9.70E-06
293' (89.3 m)	59		17	4.20E-06	39	1.85E-05
310.5' (94.6 m)	60	5.60E-06	49	3.40E-06	17	9.00E-06
317' (96.6 m)	62	1.80E-05	67	6.10E-06	59	9.40E-06
341' (103.9 m)	-51	2.20E-05	5	1.50E-05	57	2.60E-05
365' (111.2 m)	58	1.10E-05	41	1.80E-05	61	5.30E-05
388' (118.3 m)	77	2.60E-05	54	3.10E-06	49	4.30E-06
417' (127.1 m)	36	8.10E-05	16	2.90E-05	18	1.50E-05
461' (140.5 m)	70	3.10E-05	41	1.60E-06	58	3.10E-06
493' (150.3 m)	64	1.00E-04	-59	2.60E-05	-70	4.50E-06
511' (155.8 m)	36	3.10E-05	-47	1.10E-05	-50	5.80E-06
538' (164 m)	-61	1.00E-04	-63	5.40E-05	-44	4.00E-04
571.5' (174.2 m)	56	9.90E-04	49	2.10E-04	35	2.60E-04
596' (181.7 m)	72	9.80E-05	18	1.10E-05	2.3	6.00E-05
616' (187.8 m)	48	5.60E-04	61	1.70E-04	49	2.00E-04
635' (193.5 m)	77	1.60E-04	88	2.60E-05	46	
659' (200.9 m)	-9.6	4.40E-05	11	7.30E-06	52	9.80E-06
687' (209.4 m)	85	7.20E-04	77	7.50E-05	77	5.00E-05
709' (216.1 m)	68	3.60E-04	39	1.70E-04	40	1.90E-04
727' (221.6 m)	53	7.20E-04	63	3.70E-04	27	3.60E-04
757' (230.7 m)	39	5.10E-04	46	3.50E-05	49	5.70E-05
773' (235.6 m)	21	2.10E-04	6	2.80E-05	82	3.00E-05
803' (244.8 m)	51	2.10E-04	-76	2.50E-05	-49	1.50E-05
824' (251.2 m)	-26	4.40E-05	61	2.40E-05	28	3.20E-05
842' (256.6 m)	79	3.10E-05	33	4.80E-06	40	1.20E-05
871' (265.5 m)	70	7.80E-04	78	1.10E-04	83	1.20E-04
890' (271.3 m)	-45.1	1.30E-04	69	8.70E-06	-17	1.50E-05
916' (279.2 m)	78	6.60E-04	19	3.50E-05	42	4.80E-05
943' (287.4 m)	57	2.20E-04	23	1.90E-04	76	3.40E-04

Figure 79: Inclinations and intensities for natural remnant magnetization analysis of HBD-1 Neogene sediment core samples. Magnetic intensities generally increase below 490' (149 m).

Figure 80: Inclinations and intensities of 250°C thermal demagnetized HBD-1 Neogene sediment core samples. A group of reversals around 500' (152 m) may demarcate the top of the 0.78 Ma Brunhes-Matuyama magnetic epoch boundary.

Figure 81: Inclinations and intensities of 350°C thermal demagnetized HBD-1 Neogene sediment core samples. Shallow reversals may be spurious while the reversals around 500' (152 m) remain intact. Magnetic intensities still increase below 490' (149 m).

538' (164 m) half way down the Neogene sediments unit comprise a zone of reverse magnetism in the boring. A fourth sample at 596' (181.7 m) has a zero inclination at 350°C. Two reversals at 803' (244.8 m) and 890' (271.3 m) are also present in the lower Neogene sediment section. Two negatively inclined samples, 109' (33.2 m) and 130' (39.6 m), in the upper part of the boring are probably anomalous and could be related to the presence of coarse-grained and highly altered "bog iron" (Alan Lester, 1996, written comm.).

The 0.78 Ma boundary between the normal polarity Brunhes and reverse polarity Matuyama magnetic epochs (Izett and Obradovich, 1991) is best placed near the top of the 493' (150.3 m) to 538' (164 m) reverse polarity interval, although more inclinations around this zone are needed to confirm this interpretation. This interval is the only succession of reversals noted in the Neogene sediments. Placement of the Brunhes-Matuyama boundary at 493' (150.3 m) fits within the confines of the pollen data. Pollen samples at 612' (186.5 m) and 649' (197.8 m) are interpreted as early to middle Pleistocene approximately one to two million years before present.

Radiocarbon Dating

Water well drillers have encountered wood fragments throughout the Neogene section in the Tualatin Valley. A large tree branch or trunk was cored at 522' (159 m) below the surface during drilling of HBD-1 at the Hillsboro Airport. Much of the wood is found in various states of degradation, but none is known to reach the lignite stage of carbonization. Pieces of wood from the Gillenwater #1 water well on River Road south of Hillsboro (NE1/4 Sec. 21, T1S R2W) were drilled from 95 feet (29 m) below the surface (Figure 82). The contact between the Willamette Silt and underlying Neogene in this well is approximately at a depth of 70' (21.3 m). This contact is based on the first

Figure 82: Location map and stratigraphic column for the Gillenwater water well #1 in the NE1/4 of Sec. 21, T1S R2W, south of Hillsboro, Oregon. Wood collected at a depth of 93' (28.3 m) below the surface for radiocarbon dating is associated with poorly sorted, gravelly sand near the top of the Neogene sediments.

appearance of a gravelly sand overlain by clayey, very fine sandy silt (Figure 82). This drill site is approximately 300 meters from the Tualatin River, and the upper portions of the sediment cover may be Recent river deposits.

The wood sample was C¹⁴ dated to determine a minimum age of the Neogene section below the Willamette Silt. The sample was found to be older than the 43.7 ka dating limit for carbon 14 analysis (Beta Analytical, Sample # 67014). At this locality the upper most Neogene below the Willamette Silt is older than 43.7 ka as compared to the overlying 12.7 to 15.3 ka Willamette Silt deposits (Waitt, 1985).

Wood Identification

Two wood fragments drilled from a water well in Roy, Oregon (NE1/4 Sec. 8, T1N R3W) were examined to identify the tree species (Figure 83). One sample was taken from a depth of 251' (76.5 m) and the other from 350' (106.7 m) below the surface. The upper sample was identified as a species of *Picea*, most likely Engelmann Spruce, that is Pleistocene in age, while the lower sample was too degraded to be identified (Dr. Charles Miller, 1995, written comm.).

Geologic Age of the Tualatin Basin Neogene Sediments

Available pollen, diatom, and paleomagnetic data allow development of a time-stratigraphic relationship (Figure 84) that is correlatable via seismic reflection data. Neogene sediments from the base of the unit at 945' (288 m) to at least 850' (259 m) and maybe higher are upper Miocene to lower Pliocene. Diatoms present in the Neogene sediments suggest that lower to upper Pliocene deposits continue farther uphole to at least 715' (218 m). Pleistocene-aged Neogene sediments overlie the older section up to

Figure 83: Location map of the M. Duyck water well in the NE1/4 of Sec. 8, T1N R3W in Roy, Oregon. Wood extracted from a depth of 250' (76.5 m) below the surface was tentatively identified as Engelmann spruce.

Figure 84: HBD-1 stratigraphic column with interpreted ages based on pollen, diatom, and paleomagnetic data. The bulk of the sediment section is Pleistocene with only 245' (74.7 m) of upper Miocene to Pliocene aged deposits overlying the CRBG.

the Willamette Silt boundary at 82' (25 m). Pollen assemblages at 612' (186.5 m) and 649' (197.8 m) are clearly related to Pleistocene flora of this region. Another support for the extensive Pleistocene sediment package is a downhole switch from normal to reverse inclinations at 493' (150.3 m) in the HBD-1 Neogene sediments, which marks the 0.78 Ma boundary between the Brunhes and Matuyama magnetic epochs.

Results from the HBD-1 synthetic seismogram, together with HBD-1 pollen and diatom age data, indicate that the green reflection horizon occurs within lower Pleistocene sediments and the orange reflection horizon correlates with Pliocene to late Miocene deposits. Seismic reflection data in the region display successive pinch outs of older to younger event layers away from the basin center, including the orange and green horizons (Figures 66 and 67). The Neogene sediments are all Pleistocene in the Tualatin Basin north and west of the green seismic horizon pinch out where the sediment section is 400' (122 m) thick or less (Figure 69).

The age of Neogene sediment deposition may be further defined within the Tualatin Basin using three Boring Lava flows that partially intertongue and mostly overlie Neogene sediments on the northeast flank of the Tualatin Basin in the Portland Hills. The flows have been age dated at 0.26, 0.86, and 0.96 Ma (Conrey et al., 1996; Barnes, 1995). Neogene sediments in the Sylvan area are at least this old. 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.

The greater than 43.7 ka radiocarbon date of wood at the top of the Neogene sediments south of Hillsboro indicates slow sedimentation in the upper Pleistocene until

the 15.3 - 12.7 ka Missoula flood events (Waite, 1985) entered the Tualatin Valley. Stream terrace and valley floor development post-date the catastrophic flood sediments.

Paleo-ecology of the Tualatin - Willamette Valley Region

The change in pollen assemblages from late Miocene temperate, cypress-pine dominated forests in the lower 100' (30.5 m) or so of the Neogene section of HBD-1 to Plio-Pleistocene pine-fir-spruce dominated forests in the upper 650' (198 m) of the Neogene sediments of HBD-1, represents gradational climatic changes (Cathy Whitlock, 1995, personal comm.). The pollen distribution from the Miocene sediments indicates a forest assemblage similar to the present with predominantly deciduous trees in the lowlands grading to conifer dominated forests in the highlands (Wolfe, 1981). The modern forests are compositionally modified extensions of the late Miocene forests. Almost 36% of the coniferous genera and 42% of the deciduous genera have become extinct in western North America since the Miocene Epoch (Wolfe, 1981).

The HBD-1 Neogene sediments flora combinations represented in the late Miocene and late Pliocene to Pleistocene samples and the modern pollen rain of the Willamette lowland indicate a change from a more humid, temperate climate in the late Miocene to a cooler than present climate during the Pleistocene to the wet winters and dry summers of the present. This temporal sequence is also observed in Neogene core samples from the Corvallis area in the Willamette Valley (Scott Billings, 1996, personal comm.). The present lowland forests of the Willamette region are dominated by Alnus, Acer, Pseudotsuga (Douglas-fir), Quercus, and Salix (Ross, 1985). The presence of Fagus, Pterocarya, and Ulmus combined with absence of Carya, Ilex, Juglans, Liquidambar, and Tilia in HBD-1 at 649' indicates that the forest of this time was transitional from the Late Miocene - Early Pliocene assemblage to the present forests of this region.

Probable herbaceous pollen found in the Pliocene Troutdale Formation in the eastern portions of the Portland Basin indicates an open forest setting (Wolfe, 1981). The lengthening of the summer dry season, accompanied with cooler winters have attributed to the change of vegetational communities (Wolfe, 1969 and 1981).

The presence of Engelmann Spruce in the Neogene sediments has implications about the paleoclimate of the region. This cool climate species is presently found in Oregon above 4000' (1220 m) (Ross, 1985), where temperature changes between seasons are more extreme than in the Tualatin Valley. The presence of this species in the Tualatin Valley or surrounding highlands suggests that at deposition of this sample, the climate in the region was much cooler than today, possibly more closely associated with one of the glacial periods of the Pleistocene Age. Pleistocene, open forested, spruce and pine fossil pollen found in a core taken from Sublimity, Oregon also indicates a cooler climate for the Willamette Valley region (Crenna et al., 1994). The present day mixed hardwood-conifer forest of the Willamette lowland represents a warmer climate than the Pleistocene forest community (Cathy Whitlock, 1994, written comm.).

CHAPTER 5 - PROVENANCE OF THE NEOGENE SEDIMENTS

The Neogene sediments have been associated with the Troutdale Formation or Sandy River Mudstone of the Portland Basin (Trimble, 1963; Schlicker and Deacon, 1967; and Madin, 1990). Sediments in both basins should contain similar mineralogies if they are related. Provenance determination of the Neogene sediments will define whether their parent rock sources are similar. Defining the relationship of the two sediment packages provides evidence for the timing of uplift of the Tualatin Mountains and any major influence the ancestral Columbia River had on deposition within the Tualatin Basin.

Methods

Heavy Mineral Sand Separations and Point Counts for Provenance Work

Fifty-eight sand grain mounted slides from HBD-1 (17), water wells (28) and outcrops (2) in the Tualatin and Portland basins, and present day stream samples (11) were examined for the type and relative amounts of heavy minerals. Fine to very fine sand fractions were separated into light and heavy particle splits using a sodium polytungstate technique reported by Peterson and Binney (1988). The heavy minerals were point counted to characterize the relative mineral abundances and to calculate the relative abundances of augite, hornblende and hypersthene. Several sand samples contain highly altered heavy mineral grains that were unidentifiable under the petrographic microscope. Three samples were microprobed to analyze the chemical composition of the minerals for identification. Details of all the procedures are given in Appendix A.

Instrumental Neutron Activation Analysis

Rare earth and other trace element values of the sediments in HBD-1, DOGAMI shallow core borings, and a few water wells in the Tualatin Valley were determined by

Barnes (1995) through Instrumental Neutron Activation Analysis (INAA) (Gordon et al., 1968) to ascertain any chemical trend that might lead to determining the Neogene sediment depositional sequence. These values along with additional samples from HBD-1 were examined in this study and compared to similar data found in sediments of DOGAMI's MTD-1 deep boring at the Portland International Airport and to Neogene sediment data generated by Swanson (1986). The comparison data are from the Troutdale Formation and the Sandy River Mudstone in the Portland Basin region, which are possible time correlative units with the Neogene sediments in the Tualatin Valley.

Heavy Minerals: The Augite-Hornblende-Hypersthene Relative Abundances

Eleven recent and fifty-four ancient sand samples were processed for heavy mineral separation in order to ascertain the source of the Neogene sediments (Figure 85). Three hypotheses concerning the origin of the Tualatin Valley sediments are: 1) derivation from local highland sources surrounding the Tualatin Valley watershed; 2) distant transport from the Rocky Mountain Region via the ancient Columbia River system with no intervening highland between the Tualatin and Portland Basins; and 3) central Coast Range and Cascadian influences from the ancient Willamette River system (Allison, 1978a).

Most heavy minerals encountered in the samples do not uniquely single out any one source rock area; however, the augite-hornblende-hypersthene (AHH) relative percentage is of primary importance. Augite originates principally from mafic igneous rocks such as the Eocene Tillamook Volcanics Group (Glassman and Simonson, 1985) that outcrop in the Coast Range west of the Tualatin Valley. The CRBG is generally aphanitic and does not yield phenocrysts of augite from the Grande Ronde basalt (Marvin Beeson, 1996, personal comm.). Hornblende is not a source indicator as the

Figure 85: Location map of boring and stream samples used for heavy mineral provenance determination of the Neogene sediments in the Tualatin Basin and in the Portland Area.

mineral is found in the Paleogene marine sedimentary and volcanic deposits of the Coast Range, from volcanics in the Cascade Range, and from many rock types in the Columbia River watershed. The earlier Tertiary marine sediments of the northern Coast Range are also thought to be derived from the Rocky Mountains by the ancient Columbia River system (Baldwin, 1981). A particular type of blood red basaltic hornblende, chondrodite, is present in trace amounts in some samples and could be derived from the local mafic volcanic rocks.

Hypersthene is found in mafic and ultramafic rocks (Mason and Berry, 1968), particularly with calcic plagioclase in calcic volcanic terranes (Blackburn and Dennen, 1988) such as the Cascade Range of the Pacific Northwest. The Coast Range Paleogene marine sedimentary rocks contain from trace to minor amounts (up to 5% of the heavy mineral fraction) of hypersthene (Van Atta, 1971). The Rocky Mountain region is not known as a substantial source for hypersthene. The presence of elevated hypersthene levels in the Neogene sediment sands is considered in this study as strong evidence for a Cascadian provenance. The Columbia and Willamette Rivers receive hypersthene from streams draining the Cascade Range and probably have received hypersthene over the length of the Neogene.

Elevated hypersthene values are noted in the deep sediment section of the three Portland and northern Willamette Valley borings analyzed in this study (Figure 86). Hypersthene is considered an unstable ferromagnesium mineral that weathers relatively quickly as compared to most other sedimentary minerals (Pettijohn, 1941); however, the relatively high hypersthene levels in these samples indicates favorable conditions for hypersthene preservation in this region. These circumstances suggest that alteration is not the reason for the absence of hypersthene in deeper parts of the HBD-1 section.

Figure 86: Augite-hornblende-hypersthene relative ratio ternary diagram for sands from borings in the Portland Basin and northern Willamette Valley. Hypersthene ratios fluctuate widely within the same boring suggesting that the depositional sites are influenced by multiple provenances.

The recent sand samples collected from the lower drainages (below elevation 250' - 76.2 m) of the Tualatin Valley are labeled with a #1 extension (Figure 87). These samples exhibit elevated levels of hypersthene reflecting the erosion of the Willamette Silt blanketing the surface of the valley (Table 8). The upper drainage localities (above 250' - 76.2 m) are labeled with a #2 extension. The samples display a variable hypersthene content, which may be dependent on the amount of loess silt mantling the highlands. The hypersthene average heavy mineral percentage in the Portland Hills Silt is 0.5%, while hornblende is 40.8% of the heavy minerals and augite is 9.9% (Lentz, 1981). Augite is dominant (95%) in the recent Tualatin River and Gales Creek samples taken at the far west end of the Tualatin Valley (Table 8). The headwaters of these two systems erode the Eocene Tillamook Volcanics series and Paleogene sedimentary rocks west of the present valley. The Tillamook Volcanic series is a source for augite (Curt Peterson, 1994, personal comm.). The West and East Forks of Dairy Creek contain much hornblende, with subordinate levels of augite and hypersthene. These two tributaries drain a large area of Paleogene sedimentary rocks and the CRBG northwest of the Tualatin Valley. The other tributaries of the Tualatin River sampled derive their sediment from the CRBG and overlying loess deposits to the north, east, and south of the valley.

Willamette Silt (Missoula flood deposits) sand fractions in the Tualatin Valley generally contain higher hypersthene percentages than the underlying Neogene sediments (Table 8). HBD-1 34', BVD-6 24', LOD-3 20', TRB-1 28', Carter Well 40', Bich Well 20', and ODOT Brookwood 70' display relative hypersthene values between 7% and 31% and stand out from the Neogene sediment samples (Figures 88 and 89). HBD-1 73' has a much lower value (4%) as does ODOT Hwy 47 42' (5.3%). The

Figure 87: Augite-hornblende-hypersthene relative ratio ternary diagram of recent stream sediments in the Tualatin Valley and the Columbia River. Many samples contain elevated hypersthene ratios (>10%) reflecting erosion of the Willamette Silt. The Columbia River samples show an increasing hypersthene presence west of the Cascade Range.

Table 8: Relative Augite-Hypersthene-Hornblende Ratios from Missoula Flood and Neogene Sands from the Tualatin and Portland Basins.

HILLSBORO AIRPORT DEEP TEST SAMPLES (HDB-1)				TUALATIN VALLEY AND COLUMBIA RIVER RECENT SANDS			
SAMPLE NAME	Augite %	Hypersthene %	Hornblende %	SAMPLE NAME	Augite %	Hypersthene %	Hornblende %
MISSOULA FLOOD SANDS (WILLAMETTE SILT)				(all #120)			
34' (10.4 m) #230	37.6	15.2	47.2	Tualatin River	97.1	2.4	0.5
73' (22.3 m) #230	39.8	4.0	56.2	Gales Creek #1	94.7	4.8	0.5
NEOGENE SANDS				Gales Creek #2	97.7	2.3	0.0
141' (43 m) #120	87.4	0.0	12.6	E. Fork Dairy Cr. #1	20.5	27.3	52.2
226' (68.9 m) #120	66.3	2.1	31.7	E. Fork Dairy Cr. #2	37.7	22.6	39.7
300' (91.4 m) #230	19.1	6.5	74.5	Rock Creek #2	21.8	25.7	52.5
385' (117.3 m) #120	43.2	1.1	55.7	McFee Creek #1	43.5	15.0	41.6
415' (126.5 m) #120	49.9	1.8	48.3	W. Fork Dairy Cr. #1	26.0	7.9	66.1
484' (147.5 m) #230	29.2	2.6	68.2	W. Fork Dairy Cr. #2	34.1	14.7	51.2
537' (163.7 m) #120	86.4	0.9	12.7	McKay Creek #1	7.1	14.6	78.3
651' (198.4 m) #120	34.0	1.9	64.0	Columbia River	34.3	39.2	26.5
734' (223.8 m) #120	39.1	1.8	59.1				
846' (257.9 m) #120	5.9	1.4	92.7				
877' (267.3 m) #230	25.9	3.9	70.2				
898' (273.7 m) #230	47.8	5.8	46.4				
929' (283.2 m) #120	17.9	1.4	80.7				
PORTLAND AND NORTHERN WILLAMETTE BASIN SANDS							
MTD-1 411' (125.3 m) #120	81.1	16.2	2.7				
MTD-1 432' (131.7 m) #230	0.6	2.6	96.8				
MTD-1 811' (247.2 m) #120	24.5	31.1	44.3				
Sandy River Mudstone	1.6	1.0	97.4				
Carus 1035' (315.5 m) #120	45.2	52.1	2.7				
Carus 1120' (341.4 m) #120	0.0	4.2	95.8				
GDFB 830' (253 m) #230	1.6	2.2	96.2				
GDFB 1210' (368.8 m) #120	3.8	84.7	11.6

Figure 88: Augite-hornblende-hypersthene relative ratio ternary diagram for sands from water well and ODOT core samples in the Tualatin Valley. Willamette Silt samples contain higher hypersthene ratios while Neogene sediments are low in hypersthene, except in LOD-3, BVD-4, and BVD-5.

Figure 89: Augite-hornblende-hypersthene relative ratio ternary diagram of HBD-1 sands. Neogene sediments reflect relatively low levels of hypersthene (<10%). Willamette Silt samples may contain higher hypersthene ratios.

sample in HBD-1 is within ten feet (3 m) of the lower Willamette Silt boundary at the HBD-1 site and may be influenced by more distal continental sources derived by the early Missoula flood events. The ODOT sample is also very close to the Willamette Silt-Neogene sediment contact in the western part of the Tualatin Valley; however, the exact depth of the boundary at this locality is uncertain. The boring site is on the banks of the West Fork of Dairy Creek, a major tributary to the Tualatin River containing low hypersthene and high hornblende levels (Appendix E).

Two samples taken from borings next to the Tualatin River floodplain contain almost no hypersthene (EB-1 55', and ODOT TRB-1 55'). These samples contain very high relative augite levels and may represent sands from the ancient Tualatin River system. The AHH relative percentage comparison of the present main stem of the Tualatin River contains almost exclusively augite (Table 8). A third sample, ODOT Brookwood 30', has a relatively low hypersthene and high hornblende ratio. The locality of this sample is approximately two miles (5 km) east-northeast the current Tualatin River floodplain (Sec. 4 T1S R2W) along the Rock Creek drainage (Figure 85). The upper section in this boring is sandy suggesting local fluvial deposition rather than Missoula flood sediment settling. The Willamette Silt away from the Tualatin River floodplain in the central and western parts of the valley is largely silt and clay. The upper 100' (30 m) or so of the stratigraphy in the Tualatin River floodplain may reflect intermittent periods of Missoula flood deposition and local fluvial sand depositing between glacial flood episodes.

Hypersthene levels from the Neogene sediment sands in the Tualatin Valley are almost always less than 7 %, with the exception of three samples from the eastern margin of the valley, BVD-5 75' (25.4 %), LOD-3 155' (22.7%), and the COSTCO outcrop site (15.9 %). BVD-5 75' lies below the higher gamma response region

depicting the Willamette Silt unit (well repository). Water well data in the area also suggest the Willamette Silt-Neogene sediment boundary is shallower than 75' (22.6 m). LOD-3 155' occurs 105' (32 m) below the wedge of Boring Lava encountered at a depth of 30' (10 m) in the boring. All sediment below the Boring Lava is considered older than the Willamette Silt. The COSTCO site sample was collected within the stratified Neogene sediments several meters below the exposed Willamette Silt base at the construction site.

The three sample locations are close to each other (Figure 90) and may indicate a late Pleistocene Willamette River incursion in this part of the Tualatin Valley. Samples are scarce in this part of the valley, and the extent of any Willamette River influence is uncertain; however, two Neogene sediment samples located south of this area, LOD-4 125', collected at Interstate 5 and Lower Boones Ferry Road, and BVD-6 55', from Tualatin City Park, contain trace amounts of hypersthene. North of the COSTCO site area is BVD-3 at Washington Square Mall. This boring entered a CRBG structural high at a depth of 30' (10 m) and contained no Neogene sediment.

The AHH relative percentages of the HBD-1 boring sands (Table 8 and Figure 89) suggest a consistent provenance over the depositional history of the Neogene sediments in this part of the valley. The very fine sand (#230 mesh) fraction was chosen for several HBD-1 samples as this is the dominant sand class for these sands. The AHH relative percentage plots of HBD-1 and most of the other Neogene sediment samples exhibit a spread from augite to hornblende dominated values (Figures 88 and 89). Many of the augite dominated samples occur within 300' (90 m) of the surface. Several of these augite rich samples also occur close to the present Tualatin River floodplain (Figure 84).

Figure 90: Location map of shallow DOGAMI borings illustrating the differences in hypersthene levels. Higher levels of hypersthene in BVD-4, BVD-5, and LOD-3 may indicate that the Willamette River entered this portion of the Tualatin Valley (outlined) sometime in the late Neogene.

The Carter water well occurs in the southern third of the valley in Sec. 9, T2S R2W (Figure 85). The AHH relative percentages from the three Neogene sediment sands (160', 200', and 260') in this well are all augite rich (86.7% - 91.7%) and hypersthene poor, indicating that Tillamook Volcanic rocks supplied material for most of the Neogene sediments in this part of the valley.

MTD-1 411', MTD-1 811' and GDFB Well 1210' in the Portland Basin, and Carus Well 1035' in the Northern Willamette Valley contain relatively high hypersthene levels (Table 8). The hypersthene percentages range from roughly 8% to 84% among these samples. MTD-1 411' was collected from a black, hyaloclastite sand as described by Swanson (1986). Four of the eight samples analyzed contain very little hypersthene. MTD-1 432', GDFB 830', Carus Well 1120' and an outcrop of Sandy River Mudstone plot near the hornblende apex of the AHH ternary diagram (Figure 86). The Portland Basin and Northern Willamette Valley depocenters directly receive sediments from streams draining the Cascade Range. Hypersthene composition in these sediments is highly variable presumably due to the influences of random weathering and transport of sediments from a wide variety of sources. The potential for Neogene sediments to contain elevated relative hypersthene compositions in these areas is supported with these results. The Portland Basin has also directly received sediments from the northern Rocky Mountain area. The Neogene sediments in this basin are likely interlayered with sediments from both the Cascade Range and continental sources.

Several sand samples from HBD-1 contain altered mineral grains in the heavy mineral separation that were not identifiable with a polarized light microscope. The mineral grains did have distinctive features, including pleochroism from dark to light yellow brown, dumbbell shaped, prismatic outlines, and nearly parallel extinction. These characteristics in themselves do not fit known heavy mineral characteristics;

however, if they are hypersthene, then the modified AHH relative percentages would have implications on the sediment provenance and cast doubt on the hypothesis that hypersthene does not easily decompose in the greater Willamette Valley Neogene sediments. Microprobe elemental scanning of three altered sand samples revealed that these grains are hornblende (Figure 91). The elemental analysis displayed in Table 9 indicates a high (Ca-Mg ratio) indicative of hornblende (Roger Neilsen, personal comm., 1994).

Table 9: Major element chemistry of representative heavy mineral grains from HBD-1 altered sands by microprobe gamma-spectrometry. Each of these profiles best fit known hornblende compositions.

<u>Acquisition Percentages</u>				
<u>Element</u>	<u>HBD-1 836'</u>			<u>HBD-1 693'</u>
	<u>Grain #1</u>	<u>Grain #2</u>	<u>Grain #3</u>	<u>Grain #1</u>
O	59.18	59.67	60.75	59.22
Na	1.26	0.76	0.54	1.11
Mg	4.52	7.72	3.99	6.24
Al	4.12	3.43	6.67	4.86
Si	16.88	17.88	18.3	16.35
P	0	0	0.04	0.02
K	0.6	0.24	0.25	0.62
Ca	4.8	4.96	4.06	5.11
Ti	0.35	0.24	0.2	0.5
Cr	0	0	0	0.01
Mn	0.31	0.23	0.12	0.36
Fe	7.97	4.86	5.18	5.82

Figure 91: Photomicrograph of an altered hornblende mineral grain from HBD-1 836'. The mineral is identified from major element chemistry using a microprobe gamma spectrometer.

Instrumental Neutron Activation Analysis

Twenty-six sediment samples from HBD-1 and 12 shallow sediment samples from DOGAMI core borings along the eastern margin of the Tualatin Valley were analyzed by Barnes (1995) for major and trace elemental concentrations to ascertain any definitive patterns that may relate to the genetic origin of the sediments. Eighteen more samples from HBD-1 were analyzed in 1995 by Dody Orendurff, a Portland State University student, to fill in possible gaps in the depth sequence. Examination of these element abundances indicates that there is a general consistency in the Neogene sediment provenance over time in the central part of the Tualatin Valley (Appendix F). Only a few elements display an observable change with depth (Table 10), such as iron and sodium. A mudstone sample at 760' (232 m) and a siltstone sample at 763' (233 m) have relatively depressed scandium, chromium, and cobalt levels. This depth interval corresponds to the hard, siliceous unit encountered in the boring. Low chromium and scandium levels may indicate a more silicic source, such as an ash fall, in this section (Henderson, 1982).

Barnes (1995) compared these samples to Boring Lava and Neogene sediments obtained in the Tualatin Mountains and in the Portland Basin. Comparison plots of Fe vs. La/Sm, Th vs. Hf, and Hf vs. Fe and others illustrate overlapping yet distinctive geochemical populations between HBD-1 and MTD-1 sediments. Additional plots developed for this study Fe vs. Na, Sc vs. Cr, Th vs. Cr, and Na vs. La/Sm reveal the same relationships (Figures 92 and 93). Samples from the clay and silt dominated unit below 840' (256 m) in the MTD-1 boring (Appendix B) commonly fall in the HBD-1 fields on these plots. Barnes (1995) recognized three distinct geochemical distributions on scatter plots from the MTD-1 boring, a younger Columbia River section above the 400' (122 m) depth, an episodic Cascadian Volcanic unit between 400' and 800' (256-

Table 10: Selected INAA chemistry from HBD-1 sediments indicating changes with depth (Na and Fe) or unusual percentages (Sc, Cr, and Co).

<u>Depth</u> feet (meters)	<u>Na %</u>	<u>Fe %</u>	<u>Sc (ppm)</u>	<u>Cr (ppm)</u>	<u>Co (ppm)</u>
60.5' (18.4 m)	1.51	3.20	11.60	64.48	14.68
73' (22.3 m)	1.39	3.75	13.73	62.48	15.01
84' (25.6 m)	1.03	2.84	14.93	45.96	12.92
131' (39.9 m)	0.70	7.66	25.03	60.94	25.90
176' (53.6 m)	0.43	6.11	23.55	78.26	16.64
206.5' (62.9 m)	1.38	5.34	16.43	91.45	19.27
230' (70.1 m)	1.15	7.20	17.28	165.05	34.73
257' (78.3 m)	1.54	4.33	12.88	92.56	19.29
275' (83.8 m)	0.89	4.95	17.13	91.30	9.63
303.5' (92.5 m)	0.92	6.67	14.97	87.51	22.02
314' (95.7 m)	1.06	3.48	16.30	61.15	14.04
349' (106.4 m)	0.91	7.02	16.60	88.32	19.47
405.5' (123.6 m)	2.63	3.33	12.94	70.71	13.88
425' (129.5 m)	0.46	6.43	23.47	73.90	19.39
436.3' (133 m)	1.01	5.42	12.10	59.30	16.52
455' (138.7 m)	0.76	4.82	16.38	69.72	13.06
468' (142.6 m)	0.37	6.06	19.65	92.66	19.94
492.5' (150.1 m)	0.32	11.11	21.09	69.08	14.87
507' (154.5 m)	1.04	4.82	15.78	78.47	16.13
535' (163.1 m)	1.08	2.60	19.82	90.03	13.30
545.6' (166.3 m)	0.53	9.21	21.11	67.60	13.63
553' (168.6 m)	0.86	6.98	19.73	73.52	38.96
565.7' (172.4 m)	0.68	10.37	24.76	50.67	24.47
579' (176.5 m)	0.40	8.65	29.22	66.38	27.85
602.3' (183.6 m)	0.61	7.10	16.96	81.28	24.93
649' (197.8 m)	0.74	8.08	28.76	77.75	29.87
659' (200.9 m)	0.30	10.90	27.34	56.07	39.09
677' (206.3 m)	0.44	10.35	26.55	64.68	26.88
714.8' (217.9 m)	0.52	13.14	23.57	49.29	29.75
722' (220.1 m)	0.38	9.00	32.29	55.80	24.37
755' (230.1 m)	0.54	6.84	19.38	92.74	15.90
760' (231.6 m)	1.05	7.45	7.39	8.10	14.70
763.4' (232.7 m)	2.00	4.91	7.07	4.17	5.04
779' (237.4 m)	0.17	11.11	41.88	52.06	32.56
790.7' (241 m)	0.25	10.83	27.08	61.04	26.05
803' (244.8 m)	0.25	5.68	43.38	73.01	20.48
822' (250.5 m)	0.24	10.44	36.00	65.16	21.57
850' (259.1 m)	0.49	6.14	22.71	60.73	39.75
871' (265.5 m)	0.71	7.24	22.72	64.53	50.63
890' (271.3 m)	0.33	6.19	21.69	69.33	9.54
912' (278 m)	0.17	9.06	29.24	69.69	22.36
920.5' (280.6 m)	0.23	11.23	35.35	50.00	59.83
930' (283.5 m)	0.00	21.18	32.87	89.54	11.99
938.5 (286.1 m)	0.01	13.11	45.62	61.24	58.32

Figure 92: INAA chemistry between HBD-1, MTD-1, and DOGAMI shallow borings in the Tualatin Valley. Iron vs Sodium (A) and Scandium vs Chromium (B). HBD-1 and MTD-1 populations are distinct except for deep MTD-1 samples in the HBD-1 field.

Figure 93: INAA chemistry between HBD-1, MTD-1, and DOGAMI shallow borings in the Tualatin Valley. Thorium vs Chromium (A) and Sodium vs Lanthanum/Samarium (B). Populations are distinct, yet deep MTD-1 samples overlap into the HBD-1 field.

244 m), and the lower Troutdale Formation below 800' (244 m). The Sandy River Mudstone Member is contained within the lower Troutdale Formation (Bet and Rosner, 1993). Barnes (1995) noted that the geochemical signatures from the lower Troutdale sediments fit with Columbia River source sediments. Lower Troutdale sediments from other portions of the Portland Basin compare well with the lower Troutdale sediments in MTD-1 on Th vs Cr and Sc vs Cr plots (Lite, 1992, Swanson, 1986). The lower Troutdale sediments from MTD-1 that plot in the HBD-1 fields in this study are not correlative to any particular depth distributions in HBD-1, as the HBD-1 samples plot in scattered patterns.

Sodium and iron percent depth trend comparisons between the two borings indicate mixed iron and relatively lower sodium concentrations in HBD-1 Neogene sediments (Figure 94). Sodium levels decrease with depth in both borings ($r = -0.55$; $t = -4.27$ for HBD-1 and $r = 0.61$; $t = -3.54$ for MTD-1; $t_{crit} = \pm 2.42$ @ 95% confidence level), while iron percentages increase with depth in HBD-1 ($r = 0.59$; $t = 4.77$) and show no significant change in MTD-1 ($r = 0.20$; $t = 0.91$). Iron, scandium, and chromium tend to magmatically separate out into more mafic material, while sodium is more closely associated with silicic sources (Henderson, 1982). The CRBG surrounding the present Tualatin Valley could be a source for basic elements while continental granitic sources from the Columbia River system may supply sodium rich minerals into the Portland Basin. CRBG detritus is also a constituent in the Portland Basin sediments; however, this contribution is diluted by the mix with the continental and Cascadian sources.

Shallow sediment samples from DOGAMI borings along the Hwy 217 and Interstate 5 corridor (Figure 90) are either Willamette Silt or upper Neogene sediments (Appendix F). The geochemistry of these samples plotted by Barnes (1995) and in this

Figure 94: Iron (A) and Sodium (B) depth trend comparisons between HBD-1 and MTD-1. HBD-1 displays a general increase in iron and decrease in sodium with depth. MTD-1 sodium values decrease with depth, although iron does not appreciably change.

study show no strong relationship to either HBD-1 or MTD-1 sediments. The scatter values from the shallow sediments display random distributions in and around the HBD-1 and MTD-1 fields (Figures 92 and 93). BVD-4 91.4' is a white ashy lens in a silty clay layer of the upper Neogene sediments that contains relatively elevated Cs, Sr, Ta, Th, U, and Zn values and depressed As, Cr, and Na levels when compared to the other shallow sediments (Appendix F). Thorium (17.7 ppm) and chromium (39 ppm) values in BVD-4 91.4' also stand out when compared to HBD-1 and MTD-1 samples (Figure 93a) and to Boring Lava samples (Barnes, 1995). These values indicate that the ash lens is from Cascadian sources and is unlikely to be from local Boring Lava eruptions.

Neogene Sediment Sources

Analysis of heavy mineral and INAA geochemistry data from Neogene sediments collected in the Tualatin Valley indicate that the coarser sediments entered the basin from the surrounding highlands, and some of the finer fractions were airborne from outside the region. Augite grains in the Neogene black sands reported from wells in the central and southern sections of the Tualatin Basin by water well drillers came from Tillamook Volcanic Series rocks in the Coast Range. Quartz and potassium feldspar in the sands are indicative of sources other than basalt. The Coast Range contains Paleogene marine and transitional sandstones, siltstones, and mudstones containing quartz and potassium feldspar originally cycled from the continental interior in Eocene and Oligocene time. The CRBG provides abundant, weathered basalt rock fragments and fine-grained source material, usually clay-sized. Upper Neogene sands in the Lake

Oswego-Tigard area were delivered by the proto-Willamette River during the Pleistocene.

The airborne components include silt- and clay-sized ilmeno-hematite which were identified in HBD-1 Neogene sediments by Dr. Alan Lester, 1996, at the University of Colorado, written comm.). Ilmeno-hematite may be derived from Cascade Range eruptions (Dr. Ed Larson, 1996, personal comm.). Ash shards have not been observed in the Neogene sediments away from the eastern margin of the basin. Very thin (<2 mm) ash laminae were encountered in the LOD-3 (Figure 55) and BVD-4 boring along the Hwy 217 corridor. These white lenses are either from Cascade Range eruptions or from local Boring Lava vents such as Mt. Sylvania. They are not recorded from other DOGAMI cored borings located farther away from the Boring Lava vents.

HBD-1 Neogene sediment sands fall within the magmatic arc provenance field of QmFLt and QFL ternary diagrams developed by Dickinson and Suczek (1979) (Figure 95). Each diagram emphasizes a slightly different aspect of the sediment provenance. The total quartz - feldspar - unstable lithic fragment (QFL) plot stresses grain stability resulting from source rock type, weathering, provenance relief, and erosion (Figure 95a). The monoquartz - feldspar - total lithic fragment (QmFLt) plot accents the grain size of the source rock as lithic fragments from fine-grained source rocks are more common in the sand fractions of the resulting sediment (Figure 95b). Sandstones of the Spencer and Scappoose Formations in the Coast Range also fall within the magmatic arc provenance field (Cunderla, 1986 and Ketrenos, 1986), yet the Neogene sediment sands in the Tualatin Basin are rich in CRBG lithic fragments and the older sediments contain a vast quantity of andesitic volcanic fragments (Cunderla, 1986, Ketrenos, 1986, and Van Atta, 1971).

Figure 95: Ternary diagrams of mono- and poly- crystalline quartz, feldspar, and lithic fragments (A), and monocrystalline quartz, feldspar, and total lithic fragments, including polycrystalline quartz (B) from HBD-1 and other borings in the Tualatin Valley. Classification is after Dickinson and Suczek (1979).

CHAPTER 6 - NEOGENE STRUCTURE OF THE TUALATIN BASIN

A key component to developing a working model for Neogene basin development in the Tualatin Basin is to recognize the current structural configuration and combine interpretations with the known stratigraphic relationships. Mapping key stratigraphic horizons and structural features assists in this process.

Subsurface Mapping

Seismic Reflection Data

Structure contour depth maps of the green and red seismic reflection horizons were generated from shot point data on the reflection lines (Figures 96 and 97). The depth values are calculated from RMS velocities displayed on the seismic reflection data which were determined at the time of the seismic survey. The maps only cover a portion of the northern two-thirds of the Tualatin Basin. The basin south of Hillsboro and the Copper - Bull Mountain area has no interpretable seismic coverage. The green reflection horizon, lying within the lower Pleistocene sediments, displays a downwarp towards the center of the Tualatin Basin (Figure 96). The seismic line coverage indicates that faults displacing the green horizon are rare. A small subdepression on the green horizon occurs on the east side of the basin. South of this depression, the Beaverton Fault abruptly cuts out the entire Neogene sediment section.

The red horizon, representing the top of the unweathered CRBG, exhibits a more broken or faulted texture on an otherwise similar gentle downwarped surface (Figure 97). Displacements on the faults are usually less than 100' (30 m) with the exception of the Beaverton Fault where the displacement is at least 700' (213 m).

Figure 96: Computer generated structure contour map of the green seismic horizon developed from shot point time-depth interpretations. The Neogene structure at the level of the green horizon depicts an overall uniform depression.

Figure 97: Computer generated structure contour map with faults added of the red seismic horizon developed from shot point time-depth interpretations. The basin is almost divided into two depressions at this level of the CRBG.

A significant structure away from the basin edges underlies the Hillsboro - Aloha area where the red to orange reflection horizon interval thins almost completely out (Figure 64). The green horizon upwarps and continues over the top of the feature as do higher reflections. The red horizon also rises from the west before the reflection is interrupted. Three possible scenarios may explain the feature: 1) this is a structure that experienced uplift after deposition of the Neogene sediments between the red and orange horizons, with some minor movement after the green horizon was established; 2) this is a possible intrusion related to the Boring Lava episode of the region that took place after green deposition; 3) the seismic display may be an artifact. The feature is probably real as it lies along a straight section of the seismic line whereas adjacent sections of the seismic line make dramatic turns without disruption to the reflection horizons. Popowski (1996) favors the second scenario and has labeled the structure, the Elmonica high. There is no other evidence for Boring Lava features this far west into the basin.

A water well drilled approximately 1.5 miles (2.4 km) to the southeast (SW1/4 of NE1/4 of Sec.15 T1S R2W) on a line between Cooper Mountain and the seismic high entered CRBG at 575' (175 m) below the surface or about 500' (152 m) higher than expected. The seismic high could be a northwest subsurface extension of the Cooper Mountain structure.

The CRBG and the underlying Paleogene sedimentary rocks downwarp smoothly into the basin from the highlands. The seismic reflection lines generally demonstrate only slight warping of the Neogene sediments with a few scattered normal faults extending up from the CRBG to the orange or green horizons (Figure 66). Most of the faults are interpreted to be normal and do not appear to break much further upward than the red horizon of the CRBG. Faults usually occur singly; however, a few cluster in association

with larger CRBG structures (Figure 64). The Beaverton fault just north of Cooper Mountain is the most significant fault recognized on the seismic data. The entire Neogene sediments are cut out south of the fault with CRBG upthrown to the surface (Figure 66).

Structure Contour Maps

Subsurface maps were created from information on over 2400 water wells and other borings located on the valley floor and surrounding foothills of the Tualatin Valley. Structural features such as faults along the red event horizon on four seismic reflection lines in the valley influenced the interpretation of the structural aspects on the top CRBG surface. Depth to basement maps generated by Madin (1990) were also referenced during compilation of the CRBG structure. Gamma and lithology logs generated from field work were instrumental in interpreting the depths of formation boundaries.

Columbia River Basalt

The CRBG is mapped on two surfaces, the top of the lateritic soil horizon underlying the Neogene sediments and the top of the first recorded weathered basalt (Figures 98 and 99). Many driller's logs of those wells that penetrate the CRBG do not include a lithologic description of the red-clay laterite. The usual first description for the CRBG is weathered basalt or hard rock. The laterite and weathered basalt are clearly two different stratigraphic surfaces with the top laterite surface as the actual top of the CRBG; however, for completeness, both surfaces are presented. The top of basalt structure contour map is generated from 1072 data points and is considered to be the more complete of the two maps. The top of laterite structure contour map is constructed from 452 data points and much of the surface mimics the top basalt structure contour map. The thicknesses of the red clay laterite over the top weathered basalt described on

COLUMBIA RIVER BASALT
TOP LATERITE STRUCTURE CONTOUR
TUALATIN VALLEY OREGON

THE CONTOUR MAP
IN

Figure 98: Top of the CRBG laterite structure contour map for the Tualatin Basin, Oregon. The map is constructed only where there is available subsurface data that includes describing the lateritic red clay overlying weathered basalt. The northern two-thirds of the basin exhibits a broad depression relatively unbroken by major faults, while faulting is common in the southern one-third of the basin.

COLUMBIA RIVER BASALT
TOP BASALT STRUCTURE CONTOUR MAP
TUALATIN VALLEY OREGON

BASALT
STRUCTURE CONTOUR MAP
OREGON

Figure 99: Top of weathered basalt structure contour map of the CRBG in the Tualatin Basin, Oregon. This map combines subsurface borings and seismic reflection line information to include all known structural features. The northern two-thirds of the basin at this level is occasionally broken by faults that usually do not extend into the overlying Neogene sediments. The southern one-third of the basin south of the Beaverton Fault contains many more faults. The extreme western portion of the basin includes basement contours of Paleogene sedimentary rocks and the Tillamook Volcanic series.

well logs vary from a few tens of feet (>6 m) to over 50' (15 m). The geometry of the Tualatin Basin at the top CRBG consists of a large west-northwest oriented synclinal downwarp north of Chehalem and Cooper Mountains (Figures 99 and 100). The CRBG surface in the basin around the Hillsboro area is as much as 1500' (460 m) below the Tualatin Valley surface. The Beaverton Fault occurs from the north side of Cooper Mountain, westward almost to the Fern Hill area of the northern Chehalem Mountains (Figure 98). This fault may be truncated by a north-south oriented fault extending northward into the basin from between Fern Hill and Spring Hill in the Chehalem Mountains. The sense of the fault plane angle on the Beaverton Fault is not directly observed from water well or seismic reflection data. Reverse faulting following similar trends in the Tualatin Mountains suggests that this fault is also reverse. The maximum down to the north throw of the fault may be as much as 700' (213 m). A fault almost a mile (1.6 km) north of the Beaverton Fault may be interpreted on a seismic reflection line along SW 185th Avenue in the Aloha, Oregon area, indicating a step wise drop of CRBG into the Tualatin Basin.

The northeast limit of the basin is bounded by a northwest oriented fault on trend with the Oatfield Field Fault mapped in the Lake Oswego and Portland Quadrangles (Beeson et al., 1989b, 1991). The fault is mapped west to the Rock Creek area in the Linnton Quadrangle and may extend beyond. This fault may constitute the shear zone identified in the Tri-Met west side light-rail tunnel and seen as a lineament on aeromagnetic maps (Blakely et al., 1995).

The CRBG along most of the basin's northern boundary west of the Linnton Quadrangle is folded upward into the Tualatin Mountains. A more complicated structural pattern occurs at the CRBG level underlying the McKay Creek drainage just east of North Plains, Oregon. The top CRBG elevation in water wells penetrating the

Figure 100: Section A - A' east-west across the main Tualatin Basin. Structural irregularities at the Cretaceous portion of the basin. The Neogene sediments and clays with a few discontinuous sand layers covers the Neogene sediments by as much as 100 feet.

east-west across the main northern portion of the Tualatin
 al irregularities at the CRBG level are minimal in this
 basin. The Neogene sediment section is dominated by silts
 a few discontinuous sand bodies. The Willamette Silt
 gene sediments by as much as 120' (36.6 m).

unit in the northwestern corner of T1N R2W in the Hillsboro Quadrangle demonstrates two small structural highs surrounded by lows and an area where the CRBG is either absent or very deep (Figure 101). The known thickness of the CRBG in this region varies widely from 31' (9.5 m) in the O'Connell well of section 5 to more than 296' (90 m) in the Crop well of section 8. These two wells are just 2600' (762 m) apart.

Two deep water wells just north and south of Hwy 26 in section 7 (one at Sunset Lumber Company and the other at McKay Creek Farm) did not encounter expected CRBG (Figure 101). The stratigraphic relationship in these wells is either Neogene sediments lying directly on Paleogene marine sedimentary rocks, or a thickened Neogene sediment section overlying deeply buried CRBG. Water wells within a kilometer west and north of section 7 penetrate the CRBG, which is 188' (57 m) thick in the ARCO water well in section 12 of T1N R3W (Figure 101). This water well enters Paleogene sediments below the CRBG.

Aeromagnetic data over the McKay Creek region display a northwest trending lineament with a circular region of lower magnetic intensity surrounded by higher magnetic signals that coincides with the water wells in Sec. 7 T1N R2W that did not encounter CRBG (Rick Blakely, 1996, personal comm.). The observations follow a broad linear zone southward along the McKay Creek drainage suggesting faulting is a probable factor, although paleoerosional features at the top of the Paleogene sediments or CRBG cannot be ruled out (Figure 102). The existence of a fault zone with lateral and vertical components could partially or wholly cut out and/or rotate the CRBG in this area.

The north-south oriented fault between Fern Hill and Spring Hill in the Chehalem Mountains may extend as far north as Sec. 27, T1N R3W, north of Cornelius, Oregon (Figure 99). Seismic reflection data indicate a fault that cuts through the CRBG and

Figure 101: Location map with elevations of the CRBG or total depths of water wells drilled beyond the Neogene sediments in the northwest portion of the Hillsboro Quadrangle.

Figure 102: Possible geologic model explaining the missing CRBG in Sec. 7, T1N R2W of the Hillsboro Quadrangle. Faulting, such as the wrench structure could be responsible for the complicated structural picture.

into the Neogene sediments. This fault may have as much as 700' (210 m) of throw, down to the east.

The CRBG rises to the surface at David Hill and other smaller hills to the north in the Gales Creek Quadrangle. The west side of David Hill has been mapped as Paleogene marine sedimentary rocks (Schlicker and Deacon, 1967). The Gales Creek Fault zone in the Gales Creek Valley west of David Hill separates Paleogene sedimentary rocks to the east from Tillamook Volcanic Series to the west and extends southeast into Forest Grove, Oregon. Seismic reflection data on the south side of Forest Grove reveals a normally faulted Paleogene section underneath Gales Creek that dips northward into the Tualatin Basin. The red horizon of the CRBG does not consistently appear on the seismic line until Baseline Road on the east side of Forest Grove, some 7000' (2134 m) north of the fault. The Cain well in Sec. 1 T1S R4W on the west side of Forest Grove did not encounter CRBG and entered Paleogene sedimentary rocks directly beneath Neogene sediments 250' (76 m) below the surface (Figure 103). CRBG is present north of this well and dips steeply to the north into the basin (Figure 99). The Butte Oil Company well in Sec. 8 T1S R3W just north of Fern Hill and southeast of Forest Grove, entered CRBG 220' (67 m) below the surface and the Paleogene section 320' (98 m) deeper. 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.

The Tualatin Basin at the top of the CRBG south of the Beaverton Fault is structurally more complex than north of the fault. 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 Sections 25 to 28 T1S R1W is buried under Willamette Silt; although well penetrations indicate that

Figure 103: Section B-B' Oregon, dis north of Fo penetrated A branch o data north c

Figure 103: Section B - B' north-south across the western portion of the Tualatin Basin, Oregon, displaying a thick Neogene sediment sequence overlying CRBG north of Forest Grove. The Cain well at the southern end of the section penetrated Paleogene sedimentary rocks underneath the Neogene section. A branch of the Gales Creek Fault zone is indicated on seismic reflection data north of the Cain well.

no Neogene sediments are present on the horst (Figures 99 and 104). The faults bounding the horst may have throws up to 300' (90 m). 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 two miles (3.2 km), and the CRBG rock surface reaches greater than 550' (165 m) below mean sea level along the Sherwood Fault in Sec. 15 T2S R1W of the Beaverton Quadrangle. The structural low wraps around the southern end of Bull and Cooper Mountains to join a subbasin west of Cooper Mountain in the Scholls Quadrangle (Figures 99 and 105). 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 that reach up to 400' (120 m) below mean sea level or approximately 550' (165 m) below the surface.

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 (Figure 99). The subbasin may be bounded on the northeast and southwest sides by faults and the CRBG rock surface reaches a maximum depth of 300' (90 m) below mean sea level. Well data is absent along the eastern most two miles (3.2 km) of the present Tualatin River floodplain, inhibiting subsurface mapping over this interval. CRBG outcrops in uplands around the floodplain in this region and is present in the ODOT Weiss Bridge borings at the confluence with the Willamette River.

The extent of the CRBG weathered zone may help in deciphering the timing of structural activity and sedimentation in the Tualatin Basin after emplacement of the CRBG. The CRBG weathered zone is defined as the interval between the top red-clay laterite and the first occurrence of hard, black basalt from well driller's lithologic logs. The realization that differential cooling of individual lava flows or even flow lobes,

C

NORTH

Figure

Figure 104: Section C - C' north-south across the eastern margin of the Tualatin Basin, Oregon, demonstrating the faulted nature of this portion of the basin. The Neogene sediments, consisting almost wholly of silts and clays, is faulted out in the region of BVD-3. Boring Lava flows are interlayered with the younger Neogene sediments.

D

WEST

Figure 105: Section D - D' east-west section across the southern portion of the Tualatin Basin, Oregon illustrating the faulted and folded CRBG and the effect on Neogene sediment distribution.

0'

EAST

18-5

16-2

BYD-6

100-4

20-3

34-4

MISS

the Tualatin
effect on

development of soil horizons between flow events, and secondary groundwater influences on the porous lava intervals all lead to non uniform weathering of the basalt must be considered when using this interpretation. Erosion of the soil by Neogene streams also affects the weathered zone thickness. The impossibility of field checking basalt characteristics at each well site necessitates a simplified model to understand the lateral extent of the CRBG weathered profile below the Neogene sediments. The resultant CRBG weathered zone isopach (Figure 106) is constructed from 342 data points that included lithology descriptions from the laterite red-clays to the hard, black basalt. The isopach map covers portions of the subsurface extent of this interval and a small upland area. The paucity of information in the center of the basin and the variability in the thickness of the weathered zone does not lend to accurately map contours in this region. The weathered zone is generally from 60' to 120' (18-37m) thick and may exceed 200' (61 m) in places. A trend identified from this map is the increased thickness of the weathered zone along the edges of the basin towards the uplands.

Neogene Sediment Maps

The top Neogene sediment surface displays a gentle downwarp from 180' to 220' (55-67 m) above mean sea level at the basin edges to 60' (18 m) above sea level near the basin center near Hillsboro (Figures 107 and 108). Approximately 160' (50 m) of total relief exists from the basin edges, except for the uplifted Neogene sediments in the eastern most Tualatin Mountains where the relief is from 300' (91 m) to 550' (167 m). Uplifted Neogene sediments are present in the Tri-Met light-rail tunnel at an elevation of 600' (183 m). The gross pattern of the top Neogene sediment contours within the basin may represent paleostream floodplains prior to burial by the catastrophic floods that produced the Willamette Silt deposits (Figure 107). The present Dairy Creek and

COLUMBIA RIVER BASALT

TOP WEATHERED ZONE ISOPACH MAP

TUALATIN VALLEY OREGON

R BASALT

ZONE ISOPACH MAP

EY OREGON

Figure 106: CRBG top weathered zone isopach map in the Tualatin Basin, Oregon. The weathered zone, defined as the interval between the top of the lateritic soil and the top of black, hard basalt, varies in thickness up to 240' (73.2 m).

[illegible]

NEOGENE SEDIMENT STRUCTURE MAP
THE TUALATIN VALLEY OREGON

Figure 107: Top Neogene sediment structure contour map in the Tualatin Basin, Oregon. Many modern drainages follow the low trends on the Neogene sediment surface, such as the Tualatin River, the west and east forks of Dairy Creek, and Rock Creek. The top of the Neogene sediment package is interrupted by the Cooper - Bull Mountain uplift in the southern part of the basin.

E
NORTH

Figure 108: Section E - E' north-south across the central part of the Tualatin Basin, Oregon. The thickest Neogene sediment section is south of HBD-1 and is largely faulted out at the VanFleet water well situated on the western extension of the Cooper Mountain uplift.

F'
SOUTH

n across the central part of the Tualatin Basin,
ogene sediment section is south of HBD-1 and is
anFleet water well situated on the western
ountain uplift.

McKay Creek drainages overlie the low troughs of the top Neogene sediments in the Forest Grove Quadrangle, as does the Tualatin River floodplain throughout most of the valley. Beaverton Creek, Cedar Mill Creek, Willow Creek, Holcomb Creek, Fanno Creek, and most of Rock Creek also follow Neogene sediment troughs. The earlier drainages were evidently able to reestablish themselves after each flood event as the floodplain depressions were probably never completely buried.

No Neogene sediments occur on the Cooper - Bull Mountain structural high. Few faults break into the upper Neogene sediment package in the central basin; although one seismically identified fault north of Cornelius in Sec. 27, T1N R3W, cuts the Neogene sediments from below the CRBG red horizon to at least reflections just above the green horizon. The fault may continue into the upper part of the Neogene sediments. This fault may extend into the Chehalem Mountains between Fern and Spring Hills.

Faults bordering CRBG uplands in the southern part of the Tualatin Basin typically cut out the Neogene sediments (Figure 108). Seismic reflection line coverage along SW 185th Avenue in Aloha, Oregon runs up and over Cooper Mountain. The entire group of Neogene sediment 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. The Neogene sediment isopach map (Figure 69) exhibits a 900 foot (274 m) thickness change in Sec. 16 & 17, T1S R1W, from the southern upthrown side to the northern downdropped side of the Beaverton Fault. The eastern horst extension from Cooper Mountain has no Neogene sediments overlying CRBG; however, up to 550' (167 m) of sediments lie adjacent to the bounding faults (Figures 69 and 99).

The axis of the Neogene sediments parallels the CRBG west-northwest orientation and obtains a thickness of greater than 1480' (451 m) just west of downtown Hillsboro (Figure 69). The sediment unit thins north to the foothills of the Tualatin Mountains.

An interruption in this trend occurs across an anticlinal nose just east of McKay Creek in the Hillsboro Quadrangle. The sediments thin approximately 300' (92 m) over the structure. The thickness of the Neogene sediments in Sec.7, T1N R2W is uncertain as no CRBG was encountered in two water wells just east of North Plains.

The Beaverton Fault abruptly cuts the Neogene sediments east of Spring Hill in the Chehalem Mountains. Neogene sediments fill the CRBG troughs around the Cooper - Bull Mountain structures and obtain a maximum thickness of over 600' (183 m) in the northeast corner of Sec.13, T2S R1W in the Beaverton Quadrangle. Faults west and east of Cooper Mountain disrupt the lateral continuity of the Neogene sediment thickness with differences across faults or structures from 200' (61 m) on the west side to 400' (122 m) on the east side.

Structural Implications

The Tualatin Basin has developed from regional compressional stresses oriented north-south with right-lateral shear components (Yeats et al., 1991). The structural history began with simple compression that formed the Yakima fold belt in which basins have gentle eastern slopes and steep western slopes (Beeson et al., 1989a; and Terry Tolan, 1996, personal comm.).

The eastern Tualatin Mountains-Portland Hills area appears to be more structurally complicated than the northwestern extension of the Tualatin Mountains (Figure 109). The Eocene Waverly Heights basalt exposed along the Willamette River in the south part of Portland and shown on isostatic residual gravity data may act as an obstacle for shear movement in the adjacent highlands (Beeson et al., 1991). The resulting structural response is intense local stresses to the eastern part of the Tualatin Mountains causing

Figure 109: Faults at the level of the CRBG in the northeastern portion of the Tualatin Basin and over the Tualatin Mountains - Portland Hills area. A small graben structure cross-cuts the Portland Hills Fault and may also overprint the Oatfield Fault. The presumably younger fault pair comprising the graben may be related to the Beaverton Fault zone to the west. Data from the Portland and Lake Oswego Quadrangles were taken from Beeson et al., 1991, 1989a).

faulting and perhaps a shift in the local stress field from compression to the north of and to extension south of the Eocene volcanics. Structural folds mapped southwest of this area, such as Cooper and Bull Mountains, Chehalem Mountains, and two subsurface folds underlying Aloha, Oregon complicate this model.

Thrust faults mapped in the CRBG on the Portland (Beeson et al., 1991) and Lake Oswego Quadrangles (Beeson et al., 1989a) have northwest and northeast orientations. A major northwest trending, cross-cutting feature on the west side of the highlands is the Oatfield Fault zone, which is mapped on the Lake Oswego Quadrangle (Beeson et al., 1989a) and is in line with unnamed faults in the Portland (Beeson et al., 1991) and Linnton (Madin, 1990) Quadrangles. The Portland Hills Fault is offset by a cross-cutting fault in downtown Portland west of the Willamette River (Beeson et al., 1991). A pair of faults just south of this area could have influenced the displacement of the Portland Hills Fault, and they form a graben structure that extends southwest in the Lake Oswego Quadrangle to the northern mapped end of the Oatfield Fault (Beeson et al., 1989a). The Oatfield Fault trend is disrupted at this point and may pick up again northwest of the graben structure. The graben faults line up with currently mapped faults that extend from the east side of the Cooper - Sexton Mountain area (Figure 109). The southern fault of the graben may also be the northern fault of the eastern extension horst of Cooper Mountain. The northern fault of the graben may be the eastern extension of the Beaverton Fault.

Faulting in the eastern Tualatin Mountains-Portland Hills occurred in two or three episodes. The earliest faulting is the middle to late Miocene thrusts within the CRBG in the high sections of the Tualatin Mountains (Beeson et al., 1991). These faults were the result of continued compression in the area after the development of low-relief folds. A

second set of faults which may have developed concurrently or a short time after the thrust faults occurred during initiation of shear strain under transpressional stresses, causing right-lateral faults. This includes the Portland Hills Fault and the Oatfield Fault.

The third episode includes extensional features in the Tualatin Mountains-Portland Hills that overprint the older structures. The extension may be the result of late stage shear forces along the Portland Hills Fault derived in part by the presence of the Waverly Heights volcanic high in the Tryon Creek State Park area (Beeson et al., 1991). Faulting occurred between 0.25 and 0.96 Ma if the Boring Lava flows in the Portland Hills are related to the fault zones.

Cooper and Bull Mountains with the related structures to the east may have developed either in the late Pliocene or Pleistocene time. The Beaverton Fault cuts out the Neogene sediment section that includes early to late Pleistocene sediments. Seismic reflection data across Cooper Mountain and the Beaverton Fault rules out depositional geometries which would be associated with long term growth faulting, thus the uplift period was relatively short.

The Neogene sediment-filled 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 or was modified as part of the flanks of the pre-existing basin.

Popowski (1996) suggests that the long term synclinal axis of the Tualatin Basin extended northwest-southeast through the west side of Cooper Mountain and southern subbasin, following the floodplain of the present Tualatin River. This trend is subparallel to that of the Tualatin and Chehalem Mountains and, for the most part, following the deeper depression of the CRBG surface in the subsurface along the Dairy

Creek drainage. The hypothesis implies that the Tualatin River path has not appreciably changed over the length of basin development, and Neogene sediment deposition would have accumulated in the southern Tualatin Basin from the late Miocene and to Pleistocene. The sediment thickness in the depression does not exceed 550' (168 m) and is less than 300' (91 m) through most of this region (Figure 68). More than 1000' (305 m) of Neogene sediments occur in the main Tualatin Basin farther east of the present Tualatin River floodplain and north of Cooper Mountain, indicating the ancestral river must have been more mobile than suggested by this hypothesis.

The pre-Cooper - Bull Mountain uplift basin axis was located through the area of the present structures, further east than the present Tualatin River position (Figure 110). Sediments in the lower stratigraphic interval of the subbasin may have been deposited on the flanks of the original basin. Plio-Pleistocene uplift of the Cooper - Bull Mountain structures cross-cut the basin and resulted in the erosion of the capping sediments with partial filling of the surrounding depressions. Boulders and cobbles of basalt were encountered near the base of the Neogene section in water wells south of Cooper Mountain suggesting active erosion of the surrounding highlands.

Structural features in the central and western parts of the Tualatin Basin are less complicated. This area may not exhibit the binding, shear stress effects of the Waverly Heights basalt high due to the increased distance from that area. A thick section of probable Eocene volcanics underlying the northern third of the Tualatin Basin and the Tualatin Mountains, as indicated by aeromagnetic data, may have kept the region from extensive structural deformation and allowed simple subsidence in this part of the Tualatin Basin (Popowski, 1996).

Figure 110: Synclinal axis of the Tualatin Basin prior to uplift of the Cooper -Bull Mountain structures (modified from Popowski, 1996). A thick Neogene sediment package in the main basin north of Cooper Mountain necessitates shifting the axis further east than modeled by Popowski (1996).

CHAPTER 7 - TUALATIN BASIN DEVELOPMENT AND REGIONAL SETTING

Eocene to Middle Miocene Setting

The region occupied by the Tualatin Valley and surrounding highlands during the Eocene to early Miocene time was part of the Columbia trans-arc embayment in which sedimentation, volcanism, and regional tectonic adjustments combined to set the stage for CRBG emplacement. Isostatic residual gravity, and industry and government aeromagnetic data exhibit deep lows in the central part of the Tualatin Basin, which is explained by a thick package of Paleogene sedimentary rocks beneath the CRBG (Figure 111; Popowski, 1996). Gravity highs along the northern third of the valley and the Tualatin Mountains form in response to a thick Eocene volcanic package underlying a thinned Paleogene sediment section. Aeromagnetic data (Popowski, 1996) indicate that the volcanic section is thickest under and north of the Tualatin Mountains, and thins to the south into the present Tualatin Basin near North Plains. Eocene volcanics of the Waverly Heights basalt, as shown by gravity data, occupy an extensive area on the east side of the Tualatin Basin, centered southeast of Lake Oswego at the Willamette River - Clackamas River confluence. Gravity data (Popowski, 1996) show a gradient from a deep low corresponding to the thick Paleogene sedimentary package in the center of the basin to a strong high all along the north-south trending edge of the Coast Range to the west. The oldest recognized faulting in the region is the Gales Creek - Mt. Angel Fault zone, which is interpreted to have been a sinistral shear feature during the Paleogene and may be responsible for a right step in the Coast Range strong gravity gradient on the northwest side of the Tualatin Basin (Ray Wells, 1996, personal comm.). The Gales Creek - Mt. Angel Fault zone was reactivated as a dextral shear zone in the Neogene by continued rotation of the Coast Range block (Ray Wells, 1996, personal comm.). The

Figure 111: Isostatic residual gravity and aeromagnetic data anomalies for the northern Willamette Valley region. Gravity lows probably indicate thick Paleogene sedimentary rock sequences underlying the area. Gravity highs and strong magnetic signatures reflect both deep and shallow basaltic volcanic packages. Data modified from Popowski (1996).

Portland Hills - Clackamas Fault zone initiated movement in the late Paleogene, perhaps during the Oligocene, and has developed into a major northwest-southeast dextral shear feature affecting volcanic and sedimentary deposition (Beeson et al., 1989a; Beeson et al., 1985; Balsillie and Benson, 1971).

The Tualatin Basin region was covered in the Middle Miocene by basaltic lava flows of the CRBG. Sand Hollow and Ginkgo units of the Frenchman Springs Member within the Wanapum Basalt are the youngest of these flows to enter the valley.

Instrumental neutron activation analysis chemistry from weathered and unweathered basalt of the CRBG in the HBD-1 boring reveal the presence of these 15.3 Ma lava flows in the central part of the valley (Table 11; Beeson, 1996, written comm.).

Remnants of Frenchman Springs flows occur in scattered locations in both the Tualatin and Chehalem Mountains (Al-Eisa, 1980; Beeson et al., 1991).

The middle Miocene Tualatin Valley landscape after CRBG emplacement consisted of a relatively flat plain that initially received little sediment cover and was bounded on the northeastern margin by a low relief highland ridge representing the early stages of the Tualatin Mountains. The northern Coast Range to the west had begun to uplift prior to this time, but did not prevent all CRBG flows from reaching the present coast (Beeson et al., 1985). Early Miocene Coast Range uplifting tilted preexisting strata creating an east-dipping homocline in the ancestral Willamette Valley region. Middle Miocene CRBG flows were transported in an east-west direction along the Columbia Trans-Arc lowland (Beeson et al., 1989a), and the modern north-south oriented Willamette Valley had not yet developed (Yeats et al., 1991). Remnant hills with as much as 800' (245 m) of relief of Paleogene sediments that were not buried by CRBG flows may have been present in the northwestern part of the present Tualatin Valley watershed (Van Atta and Kelty, 1985).

Table 11: X-Ray fluorescence major and trace element values of Columbia River Basalt samples from the HBD-1 boring at the Hillsboro Airport and their assigned flow unit.

	693.3"	1029.5'	1042.5'	1080'
	(293.6 m)	(313.8 m)	(317.8 m)	(329.2 m)
Major and Minor Element Normalized Weight %				
SiO2	42.47	52.51	51.68	51.46
Al2O3	34	13.98	13.32	13.5
TiO2	5.27	3.16	3.01	3.2
FeO	17.21	14.44	14.46	14.69
MnO	0.11	0.143	0.227	0.223
CaO	0.25	8.24	8.43	8.37
MgO	0	3.31	4.23	3.83
K2O	0.09	0.74	1.13	1.08
Na2O	0.01	2.93	2.93	2.96
P2O5	0.6	0.563	0.586	0.71
Trace Elements (ppm)				
Ni	34	5	7	1
Cr	16	49	50	29
Sc	41	47	41	42
V	562	447	422	395
Ba	426	590	559	596
Rb	2	10	23	26
Sr	216	345	321	339
Zr	292	182	181	189
Y	29	36	41	44
Nb	28.1	16.5	16.4	17.6
Ga	35	19	24	23
Cu	43	19	13	10
ZAn	91	138	152	153
Pb	55	6	3	7
La	264	14	18	33
Ce	406	49	67	60
Th	6	6	4	6

Weathered Sand Hollow Sand Hollow Ginkgo
Not Determinable

Unpublished XRF data by GeoAnalytical Laboratory Washington State University and interpretations by Marvin Beeson, Portland State University

The top of the CRBG was exposed for a significant time period to develop a deeply weathered basalt zone capped by a bright red-brown lateritic soil. Bauxite development has been reported from this laterite in Washington County (Baldwin, 1981). Total weathered basalt thicknesses in wells in the Tualatin Valley may exceed 100' (30.5 m) (Figure 106). Many water well driller's lithology logs of wells penetrating the Neogene and CRBG south of Cooper and Bull Mountains indicate an abrupt hard basalt surface under the sediments. The weathered basalt is included on other well logs in the area. The laterite may have either been scoured off by streams in parts of this area before the CRBG was buried or is present, but not described.

Little to no sediment was deposited during lateritization, which was probably accompanied by the development of local streams. The time frame for the development of the CRBG weathered zone cannot precisely be determined, as the lower age limit of the Late Miocene Neogene sediments is not known. The formation of 100'-200' (30-61 m) thick laterites may take one to three million years (Scott Burns, 1997, personal comm.), so the oldest post CRBG sedimentation is probably between 12 and 14 Ma.

Late Miocene to Recent Sedimentation

Helvetia Formation Problem

The Helvetia Formation of Schlicker and Deacon (1967) has not been separated from the rest of the Neogene sediments in this study. Field and water well information are insufficient and inconsistent to warrant separation of these sediments. Outcrops of Helvetia Formation are extremely rare as vegetation has covered most road cuts used by Schlicker and Deacon (1967) in their formulation of this stratigraphic unit. Several samples collected at the type locality just north of Helvetia, Oregon, contain the same materials and textures as other Neogene sediments. The samples consist of red-brown,

slightly micaceous, very clayey silts with scattered, rounded, highly weathered basalt clasts up to gravel-sized, some totally altered to clay. Black iron oxide precipitated coatings are present throughout the sediment. Granite or quartzite pebbles were not noted in these sediments. Upper Neogene sediments such as those from the ODOT Cornelius Pass Road, Cornell Road, and Murray Road cores along the northern extent of the Tualatin Valley display the same textures (well repository).

Several water well driller's lithology logs in Sections 3, 4, and 5 in T1N R2W, south of Helvetia, describe a red-brown clay overlying a gray-brown clay just above the CRBG weathered zone. Most water wells located away from this area have driller's lithology logs that do not mention this stratigraphic relationship. The first sediments to reach the site of the HBD-1 boring were gray-brown, clayey silts overlain by red-brown, silty very fine sands capped by a thin, cemented, pisolitic, conglomerate containing rounded weathered basalt nodules. The lateral extent and thickness variation of this 15 foot (2.5 m) section is unknown. These red-brown sediments overlying gray-brown silts could be a subsurface extension of what has been called the Helvetia Formation; yet the red-brown coloration is the only obvious difference between these sediments and the overlying Neogene sediments.

Seismic reflection geometries indicate that early sediment deposition on top of the CRBG laterite was confined mostly to what is presently the central parts of the Tualatin Basin (Figure 67). The green seismic reflector, correlated with Pleistocene sediments in the HBD-1 boring, pinches out prior to reaching the basin edges. This implies that the previously identified Helvetia Formation sediments overlying the CRBG at the basin edges were deposited sometime later and are probably Pleistocene-aged.

Neogene Sedimentation

The presence of numerous fining-upward sediment sequences and sedimentary structures such as cross-bedding and subparallel laminae in HBD-1 and other borings in the Tualatin Valley favor a fluvial origin for most of the Neogene sediments. The silt and clay beds probably represent channel deposits from smaller tributaries and overbank and floodplain deposition from larger streams. Silt and clay dominate the Neogene sediments due to the fine-grained nature of source rocks from the highlands and the low gradient fluvial conditions in the basin. The lack of large amounts of gravel and coarse sands in the Neogene sediments denotes either low energy river environments in the valley and/or the fine grained nature of the source rocks. Both parameters were probably working together then as they are today. The CRBG laterite is composed of clay with highly weathered basalt fragments and rounded nodules that range in size from silt to gravel. The Coast Range source rocks are also generally fine-grained, consisting of basalt and the Paleogene mudstones, siltstones, and sandstones. All modern streams draining into the valley have low gradients and carry dominantly fine-grained materials.

Hart and Newcomb (1965) noted an extensive area of unusually high percentages of sand in the Neogene sediment section around the Hillsboro area. The sand percent maps generated in this report substantiate and expand on this observation (Figures 70, 71, and 72). The depositional areas are close to the present center of the Tualatin Valley, providing evidence that the basin synclinal axis has not migrated much over the history of the basin. Seismic reflection data also show the uniform symmetry of the basin center over time (Figure 67). Linear sand distributions mapped within the Neogene sediments represent broad paleo-depocenters probably resulting from stable floodplains of tributaries and the main stem of the ancestral Tualatin River. Most individual sand bodies are highly discontinuous, yet there are local areas where sands can be traced from

one well to the next. The Roy area contains a black sand aquifer that ranges from approximately -179' (-54.5 m) to -194' (-59.1 m) below mean sea level and laterally extends over at least 2000' (610 m). The differences of the sand depths over this distance could represent more than one sand bed deposited by the same stream or could result from variations of the local fluvial depositional environment.

Upper Neogene (Pleistocene) sediments from water wells and other borings in the northeast portion of the Tualatin Valley could be the product of fluvially reworked loess material originally deposited higher on the slopes of the adjacent highlands (Figure 112). Beds of remnant loess deposits may also be preserved in these borings. Stream action off the highlands may have resulted in a coalescing series of low angle fan deposits intermingled with loess deposits spreading away from the Tualatin Mountains-Portland Hills area (Figure 113).

Samples described from borings downslope of the Tualatin Mountains-Portland Hills (Figure 112) have a slightly different texture and color than other Neogene sediments away from this area. They are almost exclusively yellow-brown, micaceous, very fine sandy to clayey silt with a few interbeds of very fine to medium grained sands and rare, thin conglomeratic beds (well repository). Clay layers are almost nonexistent in these borings. Most of the borings reach depths between 100' (30.5m) and 200' (61 m). The Claremont well penetrates almost exclusively silt in the entire 380' (116 m) thick Neogene sediment unit and M102 encountered 320' (97.5 m) of silty sediment.

One million year old Neogene fluvial sediments overlie massive loess silts in the area of the Tri-Met westside light-rail alignment at Sylvan (Figure 45). These sediments are similar in texture and color to those found in the borings, yet thin, basaltic, gravel layers in the upper stratified section reflect a more proximal setting than those found downslope. Red-brown, very fine sandy, loess silts also are present between Boring

Figure 112: Location of borings containing examined Neogene sediments in the northeastern portion of the Tualatin Basin, Oregon. The upper Neogene sediments exhibit textures typical of loess deposits and are probably Pleistocene in age.

Figure 113: Schematic diagram of the northeast portion of the Tualatin Valley depicting possible interrelationships between loess deposits and subsequent reworking of loess to form fluvial sediments.

Lava flows in the Portland Hills, above the older Neogene sediments, and are between 0.26 and 0.86 Ma. Very little organic debris is noted in these sediments and the overlying Portland Hills Silt. Cooler climates of the time may have influenced the style of loess deposition.

Stream action has continued in the Tualatin Valley up to and between Missoula catastrophic flood events that entered the valley around 15.3 ka. Fluvial environments have deposition concentrated in and adjacent to major streams. Fluvial activity of the proto-Tualatin River continued between flood events, eroding flood silts and depositing new sediments to create intercalated relationships. ODOT TRB-1 and 2 at the Tualatin River south of Hillsboro contains mixtures of sand, silt, and clay units not compatible with the normal stratigraphic relationship of Missoula flood silts overlying Neogene silty clays found away from the river's floodplain (Figure 114).

Ashfall and Lacustrine Sedimentation Events

Three stratigraphic units from HBD-1 in the Neogene sediments provide evidence of sedimentary events that deviated from the normal fluvial depositional style during the history of the Tualatin Basin. An ash fall event accumulated on a low-lying, meandering river system, providing a source of mobile silica. Burial and subsequent silica dissolution in the ash layer promoted reprecipitation that cemented a 15 cm thick, clay drape at 760' (232 m) in HBD-1 into a green mudstone and eight feet (2.4 m) of very fine sand and silt layers below the mudstone. The degree of induration decreases downward. Alteration was complete as no glass shards have been found in the sediment (Dr. Alan Lester, 1996, personal comm.).

INAA chemistry of the mudstone at 760' (231.6 m) and a siltstone at 763' (232.6 m) reveals much lower than normal scandium and chromium levels and an elevated sodium concentration as compared to other HBD-1 Neogene sediments analyzed (Barnes,

Figure 114: Cross-section across the Tualatin River at the Hwy 219 bridge overpass. The simple silt down to either clay or sand pattern from the Willamette Silt to the underlying Neogene sediments that is the rule for most of the Tualatin Valley does not fit along the Tualatin River floodplain. Sands deposited by the river intertongue with flood silts all along the river from Jackson Bottom to at least the city of Tualatin and probably downstream toward the mouth of the Tualatin River.

1995). Low scandium and chromium concentrations indicate a more silicic component in the sediments than what is provided from the local highlands. An ash fall from the Cascade Range is a likely source. The silicified zone is Pliocene-aged as it lies between the Late Miocene pollen assemblage found at 850' (259 m) and Plio-Pleistocene diatoms in the lacustrine claystone unit between 715' and 730' (218-222.5 m).

The lateral extent of the silicified layer may be tentatively correlated to the orange seismic reflector across the northern main part of the Tualatin Basin. Velocity and density contrasts between the younger, lower density, diatomaceous lacustrine unit and the older, higher density silicified zone, separated by 30' (10 m) of fluvial, intermediate density sediment have combined to generate the orange reflector. Diatoms from the overlying interval have provided evidence that the lacustrine unit is extensive, yet there is no supporting evidence for the silicified zone. Volcanic ash fall events typically cover extensive areas; however, the unit has not been reported from water wells drilled to this depth in any part of the Tualatin Valley, probably because the very hard zone is so thin that drillers would not be able to detect it during normal drilling operations.

Two probable larger scaled lacustrine units have been identified in the HBD-1 core: the diatomaceous claystone interval from 715' to 730' (218-222.5 m), just below the orange seismic reflector, and a silty clay series from 574' to 606' (175-184.7 m) that corresponds to the green horizon on the seismic reflection data. The lateral continuity of these reflectors across the basin provides for either a lacustrine depositional environment or these reflections represent disconformities.

Plio-Pleistocene, low density, brown silty clay and gray-green clay interlaminated mudstones between 715' and 730' (218-222.5 m) and an underlying sand unit to 734' (224 m) contain three species of recognized diatoms. The abundant planktonic genus Aulacosira, suggests either relatively deep water conditions or a very turbid medium

(Edward Theriot, 1994, written comm.). A shallow, muddy system is favored as the diatom-rich interval is not very thick and clayey, silty, fluvial sands above and below this interval suggest the apparent low energy nature of the depositional system. The shallow lake probably covered a large percentage of the Tualatin Valley. Seismic reflection data away from the HBD-1 site illustrate the continuity of the orange reflector and provide the opportunity to determine the lateral extent of the lacustrine environment (Figure 58). The rare presence of *Rhopalodia* and *Pliocaenicus* indicates a highly eutrophic and alkaline, lacustrine environment. The laminated nature of the mudstones encasing the diatoms in HBD-1 also is suggestive of seasonal "varve" sedimentation found in lakes.

This diatomaceous unit is unique to the Neogene sediment package in the Tualatin Basin indicating that unusual depositional conditions must have been present. Boring Lava flows in the Canby Quadrangle lie on the eastern Willamette River bluffs overlooking the mouth of the Tualatin River (Trimble, 1963). Recent potassium-argon age dating from Boring Lava basalt located at Waterboard Park in Oregon City has indicated that these flows are 2.44 Ma (Conrey et al., 1996), a time that may coincide with the deposition of the diatomaceous interval in the HBD-1 boring. The Boring Lava flows blocked the ancestral Tualatin and Willamette Rivers and diverted the river courses towards the northwest up the lower Tualatin River Valley (Baldwin, 1980). An extensive shallow lake formed in the Tualatin Valley in response to restricted outflow of the Tualatin River and extra inflow into the valley by the Willamette River. The proto-Willamette River should have also been temporarily blocked at this time, forming an extensive lacustrine environment south of the Boring Lava dam site; however, there is little direct known lake evidence in the Troutdale Formation south of Oregon City or in the blue clay sequence of the Willamette Valley supporting this scenario.

The only Neogene diatoms reported from the Willamette Valley were recently discovered in the top ten feet (3 m) of the blue clay unit from an ODOT bridge geotechnical boring core on the Hwy 34 bypass around Corvallis. The diatoms sit in a Pleistocene-aged pollen assemblage whose environment consisted of organic-rich forest ponds and shallow marshes (Scott Billings, 1996, personal comm.). This site lies on the western depositional edge of the middle Willamette Valley and may have been above lake level at the time of the Boring Lava river blockage. The lacustrine environment may have been restricted to an area north of Salem, Oregon, where the Neogene basin subsidence is greatest.

Pleistocene-aged silty clay layers in HBD-1 from 574' to 606' (175-184.7 m) correspond to the green seismic reflection horizon depth, and they register lower than normal radioactivity on the gamma log (Appendix B). Sediments above and below the clay unit are recognized as dominantly fluvial.

The green horizon is the strongest event above the CRBG red horizon and extends over a great portion of the basin (Figure 99), suggesting that the clay unit is lacustrine or the reflection event represents a disconformity. No diatoms were noted in the clay unit from binocular microscope observations. Reflection geometries do not exhibit truncations under the green horizon nor are there onlapping relationships overlying this reflector indicating a major unconformity. The reason for the strength of this reflector is not well understood. Velocities above and below the silt clay series in HBD-1 vary at most by 200 ft/sec (61 m/sec) and are not appreciably different (Figure 64 and Table 7). A strong, extensive reflection horizon close to the same relative stratigraphic position to the CRBG is found on seismic reflection lines in the northern Willamette Valley (Yeats et al., 1991). An exact age relationship between the two reflectors necessitates examination of sediments at the level of the reflector in the northern Willamette Valley.

Neogene Sedimentation Rates

Post-CRBG sedimentation rates in the Tualatin Basin appear to have increased with time, reflecting basin subsidence rates. Geometries from seismic reflection data demonstrate a downwarping of the sediments with basin subsidence. Sedimentation rates differ significantly between Pleistocene and Pliocene/late Miocene deposits. The Pleistocene-Pliocene boundary in the HBD-1 boring is between Pleistocene-aged pollen at 649' (198 m) and Plio-Pleistocene-age diatoms at 715' (218 m). The 700 foot (213 m) depth is arbitrarily picked to be the Pleistocene - Pliocene contact for the purposes of calculating sedimentation rates, thus the Pleistocene thickness in HBD-1 is 618' (188 m), excluding the 82' (25 m) of the Willamette Silt. The sedimentation rate of the Pleistocene sediments at HBD-1 is 0.13 mm/yr, using a Pleistocene age limit of 1.6 Ma. (Monroe and Wicander, 1994) or 0.09 mm/yr using 2.4 Ma. for the beginning of the Pleistocene (Easterbrook, 1993). If the 0.78 Ma. Brunhes-Matuyama boundary exists at 493' (150.3 m), then the sedimentation rate for 411' (125.3 m) of the upper Neogene sediments increases to 0.16 mm/yr.

The Pliocene/late Miocene sediments in HBD-1 are 245' (75 m) thick and are treated here as one unit due to the unknown contact depth between the two epochs. The Pliocene lasted 3.7 million years from 1.6 (or 2.4) to 5.3 Ma. Calculations including only the Pliocene yields a rate of 0.02 mm/yr for the start of the Pleistocene at either 1.6 or 2.4 Ma. Seven million years are added to the calculation to account for the late Miocene, yielding a sedimentation rate of 0.007 mm/yr. These rates are an order of magnitude lower than the Pleistocene rate, indicating that basin subsidence increased during the Pleistocene. Increased sand percentages in the upper 500' (152 m) of HBD-1 suggest more coarse material entering the basin, representing higher energy deposition.

Tualatin Basin subsidence with uplifting of the northern Coast Range during Pleistocene time provided increased amounts of sediments into the basin. The other highlands surrounding the Tualatin Basin may have also been actively rising during this time as indicated by faulted rock relationships in the Oatfield shear zone in the Tri-Met westside light-rail tunnel through the Portland Hills and the cut-out Neogene section along the Beaverton Fault north of Cooper Mountain.

Willamette Silt Deposition

The catastrophic Missoula floods entered the Tualatin Valley at least twenty-two times, inundating the valley up to 400' (122 m) elevation (Allison, 1978a; Richard Waitt, 1996, personal comm.). The flood waters that constructed the Lake Oswego conglomeratic fan deposited sand for several miles up the floodplain lowlands of the Tualatin River and Fanno Creek (Figure 74). Very fine sandy silt and clayey silt comprise most of the rest of the Willamette Silt in the Tualatin Valley. The nine meter section exposed between 205' and 235' (62.5-71.6 m) above mean sea level at Hwy 217 and SW Cabot St. in Beaverton, contains graded beds approximately 15 - 20 cm thick that are cross-cut by 1 - 5 cm thick clastic dikes (Richard Waitt, 1996, personal comm.).

Floodwaters mainly entered the Tualatin Valley through Lake Oswego. The lack of well developed Missoula flood fans in the present lower stretches of the Tualatin River and in the Tonquin Scabland area does not preclude that flood waters entered these areas. The Tonquin Scabland region in the Sherwood Quadrangle according to Allison (1978a) is a slack water conduit for retreating flood waters (Figure 115). Gravel deposits present along the lower canyon of the Tualatin River may have originated from incoming flood events. The Wapato Lake bed gap south of Gaston is approximately 270' (82.3 m) above mean sea level and should have been mainly a pathway for receding floodwaters of only the largest floods.

Figure 115: Possible paths for Missoula flood waters into and out of the Tualatin Valley during the episodic events between 12,700 and 15,300 years b. p.. The short arrow into the Tualatin Valley through the Tonquin Scablands represents a possible, but not documented path.

The Willamette Silt in the Tualatin Valley usually contains organic material only near the basal contact with the underlying Neogene. The lack of organic material through most of the unit suggests that the valley floor did not have a lot of time to re-establish a significant vegetation cover between flood events.

The sedimentation rate of the Willamette Silt at the location of HBD-1 was 9.6 mm/yr, assuming continuous deposition. The total time period of Missoula flood deposition lasted 2600 years and with at least 22 flood events recorded in the Tualatin Valley, an average of 118 years lapsed between flood events assuming they occurred at regular intervals. This sedimentation rate is considered a maximum average value; however, the episodic nature of the flood events indicates rapid depositional periods followed by longer intervals of nondeposition and local stream incision.

Boring Lava Events on the East Side of the Tualatin Basin

Boring Lava eruptions in northern Oregon have occurred for at least five million years and are documented in the Portland metropolitan area between 3 and 0.26 Ma (Conrey et al., 1996). The youngest dated Boring Lava flows occur on the west slope of the Tualatin Mountains - Portland Hills in the Sylvan area, indicating transtensional stresses were acting in the region during the Pleistocene. Boring vents in the Portland Hills south of the Sylvan area have not been dated to ascertain whether there is a temporal - spatial relationship to eruptive activity in this area. The presence of Boring intrusions would suggest normal or tensional Plio-Pleistocene faulting within the basin that is deep seated enough to allow magmatic upwelling.

Tectonic Setting

Paleogene sedimentary rocks were originally deposited in the Trans-Columbia fore-arc setting and were derived from volcanic arc complexes and the continental interior to the east, as well as, from local volcanic activity (Baldwin, 1981). These sediments have

been uplifted by accretionary tectonic processes and recycled into a younger fore-arc setting overlying part of the residual basin, similar to a model presented by Dickinson and Seely (1979). The difference between their model and the present situation is the second generation basin in this case is non-marine and does not extend to the arc massive (Figure 116). The Tualatin Basin is only a part of the greater Willamette fore-arc lowland that flanks the western slope of the earlier Cascadian eruptive cycle. Gravity data indicate that the Neogene Tualatin Basin overlies an extensive package of Paleogene sediments (Popowski, 1996), suggesting that this basin lies on the eastern flanks of the older Paleogene fore-arc basin. Paleogene sedimentary rocks are also present under the CRBG in the Northern Willamette Basin (Yeats et al., 1991).

Comparison of the Neogene Geologic Histories between the Tualatin Basin and other Depositional Basins in the Willamette Valley Region

The Tualatin, Portland, and northern Willamette Basins all contain Neogene sediments that reach comparable thicknesses in the basin centers and are influenced to some degree by the same dextral fault shear couple (Portland Hills - Clackamas Fault Zone and Gales Creek - Newberg - Mt. Angle Fault Zone), implying that these basins have experienced similar, gross structural and depositional processes (Figure 117). The timing and magnitude of basin subsidence which reflects the magnitude of sediment deposition within each basin may have resulted in a divergence in basin development. All sedimentary depocenters within the entire Willamette Valley region demonstrate initial sedimentation during the late Miocene. The magnitude, length, and type of deposition varies (Crenna et al., 1994; Beeson and Tolan, 1993; Gannett, 1992; and Yeats et al., 1991).

Figure 116: Schematic diagram representing the Tualatin Basin as a composite fore-arc basin complex. Paleogene marine to transitional sediments comprise up to 14000' (4267 m) of the early basin, which stopped subsiding in early Miocene. The basin was reactivated in the late Miocene and probably continues to the present. (Modified after Dickenson and Seely, 1979).

Figure 117: Outlines and basin centers for the Tualatin, Portland, and northern Willamette Basins. The Portland Hills-Clackamas and Gales Creek-Mt. Angel fault zones have acted in concert to influence the development of these basins.

Willamette Valley South of Salem

Neogene sediment deposition in the Willamette Valley south of Salem occurs in two main subbasins, the Stayton Basin and the southern Willamette Valley (Yeats et al., 1991). Neogene sediment ages have been interpreted in this area where sediment deposition has been divided into a lower, fine-grained fluvial/lacustrine facies deposited from the ancestral Willamette River and an overlying fan gravel facies built into the valley from the Cascade Range. An ODOT geotechnical core extracted near Sublimity, Oregon, at the eastern edge of the Stayton Basin, contains about 131' (40 m) of Pleistocene-aged sediments overlying CRBG (Crenna et al., 1994). Most of the finely interbedded sand, silt, and clay core is paleomagnetically reversed belonging to the Matuyama geomagnetic-polarity epoch.

Boring cores at Monroe and Corvallis where the Neogene sediment section is less than 150' (45.7 m) in the southern Willamette Basin, contain sediments as old as late Miocene, yet the sedimentary sequence is discontinuous (Roberts and Whithead, 1984; and Scott Billings, 1996, personal comm.). Pollen samples in the Corvallis core indicate approximately 70' (21.3 m) of late Miocene to early Pliocene blue clay overlain by 50' (15.2 m) of Pleistocene-aged blue clay (Scott Billings, 1996, personal comm.). This sequence is unconformably buried under 45' (13.7 m) of gravel fan deposits and Missoula flood sediments. Not all sections in the area contain early Pleistocene - Pliocene sediments. The late Miocene-early Pliocene Monroe clay farther south is unconformably overlain by late Pleistocene terrace gravels (Roberts and Whitehead, 1984). The entire Neogene sediment section at this locality is 100' (30.5 m).

The Stayton and southern Willamette Basins initiated subsidence independently from the northern Willamette Basin in the late Miocene (Crenna et al., 1994). The Stayton Basin stopped sinking by Pliocene to middle Pleistocene time, accumulating more than

1300' (400 m) of Neogene sediments. The base of the fan gravel deposits in this basin is flat indicating there has been no subsidence in the basin since deposition of the underlying fine-grained unit.

Northern Willamette Valley

The northern Willamette Basin Neogene development may have paralleled that of the Tualatin Basin. CRBG laterite development is extensive in both regions, indicating a time of weathering with limited sediment deposition after flows of the Frenchman Springs were emplaced. Lateritic soils occur in the subsurface and on hills of CRBG, such as the Eola Hills and the Red Hills of Dundee, in the northern Willamette Valley (Yeats et al., 1991) and provide evidence for a post-CRBG period of nondeposition in this area similar to that suggested for the Tualatin Basin.

The Neogene sediment sequence thickens to over 1800' (550 m) north of the Salem, Eola, and Waldo Hills, near Woodburn, extending in a broad basin beneath French, Howell, and Elliot Prairies (Crenna et al., 1994). The only obvious structural feature bounding the basin is the Waldo Hills Fault on the southern border. The Neogene sediment sequence contains a thick section of fine-grained clastics overlain by the same fan gravels found in the Stayton Basin. These gravels obtain thicknesses greater than 200' (60 m) north of Salem. The sediment package has been uplifted and exposed northeast towards Oregon City where it is mapped as the Troutdale Formation (Trimble, 1963).

The Meadowcroft water well on Carus Road southeast of Oregon City (Figure 85) penetrated over 1000' (300 m) of fine-grained Neogene sediments before entering CRBG. These sediments are probably pre-Pleistocene in age and underlie Boring Lava

flows that may have erupted from the Highland Butte vent southeast of the well. Boring Lava flows located in Oregon City that may also be from Highland Butte were dated at 2.44 Ma (Conrey et al., 1996).

The buried Neogene deep basin sediments to the southwest of the well site may contain a significant thickness of younger material. Proprietary seismic reflection data from the deep portions of both the Tualatin and northern Willamette Basins display prominent reflectors midway up the Neogene section above the CRBG, and reflection characters above and below these high-amplitude horizons have the same patterns in both areas (Yeats et al., 1991).

Known differences between the two basins include the structural framework and provenance contributions to the Neogene sediments. Boundary regional dextral shear faults such as the Portland Hills-Clackamas Fault zone and the Gales Creek - Newberg Faults bordering the Tualatin Basin are not recognized for the northern Willamette Valley. Instead, numerous smaller scale faults are mapped in the surrounding highlands, and the Gales Creek - Newberg - Mt. Angel Fault zone runs through the middle of the northern Willamette Basin (Werner et al., 1994; Yeats et al., 1991). The Mt. Angel Fault zone is one of the more active systems in the Willamette Valley region having last had significant seismic activity in March, 1993 (Madin et al., 1993). The fault cross-cuts most, if not all, of the Neogene sediment section in the basin indicating either growth of an older fault, or this is a late stage structural feature unrelated to earlier basin development.

Neogene sediments in the Tualatin Basin are almost wholly derived from the Coast Range and surrounding CRBG highlands. Very little sand contribution from the Cascade Range is evident. The geographic position of the northern Willamette Valley clearly demonstrates that Neogene sediments were derived from both the Coast Range

and Cascade Range. Pleistocene fan gravel deposition in the basin is predominantly derived from the Cascade Range (Gannett, 1992).

The Tualatin and northern Willamette Basins appear to have had similar depositional histories since the post-middle Miocene; although detailed stratigraphic and depositional environment relationships of the Neogene sediments in the deep part of the northern Willamette Valley have not been examined. Subsidence of the northern Willamette Basin from late Miocene to at least the upper Pleistocene, and into the Holocene is evidenced by warping of the Plio-Pleistocene fan gravel base and by the broad convexity of the modern Willamette River profile (Crenna et al., 1994). The thickness of late Miocene to Pliocene sediments within the basin, and therefore, a comparison of basin subsidence rates between the Tualatin and northern Willamette Basins over this time period cannot be presently ascertained. Thickening fan gravel deposits in the southwest portion of the northern Willamette Basin reflects greater rates of subsidence during the Plio-Pleistocene interval in this part of the basin, possibly due to accelerated uplift in the northern Coast Range.

Portland Basin

The Neogene history of the Portland Basin is complex with episodes of transpression and extension that have affected the development of local structures and volcanic activity and influenced sediment accumulation in the basin (Blakey et al., 1995).

The net displacement of the top CRBG is small between the deepest portions of the Tualatin and Portland Basins, with elevations below mean sea level at -1320' (-396 m) in Hillsboro and -1400' (-426.7 m) for the MTD-1 boring. The peak elevation of the Tualatin Mountains between the two basins is 1100' (335 m) above mean sea level, indicating a net elevational change at least 2400' (732 m) for the CRBG. Although the net movement of the CRBG between the two basins is similar, various lines of

evidence indicate that the Portland Basin differs from the Tualatin Basin in the Neogene subsidence rate with time.

The thick weathered zone of the CRBG in the Tualatin Basin has not been commonly reported in water wells in the Portland Basin; however, deep lateritic zones are reported in the Portland area (Trimble, 1963). The CRBG below the base of the Neogene sediments in the MTD-1 boring located at the Portland International Airport consists of relatively fresh material. A 75 foot (23 m) section of variegated clay overlies the basalt at this location (Appendix B). The clay exhibits hues red-brown and bright ochre and contains highly weathered basalt nodules very similar to the laterite in the HBD-1 well. Sedimentary light brown, silty clay also present in the samples from this section could be drill cavings from above; however, the recovery is poor from this depth interval and the horizon of the clay is uncertain. The variegated clay unit may be the product of reworked lateritic material from higher ground and sediment brought in from the ancestral Columbia River system. There are no decomposed basalt units between the clay and fresher basalt in this boring as compared to the weathered section in the HBD-1 boring. Vesicular basalt textures typical of flow tops are missing at the top of the black basalt in the MTD-1 boring indicating that some erosion of the CRBG took place at this locality before Neogene sediment deposition (Marvin Beeson, 1996, personal comm.).

A deep lateritic weathered horizon is absent in the Guide Dogs for the Blind well drilled east of Gresham and in the Meadowcroft well drilled south of Oregon City. These wells have 1000' (305 m) and 1238' (377 m) of sediments overlying brown to black CRBG without an indication of an extensive weathered zone.

The central part of the Portland Basin contains over 1400' (427 m) of Neogene sediments as described from the MTD-1 boring at the Portland International Airport (Appendix B). The top 280' (85.3 m) are gravels and sands of Columbia River alluvial

sediments and possibly Missoula flood gravels near the top. Unconformably underlying this material are sands and silts of the upper and lower members of the Troutdale Formation that extend to the CRBG.

The Troutdale Formation as mapped in the Bridle Veil Channel, just south of the western part of the Columbia River Gorge, is almost 1400' (427 m) thick and is late Miocene to Pliocene in age (Beeson and Tolan, 1984; Marvin Beeson, 1996, personal comm.). The Troutdale Formation is capped by a 2 Ma Boring Lava flow in the Mt. Zion, Washington area (Tolan and Beeson, 1984) and is overlain by the 2.44 Ma Boring Lava flow in Oregon City (Conrey et al., 1996). These two areas are at the edges of the Portland Basin and may not reflect possible continued sedimentation in the central part of the Portland Basin. The eastward elevation increase of the top Troutdale Formation from approximately 100 meters below mean sea level in the Portland Basin to over 2000' (610 m) above mean sea level in the Bridal Veil Channel just south of the Columbia River Gorge substantiates post-Pliocene uplifting on the eastern flanks of the Portland Basin (Tolan and Beeson, 1984). The asymmetrical uplift is in response to crustal expansion caused by intrusion of Cascadian batholiths and the resultant increase in the geothermal gradient (Marvin Beeson, 1996, personal comm.). The presence of less than 100 meters 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.

A black hyaloclastic sand layer 430' (131 m) down the MTD-1 boring is probably from a Boring Lava eruption that entered the Columbia River upstream from the boring site and could be a key age indicator of the sediments if a correlation is possible. A Pliocene age interpretation of this sand implies that Pleistocene sedimentation in the Portland Basin was minimal. Any Pleistocene sediments deposited prior to the

Missoula flood events were stripped away during the glacial flood episodes. Troutdale Formation sediments at Mt. Tabor, Rocky Butte, Mt. Scott, and Mt. Talbort are present at elevations up to 450' (137 m) above sea level. Trimble (1963) has hypothesized that these sediments at Mt. Tabor and Rocky Butte are erosional remnants, and the floor of the Portland Basin has been lowered by erosive forces of the Missoula floods and subsequent stream action. This situation, if true, suggests that the Portland Basin actively subsided from late Miocene to Pliocene to collect the thick section of Troutdale Formation sediments in the center of the basin and has not significantly subsided during Pleistocene time. Troutdale sediments exposed in the Bridal Veil channel of the Columbia River Gorge illustrate basin uplift during Plio-Pleistocene time. The Tualatin Basin, by contrast, contains up to 700' (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 17).

Late Miocene - Pliocene subsidence and sedimentation rates in the Tualatin Basin were much lower with sediments of this interval composing only 26% of the HBD-1 sediment column. The sedimentation rate for this time period at the site of the MTD-1 boring is approximately 0.03 mm/yr, using 1100' (335 m) for the Troutdale Formation thickness and 10 million years from late Miocene to late Pliocene. This time interval is chosen as there are indications, such as the lack of the weathered CRBG zone, coarse sediments on top of unweathered flow tops, and interbeds at the Vantage horizon that sedimentation in the Portland Basin proceeded soon after CRBG emplacement (Marvin Beeson, 1996, personal comm.; and Beeson and Tolan, 1993). The rate climbs to 0.053 mm/yr using the same time frame as calculated for the Tualatin Basin sediments.

Table 17: HBD-1 and MTD-1 estimated sediment thickness based on age and corresponding sedimentation rates.

<u>Boring#</u>	<u>Pleistocene Thickness</u>	<u>Sedimentation Rate</u>	
		<u>for 1.6 Ma</u>	<u>for 2.4 Ma</u>
HBD-1:	~700' (213.4 m)	0.13 mm/yr	0.09 mm/yr
MTD-1:	0' to 280' (<85 m)??	<0.05 mm/yr??	<0.03 mm/yr??

<u>Boring#</u>	<u>Pliocene/ Upper Miocene Thickness</u>	<u>Sedimentation Rate</u>	
		<u>for 7 Ma</u>	<u>for 10 Ma</u>
HBD-1:	245' (74.7 m)	0.011 mm/ yr	0.007 mm/yr
MTD-1:	1100' (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 further away with an intervening structure, the Tualatin Mountains - Portland Hills, between the two basins. Early movement along the Portland Hills Fault zone and the Frontal Fault zone northeast of the Portland Basin along with uplift of the Cascade Range reflected greater subsidence in the Portland Basin and less influence in the Tualatin Basin during the late Miocene and Pliocene.

If the black sand units in the upper part of MTD-1 are Pleistocene, it would indicate that the central parts of the Portland Basin continued to subside while the basin margins to the south and east uplifted. Pleistocene subsidence in both basins would reflect a more uniform regional response to the large scale north-south stress field over time, possibly extending back to the late Miocene.

Regional Implications

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 above relationship coupled with the basin's relative positions presents an interesting pattern of relative Pleistocene uplift at the northern and southern ends of the Willamette Valley region with relative downwarping between (Figure 118). The Portland and Stayton Basins have been described as pull-apart structures (Crenna et al., 1994; Beeson and Tolan, 1993; Yelin and Patton, 1991; and Beeson et al., 1989a), yet features related to transpression are present in the Portland Basin (Blakely et al., 1995). The west and southwest margins of the Tualatin and northern Willamette Basins are bordered by the northern Coast Range, smaller scaled structures such as the Chehalem Mountains and Salem-Eola Hills monoclines, and the Waldo Hills - Scotts Mill anticline. Structural movements in the northern Coast Range, coupled with right and left step dextral shear stresses caused by regional north-south compression may bring together the observed features and conditions found in and around the Tualatin, Portland and northern Willamette Basins.

Figure 118: Willamette Valley depositional basin activity status for the Pleistocene Epoch indicating relative subsidence and uplift among the basins. The Tualatin and northern Willamette Basins have continued to subside throughout the Pleistocene, while the Portland and Stayton Basins and the southern Willamette Valley either slowed or stopped subsidence in the early Pleistocene.

CHAPTER 8 - GEOMORPHOLOGY OF THE TUALATIN VALLEY

The patterns of drainage systems and stream profiles in a watershed may provide clues to the development of the watershed, including structural, erosional, and depositional processes. Comparing the Tualatin Basin surface geology with hydrologic subbasins in the Tualatin River watershed will demonstrate the relative role of the source material to the basin deposition and groundwater - surface water interactions. Determining the nature of the Tualatin River nickpoint provides an answer to why the river runs so slow and whether anything could be done to improve flow conditions. Terrace mapping is intended to determine whether structural movement is a factor in controlling river dynamics. Mapping the lowest elevation exposure of CRBG derived residual soils provides evidence for limits of significant Willamette Silt deposition during Missoula flood events.

Geomorphologic Techniques

Hydrology

Streams in the Tualatin River drainage were ordered and drainages subdivided using methods from Leopold et al., (1964). Thirty-eight subbasins using 3rd order streams as the main stem for each subbasin were compared with surface geology maps to examine the relative source contributions to sediment deposition. Longitudinal profiles generated for the Tualatin River and six selected tributaries were used to check for nick points and to compare any differences in the profiles from one locality to another. Procedural details are given in Appendix A.

Tualatin River Terrace Mapping

One inch equals 8000' (2438 m) color air photo stereo pairs of the Tualatin River region were obtained from the Unified Sewage Agency (USA) to map the terrace development of the river and Dairy Creek. Terrace levels were mapped onto mylar overlays on top of USGS 7 1/2' quadrangle topographic maps.

Red Clay Soils Mapping

The late Pleistocene catastrophic flood waters from glacial Lake Missoula in Montana (Bretz Floods) deposited silts in the Tualatin Valley. Erratics found by Allison (1935) occur up to 400' (122 m) above mean sea level, indicating the probable maximum height of the flood waters in the valley. A maximum elevation of 250' (76 m) for silt deposition in the valley has been speculated (Schlicker and Deacon, 1967), but there has been no systematic method for testing this hypothesis. One way to project the highest elevation of sedimentation from the flood waters is to outline the lower most exposed limit of soils in the highlands around the valley that predate the flood events. Below the lower most exposed elevation of these soils is a mantle of silt deposited by the floods. A map of the lowest exposed elevation of red clay residuum and colluvium from weathered Columbia River basalt or Tillamook Volcanic series in the highlands surrounding the Tualatin Valley was compiled by tracing the lowest elevation of several soil series from maps in the Soil Survey of Washington County, Oregon (Green, 1982). The red clay soil series mapped were the Hembre, Jory, Kilchis, Olyic, and Saum. These soils are all older than 50 ka as noted by their red clay characteristics (Scott Burns, 1996, personal comm.) and so could not be formed from Missoula flood silts. Soils developed in flood silts do not have red clay characteristics and are approximately 12 ka.

Tualatin River and Tributary Subbasins

The Tualatin Valley watershed contains 39 subbasins with 3rd order main stems, which eventually lead into the 6th order Tualatin River (Figure 119). Williams Canyon and South Fork Gales Creek subbasins only contain 2nd order main stems. They are included in the inventory due to their distinctive shapes and positions relative to their primary subbasin. Several of the subbasins in the Tualatin River watershed flow directly to the upper and lower reaches of the Tualatin River; however, many may be grouped into eight designated 4th or 5th order primary subbasins based on main tributary confluences with the Tualatin River. The primary subbasins consist of Dairy Creek (including McKay Creek), Rock Creek (including Beaverton Creek), Gales Creek, Scoggins Creek, Wapato Creek, Fanno Creek, McFee Creek, and Chicken Creek (Table 13). These subbasins collect precipitation runoff and groundwater recharge from the Coast Range to the west, Tualatin Mountains - Portland Hills system to the north and east, and the Chehalem Mountain trend to the south. The margins of the watershed are bounded to the north, east, and southeast by streams that directly feed the Columbia and Willamette Rivers, to the northwest by the Nehalem River watershed, to the west by the Wilson River watershed, and to the south by the Yamhill River watershed.

The complexity of the primary drainage systems is asymmetrical in reference to geographic location. Third order subbasins to the northwest and west tend to empty into the larger fourth and fifth order tributaries, while most of the individual subbasins to the south and east drain directly to the Tualatin River main stem (Figure 119). The primary subbasins of Dairy Creek and Gales Creek, and the upper Tualatin River each have several minor subbasins that communicate ground and surface water. The Dairy Creek system is divided into ten subbasins, Gales Creek is broken into six subbasins, and the

TUALATIN VALLEY WATERSHED

3RD ORDER STREAM SUBBASIN MAP

Figure 11

TUALATIN VALLEY WATERSHED

3RD ORDER STREAM SUBBASIN MAP

Figure 119: Tualatin Valley watershed with 3rd order or higher stream subbasins. The Coast Range drainages are somewhat complex, combining several subbasins into higher order subbasins, whereas drainages from the Tualatin and Chehalem Mountains are more simplistic, with few streams

Table 13: Statistical data for third-order or higher subbasins within the Tualatin Valley watershed. Formation abbreviations are explained in Figure 122.

PRIMARY SUBBASINS/ SECONDARY SUBBASINS	Area (sq. miles)	Area (sq. km)	Drainage Density	Highest Stream Order
GALES CREEK	40.09	103.84	0.82	4
BEAVER CREEK	10.03	25.97	0.87	3
CLEAR CREEK	9.26	23.99	0.85	3
ILER CREEK	4.98	12.89	0.72	3
LITTLE BEAVER CR.	6.84	17.72	0.76	3
S. FORK GALES CR.	3.94	10.21	0.79	2
EAST FORK DAIRY CR.	50.11	129.78	0.73	4
BLED SOE CREEK	10.70	27.71	0.91	3
CAMPBELL CREEK	2.94	7.61	0.97	3
WEST FORK DAIRY CR.	45.08	116.75	0.89	4
BURGHOLTZER CR.	7.48	19.38	0.80	3
LOUSIGNONT CR.	10.36	26.82	0.91	3
MENDENHALL CR.	5.03	13.03	0.76	3
SADD CREEK	11.62	30.09	0.82	3
DAIRY CREEK	10.63	27.53		5
COUNCIL CREEK	10.72	27.77		3
SCOGGINS CREEK	34.02	88.11	0.92	4
SIAN CREEK	11.53	29.87	0.88	3
WAPATO CREEK	16.67	43.18	1.29	4
AYERS CREEK	6.32	16.37	0.33	3
GOODIN CREEK	3.50	9.07	0.68	3
McKAY CREEK	54.27	140.56	0.53	4
HELVATIA CREEK	11.94	30.93	1.07	3
ROCK CREEK	38.07	98.60	1.16	5
BEAVERTON CREEK	29.36	76.05	1.11	4
CEDAR MILL CREEK	8.51	22.04	0.84	3
FANNO CREEK	31.73	82.17	1.03	4
McFEE CREEK	15.36	39.77	0.76	4
HEATON CREEK	9.54	24.72	0.80	3
CHICKEN CREEK	7.16	18.54	0.76	4
CEDAR CREEK	9.08	23.53	0.87	3
TUALATIN RIVER	134.24	347.69	1.35	6
BURRIS CREEK	7.00	18.12	0.79	3
CARPENTER CREEK	7.36	19.06	0.79	3
CHRISTENSEN CREEK	9.72	25.18	1.00	3
LEE CREEK	8.73	22.60	0.75	3
ONION FLAT, ROCK CR.	5.91	15.30	1.12	3
ROARING CREEK	5.70	14.78	0.85	3
SUNDAY CREEK	7.91	20.48	0.80	3
WILLIAMS CANYON	4.71	12.19	1.11	2
Tualatin Watershed Total	718.14	1859.97		

Table 13 continued.

<u>PRIMARY SUBBASINS/ SECONDARY SUBBASINS</u>	<u>Width/Length Ratios</u>	<u>Draining Highland</u>	<u>Eroding Formations</u>	<u>Stream Mouth</u>
GALES CREEK	8.6	Coast Range	Tev, Tey, Tos, Tmcr	TR
BEAVER CREEK	1.8	Coast Range	Toem	GC
CLEAR CREEK	2.2	Coast Range	Tev	GC
ILER CREEK	3.5	Coast Range	Tev, Ti	GC
LITTLE BEAVER CR.	3.5	Coast Range	Tos, Tmcr	GC
S.FORK GALES CR.	2.7	Coast Range	Tev, Ti	GC
EAST FORK DAIRY CR.	4.2	Tualatin Mtns.	Tos, Tmcr, Tph	DC
BLEDSE CREEK	2.4	Tualatin Mtns.	Tmcr, Tph	EFDC
CAMPBELL CREEK	1.7	Tualatin Mtns.	Tos, Tmcr	EFDC
WEST FORK DAIRY CR.	5.6	Coast Range	Toem, Tos, Tmcr	DC
BURGHOLTZER CR.	1	Coast Range	Toem, Tey, Toem, Tos	WFDC
LOUSIGNONT CR.	2		Tos, Tmcr	WFDC
MENDENHALL CR. .	5.4	Coast Range	Toem, Tos, Tmcr	WFDC
SADD CREEK	1.70	Coast Range	Tos, Tmcr	WFDC
DAIRY CREEK	4			TR
COUNCIL CREEK	3.70	Coast Range	Tos, Tmcr, Tph	DC
SCOGGINS CREEK	5.20	Coast Range	Tev, Tey, Tos, Ti	TR
SIAN CREEK	2.40	Coast Range	Tev, Tey, Toem, Ti	SC
WAPATO CREEK	1.8	Chehalem Mtns.	Tos, Tmcr	TR
AYERS CREEK	1.9	Chehalem Mtns.	Tos, Tmcr	WC
GOODIN CREEK	1.10	Chehalem Mtns.	Tos	WC
McKAY CREEK	3.80	Tualatin Mtns.	Tmcr, Tph	DC
HELVATIA CREEK	1.90	Tualatin Mtns.	Tmcr, Tph	McC
ROCK CREEK	4	Tualatin Mtns.	Tmcr, Tph	TR
BEAVERTON CREEK	1.5	Portland Hills	Tmcr, Tpt, Qb	RC
CEDAR MILL CREEK	3.00	Portland Hills	Tmcr, Tpt, Qb	BC
FANNO CREEK	1.7	Portland Hills	Tmcr, Tph, Tpt, Qb	TR
McFEE CREEK	1.9	Chehalem Mtns.	Tmcr	TR
HEATON CREEK	1.90	Chehalem Mtns.	Tmcr	McFC
CHICKEN CREEK	2.5	Chehalem Mtns.	Tmcr	TR
CEDAR CREEK	3.20	Chehalem Mtns.	Tmcr	CC
TUALATIN RIVER				WR
BURRIS CREEK	2.5	Chehalem Mtns.	Tmcr	TR
CARPENTER CREEK	2.5	Chehalem Mtns.	Tev, Tos	TR
CHRISTENSEN CR.	2.6	Chehalem Mtns.	Tos, Tmcr	TR
LEE CREEK	4.1	Coast Range	Tev, Teom, Ti	TR
ONION FLAT, ROCK CR.	3.3	Chehalem Mtns.	Tmcr	TR
ROARING CREEK	4	Coast Range	Tev, Teom	TR
SUNDAY CREEK	3.5	Coast Range	Tev, Teom, Ti	TR
WILLIAMS CANYON	1.9	Coast Range	Tev, Tey, Tos	TR
Ave. 3.0				

upper Tualatin subbasin is directly augmented by five subbasins. A significant percentage of the Neogene fluvial sediments in the Tualatin Basin was supplied by the rocks of this area indicated by the dissection of the Coast Range by deep weathering and erosion. Rock Creek is the only major drainage system that contains three subbasins in the eastern part of the Tualatin watershed. The numerous, smaller subbasins in the Chehalem and Tualatin Mountains of the watershed have also contributed to Neogene sediment deposition.

Stream order has an exponential relationship with the progressive number of streams from one order to the next for the entire watershed (Figure 120a). This trend is expected as many watersheds in the world exhibit the same relationship (Leopold et al., 1964). Stream order also approximates an exponential correlation with average stream length per order for the composite watershed profile (Figure 120b). First and second order streams have similar lengths, the second order streams being shorter in many subbasins (Table 14). Stream lengths between 4th and 5th order streams are also very close causing the semilog curve to deviate from the trend. The average bifurcation ratio of the streams in the Tualatin Valley watershed is 3.88, slightly higher than the 3.5 average for basins measured in the United States (Leopold et al., 1964).

Individual subbasin drainage shapes are dendritic and the length to width ratios range from 8.6 to 1.0, averaging 3.0 (Table 13). Drainage densities within each subbasin vary from 2.08 in the Council Creek drainage to 0.53 for McKay Creek, although, most subbasins have densities between 0.72 and 0.90. Particular subbasin dimension ratios and drainage densities are scattered geographically around the basin. Similar values are expressed in the Coast Range, Tualatin Mountains and Chehalem Mountains as many of the subbasins have a surficial unit of either Willamette Silt or Portland Hills Silt.

Figure 120: Stream order vs. the log of the number of streams per order (A) and the stream order vs. the log of the average stream lengths per order (B) for drainages in the Tualatin Valley watershed.

Table 14: Tualatin Valley watershed stream orders and average stream lengths per stream order for 3rd order and higher streams.

PRIMARY SUBBASINS SECONDARY SUBBASINS	STREAM ORDER NUMBERS AND AVERAGE LENGTHS (Meters)					
	1	2	3	4	5	6
GALES CREEK	47 - 1327	16 - 1469	1 - 13411	1 - 26761		
BEAVER CREEK	14 - 1367	4 - 1189	1 - 5883			
CLEAR CREEK	14 - 1063	4 - 2355	1 - 3810			
ILER CREEK	9 - 1084	3 - 853	1 - 5517			
LITTLE BEAVER CREEK	12 - 1298	2 - 1234	1 - 5425			
SOUTH FORK GALES CR.	6 - 1427	1 - 4298				
EAST FORK DAIRY CR.	71 - 1603	14 - 2363	2 - 1524	1 - 28042		
BLEDSOE CREEK	9 - 1395	3 - 5507	1 - 1585			
CAMPBELL CREEK	4 - 838	2 - 1615	1 - 1250			
WEST FORK DAIRY CR.	47 - 1682	10 - 2258	1 - 3200	1 - 26640		
BURGHOLTZER CREEK	14 - 1306	3 - 1593	1 - 1158			
LOUSIGNONT CREEK	14 - 1356	4 - 1181	1 - 5852			
MENDENHALL CREEK	5 - 1561	2 - 1173	1 - 7010			
SADD CREEK	23 - 1010	2 - 5649	1 - 2164			
DAIRY CREEK	3	1			1	
COUNCIL CREEK	8	2	1			
SCOGGINS CREEK	40 - 1362	15220	1 - 14874	1 - 9449		
SIAN CREEK	18 - 1031	3 - 2428	1 - 8230			
WAPATO CREEK	21 - 1348	1 - 3729	1 - 1554	1 - 4999		
AYERS CREEK	7 - 1208	3 - 2266	29587			
GOODIN CREEK	10 - 738	3 - 1443	1 - 1554			
McKAY CREEK	41 - 1655	11 - 3840	1 - 7468	1 - 14600		
HELVATIA CREEK	7 - 2565	2 - 4221	1 - 2591			
ROCK CREEK	36 - 1261	6 - 3769	2 - 1539	1 - 9388	1 - 4724	
BEAVERTON CREEK	22 - 1495	6 - 3968	1 - 4328	1 - 7620		
CEDAR MILL CREEK	17380	3 - 1260	1 - 6949			
FANNO CREEK	44 - 1188	10 - 1591	1 - 8635	1 - 2804		
McFEE CREEK	25 - 1190	8 - 998	2 - 3688	1 - 7315		
HEATON CREEK	15 - 1530	3 - 1059	1 - 4877			
CHICKEN CREEK	12 - 1372	3 - 1240	1 - 2560	1 - 1585		
CEDAR CREEK	15 - 1195	3 - 472	1 - 7742			
TUALATIN RIVER	117 - 1270	24 - 2415	1 - 1280	1 - 24384	1 - 24750	1
BURRIS CREEK	11 - 1252	3 - 1392	1 - 4877			
CARPENTER CREEK	10 - 1376	29618	1 - 6340			
CHRISTENSEN CREEK	11 - 1361	2 - 3627	1 - 2835			
LEE CREEK	18 - 863	4 - 1463	1 - 8656			
ONION FLAT, ROCK CR.	5 - 1006	2 - 960	1 - 6675			
ROARING CREEK	10 - 1101	3 - 1585	1 - 1585			
SUNDAY CREEK	15 - 916	4 - 1265	1 - 6797			
WILLIAMS CANYON	7 - 1123	1 - 3078				
Total Number of Streams	825	192	40	12	3	1
Average Stream Length (meters)	1318.7	2175.2	4951.4	13632.2	14737.1	72421
Bifurcation Ratio	4.3	4.8	3.3	4	3	

MAIN STREAM LENGTHS

STREAM NAME	GALES	E. F. DAIRY	W. F. DAIRY	SCOGGINS	McKAY	T. R.
KM	47.14	34.95	33.81	29.31	33.51	127.9
STREAM NAME	ROCK	BEAVERTON	FANNO	McFEE	CHICKEN	
KM	26.15	14.23	21.66	13.11	11.06	

The relative amount of rain catchment for each subbasin has a direct relationship with surface area; however, the amount of surface water available to the shallow groundwater is in part dependent on the soil or rock permeability the precipitation runoff is falling on, the drainage densities (Chorley, 1964), and on the aerial size of the feeding subbasins. Subbasin areas were calculated (Table 13) to determine the relative sediment contributions from the surrounding highlands into the basin for deposition and to determine surface water interactions with shallow groundwater flow. The entire Tualatin River watershed comprises 1859 km². The drainages of the Dairy Creek system, including McKay Creek, together cover the most extensive sediment source area to the valley, consisting of 598 km² or 32 % of the total watershed (Figure 121). Paleogene marine to nonmarine sedimentary rocks and the CRBG are the two source rock types from the Dairy Creek system (Figure 122; Schlicker and Deacon, 1967). The Paleogene units include the Yamhill, Cowlitz, Spencer, Keasey, Pittsburg Bluff, and Scappose Formations. The descriptions of these formations may be found in (Van Atta, 1971; Baldwin, 1981; Van Atta and Kelty, 1985; Cunderla, 1986; Ketrenos, 1986; and Farr, 1989). The McKay Creek subbasin contains the Scappose Formation and the CRBG. The Tualatin River main stem (26.6 %), Gales Creek (10.5 %), Rock Creek ((10.4 %) including Beaverton Creek), McFee Creek (3.5 %), and Fanno Creek (4.4 %) drainages also cover significant areas around the watershed (Figure 121). The Tualatin River and Gales Creek subbasins provide sediments from the Yamhill and Spencer Formations, the Eocene Tillamook Volcanic Series, and the CRBG (Schlicker and Deacon, 1967). The other drainage systems bring weathered products of the CRBG to the valley.

Outcrop - subbasin area relationships have probably not been constant over the post-Middle Miocene time period. The amount of Paleogene source influence to Neogene

Figure 121: Drainage areas for primary subbasins in the Tualatin Valley given as percent of total watershed area for third order or higher streams.

SURFACE GEOLOGY MAP OF THE TUALATIN VALLEY WATERSHED OREGON

FACE GEOLOGY MAP OF THE
LATIN VALLEY WATERSHED OREGON

Figure 122: Surface geology map around the Tualatin Valley watershed. Geologic interpretations are modified from Schlicker and Deacon, (1967), Beeson et al., (1989b, 1990), and Wells et al., (1994). combining before entering the Tualatin River.

deposition in the Tualatin Basin is largely dependent on the thickness and weathering resistance of overlying younger material in the Coast Range. CRBG flows are the only known post-Oligocene units in the highlands that are older than the Neogene sediments in the basin. Understanding the original distribution and thickness of the CRBG in the eastern Coast Range and the geomorphology of the region at deposition of the first CRBG flows are important when considering the erosive access time of the Paleogene sedimentary and volcanic sources to the Tualatin Basin.

Longitudinal profiles of the Tualatin River and its main tributaries provide a clue to the late structural development of the Tualatin Basin. 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 60' to 70' (18.3-21.3 m) above the Willamette River confluence (Figure 123). The Tualatin River's nick point, the first change from steeper to gentler river gradient, is located along the first 1.75 miles (2.8 km) from its mouth near West Linn where the river rises 31.4 ft/mile (5.95 m/km) from 35 feet (10.7 m) to the 90 feet (27.4 m) above mean sea level. The river runs between two highlands of CRBG, Pete's Mountain to the southwest and hills to the northeast near West Linn. The canyon that the Tualatin River cuts from the nickpoint to the mouth is erosional. The CRBG units in the surrounding highlands do not appear to have been faulted as no significant displacement of the basalt flows is noted from the north to the south side of the river valley (Marvin Beeson, 1996, personal comm.). A set of ODOT borings for the Weiss Bridge crossing near the mouth of the Tualatin River indicates that CRBG is about a meter below the surface at river level (Figure 124). The profile flattens to 0.67 ft./mile (0.13 m/km) towards the west through the valley, gaining 30' (9.1 m) from river mile 1.75 at the nickpoint to the 120' (36.6 m) level at river mile 46.8 (75.3 km) southeast of Forest Grove, Oregon. The

Figure 123: Longitudinal profile of the Tualatin River from the confluence with the Willamette River (left) to the source in the Coast Range (right). The Tualatin River nick point is 1.75 miles (2.8 km) upstream from the confluence (inset). The river profile dramatically flattens upstream for approximately 60 river miles (96.5 km) before steeply rising in the Coast Range.

Figure 124: Cross section of the ODOT Weiss Bridge geotechnical borings in the NW 1/4 of Sec. 2, T3S R1E. The CRBG occurs just below the Tualatin River channel. The CRBG may also be below the river's nick point 1.75 miles (2.82 km) upstream, slowing upstream back-cutting into the Tualatin Valley.

profile slightly increases to 3.1 ft/ mile (0.59 m/km) between river miles 50 (80.5 km) and 63 (101.4 km) south of Forest Grove and continues to steepen towards the Coast Range headwaters, averaging 113 ft /mile (21.4 m/km). 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 (Waite, 1985) that cap the valley surface.

The main tributaries flowing into the Tualatin River exhibit two main types of longitudinal profiles: those with steadily increasing gradients that yield a rounded profile like East Fork Dairy Creek, Gales Creek, Scoggins Creek, and Fanno Creek (Figures 125 and 126), and those that display an abrupt change from a flat downstream to a steep upstream gradient yielding a backward L shape similar to the Tualatin River profile. West Fork Dairy Creek, Rock Creek, McKay Creek, Chicken Creek, Beaverton Creek, and McFee Creek exemplify the latter profile (Figures 127, 128, and 129). Streams with the rounded profile drain from the rolling foothills of the surrounding highlands and do not significantly traverse the flat Tualatin Valley floor before they empty into a higher order stream. The flat downstream portions of the backward L profiles compose over one-half of the total stream lengths and are generally below the 200 foot (61 m) level. Chicken and McKay Creeks represent many of the upstream sections that demonstrate steps in the profile (Figure 128) indicating uneven stream erosion presumably caused by either faults, ancient landslides, or lithology differences in the parent rocks. The two main longitudinal profile shapes are found in streams draining the Tualatin Mountains, Chehalem Mountains, and the Coast Range.

The distance of each stream's nick point from their mouth may be a function of the rock type the stream is flowing across. All streams with nick points 3 to 5 miles

(A)

Gales Creek Longitudinal Profile

Figure 125: Longitudinal profiles for East Fork of Dairy Creek (A) and Gales Creek (B) exhibiting steadily increasing gradients. The nick points are 14 miles (22.5 km) and 12 miles (19.3 km), respectively upstream from the mouth.

Figure 126: Longitudinal profiles of Scoggins Creek (A) and Fanno Creek (B) displaying rounded profiles. Nick points occur at 8.5 miles (13.7 km) and 3 miles (4.8 km), respectively, upstream from their mouths.

(A)

(B)

Figure 127: Longitudinal profiles of West Fork of Dairy Creek (A) and Rock Creek (B) displaying a steep upstream section and a flat downstream reach. The nick points are 12 miles (19.3 km) and 11 miles (17.7 km), respectively, upstream from their mouths.

Figure 128: Longitudinal profiles of McKay Creel (A) and Chicken Creek (B) displaying flat downstream gradients and steep upstream profiles. Nick points are located 13.5 miles (21.7 km) and 3 miles (4.8 km), respectively, upstream from their mouths.

Beaverton Creek Longitudinal Profile

(A)

(B)

McFee Creek Longitudinal Profile

Figure 129: Longitudinal profiles of Beaverton Creek (A) and McFee Creek (B) illustrating flatter lower reaches and steep upstream gradients. Nick points occur 3 miles (4.8 km) and 5 miles (8 km), respectively, upstream from their mouths.

(4.8-8 km) up from their mouths, such as Beaverton , Chicken, Fanno and McFee Creeks, are underlain by CRBG. Streams with nick points farther upstream are underlain by Paleogene sedimentary rocks, with the exception of Rock Creek that apparently is eroding only CRBG.

The Tualatin River follows an atypical drainage pattern as compared to other drainage systems in Pacific Northwest forearc basins. The 1.75 mile (2.82 km) upstream nickpoint position of the Tualatin River is unique when compared to other Willamette River tributaries (Figures 123 and 130). The nick points of rivers draining the Coast Range and Cascade Range into the Willamette Valley are generally many miles from their mouths. The closest nick point to a river mouth is ten miles (16 km) in the Clackamas River. The nickpoints of the South Yamhill, Luckiamute, Mary's, Mollala, and South Santiam Rivers are 20 to 45 miles (32 to 72 km) upstream. The downstream reaches of these rivers are underlain by easily eroded Neogene sediments, that have been cut back through a good portion of each river's drainage.

CRBG underlying the last two miles (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.

Tualatin River Terrace Mapping

Mapping terrace levels may yield information about the rate of uplift in the Coast Range or the rate of Tualatin Basin subsidence during the Late Pleistocene and may be linked to the deposition of sediments from the catastrophic Missoula floods. 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

253

Figure 130: Longitudinal profiles with labeled nick points of representative Willamette River tributaries in the Willamette Valley. The nick points generally occur from 10 to 40 miles (16-72 km) upstream from the river mouths. The Luckiamute, Mary's, and South Yamhill Rivers originate from the Coast Range, while the other three rivers drain the Cascade Range. (Written communication, geomorphology class, G574, Portland State University, Spring, 1996).

surface that represents the main Tualatin Valley floor (Figure 131). These surfaces may be vertically separated by as much as 30' (10 m). An intermediate bench between the floodplain and the valley floor is intermittently present in the lower stretches of the river, south of Hillsboro, Oregon. The river channel is incised into the Willamette Silt 20 to 30 feet (6-10 m) below the floodplain surface.

The age of these benches is uncertain; however, the lower surface includes present day sediment deposition from local flood events such as the February, 1996 flood. The establishment of this floodplain developed since the last of the Missoula floods approximately 12.7 ka (Mullineaux et al., 1978). The Willamette Valley geomorphic surfaces have been studied in greater detail (Mc Dowell, 1991; and Roberts, 1984). Correlations into the Tualatin Valley are uncertain; the Horseshoe, Ingram, and Winkle geomorphic surfaces are all post-Willamette Silt deposition between 12,000 and 300 years ago (McDowell, 1991). Parsons (1969) stated that the floodplain of the Tualatin River upstream from the river's nickpoint is part of the Winkle surface; however, also given is the definition of the younger (<300 years old) Horseshoe surface which includes present stream channels and annual floodplains of the Willamette River and the major tributaries that feed into the river. Reckendorf (1992) furthers the definition by specifying that the Horseshoe surface consists of channel and point bars, and marginal accretion sediments. The Winkle surface, on the other hand, is the oldest geomorphic surface associated with the modern Willamette River, representing the abandoned floodplain with fine grain sediments and organic layers (Parsons, 1969; and Reckendorf, 1992). The Tualatin River is considered a major tributary to the Willamette River, and the mapped floodplain in this study includes cutoff meander oxbows and adjacent areas that are flooded during modern inundations. The Tualatin River floodplain appears to fit between the definitions of these surfaces. The floodplain

TUALATIN RIVER TERRACE MAP TUALATIN VALLEY OREGON

TERRACE MAP Y OREGON

Figure 131: Tualatin River terrace map displaying geomorphic surfaces from the floodplain to the lower foothills of the surrounding region in the Tualatin Valley, Oregon.

is most likely older 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 nickpoint near West Linn may have attributed to this unique situation.

The middle bench is discontinuously present from Jackson Bottom south of Hillsboro to the Tualatin, Oregon area where Interstate 5 crosses the Tualatin River. This surface is approximately 15'- 20' (4.6-6.1 m) above the floodplain and 10'-15' (3-4.6 m) below the upper bench. Aerial photographs generally display the middle bench as a distinct flat surface bounded with gentle slopes toward the surrounding surfaces. The largest mapped extent of this surface lies on either side of the floodplain south of Cooper and Bull Mountains in the Scholls and Beaverton quadrangles. Isolated fragments of the middle bench are mapped along the floodplain northwest from this interval to Jackson Bottom. This surface is not distinguished on aerial photographs west of Hillsboro.

A study of peat bog deposits from the middle bench on either side of Interstate 5, just south of Nyberg Road in Tualatin indicates that the bench is equivalent to the Winkle surface of the Willamette Valley (Scott Burns, 1996, personal comm.). A radiocarbon date of 11,300 years b.p. for organic matter associated with a mastodon found in Tualatin supports this interpretation (Tualatin Times, 1992). This surface in the Tualatin Valley may represent slack water erosion as the last of the Missoula catastrophic flood waters receded from the Tualatin Valley 12.7 ka (Scott Burns, 1996, personal comm.). Reckendorf (1992) states that the main surfaces of Jackson Bottom and Onion Flat, south of Bull Mountain, are part of the Winkle surface based on 12.24 ka radiocarbon dated peat from Onion Flat, south of Sherwood. These surfaces are not evidently separated from the Tualatin River floodplain on the aerial photographs and are only 10'-15' (3-4.6 m) above the Tualatin River channel. The middle bench is present at

Jackson Bottom as isolated islands surrounded by the floodplain or as extensions from the upper bench surface. Onion Flat is bounded to the east by an extensive middle bench surface; however, the main surface of this locality is lower in elevation and is mapped as part of the floodplain surface.

The upper bench that runs along the Tualatin River floodplain is the main valley floor which extends upward from approximately the 150 foot (45.7 m) elevation. There are several places in the valley where the river abuts and is eroding the upper bench (Figure 131). Willamette Silt sediments underlie this surface and consist predominantly of clayey silt with sparsely distributed thin interlayers of silty clay. The Willamette Silt is correlative with the Greenback Member of the Willamette Formation of Balster and Parsons (1969) and Roberts (1984). The upper bench is correlative with the 13 ka Senecal surface of the Willamette Valley, in agreement with Parsons (1969). Parsons included other surfaces such as the Ingram and Champoeg on the down stream sections of the Tualatin River in the Lake Oswego Quadrangle. Parsons' Ingram and Champoeg surfaces include the floodplain and the upper Winkle surface, respectively.

The slopes above the main valley floor vary from gentle to steep rising toward the surrounding highlands. Parsons (1969) assigned the highlands near Lake Oswego to the Dolph and Eola surfaces. The slopes are all underlain by CRBG east of Forest Grove in the Forest Grove Quadrangle. Eocene marine sedimentary rocks and volcanic intrusives border the river's floodplain west of Forest Grove.

Dairy Creek is the most prominent tributary of the Tualatin River that displays on aerial photographs two geomorphic surfaces. The elevation difference between the valley floor and the Dairy Creek floodplain is approximately 15' -20' (5-7 m). The

lower Dairy Creek drainage may be older than the other tributaries that extend onto the valley floor. McKay and Gales Creeks also show some development of a two stepped terrace form, although mapping exact topographic relations on the aerial photographs proved difficult upstream from their respective confluences with Dairy Creek and the Tualatin River. The other main tributaries do not cut as deeply, incising the valley floor without creating extensive floodplains.

Terraces along the river system cannot be evaluated as an indicator of the area tectonics because of the slow migration of the nick point upstream in the past 12,000 years. 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 nick 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, poly-cyclic terrace development (Chorley et al., 1984). The Willamette Silt deposits originate outside the valley, and the Tualatin River has had to respond to this influx by downcutting to its base level within the valley.

Residual Soil Mapping

The lower elevation limit of residual soils derived from either the CRBG or Paleogene sedimentary rocks was mapped in the highlands surrounding the Tualatin Valley from annotated Soil Conservation Service aerial photographs (Green, 1982) and corresponding U.S.G.S. 7.5' quadrangle topographic maps. These older soils pre-date the inflow of the late phase Missoula flood events (Waitt, 1985). Water wells and other borings along the fringes of the valley indicate that these soils extend into the subsurface

beneath the Willamette Silt. Soils developed from the Willamette Silt or Neogene sediments are present down slope from the residual soils. Soils formed from the Portland Hills Silt intermingle with the older residual soils in the highlands, primarily on the east and north sides of the valley.

The lower elevation limit of the exposed residual soils may mark the upper limit of significant sediment deposition of the Missoula flood waters. This hypothesis relies on assumed level geographical distribution of sedimentation in the temporary lakes formed by the flood events. The combined lower elevation limit of the Hembre, Jory, Kilchis, Melbourne, Melby, Olyic, Pervina, and Saum soil series varies with geographic position around the periphery of the Tualatin Valley, although the 250' and 300' (76.2-91.4 m) elevation interval is the most consistently mapped minimum elevation for the residual soils. Cornelius, Helvetia, Wapato, and Willamette soil series formed on Neogene sediments or Portland Hills Silt cover the residual soils above 300' (91.4 m) in the Tualatin Mountains - Portland Hills region. The elevation differences of the lower limit might be attributed to local redeposition of eroded soils from above or to erosion of flood silts to expose the residual soils. Soils of the Melbourne, Saum, and Jory occur around the Chehalem Mountains while the Hembre, Kilchis, Jory, Olyic, and Pervina series occur in the Coast Range foothills and in the western part of the Tualatin Mountains. These soils may occur further east; however, they are covered by soils of the Portland Hills Silt and cannot be mapped from aerial photography. The residual soils exposed display extensive dissection by local streams draining the highlands (Figure 132).

Flood waters may have reached a maximum elevation of 400' (122 m) above sea level in the Willamette Valley region based on the elevation sites of ice rafted glacial erratics carried in by the flood waters (Allison, 1935). Glacial erratics found at the 400'

REDSIDUAL RED SOIL
MINIMUM ELEVATION MAP
TUALATIN VALLEY OREGON

RED SOILS DERIVED FROM CHALK
RED SOILS DERIVED FROM BASALT
OTHER UPLAND AND VALLEY SOILS
MINIMUM ELEVATION 300'
MINIMUM ELEVATION 250'
MINIMUM ELEVATION 200'
MINIMUM ELEVATION 150'

US HWY 26
US HWY 30
US HWY 10

Forest Grove
Hillsboro
Beaverton
Tualatin
Shepherd

SCALE 6 MI 9.7 KM

X GLACIAL CRATICS LOCATED BY ALLISON (1935)

X GLACIAL ERRATICS LOCATED BY ALLISON (1935)

RED SOIL
ELEVATION MAP
ALLEY OREGON

Figure 132: Residual red soils minimum elevation map and general locations of erratics (X) above 225' (68.6 m) recorded by Allison (1935). The minimum elevation of the residual soils reflects the average depositional level of the Missoula catastrophic flood sediments.

(122 m) elevation in the highlands surrounding the Tualatin Valley support this hypothesis (Figure 132). The lower minimum elevation of the exposed residual soils indicates that most sedimentation from the flood events was restricted below the 250' - 300' elevation interval. Flood waters would have at least temporarily been up to 150' (45.7 m) above the lake bottom. The 250 foot (76.2 m) elevation sedimentation limit is in agreement with Schlicker and Deacon's (1967) selected depositional border between sediments of the Willamette Silt and the Portland Hills Silt in the eastern part of the Tualatin Valley.

The Tonquin Scabland in the Sherwood quadrangle lies between Onion Flat in the Tualatin Valley and Seely Ditch in the Willamette Valley. This feature formed from slack water erosion of Missoula flood events (Allison, 1978a). The lower elevation limit of the residual soils around Parrett Mountain on the west side of the Tonquin Scablands is 250' - 300' (76.2-91.4 m; Figure 131). This limit could be a result of erosion of any previous overburden on the slopes of Parrett Mountain during the Missoula flood events.

A large gap appears between exposures of the residual soils southwest of Forest Grove and in the Gaston area (Figure 132). The lower minimum elevation of residual soils in this region ranges from 200' - 240' (61-73.2 m) in Patton Valley to 240' - 300' (73.2-91.4 m) on the west side of Chehalem Mountain. The Wapato Lake Bed lies in this gap. The lake bed extends southward on the Gaston quadrangle close to the edge of the modern Tualatin Valley watershed where the divide to the Yamhill River watershed is below the 280 feet (85.3 m) elevation. The Wapato Lake gap would have been a conduit for the largest flood events to communicate between the two valleys.

Tualatin River Plio-Pleistocene History

The CRBG is absent in a narrow east-west path on the east side of the Willamette River across from the mouth of the present Tualatin River in Oregon City (Trimble, 1963). This is the ancestral channel and floodplain of the Tualatin River that extended farther east to meet the Willamette River (Figure 133A) and has been filled by Troutdale Formation sediments (Baldwin, 1981). The sediments filling the old channel are overlain by Boring Lava flows dated at 2.44 Ma (Conrey et al., 1996). These flows blocked the Willamette River channel which backed up the Tualatin River and may have redistributed flow from both rivers during the late Pliocene and Pleistocene epochs through the Lake Oswego area to empty back again into the Willamette Valley north of the Boring Lava flows (Baldwin, 1981; Figure 133B). Borings and exposures of Upper Neogene sediments in the Tigard, Oregon area contain elevated levels of Cascade Range derived hypersthene, suggesting that the Willamette River waters and associated sediments traveled through this area prior to the Missoula flood events.

If the Tualatin River emptied into the Willamette River through Lake Oswego prior to the Missoula catastrophic floods, then either uplift of the area or fan construction at the west end of Lake Oswego during the flood episodes aggraded to a point to cause the Tualatin River to divert southeastward to flow through a low point between Pete's Mountain and the West Linn highlands (Figure 133C). The low elevation of this area near Oregon City must have allowed the Missoula floods to pass through and put gravel deposits on the upper banks of the present lower Tualatin River canyon. Remnants of these gravels are present in the subsurface of the ODOT Weiss Bridge borings (Figure 124). The Tualatin River was able to cut through these deposits, but the underlying CRBG significantly slowed the backcutting.

Figure 133: Water flow relationships between the Tualatin and Willamette Rivers during Plio-Pleistocene time. The Tualatin River initially extended farther east into the northern Willamette Valley than it does today (A). Boring Lava flows damming the Willamette River approximately 2.44 million years ago, diverted flow up the lower reaches of the Tualatin Valley and out through a gap in the Lake Oswego area (B). Missoula flood waters and sediment built a fan across Lake Oswego, causing the Willamette and Tualatin Rivers to divert back to near original conditions (C).

Entrenchment of the lower part of the Dairy Creek drainage as well as the Tualatin River, together with subsurface sediment lithology from borings and the topology of the top Neogene sediment structural surface (Figure 107) suggest that these two drainage systems may have been close to their present positions prior to the Missoula flood events. Water wells and other borings along the Tualatin River contain a lot of fine sand to depths of approximately 100' (30 m), whereas silt and clay make up the subsurface away from the river. ODOT borings on either side of the Hwy 219 bridge over the Tualatin River display an interbedded nature of the sand and silt deposits, which may reflect local fluvial deposition between flood events (Figure 114).

CHAPTER 9 - NEOGENE SEDIMENT HYDROGEOLOGIC PROPERTIES AND GROUNDWATER MAPPING

Willamette Silt and the Neogene sediment groundwater resources are studied to understand these aquifers' roles in the Tualatin Basin hydrologic cycle and build a foundation for future hydrogeologic work. Water quality of the CRBG and Neogene sediment aquifers is examined to search for geologic trends or structures not otherwise noticeable from water well data. Hydrogeologic units in the Tualatin Basin are contrasted with those in the Portland Basin to emphasize the hydrologic differences between the two areas.

Porosity and Permeability Measurements of HBD-1 Sediments

Helium porosity and horizontal air permeability measurements were conducted at Core Laboratories on 29 Neogene sediment sand units and eight silt and clay units from the HBD-1 core. The porosity values range from 25 % to 50 % and permeability from 7.9 mD to 10983 mD (Table 15). There is an increase in porosity with depth, which is reverse of the normally expected decrease in porosity with depth (Figure 134). Clay x-ray diffraction work has identified smectites as the dominant clay in most samples analyzed, which presents a potential problem of clay shrinkage as the samples dry. Core Laboratories dried the samples as part of their preparation process, possibly leading to clay shrinkage that would result in more pore volume in each sample. Smectite shrinkage volumes in sands can vary from 20% to 26%; however, the amount of shrinkage is very dependent upon the clay composition and the amount of clay in the sample (Core Laboratories, 1996, written comm.). Porosity ranges were calculated for each sample using the discount shrinkage factor of 26% as the extreme (Table 15). The porosity and permeability values given in this report must be treated as rough estimates of the sediment subsurface conditions.

Table 15: HBD-1 porosity and permeability measurements from sands and finer-grained sediments. Reduced porosity values are calculated for compensation of percentage fracture development based on smectite amounts in the samples.

Depth feet (meters)	Porosity (percent)	Por. *,74 (percent)	k (mD)	Lithology	Bulk Density	Grain Density
34' (10.4 m)	34.8	25.8	7.4	SILT-sandy	1.92	2.66
73' (22.3 m)	25.8	19.1	59	SILT-clayey		
90' (27.4 m)	31.4	23.2	179	SAND - vf,clayey	1.98	2.55
108' (32.9 m)	38.5	28.5	87	SAND - vf,clayey		
141' (43 m)	39.5	29.2	1349	SAND - vf-c, silty		
162' (49.4 m)	40.3	29.8	761	SAND - vf-m, silty	1.89	1.49
226' (68.9 m)	40.7	30.1	405	SAND - f, silty		
236' (71.9 m)	41.7	30.9	123	SAND - vf-p, silty	1.82	1.5
260' (79.2 m)	35.7	26.4	110	SAND - vf-m, silty		
300' (91.4 m)	31.5	23.3	106	SAND - f, silty	1.77	2.47
330' (100.6 m)	36.9	27.3	704	SAND - vf, clayey		
337' (102.7 m)	35.2	26.0	65	SAND - vf-f, silty		
347' (105.8 m)	32.3	23.9	176	SAND - vf, silty		
385' (117.3 m)	34.9	25.8	545	SAND - vf-f,silty	1.87	2.54
412' (125.6 m)	38.3	28.3	1389	SAND - vf-md		
448' (136.6 m)	38.8	28.7	614	SAND - vf-m, silty	1.9	2.46
484' (147.5 m)	36.3	26.9	1428	SAND - vf-c		
522' (159.1 m)	43	31.8	540	SAND - vf-m, silty	1.83	2.47
537' (163.7 m)	40.4	29.9	573	SAND - vf-vc., silty		
565.5 (172.4 m)	44.7	33.1	221	SAND - vf-p	1.76	2.68
609.8' (185.9 m)	46.6	34.5	248	SAND - vf-p		
657' (200.3 m)	43.1	31.9	563	SAND - vf-f	1.88	2.6
683' (208.2 m)	40.6	30.0	125	SAND - f		
693' (211.1 m)	42	31.1	146	SAND - vf-p		
734' (223.7 m)	39.7	29.4	682	SAND - vf-p	1.81	2.36
760.6' (231.8 m)	59	43.7	1823	SAND - fine, hard (fractured)		
877' (267.3 m)	40.2	29.7	585	SAND - vf-f		
929' (283.2 m)	45.1	33.4	34	SAND - vf-f, clayey	1.88	2.71
932' (284.1 m)	50.3	37.2	126	SAND - vf, silty		
Neogene Silts and Clays						
229' (69.8 m)	33.2	24.6	61	SILT - vf sandy, clayey		
292' (89 m)	31.1	23.0	51	CLAY - v silty		
420' (128 m)	27.1	20.1	176	SILT - clayey (fractured)		
499' (152.1 m)	28.8	21.3	85	CLAY - silty (fractured)		
640' (195.1 m)	46.3	34.3	114	SILT-v. sandy		
769' (234.4 m)	41.3	30.6	10983	CLAY - silty (fractured)		
836' (254.8 m)	43.2	32.0	289	SILT - clayey (fractured)		
846' (257.9 m)	43.7	32.3	190	SILT-v. sandy	1.85	2.51

k=permeability in millidarcies (mD); vf=very fine; f=fine; m=medium; c=coarse
p=pebbly

Figure 134: HBD-1 sediment air porosity and permeability trends with depth. The high end of the porosity ranges is the measured porosity. Porosities at the end of the range are calculated based upon a maximum 26% porosity reduction due to smectite clay desiccation in the samples prior to the measurements.

The permeability values cannot be compensated for clay shrinkage so those samples with extremely high values are certainly shrinkage controlled (Table 15). Permeability does not display a significant increase with depth (correlation coefficient = 0.1254 and $t = 0.6572$; $t_{crit} = 1.70$ at the 95% confidence level; Figure 134).

Hydraulic conductivity and transmissivity values calculated from HBD-1 intrinsic permeability data (Table 16) are equivalent to the sands and finer-grained sediments (Freeze and Cherry, 1979). The equation employed to convert the intrinsic permeability data to hydraulic conductivity, $K = k\rho g/u$ (where k =air permeability, ρ =fluid density, g =acceleration due to gravity, and u =fluid viscosity), used a viscosity of 1.235 centipoise for an average aquifer water temperature of 12°C (Freeze and Cherry, 1979). Almost all sand beds measured for permeability were also analyzed for grain size distribution to determine the relative percentages of sand, silt, and clay (Table 3). Estimated hydraulic conductivities from grain-size-distribution curves (Driscoll, 1986) approximate those calculated from the intrinsic permeability data. These values should be considered rough estimates of the aquifer conditions as the calculations of transmissivities from hydraulic conductivity or permeability data are less valid than other methods (Driscoll, 1986).

Groundwater Mapping

Hydrogeologic units in the Tualatin Basin are defined by stratigraphic position, lithology contrasts, and aquifer conditions such as flow yield. At least four aquifer systems exist in the basin: 1) the confined aquifers of the Paleogene marine sediments, 2) the CRBG, 3) the Neogene sediments, and 4) the Willamette Silt unconfined aquifer. Paleogene sediments located in the near subsurface southwest of Forest Grove have water drawn from various sandstones for both residential and commercial use. This

Table 16 : Hydraulic conductivities converted from intrinsic permeability measurements of HBD-1 sands and finer-grained sediments. Transmissivities are calculated from the formula $T=K*b$ for confined aquifers (Freeze and Cherry, 1979).

<u>Depth</u> feet (meters)	<u>Thickness</u> feet (meters)	<u>Lithology</u>	<u>k</u> (darcy)	<u>K</u> (cm/sec)	<u>T</u> (sq. cm/sec)
34' (10.4 m)	17' (5.18 m)	Silt	0.0074	0.0001	0.03
73' (22.3 m)	18' (5.49 m)	Silt	0.059	0.0005	0.25
90' (27.4 m)	13' (3.96 m)	Sand	0.179	0.0014	0.56
108' (32.9 m)	13' (3.96 m)	Sand	0.087	0.0007	0.27
141' (43 m)	7' (2.13 m)	Sand	1.349	0.0106	2.25
162' (49.4 m)	5' (1.52 m)	Sand	0.761	0.0060	0.91
226' (68.9 m)	5' (1.52 m)	Silt	0.405	0.0032	0.48
229' (69.8 m)	5' (1.52 m)	Silt	0.061	0.0005	0.07
236' (71.9 m)	7' (2.13 m)	Sand	0.123	0.0010	0.21
260' (79.2 m)	7' (2.13 m)	Sand	0.11	0.0009	0.18
292' (89 m)	2.5' (0.76 m)	Clay	0.051	0.0004	0.03
300' (91.4 m)	2' (0.61 m)	Sand	0.106	0.0008	0.05
330' (100.6 m)	2.5' (0.76 m)	Sand	0.704	0.0055	0.42
337' (102.7 m)	1.5' (0.46 m)	Sand	0.065	0.0005	0.02
347' (105.8 m)	2' (0.61 m)	Sand	0.176	0.0014	0.08
385' (117.3 m)	4' (1.22 m)	Sand	0.545	0.0043	0.52
412' (125.6 m)	8' (2.44 m)	Sand	1.389	0.0109	2.66
420' (128 m)	2' (0.61 m)	Silt	0.176	0.0014	0.08
448' (136.6 m)	12' (3.66 m)	Sand	0.614	0.0048	1.76
484' (147.5 m)	12' (3.66 m)	Sand	1.428	0.0112	4.10
499' (152.1 m)	15' (4.57 m)	Clay	0.085	0.0007	0.30
522' (159.1 m)	6' (1.83 m)	Sand	0.54	0.0042	0.77
537' (163.7 m)	2.5' (0.76 m)	Sand	0.573	0.0045	0.34
565.5' (172.4 m)	1' (0.30 m)	Sand	0.221	0.0017	0.05
609.8' (185.9 m)	2.5' (0.76 m)	Sand	0.248	0.0019	0.15
640' (195.1 m)	1.5' (0.46 m)	Sand	0.114	0.0009	0.04
657' (200.3 m)	5' (1.52 m)	Sand	0.563	0.0044	0.67
683' (208.2 m)	4.5' (1.37 m)	Silt	0.125	0.0010	0.13
693' (211.1 m)	1' (0.30 m)	Sand	0.146	0.0011	0.03
734' (223.7 m)	6' (1.83 m)	Sand	0.682	0.0053	0.98
836' (254.8 m)	9' (2.74 m)	Silt	0.289	0.0023	0.41
846' (257.9 m)	2' (0.61 m)	Silt	0.19	0.0015	0.09
877' (267.3 m)	3' (0.91 m)	Sand	0.585	0.0046	0.42
929' (283.2 m)	3' (0.91 m)	Silt	0.034	0.0003	0.02
932' (284.1 m)	5' (1.52 m)	Silt	0.126	0.0010	0.15

k = intrinsic permeability; K = Hydraulic conductivity; T = Transmissivity

Water viscosity used is 1.235 centipoise for an average water temperature of 12 C.

unit is usually within 100' (30 m) of the surface in Patton Valley and the Wapato Lake bed area near Gaston, Oregon. These lowland extensions of the Tualatin Valley do not contain Neogene sediments and are not considered to be within the main confines of the Tualatin Basin. The Paleogene sediments are not a significant contributor to the main part of the Tualatin Valley as the aquifers are too deep.

The CRBG typically yields much higher quantities of water than the Neogene sediments (Hart and Newcomb, 1965), yet the great depth to CRBG in the middle of the Tualatin Basin financially prohibits most landowners from tapping this source. Quality of CRBG groundwater is usually very good; although, a few wells report high iron oxide bearing waters. Potentiometric contour lines on the CRBG static water level map do not cover the center of the Tualatin Basin (Figure 135) as only a few scattered water wells penetrate the CRBG in this area. The CRBG groundwater heads in the valley range from 100' (30 m) to 200' (61 m) above mean sea level, sloping gradually towards the center of the valley. Subsurface heads from different stratigraphic aquifers within the CRBG rise toward the basin center to create a fairly uniform well head distribution around the valley. Flowing artesian wells from the CRBG aquifers are present throughout the Tualatin Basin and are especially common around the western basin margin (Figure 136).

Most residential groundwater usage away from basin edges is from Neogene sediment sand units, although, a few fractured Neogene sediment clay sources have been reported. Some sand units do not bear recoverable water due to their high silt and clay content, or they are surrounded by confining units. Tualatin Valley water well yields from Neogene sediment sands that produce water typically yield 6-10 gpm (22-38 lpm) and may exceed 100 gpm (380 lpm; well data repository volume).

STATIC WATER LEVEL M
OF THE COLUMBIA RIVE
IN THE TUALATIN VALLI

Figure 135: Potentiometric surface map developed from initial static water levels of water wells tapping groundwater from the CRBG in the Tualatin Valley. The lack of contours in the central portion of the valley reflects the paucity of CRBG wells in this region.

Figure 136: Water wells in the Tualatin Valley tapping CRBG aquifers that contain either high iron oxide content, saline water, and/or have artesian flow. Most salt water wells occur in the foothills of the Tualatin Mountains along the northeastern margin of the valley, while artesian flow is common around the edges of the valley. High iron oxide levels are geographically scattered around the valley.

The potentiometric surface of Neogene sediment aquifers subparallels the ground surface forming a gentle slope towards the basin center from 260' (79 m) above mean sea level in the Tualatin Mountains near Sylvan Hill to 100' (30 m) in the lower reaches of the Tualatin River in the Beaverton and Canby Quadrangles (Figure 137). The lowest elevations follow the major drainages in the valley as expected yet there are low areas not associated with an overlying stream in the Forest Grove and Hillsboro Quadrangles.

The potentiometric surfaces of the Neogene sediment sand and CRBG aquifers display similar characteristics and in the eastern and southeastern parts of the valley the water level elevations are very close to each other (Figures 135 and 137). The CRBG aquifers are from several hundred to over 1500 feet (up to 450 m) stratigraphically below the Neogene aquifers. Similar static water levels between the CRBG and Neogene sediment aquifers suggests that they may be at least indirectly connected.

The Willamette Silt aquifer water level rises and falls with short term and seasonal variations in precipitation amounts. Wells pumping from the aquifer formerly provided many rural homes with drinking water, and many today are used for small scale irrigation. Tualatin Valley water wells compiled for this report indicate that the Willamette Silt aquifer usually yields less than 6 gpm (22 lpm).

Ground Water Quality

Groundwater in the CRBG and Neogene sediments is generally potable yet salty. Brackish, and high iron oxide content waters have been documented by water well drillers and landowners in the Tualatin Valley (Figures 136 and 138). Saline groundwater from Neogene sediment sands is reported from only two wells spaced widely apart in the valley, while high iron oxide content bearing waters are present in 24 widely scattered wells (Figure 138). The high iron content may be from leaching of

TUALATIN VALLEY OREGON

Figure 138: Water wells in the Tualatin Valley pumping Neogene sediment aquifers that contain either high iron oxide content, saline water, and/or artesian flow. All of the mentioned conditions are randomly distributed. The most common water quality problem for the Neogene aquifers is clay and silt infiltration into wells (not shown).

basaltic rock fragments in the Neogene sediments or from weathering within the CRBG or Tillamook Volcanic series.

Salty groundwater occurs in seven wells drawing from the CRBG in the northeastern part of the valley on the west slope of the Tualatin Mountains and the associated foothills (Figure 136). Saline water could originate from the underlying marine Paleogene sediments; although there is no known obvious conduit such as a fault that would account for the migration into CRBG aquifers. High iron content groundwater is also reported from eight wells in the foothills of the Tualatin Mountains, one well in the town of Roy, three wells on the east side of David Hill in the Gales Creek Quadrangle, and three wells in the southern part of the basin northeast of the Chehalem Mountains.

Flowing artesian wells are much more common from aquifers in the CRBG than the Neogene sediments. They occur in four main areas around the Tualatin Valley margins:

- 1) The largest area occurs on the west side of the valley in the Forest Grove and Gales Creek Quadrangles. Thirty-five wells covering an area approximately six miles (9.6 km) on a side tap CRBG aquifers that flow are flowing artesian.
- 2) Eleven flowing artesian wells are located in the northeast portion of the valley in the Linnton Quadrangle.
- 3) Eighteen flowing artesian wells are present around the narrow Tualatin River floodplain in the Scholl's Quadrangle between Chehalem and Cooper Mountains.
- 4) A loose group of ten wells flowing to the surface occur in the Beaverton and Lake Oswego Quadrangles north, south, and east of Bull Mountain.

Groundwater flow in the CRBG from the adjacent highlands must be sufficient to provide heads of this magnitude. There are no known wells with flowing artesian conditions where the CRBG is most deeply buried in the basin around Hillsboro.

Groundwater Characteristics of Sediments in the Tualatin Basin

Willamette Silt

Groundwater in the Willamette Silt is unconfined throughout the Tualatin Valley with the elevation of the water table surface highly influenced by seasonal precipitation rates. Hydraulic conductivity values calculated from permeability measurements of two HBD-1 samples are low supporting observations of limited water production from the Willamette Silt (Tables 15 and 16). Core samples collected from depths of 34' (10.4 m) and 73' (22.3 m) have measured intrinsic permeabilities of 7.4 millidarcies (mD) and 59 mD, respectively. Resulting hydraulic conductivities of 0.0001 cm/sec and 0.0005 cm/sec are compatible with empirical values for silt (Freeze and Cherry, 1979).

Low conductivity (Table 16) coupled with low hydraulic gradient created by the gentle topographic terrain of the Tualatin Valley floor point to slow groundwater movement in the Willamette Silt toward local drainages. During dry periods the Tualatin River may lose water to the Willamette Silt as indicated by summer river levels similar to static water levels in wells near the river (Hart and Newcomb, 1965). Most wells tapping water from the Willamette Silt in the Tualatin Valley are old, less than 50' (15.2 m) deep, and many were hand excavated. Water uses are restricted to domestic activities, including small area irrigation. Many of these wells have been abandoned due to fecal coliform bacterial shows presumably from nearby leaking septic systems. Many more Willamette Silt groundwater monitoring wells have been installed in recent years around urbanized areas during clean up of leaking underground storage tanks and other pollution sources.

Neogene Sediments

Most of the underlying Neogene sediment aquifers are under confined conditions as most silt, clay, and even muddy sand units within the Neogene sediments form aquitards and aquicludes around the aquifer sands. The Neogene sediments were deposited primarily by low gradient, meandering fluvial systems that tend to produce, discontinuous, shoestring sand bodies surrounded by finer grained materials. There are only a few localized areas within the basin in which individual sand bodies can be correlated across more than one well.

A common Neogene sediment aquifer type reported from driller's logs in the Tualatin Valley is black sand. Samples of black sand recovered and examined during this study usually have a blue-gray to green-gray tinge indicating reducing conditions within the aquifer (see Gillenwater #1 well lithology description in the well data repository volume). Black sands contain a significant percentage of weathered, black basalt grains ranging in size from very fine sand to small gravel. These sands usually occur in the top 400' (122 m) of the Neogene sediment section and are present in lesser amounts throughout the section. Blue and brown sand aquifers labeled on driller's logs occur throughout the Neogene sediments and indicate lithological composition changes from the black sands, yet the water yields are similar.

Several water wells in the Tualatin Basin are extracting water from what the drillers' well logs refer to as fractured clays. Most drillers do not usually use the word silt in their lithologic descriptions on well logs as distinguishing between a silty clay and a clayey silt during drilling. The fractured clays are probably silts with enough porosity and permeability to allow groundwater extraction similar to water conditions in the Willamette Silt. The water yields from these zones are usually 10 gpm or less. There

are too few wells tapping these sources to determine any spatial trends that might relate to either depositional environment changes or to structural influences within the basin.

Neogene Sediment Groundwater Temperatures

Groundwater temperatures reported from driller's well logs are scarce prior to the 1970's and become more common from more recently drilled wells. Reporting the groundwater temperature after drilling is currently required by the Oregon State Water Resources Department. Neogene sediment aquifers have temperatures ranging from 52° to 60°F (11°-16° C) in contrast to groundwater temperatures from the deeper CRBG aquifers, which can reach greater than 70° F (>21° C) (well repository).

A temperature survey of the HBD-1 boring by DOGAMI (Jerry Black, 1996, written comm.) provides a heat flow gradient of the Neogene sediment section and top of the CRBG (Figure 139). The bore hole temperatures in the Neogene sediment interval reach 60° F (16° C) by 558' (170 m) and increase to 63° F (19° C) at the bottom contact with the CRBG. The temperature gradient for the Neogene sediments in HBD-1 is 0.0085 °F/foot (21° C/Km). The bore hole temperatures slightly increase to 64° F (20° C) in the CRBG at the bottom of the boring, indicating no major jump in the temperature gradient from the Neogene sediments to the CRBG. If this temperature gradient is used basin wide for the Neogene sediments, then the lower groundwater temperatures reported from well drillers reflects recharge influence of the aquifer system to keep the water temperatures from equilibrating with the sediment temperatures. Groundwater residence times are long enough for groundwater to equilibrate if no outside influence disturbs the system. High meteoric recharge rates in a wet climate such as occurs in the Pacific Northwest is a likely process to keep adding cooler water that mixes with the Neogene sediment system.

Figure 139: HBD-1 bore hole temperature curve. The temperature gradient is approximately $0.021^{\circ}\text{C} / \text{m}$, in line with regional temperature gradients (data provided by DOGAMI, 1996).

Hydrogeologic Model of the Willamette Silt and Neogene Sediments

Mean horizontal (K_x) and vertical (K_z) hydraulic conductivities were calculated for four heterogeneous, anisotropic layers within the Willamette Silt and Neogene sediments following the method described in Freeze and Cherry (1979) using the hydraulic conductivity values in Table 16. The calculated K_x and K_z for the Willamette Silt layer are an order of magnitude lower than values calculated for the Neogene sediments. (Table 17).

Table 17: Weighted mean horizontal and vertical hydraulic conductivities for four heterogeneous, anisotropic sediment layers in HBD-1.

	<u>Hydraulic Conductivity (cm/sec)</u>	
	K_x	K_z
Willamette Silt (to 82', 25 m)	0.00029	0.00012
Neogene Sediment Layer 1 (82' - 500', 25 - 152 m)	0.00523	0.00140
Neogene Sediment Layer 2 (500' - 700', 152 - 213 m)	0.00212	0.00165
Neogene Sediment Layer 3 (700' - 945', 213 - 288 m)	0.00260	0.00092

The Neogene sediments in HBD-1 were divided into three hydrologic layers: 1) the top layer extends from the base of the Willamette Silt down 127 m and is separated from the underlying material because 65% of the Neogene sand units in HBD-1 occur in this interval; 2) the second layer is 60 m thick and extends to 213 m below the surface at the Pliocene-Pleistocene boundary; and 3) the third layer is 74.6 m thick, bottoming at the Neogene sediment - CRBG laterite contact. The mean hydraulic conductivity values for each layer and among layers are similar indicating that the Neogene sediment section could be treated as one hydrogeologic unit (Table 17).

Contrast of Hydrogeologic Units Between the Tualatin and Portland Basins

The four Tualatin Basin hydrogeologic units recognized in this report, the Paleogene sediments, the CRBG, the Neogene sediments, and the Willamette Silt, provide a gross structure for groundwater models. The Neogene sediments are grouped into one hydrogeologic unit primarily due to the lack significant changes in lithology with depth and laterally across the basin. Continuous core from the HBD-1 boring provides the only source for detailed observations of a significant thickness of the Neogene sediments in the Tualatin Valley. Water well logs and drill cutting samples from water well drilling away from the HBD-1 site cannot provide the necessary stratigraphic detail needed to subdivide the Neogene sediments hydrogeologic unit. Many thin stratigraphic layers are missed during normal water well drilling.

Eight hydrogeologic units have been interpreted in the Portland Basin: older rock units that include the CRBG, a sand and gravel aquifer of the lower member of the Troutdale Formation, confining unit #2, the Troutdale sandstone aquifer, confining unit #1, undifferentiated fine-grained sediments of the lower Troutdale Formation, the Troutdale gravel aquifer, and an unconsolidated sedimentary aquifer (Swanson et al., 1993). The undifferentiated fine-grained sediments unit is used when the sand and gravel aquifer, confining unit #2, and the Troutdale sandstone aquifer cannot be separated.

The MTD-1 boring at the Portland International Airport encounters six of the eight hydrogeologic units (Figure 140). The boring reaches total depth in the CRBG older rocks unit, which is overlain by undifferentiated fine-grained sediments from 1420' (432.8 m) to 860' (262.1 m) below the surface. The presence of sand and gravel above 860' (262.1 m) and black, hyaloclastic sand beds in the depth range 750' to 390' (228.6-118.9 m) indicate that the Troutdale sandstone aquifer (Swanson et al., 1993) probably

Figure 140: Hydrogeologic units of the Tualatin Basin separated in this report and a comparison with units developed in the Portland Basin by Swanson et al., (1993). The MTD-1 boring at the Portland International Airport is correlated with the Portland Basin hydrogeologic stratigraphy.

exists in MTD-1 over the undifferentiated fine-grained sediments to approximately 390' (118.9 m). Confining unit #1 probably represents the fine-grained section in MTD-1 from 390' to 340' (118.9-103.6 m) below the surface. Confining unit #1 is overlain by the Troutdale gravel aquifer from a depth of 340' (103.6 m) to approximately 250' (76 m), where the highest cobble and boulder layers are present. The sand rich, unconsolidated sedimentary aquifer caps the Troutdale Formation from 250' (76 m) to the surface. This top aquifer consists of catastrophic Missoula flood deposits and Columbia River alluvium (Swanson et al., 1993).

The differences in the fluvial depositional energy and history between the Portland and Tualatin Basins is evident from the hydrogeologic units in each area. The subdivision of the Troutdale Formation and overlying catastrophic Missoula flood deposits into several hydrogeologic units in the Portland Basin illustrates the relative ease in interpretation based on notable changes in lithology with depth over the area of the basin (Swanson et al., 1993). Boundaries between units are usually marked by grain size changes and sometimes by lithology, as in the case of the black, hyaloclastic sands for the Troutdale sandstone aquifer. The consistent fine-grained nature of the Neogene sediments in the Tualatin Basin requires greater care in the examination of the sediments to subdivide the hydrogeologic unit. More continuous Neogene sediment core extractions similar to HBD-1 in other parts of the Tualatin Valley are needed to successfully identify any lithological trends that would merit subdividing the Neogene sediment hydrogeological unit. One possible trend is the apparently higher sand bed content in the upper 500' (152.4 m) of the Neogene sediment section in HBD-1 than below this depth in the boring.

CHAPTER 10 - PHOSPHORUS IN THE WILLAMETTE SILT AND NEOGENE SEDIMENTS

The Tualatin River experiences summer algal blooms due to two main factors, the low rate of river flow and the high concentrations of phosphate in the river water. Runoff from agricultural lands and effluent from waste water treatment plants introduces phosphate to the Tualatin River system. These sources may not fully account for the levels of phosphate observed in the river. The purpose of this section is to investigate the contribution potential of the sediments to provide phosphate via groundwater to the Tualatin Basin hydrologic system.

Phosphorus Analyses

Forty sediment samples collected from the HBD-1 core, shallow DOGAMI and Tri-Met borings, soil pits in the Tualatin Valley, and various water well drill cuttings were analyzed at the Oregon Graduate Institute for their phosphorous content. The analyses were part of a joint study with Dr. Wesley Jarrell to investigate the natural phosphorous content of the Neogene sediments in conjunction with recorded high phosphate levels in the Tualatin River. The procedures used to determine the orthophosphate levels involved saturating the soil/sediments into a paste and extracting solution from the paste as described in Murphy and Riley (1962) and Richards (1954). Orthophosphate concentrations were determined from the solution. An iron phosphate mineral, vivianite, was identified by x-ray diffraction and scanning electron microscope techniques (Carl Palmer, 1995, personal comm.). Details are given in Appendix A.

HBD-1 Phosphorus Profile

HBD-1 phosphate concentrations average 0.12 mg/l (± 0.01 mg/l) in the Willamette Silt (Table 18). The orthophosphate levels in solution derived from silt and clay samples in the top 200' (61 m) of the Neogene sediments vary from approximately 0.1 to 0.81 mg/l (Figure 141). The next one hundred feet (30 m) down the sediment section (300'-400'; 91-120 m) contains the highest overall phosphorus levels in the entire Neogene sediment column, reaching a maximum measured value of 3.17 mg/l at 302' (92 m). The higher levels of phosphorus are most closely associated with silt units, although one clay unit sample has a phosphorus level of 1.54 mg/l at 316' (96 m). The phosphate levels generally drop off under 0.1 mg/l level below the 400' to 500' (120-152 m) interval. Comparison of the population mean (0.68 mg/l) and standard deviation (± 0.90 mg/l) of the phosphate concentrations above 500' with the same statistics for the phosphate levels below 500' (Mean=0.1 mg/l; SD= ± 0.14 mg/l) indicates that different conditions exist between these two intervals in the Neogene sediments.

Tualatin Valley Samples

Boring and water well phosphorus sampling locations are dispersed throughout the Tualatin Valley (Figure 142). Most samples were collected from depths less than 120' (36.6 m) below the surface; however, three sampled borings were drilled below 200' (61 m), two of which covered the entire Neogene sediment interval at the Cain well in Forest Grove, Oregon and at the Leisigang well in Roy, Oregon (Appendix H). Figures 143 to 145 illustrate the distribution of phosphorus in relation to depth. The borings are presented in groups by region within the valley.

Sediment samples from ODOT borings in the northeast part of the Tualatin Valley (Figure 143A) contain lower phosphorus levels than in similar sediments collected from

Table 18: HBD-1 analyzed orthophosphate concentrations and lithologies.
Phosphate levels do not appear to be lithology dependent.

Depth feet (meters)	Lithology	P (mg/l)	Depth feet (meters)	Lithology	P (mg/l)
20' (6.1 m)	Silt	0.11	493' (150.3 m)	Silt	0.202
37' (11.3 m)	Silt	0.097	509' (155.1 m)	Clay	0.017
61' (18.6 m)	Silt	0.125	525' (160 m)	Silt	0.009
80' (24.4 m)	Silt	0.129	539' (164.3 m)	Sand	0.011
101' (30.8 m)	Sand	0.447	559' (170.4 m)	Silt	0.01
121' (36.9 m)	Silt	0.447	579' (176.5 m)	Clay	0.05
139' (42.4 m)	Sand	0.736	600' (182.9 m)	Silt	0.167
164' (50 m)	Clay	0.026	634' (193.2 m)	Silt	0.01
180' (54.9 m)	Silt	0.512	647' (197.2 m)	Silt	0.01
202' (61.6 m)	Silt	0.186	674' (205.4 m)	Silt	0.04
223' (68 m)	Silt	0.242	689' (210 m)	Silt	0.015
240' (73.2 m)	Silt	0.81	709' (216.1 m)	Clay	0.416
255' (77.7 m)	Silt	0.06	723' (220.4 m)	Clay	0.064
280' (85.3 m)	Silt	0.231	769' (234.4 m)	Clay	0.249
302' (92 m)	Silt	3.17	789' (240.5 m)	Silt	0.009
316' (96.3 m)	Clay	1.54	811' (247.2 m)	Clay	0.108
340' (103.6 m)	Silt	2.62	830' (253 m)	Clay	0.525
360' (109.7 m)	Clay	0.016	850' (259.1 m)	Clay	0.01
380' (115.8 m)	Silt	2.58	870' (265.2 m)	Silt	0.157
406' (123.7 m)	Silt	1.51	890' (271.3 m)	Clay	0.074
424' (129.2 m)	Clay	0.339	909' (277.1 m)	Clay	0.075
453' (138.1 m)	Silt	0.018	938' (285.9 m)	Silt	0.039
469' (143 m)	Clay	0.182

Figure 141: Orthophosphate concentration depth trend in the HBD-1 boring at the Hillsboro Airport. Population means and standard deviations for the intervals above and below 500' (152 m) indicate differences in sediment conditions.

Figure 142: Sample locations for Tualatin Valley phosphate analyses. The ODOT and Tri-Met samples are from several borings, each on a linear trend following the proposed west side light rail line. Starred locations indicate vivianite occurrences. The M. Duyck water well contains vivianite, but was not tested for phosphate levels.

Figure 143: Orthophosphate concentrations from ODOT (A) and Tri-Met (B) core samples along the westside light-rail alignment in the northeastern portion of the Tualatin Valley. Most of the levels in the Neogene sediment Tri-Met samples are above 0.40 mg/l, in contrast to low levels in ODOT samples further up slope on the Tualatin Valley margin.

Figure 144: Orthophosphate concentrations of DOGAMI core samples along the Hwy 217 and I-5 corridor (A) and from water wells in the Hillsboro area (B). Phosphorus levels predominantly run in a zone between 0.0 and 0.6 mg/l. Most of the higher concentrations are from Neogene sediments, although a few are from the Willamette Silt.

Figure 145: Orthophosphate concentrations from the VanDomelen water well south of Hillsboro (A) and from two western Tualatin Valley water wells, one in Forest Grove and the other in Roy (B). Most levels are very low with the exception of three high values in the Leisigang well and one spurious value near the top of the Cain well.

the Tri-Met westside light-rail borings downslope from the Portland Hills (Figure 143B). Samples from all borings have phosphorus levels under 0.4 mg/l (Figure 143A), and those samples considered to be in the Willamette or Portland Hills Silt are under 0.22 mg/l.

The Tri-Met borings were drilled in Beaverton, Oregon on the valley floor, and most did not exceed a total depth of 100' (30.5 m), although one boring (B 860) at SW 185th Avenue and Baseline Road reached 160' (48.8 m).

Samples from the DOGAMI borings along the Hwy 217 to Interstate 5 corridor display no depth enrichment trend of phosphate (Figure 144A). Almost all samples contain less than 0.8 mg/l phosphate, and 8 of 13 samples higher than 0.4 mg/l are in the Neogene sediments. The highest measured value of phosphorus occurs at the 20' (6.1 m) in BVD-4. The Willamette Silt - Neogene boundary is interpreted to be between 20' and 23' (6.1-7 m) based in part on the vivianite occurrence at 23' (7 m) in the boring.

Scattered phosphorus levels in both the Willamette Silt and in the Neogene sediments are observed in water well samples in the central and western parts of the Tualatin Valley (Figures 144B and 145). Most determined concentrations from the central region are below 0.4 mg/l (Figure 144B and 145A), while those from the two wells in the western part of the valley are mainly below 0.1 mg/l (Figure 145B). Three samples from the 118' (36 m) to 165' (50 m) depth interval of the Leisigang well in Roy, Oregon, yielded from 1.07 to 1.48 mg/l orthophosphate, all in Neogene sediments.

Phosphate is present in Willamette Silt samples collected from depths between 20' and 40' (6-12 m) in three borings (Appendix H) of the central region in Hillsboro. Values range from 0.45 mg/l at 30' (9.1 m) below surface in the Gillenwater #1 well to 0.93 mg/l at the 19 foot (5.8 m) depth in Jackson Bottom. Phosphate levels are between

0.4 mg/l and 0.8 mg/l in Neogene samples collected from the Dremer well at 95' (29m) and 105' (32 m) and the Van Domelen well at 95' (29 m).

Vivianite Occurrence

Vivianite is an iron phosphate ($\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$) that was found as disseminated concentrations of microcrystalline nodules from 1 to 6 mm in diameter in Neogene sands, silts, and clays (Figure 21). Several known locations of vivianite around the Tualatin Valley include: 1) in a hard clay on Fern Hill in the Chehalem Mountains (The Mineralogist, 1939); 2) in HBD-1; 3) DOGAMI borings; and 4) in water wells in the central and western part of the valley (Figure 143). The iron in the white powdery nodules from freshly opened sediment samples oxidizes within a 24 hour period to color the mineralization a rich dark blue. The blue phase is indefinitely stable at atmospheric conditions (Nriagu, 1972) and has been named kerchenite (Palache et al., 1951). The vivianite nodules may have other phosphate minerals in association such as reddingite and strengite (Slansky, 1986; Lindsay, 1979); however, x-ray diffraction patterns of the vivianite samples do not indicate the presence of these minerals. Two occurrences of vivianite in HBD-1 at 491' (149.7 m) and 663' (202 m), consist of small prismatic crystals lining fractures and vugs (Figure 23).

Vivianite is found at shallow depths in the thin Neogene section underneath the Hwy 217 area along the eastern flanks of the valley. DOGAMI boring BVD-4 contains powdery vivianite from 23' (7 m) to 42' (12.8 m) below the surface. Mineralization at 42' is associated with a one inch (2.54 cm) thick organic rich zone. Vivianite nodules have also been noted in drill cuttings from 400' - 600' (125-188 m) below the surface in water wells in Roy, Oregon and north of Hillsboro.

Phosphorus in the Tualatin Basin

The phosphorus levels discovered in the Neogene sediments are much higher than the 0.07 mg/l total maximum daily load value (TMDL) set by the Department of Environmental Quality for phosphorus entering the Tualatin River. The Unified Sewerage Agency of Washington County has been able to maintain effluent output to the Tualatin River to 0.04 mg/l total phosphorous (Scott Burns, 1996, personal comm.). The potential is high for natural groundwater phosphorus concentrations in the Tualatin Valley to contribute to the overloaded surface water system. Phosphate levels in surface water samples from the Tualatin River and its tributaries greatly exceed the 0.07 mg/l TMDL, not all of which can be attributed to agricultural, residential or industrial influences (Stewart Rounds, 1996, personal comm.). Shallow groundwater monitoring from wells up to 200' (60 m) deep around the main stem of the Tualatin River reveal total phosphate levels above 1.0 mg/l.

The phosphate levels in the Neogene sediments of HBD-1 have an inverse relationship with the observance of vivianite in the sediments (Figure 141). High phosphate levels in HBD-1 occur above the 400 foot depth (122 m), while vivianite is first recorded in HBD-1 at 491' (149.7 m). Vivianite is present from this depth almost to the 930' (283.5 m) level. Phosphorus in the sediments above 491' (149.7 m) could be in the form of a H_2PO_4^- complex adhered to surfaces of iron oxide minerals such as goethite, a weathering product from basalt (Wes Jarrell, 1996, personal comm.), and ilmeno-hematite, derived either from diagenesis of iron minerals or from andesitic volcanic materials (Alan Lester, 1996, personal comm.). These phosphate complexes may also be involved in co-adsorption onto iron or aluminum ions in acid soils where the phosphorus is available for dissolution (Tan, 1982). The complex may be more

readily available to solution than the phosphorus in vivianite (Lindsay, 1979), thus the higher solution levels of phosphorus above 400' (122 m) in HBD-1.

Vivianite is usually an early stage diagenetic iron phosphate mineral that is precipitated as a primary mineral from pore fluids in sediments soon after deposition (Nriagu and Dell, 1974). Iron phosphates in freshwater sediments form just below the surface of the water-sediment interface in lacustrine environments, in bog ore deposits, or as replacements or cements in clays, sands, and bone material. High activities of water and iron with available phosphorus in freshwater systems under anoxic conditions with a pH range from 7 to 9 favors vivianite formation. A nuclei particle must be present to initiate precipitation (Emerson and Widmer, 1978). Vivianite nodules present in the Tualatin Basin have not shown any presence of foreign material within the nodule interiors; although at least one occurrence is associated with a zone of organic material in the DOGAMI BVD-4 boring. Organic, woody debris is present in variable amounts throughout the Neogene sediments, so the possibility of vivianite nodules originally having organic material in their nuclei is not unrealistic.

Chemical conditions in the sedimentary aqueous system and the nature of the source material are the primary factors guiding vivianite formation. The source of the phosphorus may include: 1) in situ organic material; 2) the weathered CRBG; and 3) connate groundwater from the Paleogene marine sediments are possible contributors of phosphorus to the groundwater system. Typical P_2O_5 concentrations in unweathered CRBG range from 0.25% to around 0.60%. Phosphate complexes may be leached during the weathering process, or they may be adsorbed by iron compounds resulting in enrichment processes in lateritic soils and bog iron ores (McFarlane, 1976). If organic nuclei acted as sites for iron phosphate precipitation, then the phosphorus available from

the organic debris may have been a significant source. Marine waters tend to have higher percentages of P_2O_5 than freshwater systems. Groundwater mixing and filtering into the Neogene sediments from connate water in the Paleogene sediments in uplands on the west side of the Tualatin Valley may also provide a source of phosphorus. Faults may also act as conduits to connect buried Paleogene sediment waters with Neogene groundwater.

The sediment and groundwater conditions at the time of vivianite formation must have been anoxic and mildly alkaline. An alkaline lacustrine environment is hypothesized for the diatomaceous unit in the HBD-1 boring, and vivianite is present in these sediments. The anoxic conditions for the fluvial environment favors low gradient stream conditions in which local ponding is common. Vivianite formation controls the concentration of phosphorus and iron in sediment porewaters (Manning et al., 1991), thus affecting the amount of mobile phosphorus available for groundwater transport down gradient of the precipitation region. Once formed, vivianite can be very stable and persist over long geologic periods (Nriagu, 1972; and Tien, 1974); although, the mineral may dissolve soon after formation in some lacustrine environments (Nriagu and Dell, 1974). Vivianite nodules are present in sediments as old as late Miocene in the HBD-1 boring.

The groundwater chemistry of the upper 500' (152.4 m) in the vicinity of the HBD-1 boring changed at some point in the Pleistocene or Holocene to either inhibit vivianite formation or dissolve the mineral above this level. The absence of vivianite in the upper sediment section may indicate a lack of sufficient redox conditions and iron activity (Lindsay, 1979).

Magnetic intensities of the sediments are stronger below a depth of 500 feet (151 m) than those above this level (Figures 98, 99, and 100). The difference in magnetic

intensities above and below this depth may be caused by different magnetic minerals in the fine grained sediment. Polished sample sections taken above and below this depth reveal a loss in magnetite content above this level to the boundary between the Neogene and overlying Willamette Silt. Silt sized ilmeno-hematite is present in various amounts throughout the Neogene section. This solid solution series may be derived from andesitic sources or from diagenesis of other iron minerals in acidic groundwater conditions (Alan Lester, 1996, personal comm.). Magnetite is a much stronger magnetic receptor and carrier than ilmeno-hematite so intensities are higher with increased magnetite levels. Magnetite easily dissolves in acidic conditions (Ed Larson, 1996, personal comm.) and is not common in the upper interval possibly because it was exposed to lower pH groundwater.

The presence of higher concentrations of magnetite below 500' (152.4 m) in the boring and the dissolution of this mineral above this level also indicates that groundwater became more acidic (Ed Larson and Alan Lester, 1996, personal comm.). Vivianite stability weakens below pH 6.5 (Nriagu and Dell, 1974), thus vivianite dissolution is also likely, freeing phosphate complexes to the groundwater system.

Vivianite is also present at shallow depths (23' to 42' (7-12.8 m)) in the BVD-4 boring at the Hwy 217 and Hwy 99 intersection, indicating that the same groundwater chemistry conditions affecting vivianite dissolution in the central part of the Tualatin Basin cannot be present in the eastern part.

CHAPTER 11 - SUMMARY AND CONCLUSIONS

The post-middle Miocene Tualatin Basin is characterized by a subsiding structural low created by north-south compressional stresses with right-lateral shear components and is filled with fluvial - lacustrine clastic sediments. The sediments were studied by examining the HBD-1 Hillsboro Airport boring core and a host of samples collected from other penetrations across the Tualatin Valley.

The HBD-1 core consists of 945' (288 m) of sediment overlying an 85' (26 m) lateritic paleosol belonging to the CRBG (Figure 84). Weathered Sand Hollow and Ginkgo flows of the Frenchman Springs Member of the CRBG extend 85' (25.9 m) below the sediments and grade into fresh black Ginkgo basalt. The top 82' (25 m) of the sediment package is assigned to the Willamette Silt, which was deposited by the late Pleistocene Missoula catastrophic glacial flood episodes. Sediments between the Willamette Silt and the top CRBG laterite are called Neogene sediments in this report.

Neogene sediment sand, silt, and clay unit percentages by thickness in the HBD-1 core are 18.3%, 43.7%, and 28.5%, respectively. Most of the Neogene sediments were deposited in a fluvial environment, representing low energy conditions from small stream channels to distal floodplain settings. Many sand beds range in thicknesses from 13' (4 m) to 0.5' (0.15 m), averaging 3' (1 m) and are part of fining upward sequences. Sedimentary structures include parallel and wavy laminae and low angle, planar cross-bedding. Organic woody material is dispersed throughout the section. Sixty-two percent of the total sand body thickness in HBD-1 occurs in the top 488' (149 m) of the Neogene section, indicating increased stream activity with time in the area of HBD-1. Sand percent maps for the upper 500' (152 m) and possibly all of the Neogene suggest most sand deposition occurred close to the basin center in broad, linear trends.

Two probable lacustrine sections are recognized in the Neogene sediments of HBD-1. The upper section occurs from about 585' to 606' (178 - 184.7 m) in depth and consists of dense to incompetent silty clay. The zone correlates to the prominent, basin-wide, "green" seismic horizon on the seismic reflection line data shot in the Tualatin Valley (Figure 64). The reflector either signifies an extensive lacustrine environment or a disconformity. A more certain interpretation of a lacustrine environment is found in a diatomaceous unit between 715' and 730' (217.9 - 222.5 m) in depth. Diatom forms suggest they were deposited in a large, shallow, alkaline, and muddy lacustrine environment. The cored section is much less dense than surrounding layers and displays rhythmically distributed brown and gray-green clay laminae typical of a lacustrine setting. The diatomaceous interval closely correlates to the relatively continuous "orange" horizon on seismic reflection line data in the valley, supporting the extensive nature of the lake environment (Figure 64).

Neogene sediment sands are immature with moderate to poor sorting, medium to very fine grained textures and contain significant levels of silt and clay. No analyzed sand from HBD-1 contains more than 75 % sand-sized or larger material. Average sand unit compositions are dominated by abundant, highly weathered, basaltic rock fragments (49 %) along with plagioclase (21 %) and lesser amounts of quartz (16 %), potassium feldspar (3 %), and micas (3 %). Significant heavy mineral constituents (4%) include iron oxide opaque minerals, augite, hornblende, epidote, garnet, clinozoisite, and zircon. The sand unit compositions are classified as either litharenites or feldspathic litharenites (Folk, 1968) and fall within the magmatic provenances window on the quartz-feldspar-lithic fragment ternary diagram of Dickinson and Suczek (1979).

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

The ages of the Neogene sediments in HBD-1 are derived from pollen, diatom, and paleomagnetic data. The pollen assemblage at 612' (186.5 m) and 649' (197.8 m) in HBD-1 characterizes the Pleistocene interval with open spruce, fir, and pine forests. An interpretation of the 0.78 Ma Brunhes-Matuyama paleomagnetic epoch boundary at 490' (149.4 m) fits well with the palynological data. Paleomagnetic inclinations from silts and clays in HBD-1 switch from normal to reverse at this depth. Pliocene to late Miocene sediments underlie the Pleistocene sequence to the top laterite soil of the CRBG. A diatomaceous zone from 715' to 730' (217.9 - 222.5 m) contains probable late Pliocene forms; therefore the top 700' (213 m) is considered Pleistocene. Pollen extracted from 850' (259 m) and 922' (281 m) in HBD-1 belong to a partially exotic assemblage dated in other parts of the Willamette Valley as late Miocene.

Radiometric age dates 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 Neogene (95' (29 m) below the surface) extracted during the drilling of a water well south of Hillsboro is older than 43.7 ka. This suggests that the central Tualatin Valley surface prior to the Missoula floods is at least this age. Available age dates from Boring Lava flows near Sylvan Hill in the eastern part of the valley require the underlying Neogene sediment ages in this part of the valley to be one Ma or older.

Heavy mineral suite and INAA geochemistry comparison analyses from HBD-1 and other penetrations in the Tualatin and Portland Basins indicate that the Neogene sediments were primarily derived from the Coast Range and surrounding highlands (Figures 88, 89, and 92). The Tualatin Mountains were an early topographic high feature in the Neogene history of the Tualatin - Portland Basins, which kept the Columbia River system from entering the Tualatin Valley. Augite-hornblende-hypersthene (AHH) relative percentages from Neogene sediments in the Tualatin Basin

are deficient in hypersthene and contain dominant levels of augite or hornblende, which supports local sources for fluvial sediment deposition. 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. A small area near Tigard, Oregon contains upper Neogene sediments with higher levels of hypersthene indicating that the Willamette River may have flowed in the basin during the late Pleistocene.

The Willamette Silt in the Tualatin Valley contains higher percentages of hypersthene than the Neogene sediments, reflecting the Cascade Range influence on the Missoula flood passage through the Columbia River Gorge. Recent stream sediments in the Tualatin Valley that are eroding the Willamette Silt and those from the Columbia River west of the Cascade Range also have higher levels of hypersthene.

Major and trace element chemistry of Neogene sediments from HBD-1 and MTD-1 displays partially overlapping, yet distinct populations further suggesting that the fluvial sediments in the two basins have different provenances (Figures 92 to 94). Unusually low scandium and chromium levels from a siliceous mudstone at 760' (231.6 m) demonstrate that volcanic ash from Cascade Range air fall events at least once covered the Tualatin Valley.

Seismic reflection data in the Tualatin Valley coupled with primary wave velocity data from HBD-1 have been utilized to generate a synthetic seismogram for correlation across the valley (Figure 59). Three main reflectors from the seismic data are used to tie to the boring: a "green" and "orange" couplet in the middle of the seismic profile represented by two possible lake deposits and a "red" horizon representing the top of the hard CRBG.

The Neogene sediment 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 the "green" horizon and a noisier section of more varied clastic sediments above the "green" horizon, agreeing with observations of more sand deposition in the upper 500' (152 m) found in HBD-1. The "orange" and "green" reflectors represent deposition in a lacustrine environment. Seismic reflection data in the northern Willamette Valley display a similar top of the CRBG to the surface reflection profile for Neogene sediments in that basin.

Stratigraphic information from numerous water well and other boring logs and samples, together with the seismic information, suggest a segmented basement in the Tualatin Basin. The Tualatin Basin is composed of 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. The bulk of the basin above the CRBG north of the Beaverton Fault, which extends from the western Chehalem Mountains to the Portland Hills, is a gently warped synclinal fold oriented northwest-southeast. Most faulting in this area is restricted to the CRBG and below. There are four exceptions, denoting structural activity in the basin during the Pleistocene. Seismic reflection data display an uplift feature under the Aloha area disrupting the sediments to at least the "green" horizon and a fault that displaces sediments above the "green" level under Dairy Creek in the Forest Grove Quadrangle. The CRBG has not been found in a small area just east of North Plains which may be due to a fault zone extending into the Neogene sediments. Water well information just north of Spring Hill in the western Chehalem Mountains indicates a north-south fault with as much as 900' (274 m) of displacement in the Neogene sediment column.

The top of the CRBG is faulted south of the Beaverton Fault. Most faults are roughly oriented east-west. This faulted area may have been active in the Pleistocene as all of the Neogene sediments have been removed south of the Beaverton Fault on

Cooper and Bull Mountains and on a buried horst to the east under the Washington Square Mall in the Beaverton/Tigard area. Most other faults in this area also cut into the Neogene sediments. Neogene sediments examined for heavy minerals in the lowland area around Cooper and Bull Mountains have high augite relative percentages in the AHH relative percentages, similar to upper Neogene sediments in the central basin. These sediments may have been deposited in the Pleistocene in response to the developing lows between the Cooper-Bull Mountains structure and the Chehalem Mountains.

Boring Lava activity in the eastern Tualatin Mountains and Portland Hills is restricted to the Pleistocene, implying extensional dynamics, possibly related to shear stresses, were in place during this time. Faulting along the Tualatin Mountains occurred in two or three stages: a middle to late Miocene series of events that produced the Portland Hills Fault, possibly the Oatfield Fault lineament found on aeromagnetic data, and thrust faulting, and a Pleistocene event that included Boring Lava eruptions.

Neogene sedimentation rates in the Tualatin Basin calculated from age relationships in HBD-1 increase one order of magnitude from the late Miocene-Pliocene (0.01 mm/yr) to the Pleistocene (0.12 mm/yr). Increased sediment supply to the basin implies an increase in basin subsidence and/or relative uplift of surrounding highlands, especially the Coast Range. Augite derived from the Tillamook Volcanic Series in the Coast Range dominates AHH relative percentages from shallow Neogene sediment sands in the central and southern Tualatin Valley, supporting the notion of increased Coast Range input. The 1100' (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 may compare well with the northern Willamette Basin as several similarities are noted between the two areas. These basins have thick sequences of fine-grained, Neogene clastic material, seismic reflection line data in each basin exhibit similar reflection characters and trends, both basins have subsided during the Pleistocene, the basins share a common major structural lineament in the Gales Creek - Mt. Angel fault zone, and both basins are adjacent to the northern Coast Range. The south Willamette Valley, including the Stayton Basin, downwarped and received thick sequences of late Miocene and Pliocene sediments and stopped subsiding at the beginning of the Pleistocene. Cascadian uplift during the Pleistocene may have slowed or stopped subsidence in the Portland Basin.

The Missoula floods entered the Tualatin Valley at least 22 times through the Lake Oswego gap with at least one flood forming a fan deposit, locally depositing gravels that grade westerly into a sand facies and finally into silts and clays (Willamette Silt) that cover most of the Tualatin Valley away from the recent drainages. The Tonquin scablands south of Sherwood, the valley cut by the present Tualatin River, and the Wapato Lake Bed area at Gaston, Oregon are other probable avenues for either entry or drainage of Missoula flood episodes. Mapping the minimum elevation of residual CRBG soil exposures around the valley indicates the larger Missoula flood events deposited silt and clay to approximately 250' (76 m) above sea level. One or more flood events transported in ice-rafted erratics to elevations of 400' (122 m).

Three post-Missoula flood geomorphic surfaces are present along the Tualatin River and two persist into the adjoining major tributaries (Figure 131). The main valley floor is equivalent to the Senecal surface (12.7 ka) of the Willamette Valley, while a middle level that is discontinuous is the upper Winkle surface (10 - 12.7 ka). The age of the modern Tualatin River floodplain is between that of the Horseshoe (300 years old) and the Winkle surfaces as it applies to parts of both definitions.

The Tualatin River watershed has been subdivided based on 3rd order main stems to compare the relative geologic influences of the various tributaries to the entire watershed (Figure 119). Longitudinal profiles of the major tributaries display two main forms, an L-shape and a J-shape; however, neither form is dominant from a particular highland.

The Tualatin River's nickpoint is within two miles (3.2 km) of its confluence with the Willamette River, as opposed to other Willamette River tributaries whose nickpoints are tens of miles upstream from their mouths. Drill hole 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 (Figure 123). The slow flow conditions above the nickpoint are partly responsible for the development of summer low water algal blooms.

A high phosphate level in the Tualatin River is the other culprit for algal activity, and a good portion of this phosphate is derived from the Neogene sediments. Orthophosphate levels from Neogene sediments in HBD-1 are elevated (up to 3.17 mg/l) to about 500' (152 m) below the surface and then fall below 0.1 mg/l below this depth. Samples from other subsurface borings and soils throughout the Tualatin Valley also contain high levels of phosphate. Vivianite and magnetite are recognized in HBD-1 below 500' (152 m) to the top of the CRBG laterite. Lower magnetite levels and no vivianite above 500' (152 m) in HBD-1 indicate that acidic groundwater at some point in the past has dissolved these minerals and made phosphorus more mobile, possibly as complexes loosely adhering to iron oxide minerals. Possible sources of the phosphorus to form vivianite may include the CRBG lateritic soil, organic matter buried with the Neogene sediments, and/or connate groundwater from marine Paleogene sediments below the CRBG. The elevated orthophosphate levels in the upper 500' (152 m) of the section indicate that the

sediments are a natural source of phosphorus in the groundwater entering the Tualatin River.

Four hydrogeologic units are recognized in the Tualatin Basin: the Willamette Silt unconfined aquifer and the confined aquifers of the Neogene sediments, the CRBG and the Paleogene sediment package. The Willamette Silt and Paleogene aquifers have limited use in the Tualatin Valley due to low water yields and in the case of the Paleogene sediments, the great depth of the unit throughout most of the valley. CRBG and Neogene sediment groundwater potentiometric surface maps in the Tualatin Basin display gentle basinward slopes from the surrounding highlands (Figures 138 and 140). The two surfaces are very close in elevation in the southern part of the basin.

The CRBG aquifers provide users with high flow levels and generally good water quality, yet financial accessibility due to the great depths of the CRBG in the center of the valley has restricted the use to industry. High iron oxide levels and saline groundwater has been noted from a few CRBG wells on the west slope of the Tualatin Mountains (Figure 136). The Neogene sediments provide drinking water to the bulk of the residents in the rural parts of the central valley. The most common problems for users are high iron oxide levels in groundwater, and silt and clay infiltration into the wells. Groundwater temperatures are cooler than ground temperatures in both hydrogeologic units suggesting that meteoric groundwater is continuously mixing to keep water temperatures from equilibrating with the subsurface conditions. Flowing artesian wells are rare in the Neogene sediments, while those in the CRBG are not uncommon, especially around the margins of the Tualatin Valley.

CHAPTER 12 - RECOMMENDATIONS FOR FUTURE WORK

The age profile of the Neogene sediments in the Tualatin Basin is based on interpretations from different dating media. Refinement of the age distribution may be accomplished through continued paleomagnetic analyses of the Neogene sediments in HBD-1. Closer spaced sampling for paleomagnetic inclinations is warranted to determine whether the group of reverse inclinations at the 500' (152 m) depth truly marks the boundary between the Brunhes and Matuyama epochs. Tighter sampling around the deeper singular and the shallow spurious reversals is also needed to determine whether the Gauss or Gilbert paleomagnetic boundaries are present in the sediment section.

Diatom studies of the Neogene sediments south of Oregon City in the northern Willamette Basin would help determine the southern extent of a lake formed as a result of damming the ancestral Willamette River 2.44 million years ago by a Boring Lava flow.

The Neogene sediment package is approximately 500' (152 m) thicker beneath downtown Hillsboro and under portions of Dairy Creek farther west than at the HBD-1 site. Seismic reflection data indicate that at least part of that extra section is stratigraphically below the lowest sediments in HBD-1. No sediment samples are currently available from wells or borings that penetrate the Neogene sediments in these areas. Sampling of the deep Neogene sediments for age, lithology, and provenance studies would greatly enhance the understanding of basin development.

Focusing on the major aspects of the structural components that have influenced basin subsidence and highland development such as carefully mapping evidence for age of activity and type of movements along the major bounding fault systems is critical to understanding the relationship between the Tualatin, Portland, and northern Willamette Basins. Most faults in the area are buried and are interpreted from water well and

aeromagnetic data. Shallow seismic studies across suspected faults may increase the chances of determining the age of fault activity. The North Plains area with the complex CRBG structural setting is a prime location for study in the valley.

Further work is needed to develop a better picture of the Pleistocene history of the Willamette River flow in the area of the Tualatin Valley. Continued augite-hornblende-hypersthene analysis of Neogene sediments in the southeastern part of the Tualatin Valley could yield a better constructed geographic outline of deposits with elevated hypersthene levels. These Cascade Range derived sediments would reflect the path of the Willamette River in the Tualatin Valley area.

Groundwater resources from the Neogene sediments have not been studied in detail, yet are pertinent in the analysis of water availability for the rapidly growing population of Washington County. Groundwater modeling of the regional hydrogeologic setting and local aquifer conditions is necessary to ascertain producible water volumes and rates of groundwater migration in the Neogene sediment aquifers. This could help in determining whether groundwater resources in the Neogene sediments are viable for production. A study of this should have high priority as continued fast paced development within the Urban Growth Boundary of Washington County is decreasing the land available for large scale water well production.

Understanding the subsurface conditions determining the source and mobility of phosphorus in the Neogene sediments would serve as a model for similar environmental conditions elsewhere. Detailed studies should include focusing on the chemical nature of phosphorus in the sediments and on the groundwater chemistry conditions to better understand why magnetite and vivianite decline in occurrence in the upper Neogene. Systematic research of HBD-1 vivianite core samples to determine the exact chemical composition of the vivianite and associated diagenetic minerals could shed light on groundwater dynamics with the sediment.

Focused work on terrace mapping of the Tualatin River should be employed to better understand the river's relationship to the Missoula flood events and post catastrophic flood river activity. Detailed field relationships and correlations are important in this type of study. Understanding the river's post-Missoula flood history may help agencies when making seasonal flood predictions and making recommendations to better prepare for future floods.

Detailed subsurface sampling of the Neogene sediments is needed in the east and southeast portion of the Tualatin Valley to better understand the Plio-Pleistocene water flow history of the Willamette and Tualatin Rivers.

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APPENDIX A
METHODS AND TECHNIQUES

Sample Cuttings and Core Descriptions

Sediment samples for describing the lithology of the Neogene section consisted of three inch diameter HQ wire-line cores, four inch cores drilled with a hollow stem auger tool, one and one-half inch diameter SPT split-spoon cores about one and one half feet long, and water well drill cuttings from either mud rotary, air rotary or cable tool drilling. Hand specimens from two Willamette Silt outcrop locations on the Tualatin River were also examined. The descriptions were in two phases: field examination and description with a 10x hand lens and a more detailed analysis with a binocular microscope. The core samples were split length-wise in half to discern any internal structures such as laminations or burrow fills. Selected sections were photographed to document these structures. Drill cuttings were washed and then were examined with the binocular microscope. Colors assigned to the sediments follow the standard Geological Society of America color rock chart (Goddard et al., 1948).

Grain Size Analyses

A total of 39 samples from HBD-1 (21 sands, 6 silts, and 12 clays) and three sand cores from Tualatin Valley borings were subject to the grain size analysis. Two additional sand samples collected from water well drilling operations and seven samples collected from streams of the Tualatin Valley were sieved.

A known amount of sample was placed into a 400 ml beaker with 50 ml of a sodium hexametaphosphate (50 g/l) solution. The contents were mixed to break up sediment peds and left to sit overnight. The next day the contents were stirred and subject to ultrasonic vibrations for one minute further disperse the sand, silt, and clay fractions. The contents were poured into a pre-wet #230 sieve to separate the sand fraction from the silt and clay fractions. The silt and clay were caught in a funnel which

led to an 800 ml beaker. The samples were washed until clean water flowed through the sieve and into the larger beaker. The #230 sieve was placed on a ceramic evaporating dish and put into an oven at $\sim 200^{\circ}\text{F}$ to completely dry. The contents in the 800 ml beaker were poured into a 1000 ml hydrometer column.

The dried sand fraction was placed into a sieve stack with the following mesh sizes: #10 (gravel -if necessary), #18 (very coarse sand), #35 (coarse sand), #60 (medium sand), #120 (fine sand), and #230 (very fine sand). A pan was attached to the bottom of the stack to catch any silt or clay fractions not previously separated. The sieve stack was shaken for ~ 10 minutes on a mechanical sieve shaker. The sand fractions were extracted from each sieve. They were then stored in plastic vials and sealed. Any extra silt/clay in the pan was added to the hydrometer. The masses obtained from each sand fraction were divided by the total mass of the sample to calculate the fraction percentage of each and the total sand percent of the sample.

The silt and clay hydrometer column procedure was used to determine the percentages of silt and clay in the sample. The hydrometers were filled to the 1000 ml level with temperature stabilized distilled water and stirred vigorously for five minutes. A 152H hydrometer was used to take the readings (individual hydrometer ID # is with the data in Appendix D at the following time table: 30 seconds, 1, 2, 6, 20 minutes, 1, 3, 16, 24 hours, and at 3 days. The first four readings of the hydrometer were repeated twice to stabilize the readings. A hydrometer column filled with the standard concentration of the dispersant was used to determine the zero correction factors for later calculations of grain size. Grain size was determined using the following formula based on Stoke's Law for settling particles through water. Grain size diameter = $.01365 * (\text{effective depth}/\text{time})^{1/2}$. The effective depth was determined by calculating the corrected reading (hydrometer reading - correction from the standard)

and using the method by Gee and Bauder (1986). The hydrometer cumulative percentage for each size fraction was calculated using $\% = (1 - (\text{corrected reading} / \text{total mass})) * 100$. Each sample was plotted as percent on a cumulative frequency curve and the silt/clay percentages were determined based on where the frequency curve crossed the .002 mm line (silt - clay boundary).

Heavy Mineral Separations and Point Counts for Provenance

Sand samples from HBD-1, shallow borings, water wells, outcrops, and present day stream samples in the Tualatin and Portland basins were examined for their type and relative amounts of heavy minerals. Sand fractions were separated into light and heavy particle fractions using a sodium polytungstate technique outlined by Peterson and Binney (1988). Sodium polytungstate was mixed with distilled water to form a solution with a density of 2.98 g/ml.

Sand fractions collected from #120 (fine sand) and #230 (very fine sand) mesh sieves during wet sieving were placed in plastic centrifuge tubes. The tubes were half-filled with the polytungstate solution and the mixture stirred. The tubes were centrifuged to approximately 7000 rpm for 5 minutes. Minerals denser than 2.98 g/ml collected at the bottom of the centrifuge tube while the lighter minerals migrated to the top of the liquid column. The lighter minerals and the polytungstate solution were separated from the heavier minerals by placing the tubes in liquid nitrogen to freeze the bottom of the tube. The heavy minerals were washed, dried and mounted with Piccolite (R.I. = 1.52) on glass petrographic microscope slides for point counting.

Heavy minerals were point counted to determine their relative abundance, especially augite, hornblende, and hypersthene. A characterizing set of samples (19) were used to identify all mineral types. Four samples included the count of opaques, which are a very

common component of most heavy mineral fractions. Counts varied from 250 to over 700, depending on the amount of available material and on the relative percentage of the hornblende-augite-hypersthene. The higher counts were made on samples containing nearly equal amounts of at least two of the three minerals. Mineral counts were made on both #120 and #230 mesh sizes from several samples to see if hypersthene was selectively concentrated in the natural fluvial sorting process.

The rest of the samples were examined for the relative amounts of hornblende, augite, and hypersthene. The relative amounts of these three minerals provide the best information for interpreting the origin of the sediments. The origin for hypersthene is almost exclusively from the Cascade Range (Curt Peterson, 1994, personal comm.), while the source of augite is from the Upper Eocene Tillamook Volcanics in the Coast Range (Ray Wells, 1996, personal comm.). The Coast Range Paleogene marine sedimentary rocks, rocks of the Cascade Range, and the Columbia River all yield hornblende. The Coast Range marine sedimentary rocks were derived from the continent via an ancestral Columbia River system (Baldwin, 1981) and therefore contain many of the same minerals carried by the present day Columbia River. Hypersthene is carried in the present Columbia River, however, most of the marine sediments from the Coast Range are older than the Cascade Range and contain only a very small percentage of hypersthene (Van Atta, 1971; Cunderla, 1986; Ketrenos, 1986; and Van Atta and Thoms, 1993).

Microprobe Work

Several of the heavy mineral samples from HBD-1 contain highly altered heavy mineral grains exhibiting a pleochroic translucent to opaque medium yellow-brown color with nearly parallel extinction (0° to 5°). The grain shapes range from dumbbell

to prismatic. The birefringence under cross-nicols is extreme, making identification of the mineral grains almost impossible. Three samples of altered grains, HBD-1 693' (211.2 m), 836' (254.8 m), and 932' (284.1 m), were taken to the Oregon State University Cameca SX50 4 spectrometer wavelength dispersive electron microprobe in the Oceanography Department. Dr. Roger Nielsen prepared the samples for analysis. The samples were probed using x-ray spectrometry for elemental content and percentage to identify the mineral species. Photomicrographs and spectral elemental graphs were taken along with elemental percentage charts for selected mineral grains. These techniques and products were the basis of the mineral identification.

Preparation of Clay Minerals and X-ray Diffraction Analysis:

Clay sized material separated from clays and silts of HBD-1 was subjected to the following treatments to ensure the development of good x-ray diffraction peaks for clay mineral identification (Reka Gabor, Portland State University Geology Dept., 1994, personal communication). Each fraction was treated to remove aluminum oxide and iron oxides, then saturated with calcium ion. Four splits of each sample were additionally treated, one saturated with magnesium and three with potassium for expandable clay minerals containing these elements. The three potassium splits were made to expose the clay minerals to various heat conditions. The slurry splits were dropped on ceramic plates by a pipet, and the clay minerals were pulled on and in the plates by a vacuum suction process. The coating process was repeated three times to provide a smooth, thick coat on the plate. This process ensured that good x-ray diffraction peaks developed when analyzed. The three potassium splits were readied for final analysis. One split was left at room temperature, another split was heated to 300⁰ C for four hours, and the third was heated to 600⁰ C. The heating process

dehydrates any expandable clays, and at 600⁰ C any kaoline becomes amorphous while the 14 angstrom chlorite peak (if any chlorite is present) is enhanced. The magnesium saturated split was treated with a drop of glycerol and left to sit for 24 hours. The glycerol expands swelling clays which effectively separates these diffraction peaks from nonexpandable clay mineral diffraction peaks, making mineral identification more certain.

The clay minerals were analyzed with a XRG 3000 Phillips high intensity x-ray unit containing a Copper tube at 40 Kv and 20 mA. The scan speed of the x-ray goniometer was set at 1 degree per minute and the chart recorder speed was set at 1/2 " per minute. The receiving voltage at the recorder was manually manipulated depending on the incoming signal from the x-ray unit. The most common voltage used was 1kV; however, voltages up to 5kV were implemented when diffraction peaks went off the chart scale.

Gamma Logging Recordings

A Well Reconnaissance, Inc. (10406 Model) Portable Geo-Logger unit was used to record the gamma radiation of the Tualatin Valley sediment package from over 50 bore holes and water wells. The gamma radiation detector is located five feet from the top of a six foot long and 1 1/4" (3.2 cm) diameter probe. The probe is connected to approximately 980 feet (298.7 m) of cable, limiting radiation recording to the top 970 feet (295.7 m) of any open hole. Four available borings were deeper than 1000 feet (305 m), HBD-1 at the Hillsboro Airport, the Townsend Nursery water well south of North Plains, MTD-1 at the Portland Airport, and the Carus Road water well southeast of Oregon City. The recording unit consists of a Texas Instruments remote control console with two floating recording pens. The recording unit was consistently set at

100cps with a time constant of two. The absolute radioactivity was not determined, but let to run on a relative scale.

The probe can be used in any cased hole; however, water wells with installed water pumps prohibit the use of the probe. The sensitivity of the gamma detector is somewhat dampened by the hole size and type of casing material present in the hole. Figure A1 exhibits the response magnitude of the gamma recording in the open hole and in casing. The higher radiation recording corresponds to the open hole. Most of the water well recordings begin at total depth with a radiation profile that decreases up hole for about five to ten feet before stabilizing. This phenomenon probably is attributed to an open hole at the well base, followed by the cased portion of the well.

Casing size of logged borings varies from 2" to 6" PVC and 6" to 12" steel. Most water wells contain 6" or 8" steel casing, although deeper wells may have a 12" steel surface casing. The larger holes yield less sensitive gamma radiation response variations due to the interval width of the detection of the gamma probe (Schlumberger, 1972). The casing size of the gamma log in Figure A2 is 6" and that of Figure A3 is 12". Note the difference in the gamma response spread. The gamma response from steel casing is slightly dampened when directly compared to similar sized PVC casing (Figure A3). The lateral distance between the two holes in Figure A2 is approximately 42". These differences do not hinder the overall effectiveness of the gamma interpretation.

Another possible factor affecting the radiation response is the use of bentonite sealer near the top of the water wells. Fresh bentonite occasionally gives spikes well above the normal levels found in the section due to various natural levels of uranium in the bentonite (Figure A4). These peaks were recorded in only a few newly completed wells.

Figure A1: Gamma response difference between a cased section and a uncased section of a water well located in the CRBG. Townsend Nursery water well south of North Plains, Oregon. The 10' casing is steel.

Figure A2: Gamma response variations due to type of casing material. Activity of curve is slightly dampened in the steel cased well. Wells are 42" (1.07 m) apart in the field. Bennett water wells are in Sec. 17, T1N R2W, north of Hillsboro, Oregon.

Figure A3: Gamma response in sediments from a water well with a 12" diameter steel casing. Compare the response with the responses displayed for a 6" steel cased well in Figure A2 and a 10" steel cased well in Figure A1. Pumpkin Ridge golf course well in Sec. 36, T2N R3W.

Figure A4: Gamma spike in an unfinished water well. Driller used bentonite to seal the top of the well as casing was advanced down hole while drilling. The spike may result from radioactive elements in the bentonite.

Age Dating Techniques

Palynology

Seventeen HBD-1 core samples of silty clay were sent to Dr. Cathy Whitlock of the Geography Department at the University of Oregon for palynological examination. Sediment samples colored blue-gray or green-gray were used as indicators for reducing conditions. Pollen does not preserve well under oxidizing conditions (Kathy Whitlock, personal comm., 1993). The samples were washed and crushed to pea-sized. Ten grams of each sample was successively treated with 10% HCL, 40% hot HF, and finally 5% KOH solution. An exotic pollen tracer was added to each sample for control prior to treatment. Samples that contained pollen were subjected to acetolysis and sieved through 150-micron mesh screen. Clays were separated from the pollen grains by sieving the sample through a 7-micron mesh screen. The residue was stored in silicon oil.

Approximately 380 pollen grains were identified and counted at magnifications of 400x and 1000x for each sample. Percentages of palynomorphs are based on terrestrial trees, shrubs, herbs, and pteridophytes as the denominator. A written report was sent outlining the results of the analyses.

Phosphorous Analyses

The mineral vivianite was identified using the X-ray diffraction method on powder samples and by scanning electron microscopy in conjunction with an x-ray dispersive spectrometer. Several samples of the naturally occurring vivianite powder from various depths in HBD-1 were placed on standard powder diffraction metal slides with scotch tape backing to hold the powder. The samples were run in the same Phillips

x-ray diffractometer as the clay samples described above. Diffraction peaks were interpreted and compared to the known d-spacing diffractions for vivianite.

One microcrystalline and one macrocrystalline vivianite sample each were prepared for examination with an ISI 40 scanning electron microscope. The samples were first coated with a palladium-gold alloy for conductivity and then placed into the microscope chamber. An energy dispersive x-ray spectrometer connected to the microscope was used to determine the elemental content of the samples. Spectral peaks at distinctive wavelengths identified elements within the samples.

Seismic Reflection Data Lines

The seismic lines available for this study are migrated with 24 fold stacking and are considered to be of good quality data. Coffeen (1978) presents a detailed synopsis of seismic reflection processes and data characteristics. A shot point map included with the lines reveals the exact locations of the shot points for each seismic line. This map may not be published, although is essential for correct correlations with selected borings in the valley. RMS velocities are calculated on the seismic lines at selected interval shot points to aid the interpretation from time depth to linear depth. This proved especially important where borings were correlated to seismic horizons.

Time depths of the three horizons at each shot point were recorded and converted to linear depth by implementing the nearest shot point RMS velocity scale recorded on the seismic lines (Figure A5). The RMS velocities are given in two way time and appear to be reliable when tested against boring depths of the hard basalt rock (Figure A5). The top of basalt depth in the boring matched the time depth on the seismic red horizon to reasonable degree when using the RMS velocities. The time and depth of each horizon at each shot point were entered into the Gridzo package of the Rockware computer

Figure A5: Depth-time correlation between water well horizon picks and seismic reflection horizons based on RMS velocity-time grids generated by the seismic reflection data. The CRBG hard reflecting surface time-depth conversion corresponds well with the top basalt depth recorded by the water well driller.

program to generate structure contour maps of these horizons. The Gridzo contour program does not recognize faults, so they were hand drawn on the maps.

Cross-sections of the seismic information were produced to exhibit the depositional geometries of the Neogene sediments near the basin margins. This information influenced the development of the paleogeographic maps and was used in the interpretation of the basin structural history.

Geomorphologic Techniques

Hydrographic Subbasin Divisions

The Tualatin River watershed was subdivided into 3rd order stream subbasins in order to quantify the contributions of potential sediment sources from the major tributaries into the Tualatin Valley. Fifteen USGS 7 1/2' quadrangle topographic maps covering the Tualatin River watershed were utilized to divide the watershed into 38 smaller watersheds or subbasins containing 3rd order or higher streams as the main stem. The subbasins were drawn onto mylar overlays and subsequently digitized into the ARC/INFO Geographic Information System to calculate each subbasin area. The data files were later transferred to the Rockware basemap program called Rockbase so the maps could be incorporated with other maps digitized into the Rockware package.

Stream Ordering and Longitudinal Stream Profiles

The streams in the Tualatin Valley expressed on the USGS 7 1/2' quadrangles were ordered according to standard procedures given in Leopold et al. (1964). This procedure is useful for determining relative runoff contributions and hydrographic characterization of the Tualatin watershed. Various basin and stream drainage statistics were computed from these data.

Longitudinal profiles of the Tualatin River and six major tributaries representing drainage from all highland areas around the watershed were measured and graphed to yield information about the structural influences in recent basin development and erosion processes in the valley. A round map planimeter was employed to measure on USGS 7 1/2' quadrangle topographic maps the distance between contour lines intersecting the streams from the stream's mouths to their sources. The distances between contours were plotted against the elevation of the contours to yield the longitudinal profiles.

APPENDIX B

HBD-1 AND MTD-1 STRATIGRAPHIC DESCRIPTION LOGS AND GAMMA LOGS

**HBD-1 Hillsboro Airport Deep Test
1N2W28 bcdB Elevation. 202' TD 1095'**

Lithologic Description of the Stratigraphic Column (by the author)

Surface Soil - Aloha-Amity-Dayton Association - Dayton silt loam

0 - 10' : (Drill cuttings only) Medium brown, micaceous, clayey SILT.

10 - 20' : (Drill cuttings only) Blue-gray, clayey, micaceous SILT.

20 - 37' : Medium blue gray, micaceous, slightly clayey, v. fine sandy SILT with scattered 1-1.5" thick v. fine sand lenses, traces of organic matter, and white mineral crust on fracture linings at 37'.

45 - 47' : Medium blue gray, massive, micaceous, slightly sandy, clayey SILT with occasional subrounded basalt gravel up to 13mm.

55 - 75' : Mottled light to medium blue gray, massive, micaceous, v. fine sandy, clayey (10%) SILT with possible bioturbation. @ 61' - white scattered spots appear to be bleached clean silty areas (ashy?). @ 66-67' - color mottles with light brown and pale orange, and v. thin, clean, v. fine sandy lenses showing crude laminations (ashy??). @ 73' - scattered rounded medium -sized sand grains.

75 - 77' : Blue gray & olive brown, dense, micaceous, silty CLAY with much organic matter at 77'.

77 - 80' : Mottled blue gray-light brown, v. fine sandy, clayey SILT with organic material and scattered gravel up to 4-5mm. Light brown color % increases with depth.

80 - 93' : Mottled lt. brown-blue gray-pale orange, v. loose, micaceous, cross laminated, subangular to subrounded, mod. well sorted, clayey, v. fine - fine sandy SILT with organic matter and Fe+3 concretions (2mm). Coarsens to v. fine - fine grained SAND downward in several small upward fining sequences. @ 83-84' & 85-86' - thin lenses (1-4") of clayey SILT. @ 84' 6" to 93' - scattered round, coarse basalt sand grains.

93 - 94' : Pale yellow brown, subangular to subrounded, moderately well sorted, micaceous, silty, v. fine, lithic SAND.

94 - 96' : Pale yellow brown, microlaminated, micaceous, v. fine sandy, SILT with pale orange ashy? lenses. @ 95' 6" - dark red-brown Fe+3 concretions - paleosol?

- 96 - 109' : Light gray brown, microlaminated, subangular to subrounded , well sorted, silty, v. fine, lithic SAND with Fe+3 elongated blebs and lenses of v. fine sandy, clayey SILT @ 98' and 105'. @ 107' - Light yellow brown, angular to rounded, mod. well sorted cross-laminated, v. fine to medium, lithic, quartzose SAND with trace organic matter.
- 109 - 110' 6" : Blue gray, micaceous, clayey, SILT.
- 115 - 115' 6" : Medium blue gray, clayey SILT with red brown concentrations of Fe+3.
- 115' 6" - 116' : Blue gray to light brown, endurated, cross-laminated, subangular to rounded, moderately poorly sorted, v. fine to coarse, lithic, quartzose SANDSTONE.
- 116' - 117' : Gray black, incompetent (very loose), silty CLAY.
- 118' 6" - 119' : Blue gray, sticky, clayey SILT.
- 119' - 120' : Blue gray to light brown, silty CLAY.
- 120' - 126' : Blue gray, micaceous, clayey, SILT with at least two 4"-6" v. fine Sand lenses, interbedded swelling, silty Clay stringers, and gravelly round clay clasts.
- 126' - 127' : Gray green to medium gray, slightly silty, soft, plastic, CLAY with organic matter.
- 127' - 131' : Blue gray, slightly micaceous, clayey SILT with occasional lenses of blue gray to green gray, silty CLAY (up to 2-3" thick) and trace wood slivers.
- 131' - 133' : Variegated blue gray to green gray, silty CLAY with white clayey blebs.
- 133' - 134' : Mottled light brown, blue gray, green gray, clayey SILT with scattered coarse Sand grains (up to 20%).
- 134' - 136' 4" : Medium brown, subangular to subrounded, moderately well sorted, fine to medium, lithic, quartz bearing SAND.
- 136' 4" - 137' : Blue gray, silty CLAY.
- 137' - 138' 6" : Medium brown, subangular to subrounded, cross-laminated, moderately well sorted, fine to medium, lithic, quartz bearing SAND.

- 140' - 147' : Light to moderate brown, v. friable, cross-laminated, subangular to subrounded, moderately sorted, fine to coarse, lithic SAND with thin interbeds of blue gray clayey Silt.
- 147' - 148' : Blue gray, micaceous, v. fine sandy SILT.
- 148' - 149' : Blue gray to light brown, subangular to subrounded, well sorted, v. fine SAND.
- 149' - 157' : Blue gray, micaceous, v. fine sandy SILT to silty v. fine SAND with about 10% clay. @ 156'+ - wood in silty matrix (5%).
- 157' - 162' : Blue gray, angular to subrounded, moderately sorted, v. fine to medium, silty, lithic, quartzose SAND with scattered wood. @ 161' - scattered gravel sized grains and larger wood pieces (up to 2").
- 162' - 166' 6" : Blue gray, micaceous, somewhat plastic, silty, CLAY.
- 166' 6" - 167' : Blue gray, micaceous, clayey SILT.
- 167' - 168' : Blue gray to light brown, angular to rounded, moderately well sorted, v. fine to fine, lithic, quartzose SAND.
- 174' 8" - 178' : Blue gray with gray brown mottling, sticky, plastic, silty CLAY. @ 176' light brown color added.
- 180' - 181' : Blue gray, micaceous, clayey SILT.
- 181' - 186' : Moderate yellow brown, angular to subrounded, moderately well sorted, loose, clean, v. fine to fine, lithic, quartzose SAND with faint microlaminae. @ 185'+ Sand coarsens to lower medium, but is clayey and silty.
- 186' - 188' : Mottled gray green to brown gray, micaceous, clayey SILT alternating with olive green gray to blue gray, v. fine sandy SILT.
- 188' - 188' 6" : Light yellow brown, micaceous, subangular to subrounded, well sorted, v. fine SAND.
- 188' 6" - 190' 8" : SILT as above in 186' - 188', very sticky.

- 195' - 200' : Olive brown, micaceous, microlaminated, v. fine sandy (in places), clayey SILT. @198' - Blue gray color present.
- 200' - 201' : Blue gray, micaceous, silty CLAY.
- 201' - 212' : Medium gray, micaceous, v. stiff to dense, clayey to variable v. fine sandy, SILT. (sand approx. 10-15%).
- 212' - 212' 6" : Blue gray, subangular to subrounded, moderately sorted clayey, silty, v. fine SAND.
- 212' 6" - 213' : Medium gray, dense, silty CLAY.
- 215' - 216' : Blue gray, micaceous, clayey, v. fine sandy, SILT.
- 216' - 217' : Blue gray, clayey SILT interbedded with light yellow brown, subangular to subrounded, well sorted, v. fine to fine, lithic SAND lenses.
- 217' - 221' : Medium gray to blue gray, stiff, plastic, silty CLAY.
- 221' - 224' : Blue gray, micaceous, clayey, v. fine to fine sandy, SILT with Clay lenses.
- 224' - 229' : Blue gray, angular to rounded, microcross-laminated, well sorted, fine, lithic, quartzose SAND.
- 229' - 234' : Blue gray, v. fine sandy, clayey (approx. 10%) SILT with variable sand percentages (up to approx. 20%) throughout interval.
- 235' - 242' : Olive brown, v. fine to fine sandy, clayey (approx. 10%) SILT with lenses (1"-3" thick) of gravelly, subangular to rounded, cross-laminated, poorly sorted, fine SAND. @240' - 241' - Blue gray, dense, silty CLAY lens.
- 242' - 243' 6" : Mottled blue gray to light brown, silty CLAY.
- 245' - 255' : Blue gray, micaceous, silty CLAY to clayey SILT with a hint of microlaminations.
- 255' - 257' : Blue gray, micaceous, clayey, v. fine sandy SILT with scattered spots of Fe+3 oxidation and a hint of microlaminations.

- 257' - 264' : Pale yellow brown to blue gray, micaceous subangular to subrounded, moderately sorted, silty, v. fine to fine lithic SAND which coarsens downward to a cross-laminated, poorly sorted, v. fine to gravelly, subangular to rounded, SAND with wood chips @ 262' - 264'. @263' a large, orange pink, rounded clay (ashy?) clast approx. 3.5 cm dia.
- 265' - 267' : Blue gray with sharp bounded dark chocolate brown interfingering lenses beginning @ 266' 3", silty CLAY.
- 267' - 268' : Dusky brown, microlaminated, angular to subrounded, moderately sorted, clayey, silty, v. fine SAND with possible organic staining throughout.
- 268' - 277' : Blue gray, micaceous, silty CLAY with white, anhedral mineral crystals (zeolite?) dispersed throughout.
- 277' - 279' : Blue gray, micaceous, clayey SILT to silty CLAY with stringers of v. fine sandy SILT, dispersed organic matter, and local Fe+3 staining.
- 280' - 282' : Blue gray, rubbly, v. fine to medium sandy, clayey (approx. 20%) SILT.
- 282' - 284' : Blue gray alternating clayey SILT to silty CLAY with v. fine sandy SILT stringers.
- 284' - 290' 6" : Dark to medium gray, incompetent, organic bearing, silty CLAY.
@ 287' - 287' 6" - dark gray, clayey SILT lens. @288'+ - occasional, rounded, small gravel basalt.
- 290' 6" - 291' 6" : Olive brown, micaceous, v. fine sandy, clayey, SILT with trace organic matter.
- 291' 6" - 294' : Olive brown to blue gray, micaceous, silty CLAY.
- 294' - 298' : Blue gray to mottled light brown, micaceous, v. fine sandy, clayey SILT with crude layering suggested. @297' - sand % increases to approx. 25% with fine to medium grains.
- 298' - 300' : Blue gray to light brown, wavy laminated, subangular to subrounded, well sorted, fine to medium SAND with trace organic material.
- 300' - 302' 6" : Blue gray, sticky, clayey SILT grading downward to layers of organic bearing, v. fine sandy SILT. @ 302' - small blebs of white powdery mineral (altered plagioclase?).

302' 6" -303' : Blue gray, subangular to rounded, poorly sorted, clayey, silty, v. fine to v. coarse SAND.

303' - 304' : Mottled blue gray to red brown, micaceous, clayey SILT.

304' - 317' 6" : Gray green changing to dark gray @307', blue gray @309', and mottled blue gray to olive brown-light brown @ 311', dense, slightly silty, CLAY. @307' - 308' - clay is incompetent, very crumbly. @313' 6" - ashy?? component, @ 314' - 314' 6" - v. thin lenses of clayey SILT.

322' - 325' : Mottled blue gray to light brown, micaceous, clayey SILT coarsening downward to a v. fine sandy, SILT @ 324'.

325' - 326' : Blue gray to light brown, micaceous, subangular to subrounded, moderately sorted, silty, v. fine to fine SAND.

326' - 328' : Blue gray to light brown, micaceous, v. fine sandy, clayey SILT.

328' - 330' 6" : Light blue gray, angular to subrounded, micaceous, very loose, well sorted, v. fine to fine, lithic SAND. @ 329' - Thin lens of blue gray, micaceous, v. fine sandy, clayey SILT.

332' - 335' 6" : Blue gray, micaceous, v. fine sandy, clayey SILT.

335' 6" - 337' : Mottled light brown to blue gray, micaceous, poorly sorted, clayey, silty, v. fine SAND with scattered coarse rounded sand grains of basalt.

337' - 341' : Mottled blue gray to light brown, micaceous, v. fine sandy, clayey, SILT with scattered coarse, rounded, sand grains.

341' - 344' 6" : Light brown to blue gray, silty CLAY.

344' 6" - 346' : Mottled, blue gray to light brown, micaceous, v. fine sandy, clayey SILT.

346' - 348' : Blue gray to light brown, micaceous, subangular to subrounded, moderately sorted, clayey, silty, v. fine to medium, lithic SAND. - silt and clay content highly variable.

348' - 350' : SILT - as above @ 344' 6" - 346'.

- 350' - 353' : Blue gray with some light brown splotches, micaceous, silty CLAY to clayey SILT. @ 352' - 353' - color change to dark brownish gray.
- 353' - 366' : Dark brownish gray, v. stiff to dense, silty CLAY. @ 356' - color becomes mottled blue gray to light brown. @ 358' - color changes to olive brown - gray brown - blue gray.
- 366' - 367' : Olive brown green with red brown Fe+3 staining, sticky, silty CLAY to clayey SILT with scattered Fe+3 concretions (approx. 2mm dia.).
- 367' - 373' : Medium to light gray mottled with light brown, slightly silty CLAY. @ 371' - 373' - becomes very sticky.
- 378' - 380' : Light olive greenish brown to light brown, micaceous, clayey SILT with Fe+3 concretions 2-3mm dia.
- 380' - 384' : Gray green to light brown, subangular to subrounded, poorly sorted, v. clayey, silty, v. fine to fine, lithic SAND coarsening @ 382' to include gravel and coarse sized rounded basalt and clay clasts with organic and silt stringers.
- 384' - 385' : Gray green to light brown, micaceous, v. fine sandy SILT.
- 385' - 388' : Gray green to light brown, micaceous, subangular to subrounded, moderately sorted, silty, v. fine SAND with organic matter @ 387'.
- 388' - 388' 8" : Medium gray, silty CLAY.
- 388' 8" - 390' : Medium gray, subangular to subrounded, moderately well sorted, clayey, silty, v. fine SAND.
- 390' - 394' : Medium gray green, micaceous, plastic, clayey, v. fine sandy SILT with rounded clay clasts and scattered Fe+3 staining.
- 394' - 397' : Light blue gray with light brown, faintly cross-laminated, subangular to rounded, moderately sorted, clayey, silty, v. fine to fine, lithic, quartzose SAND.
- 398' - 399' : SAND as above, but fine to medium grained and much less clay.
- 399' - 403' 6" : Mottled medium gray to light brown, micaceous, clayey SILT becoming fractured @ 402'.

403' 6" - 405' : Medium gray, stiff, slightly silty CLAY.

405' - 407' : Light blue gray, micaceous, v. fine sandy, clayey SILT.

407' - 415' : Mottled light blue gray to light yellow brown, slightly micaceous, wavy laminated, angular to rounded, well sorted, friable, v. fine to fine lithic, arkosic, quartz bearing SAND with blue gray clay drapes. @ 411' - sand becomes medium grained. @ 414' - coarsens to include rounded coarse sand and gravel basalt and clay clasts.

417' - 418' : Mottled medium gray to light brown, silty CLAY.

418' - 420' : Mottled blue gray to light brown, micaceous, clayey SILT.

420' - 427' 6" : Mottled blue gray to light brown to olive green brown, silty CLAY becoming fractured @ 423' - 424'. @424' - becomes very dense.

435' -437' : Mottled blue gray to light brown, micaceous, v. fine sandy SILT (clay 5-10%) - note: bottom grades to sand below.

437' - 449' : Blue gray to light brown, subangular to subrounded, well sorted, fine, lithic, quartzose SAND coarsening to medium grained @440' with rounded clay clasts and trace organic matter (bioturbated?). @ 443' coarsens to coarse sand and small gravel. @ 443' 6" - thin, medium brown, clayey, gravelly SILT lens. Below 445' - SAND is angular to subrounded, fine to medium, cross laminated, well sorted with euhedral quartz crystals (overgrowths?).

449' - 453' : Medium gray, micaceous, v. dense, silty CLAY with trace organic matter and scattered gravel sized material at the top.

453' - 454' : Mottled blue gray to light brown, micaceous, clayey SILT.

454' - 455' : Light blue gray to light brown, micaceous, silty CLAY.

455' - 456' : Mottled blue gray to light brown, micaceous, angular to subrounded, moderately sorted, clayey, silty, v. fine to fine SAND.

456' - 461' : Light blue gray to light brown, micaceous, silty CLAY.

463' - 464' : Mottled blue gray to light brown, micaceous, clayey, v. fine sandy SILT grading downward to sand.

- 464' - 465' : Mottled blue gray to light brown, subangular to subrounded, moderately sorted, clayey, v. fine to fine SAND.
- 465' - 466' : Mottled blue gray to light brown, micaceous, clayey, v. fine sandy SILT.
- 466' - 471' : Medium gray, incompetent, silty CLAY. @ 471 - clay becomes very sticky and dense.
- 471' - 471 6" : Blue gray, clayey, SILT.
- 473' - 476' : Blue gray, micaceous, v. fine sandy, slightly clayey SILT.
- 476' - 488' : Grayish yellow, angular to rounded, well sorted, low angle cross-laminated, silty to fine, lithic, quartzose SAND. @ 480' - sand is fine to medium grained, friable with few rounded clay clasts. @ 484' - sand becomes blue gray to dark olive green, fine to coarse, with cross-laminations.
- 488' - 490' : Olive green to medium gray, micaceous, v. fine sandy SILT.
- 490' -491' : Medium gray to olive brown, slightly micaceous, silty CLAY.
- 491' - 494' : Blue gray, v. hard (cemented?) from 491' 6" to 492' 6" - otherwise sticky, dense, clayey SILT.
- 497' - 512' : Mottled blue gray to light brown, slightly micaceous, sticky, dense, silty, CLAY. @ 502' - color changes to medium gray and then a mix of all three colors. @ 505' - higher silt percentage noted. @ 510' - color changes to dark green.
- 512' - 514' : Blue gray, micaceous, clayey, v. fine sandy SILT.
- 515' - 516' 6" : Grayish olive green, incompetent, swelling, silty CLAY.
- 516' 6" - 517' : Grayish olive green, micaceous, v. fine sandy, clayey SILT.
- 517' - 523' : Blue gray to light yellow brown, micaceous, angular to rounded, moderately sorted, clayey, silty, v. fine to medium, lithic, quartzose SAND, coarsening to v. fine to coarse grained sand with scattered wood fragments, including a 1" core plug of wood @ 522'. @ 523' - Sand becomes v. coarse with rounded basalt and clay clasts

- 525' - 527' 6" : Dark olive green to medium gray, micaceous, v. fine sandy, clayey SILT grading to sand below.
- 527' 6" - 531' 6" : Medium gray to olive green, micaceous, subangular to subrounded, massive, moderately well sorted, v. fine to fine, lithic SAND with clast drapes @ 529' - 531'.
- 531' 6" - 535' : Alternating lenses of medium gray, micaceous, V. fine sandy, clayey SILT and v. fine silty, clayey SAND.
- 535' - 537' 6" : Gray brown, angular to rounded, poorly sorted, v. fine to v. coarse, lithic, quartzose SAND with rounded basalt and clay clasts, wood fragments, and white turning blue powdery vivianite, pore filling mineral.
- 537' 6" - 539' : Blue gray, v. fine sandy, clayey SILT with stringers of gravelly SAND.
- 539' - 544' : Blue gray, subangular to subrounded, medium well sorted, clayey, silty, v. fine to fine SAND with dispersed wood fragments. @ 542' - trace coarse sand grains.
- 544' - 548' : Blue gray, micaceous, incompetent, somewhat sticky, clayey SILT with medium gray mineralized concentrations (approx. 1-2cm) similar to liesegang rings @ 545'. Silt becomes dense @ 546', becoming brown gray @ 547'.
- 548' - 549' : Brown gray, subangular, moderately sorted, clayey, fine to medium SAND.
- 549' - 554' : Brown gray, micaceous, clayey SILT interlayered with stringers of v. fine SAND and subangular to rounded, poorly sorted, v. fine to coarse, lithic SAND. @ 553' - scattered thin buff (ashy?) blebs and white turning blue powdery vivianite.
- 554' - 557' : Gray brown, silty CLAY. @ 556' - v. thin veins? of zeolitic? crystals associated with trace organic material.
- 557' - 563' : Gray brown, micaceous, clayey SILT lenses interfingered with silty CLAY. @ 562' - crude thin lenses (5-10 mm) of v. fine sandy SILT and stringers of v. fine to fine SAND.

- 563' - 564' : Gray brown, subangular to subrounded, micaceous, moderately sorted, v. fine to fine, lithic SAND.
- 564' - 565' : Gray brown , silty CLAY to clayey SILT with stringers of silty, v. fine SAND.
- 565' - 566' : Gray brown, subangular to rounded, poorly sorted, medium to gravelly SAND with wood fragments and possible pumice or ash blebs.
- 566' - 568' : Brown gray, micaceous, v. fine sandy, clayey SILT.
- 570' 6" - 574' : Brown gray, micaceous, v. fine sandy, clayey SILT with thin stringers of v. fine sandy SILT.
- 574' - 575' : Brown gray, micaceous, silty CLAY.
- 577' - 583' 6" : Mottled blue gray to olive brown, stiff to dense, blocky, silty CLAY.
@ 579' - lenses of v. clayey SILT.
- 585' - 586' : Medium gray, dense, dry, micaceous, silty CLAY with scattered white to blue powdery vivianite.
- 594' - 597' : Medium gray, incompetent to stiff, sticky, silty CLAY with white to blue powdery vivianite.
- 597' - 602' 6" : Alternating succession of stiff and blocky - blue gray and medium gray, micaceous, clayey SILT and green gray, slightly silty CLAY (approx. 5mm thick) with white rounded polygonal ashy? pattern on the green clay @ 601' 8".
- 605' - 606' : Greenish black, dense, blocky, silty CLAY.
- 606' - 607' 6" : Green gray, micaceous, v. fine sandy SILT with occasional gravel lenses (5-8mm thick) and scattered fine to medium sand.
- 607' 6" - 610' : Green gray, subangular to rounded, poorly sorted, clayey, medium to coarse, gravelly, lithic SAND.

- 610' - 622' 6" : Medium gray to green gray, micaceous, v. fine sandy, clayey SILT (thin stringers of clayey SILT and sandy SILT with sharp boundaries) with lenses of v. fine to medium SAND. @ 615' - scattered gravel in silt with light brown coloration. @ 618' - fracture filled pockets of milky white botryoidal crystals (zeolite?).
- 622' 6" - 625' : Mottled blue gray to light brown, sticky, silty CLAY.
- 625' - 630' : Alternating blue gray to light brown, slightly micaceous, clayey SILT to silty CLAY.
- 630' - 633' : Medium blue gray with trace light brown, sticky, clayey SILT becoming v. fine sandy SILT @ 632'.
- 633' - 634' : Blue gray, massive, poorly sorted, clayey, silty, v. fine - fine SAND with lenses of clayey SILT and red brown clay filled fractures.
- 634' - 636' : Blue gray with trace light brown, clayey SILT with thin stringers of clayey, v. fine SAND.
- 637' 6" - 639' : Mottled blue gray, olive brown, light brown, micaceous, very sticky, clayey, v. fine sandy SILT with occasional round coarse basalt grading downward to sand.
- 639' - 640' 6" : Medium blue gray, subangular to subrounded, well sorted, micaceous, v. friable, clean, v. fine SAND with scattered round coarse basalt.
- 640' 6" - 642' : Gray brown, micaceous, v. fine sandy SILT.
- 642' - 647' : Brown gray, micaceous, silty CLAY with traces of organic matter and white lenticular spots (3-5mm dia.) of subrounded, silt to v. fine sand sized botryoidal crystals (zeolite?).
- 647' - 653' : Variegated medium gray to grayish green, micaceous, clayey SILT with two 2" lenses of blue gray to light yellow brown, angular to rounded, moderately well sorted, water bearing, fine to medium, lithic, quartzose SAND @ 651' and 651' 3". @ 652' - Silt becomes v. fine sandy and clayey. @ 649' - pollen of Spruce tree species have been identified - tentatively suggested as Pleistocene.

653' - 658' : Blue gray, massive, subangular to rounded, moderately well sorted, clayey, v. fine to fine, lithic SAND coarsening downward to medium grained and becoming water bearing @ 656'. Note: red brown and green weathered basaltic material in the sand.

658' - 667' : Mottled blue gray light brown, micaceous, clayey SILT with scattered coarse sand grains to 658' 6". Irregular lenses of v. fine silty SAND (1-2mm) and light brown silty CLAY from 660' to 661'. @ 662' - trace rounded, coarse basalt. @ 663' - 1.5" zone of blue mineralization on one side of core with fracture crystalline linings of elongate, translucent cobalt blue crystals (vivianite) and botryoidal v. light yellowish brown crystals. @ 666' - thin lens of v. fine sandy SILT with scattered coarse grains.

667' - 668' 8" : Blue gray with a trace of light brown, micaceous, slightly silty CLAY.

670' - 672' : Mottled blue gray to light brown, micaceous, silty CLAY coarsening to downward.

672' - 677' : Mottled blue gray to light brown, micaceous, stiff, clayey SILT with occasional blocky (approx. 5mm) clay clasts. @ 675' - coarsening to v. fine sandy, clayey SILT. @ 676 - back to clayey SILT with clay lenses.

677' - 681' : Mottled blue gray, grayish green, and light brown, micaceous, silty CLAY with occasional lenses of clayey SILT with clay clasts.

681' - 684' 6" : Blue gray, micaceous, subangular to subrounded, moderately poorly sorted, clayey, v. fine to medium sandy SILT with an 8mm thick lens of light yellow brown, subangular to subrounded, well sorted, fine SAND @ 683'.

684' 6" - 692' 8" : Gray brown, micaceous, v. fine sandy, slightly clayey SILT with white turning blue vivianite in a 1" zone. @ 686' 3" - yellow brown mineralization in fractures. Note: sand content in silt increases with depth @ 686'.

692' 8" - 694' : Medium blue gray with medium brown clay clasts, micaceous, subangular to rounded, poorly sorted, fine to gravelly (up to 6mm), lithic, quartz bearing SAND with rounded clay clasts and basalt.

694' - 695' : Gray brown, micaceous, v. fine sandy, clayey SILT.

695' - 711' : Brown gray, micaceous, v. incompetent, slightly silty, CLAY. - breaks very easily. @ 706' - clay beginning to hold up on its own and is microlaminated. @ 707' - color change to olive brown with white turning blue powdery vivianite. @ 709' - color change to a ruddy blackish brown, clay becomes very hard and is highly organic bearing.

711' - 711' 4" : Gray brown, micaceous, v. fine sandy, clayey SILT with white pumaceous or zeolitic? blebs.

711' 4" - 712' 6" : Gray brown, moderately sorted, clayey, v. fine to fine SAND.

712' 6" - 714' 6" : Gray brown, micaceous, v. fine sandy, clayey SILT.

714' 6" - 715' 2" : Gray brown, moderately sorted, clayey, v. fine to fine SAND.

715' 2" - 730' 4" : Blue gray, micaceous, silty CLAY with white turning blue powdery vivianite. @ 716' 2" - 716' 6" - Blue gray, v. fine to fine SAND lens. @ 721' - color change to gray brown, stiff, but crumbles easily (blocky), faint discontinuous wavy laminations, and possible burrows or fractures filled with organic matter in spots @ 725' - 727' - alternate laminations or lenses of olive brown silty CLAYSTONE and gray green purer CLAYSTONE with white some turning blue vivianite streaks, organic matter, and v. thin (1-2mm) stringers of light brown, clayey SILT all of relatively low density.- Abundant broken diatoms have been identified in this interval as the genus Aulocosira.

730' 4" - 736' : Blue gray, v. friable, subangular to rounded, moderately well sorted, v. fine - fine lithic SAND coarsening to medium grained @ 731' 6", with scattered coarse to gravel sized basalt and white turning blue powdery vivianite @ 732' 8"+. Water bearing @ 734'. Also noted are angular quartz grains, rounded basalt (up to 3mm), and clayey matrix around grains @ 735'.

736' - 740' : Gray brown, micaceous, silty CLAY changing color to green gray @ 738' and large (up to 2mm) white turning blue powdery vivianite blebs @ 739'.

749' 6" - 750' 8" : Olive brown to gray brown, stiff, v. incompetent, silty CLAY.

750' 8" - 751' 5" : Gray brown, micaceous, v. fine sandy, clayey SILT coarsening downward to sand.

- 751' 5" - 753' : Gray brown, subangular to subrounded, moderately sorted, clayey, silty, v. fine SAND.
- 753' - 759' 6" : Gray brown, micaceous, v. fine sandy, clayey SILT losing the sand @ 754'. @ 755' - 756' - v. incompetent silty CLAY. @ 756' - back to v. fine sandy, clayey SILT. @ 759' - silty CLAY.
- 759' 6" - 760' : Green gray, endurated, highly contorted layered or banded, siliceous SILTSTONE with rippled CLAYSTONE lenses.
- 760' - 760' 4" : Medium brown, moderately endurated, rippled, siliceous, v. fine sandy SILTSTONE with clay lenses.
- 760' 4" - 761' 6" : Medium brown, moderately (somewhat friable) endurated, cross-bedded, subrounded to rounded, well sorted, fine to medium, silica cemented, quartzose SANDSTONE.
- 761' 6" - 765' : Olive brown, v. fine sandy SILTSTONE with organic parallel laminae @ 761' 6". @ 762' - discontinuous medium sand lenses and thin, cross-bedded (approx. 20), brown clay drapes, organic lenses, clay rip-up clasts, and scattered v. fine to fine sand. @ 763" - Siltstone becomes more massive with faint laminae. @ 764' - more organic laminae. @ 764' 6" - massive to faintly parallel laminated and cross-bedded with clay rip-up clasts.
- 767' - 768' : Medium brown, slightly endurated, wavy laminated, organic bearing clayey SILTSTONE with rounded clay clasts in top 5" and discontinuous clay lenses below. Note: fairly sharp contact with clay below.
- 768' - 773' : Mottled blue gray to light brown, v. incompetent, silty CLAY with traces of coarse sand and dark brown blocky structures (approx. 1-2mm dia.).
- 773' - 777" : Mottled blue gray to light brown, clayey SILT with occasional round, v. coarse sand (basalt). @ 775' - color to gray brown and v. incompetent.
- 777' - 783' : Mottled blue gray to light brown to olive brown, micaceous, silty CLAY with trace organic matter.
- 783' - 796' 6" : Mottled blue gray to light brown, micaceous, v. fine sandy, clayey SILT with sandy sections in the light brown and clayey sections in the blue gray color. @ 791' - streaks of rounded, v. coarse sand to gravelly (up to 3-4mm)basalt.

796' 6" - 799' : Light brown, subangular to rounded, moderately sorted, clayey, silty, v. fine to fine SAND with occasional coarse, round basalt.

799' - 803' : Mottled blue gray to light brown, micaceous, dense, plastic, clayey SILT interlayered with silty CLAY.

803' - 807' : Blue gray, v. incompetent, slightly silty CLAY.

807' - 808' 6" : Mottled blue gray to light brown, micaceous, stiff, clayey SILT with silty CLAY, coarsening downward to a v. fine sandy SILT.

808' 6" - 811' : Blue gray, subangular to subrounded, moderately well sorted, clayey, v. fine to fine, lithic, quartzose SAND with rounded clay clasts and occasional coarse basalt.

811' - 835' : Mottled blue gray to light brown, micaceous, silty CLAY with lenses of clayey SILT and trace organic matter @ 813'. @ 815'+ - occasional medium to coarse lithic sand grains and white turning blue powdery vivianite. @ 818' - scattered subround to rounded coarse sand grains more common (approx. 5%) and then decreases below 820'. @ 822' 3" - white ashy blebs (1mm) and rounded yellow brown clay clasts. @ 824' - faint laminae present. @ 829' - blue gray color dominant. @ 832' 5" - clay becomes v. incompetent and mottled with light brown and gray brown.

835' - 844' : Mottled blue gray to light brown, micaceous, stiff, clayey SILT, becoming almost all blue gray @ 836'. @ 837' - silt becomes slightly sandy with vertical clay filled fractures and trace organic matter. @ 839' - trace medium gray blotches. @ 842' - silt becomes v. fine sandy and clayey. @ 843' - faint microlaminae of green gray with blue gray and brown gray of clayey SILT with trace white ashy? blebs (2mm).

844' - 845' : Brown gray, incompetent, sticky, silty CLAY.

845' - 846' : Blue gray, micaceous, v. fine to fine sandy SILT.

846' - 848' : Blue gray to yellow brown, micaceous, subangular to subrounded, moderately sorted, clayey, silty, v. fine to fine, lithic, quartzose SAND with yellow brown crystalline fracture fill.

848' - 848' 6" : Gray brown, silty CLAY with white turning blue powdery vivianite blebs (up to 6 mm).

- 848' 6" - 849' 5" : Blue gray to yellow brown, subangular to rounded, poorly sorted, silty, v. fine to coarse SAND with yellow brown crystalline fracture fill and white turning blue powdery vivianite.
- 849' 5" - 855' : Gray brown, micaceous, massive, silty CLAY with trace white to blue blebs and glassy brown streaks. @ 850' - pollen of Eastern North American hardwood tree species identified - tentatively suggested as late Miocene or early Pliocene.
- 855' - 857' : Mottled blue gray to light brown, sticky, silty, v. fine sandy CLAY to v. clayey SILT.
- 857' - 864" : Medium gray to mottled gray brown - gray green, slightly silty CLAY white turning blue powdery vivianite. Clay incompetent in places, but stays competent below 861'.
- 864' - 865' : Blue gray, micaceous, clayey SILT.
- 867' - 873' : Blue gray, micaceous, clayey SILT with occasional lenses of blue gray CLAY. @872' - silt coarsens to v. fine sandy, clayey SILT.
- 873' - 876' : Medium gray, subangular to rounded, moderately sorted, clayey, v. fine to fine, lithic SAND becoming medium grained @ 873' 4" and coarse fragments present with 1" clay lenses @ 874'. @ 875' - clay clasts and gravel sized material present.
- 876' - 877' : Medium gray, incompetent, micaceous, silty CLAY.
- 877' - 879' 3" : Sharp contact with underlying medium blue gray, micaceous, subangular to subrounded, moderately sorted, loose, clayey, silty, v. fine to fine, lithic, arkosic SAND with occasional medium grained round basalt and trace organic matter with clay laminae. - becoming well sorted 3" down.
- 879' 3" - 880' : Sharp contact with underlying blue gray, clayey SILT.
- 880' - 881' : Blue gray, incompetent, silty CLAY with light brown splotches of v. fine sandy, clayey SILT
- 885' 6" - 886' : Green gray, incompetent, silty CLAY with white turning blue powdery vivianite.

- 886' - 888' : Irregularly layered green gray to light brown, micaceous, clayey SILT and rounded, v. coarse sandy to gravelly, clayey SILT.
- 888' - 889' : Mottled brown gray, light brown, micaceous, v. fine sandy SILT.
- 889' - 891' : Mottled brown gray, blue gray, light brown, silty CLAY.
- 891' - 894' : Mottled brown gray, blue gray, light brown, clayey, v. fine sandy SILT with fractures filled with Fe+3 and occasional rounded coarse sand grains increasing % with depth (up to 5%).
- 894' - 897' : Mottled light brown to green gray, alternating lenses of silty CLAY and v. fine sandy, clayey SILT with vertical fractures filled with clay (burrows?).
 @ 895' - 896' - slickensides noted on clay in fractures and rounded v. coarse sand in vertical lenses. @ 896' - incompetent sandy SILT.
- 897' - 898' 2" : Light brown, micaceous, wavy laminated, subangular to subrounded, moderately sorted, clayey, silty, v. fine to fine SAND.
- 898' 2" - 906' : Mottled blue gray to light brown, micaceous, silty CLAY with interlayers of silty, v. fine SAND. @ 901'-902' - occasional coarse sand grains. @ 903'+ - light brown to light gray coloration.
- 906' - 908' : Interlayers of dark gray brown purer CLAY and light blue gray with splotches of gray brown and light brown, micaceous, organic bearing, v. fine sandy, clayey SILT.
- 908' - 915' : Light brown to blue gray, sticky, silty CLAY with slickensides inside core.
- 915' - 916' : Gray brown, v. fine to fine sandy SILT.
- 916' - 918' : Gray brown, micaceous, organic bearing, silty CLAY with interlayers of sticky, stiff, clayey SILT and white, purer CLAY lenses.
- 918' - 922' : Mottled blue gray to light brown, clayey SILT with microfractures filled with silicate crystals, becoming mostly blue gray @ 919'. @ 920' - silt becomes v. fine sandy (20 -25%) with clay rinds on grains and trace orange Fe+3 staining, then back to clayey SILT @ 920' 3". @ 921' - microvugs of crystals and organic matter.
- 922' - 923' : Blue gray, silty CLAY with scattered medium to coarse sand grains.

- 923' - 923' 6" : Mottled blue gray to light brown, clayey SILT.
- 923' 6" - 926' 6" : Mottled blue gray, v. fine sandy SILT to mostly clayey, silty, v. fine SAND with clay clasts @925' - 926'.
- 926' 6" - 927' - Medium gray, dense, micaceous, silty CLAY with organic matter.
- 927' - 929' 8" : Light blue gray, micaceous, subangular to rounded, moderately well sorted, clayey, v. fine to fine SAND with organic matter and red brown Fe+3 liesegang banding.
- 929' 8" - 930' 7" : Light yellow brown to red brown, rounded, endurated, silica cemented, totally altered gravel sized basaltic CONGLOMERATE. Sharp upper and lower boundaries.
- 930' 7" - 936' : Moderate red brown, micaceous, subangular to rounded, moderately sorted, clayey, silty, v. fine, lithic SAND with 3cm gravel pieces at the top, thin laminations of organic matter, and occasional coarse sand grains.
- 936' - 939' 6" : Medium brown, micaceous, v. fine sandy, clayey SILT with cross-laminations and lenses of blue gray subangular to subrounded, moderately sorted, bioturbated?, v. fine SAND.
- 939' 6" - 944' : Medium gray to gray brown, micaceous, silty CLAY with red brown clay clasts @ 941'. @ 943' - color changes to mottled blue gray and gray green with whitish red nodules of highly weathered basalt (approx. 1mm). Sharp lower boundary indicates boundary between sediments and laterized basalt soil - **Columbia River Basalt Group**.
- 944' 6" - 945' 6" : Red brown with blue gray streaks, endurated, rounded, highly weathered, basalt pisolitic nodules in a clayey matrix.
- 945' 6" - 948' : Red brown, silty, clayey matrix supporting sand and gravel sized rounded basalt material - moderately to highly weathered.
- 954' - 958' 2" : Highly variegated (red, orange, light blue gray, yellow, and gray brown), silty, clayey matrix with clay nodules (bright red) and scattered fine sand sized basalt grains. Horizons of very sticky, red brown, silty CLAY. @ 957' - 958' - medium gray color added with weathered plagioclase crystals (highly weathered basalt).

- 961' - 973' : Medium gray to red brown, orange, highly weathered BASALT - note: entire section easily breaks down exhibiting various stages of weathering.
 @ 965' 8" - 966' - Medium gray black, sort, BASALT with weathered yellow white plagioclase crystals. @ 966' - basalt blebs in highly weathered matrix are round and vary from black to orange (altered to clay).
 @ 967' - vein of highly weathered silica and basaltic concretionary rinds throughout. @ 967+ - section becomes grayish red to moderate red with white clay areas. @ 970' - Bright grayish red CLAY with a silty matrix and white/yellow plagioclase/clay/silica streaks and veins.
- 979' - 999' : @ 979' - Dark ocher, very sticky, plastic CLAY with white plagioclase crystals (<1mm) - smears easily. @ 979' 6" - Gray brown, plastic CLAY with white and yellow weathered plagioclase crystals. @ 980'+ - Variegated (dominantly yellow brown), grainy textured, black grains of basalt in red brown CLAY with layers of salt and pepper and yellow brown clayey material, round yellow brown nodules of clay, highly weathered plagioclase crystals, and occasional black soft basalt layers (approx. 1" thick).
- 1000' - 1008" : Medium gray to red brown, sticky, CLAY decomposed from basalt with yellow to ocher red clay globules (altered plagioclase) with relict basalt texture. Scattered black soft basalt remnants. @ 1002' - 1008' - red brown color dominates.
- 1010' - 1025' : Moderate brown, to black, highly weathered, very soft BASALT with mostly decomposed yellow clayey plagioclase crystals. @ 1013' - color changes to gray brown, is mostly decomposed to CLAY with light brown to dark orange brown altered plagioclase (highly variegated in places). @ 1016' - spotty fresher pebbles of basalt and color dominantly moderate brown. @ 1019' - color mostly moderate yellow brown with fracture filled veins of greenish yellow altered to clay from silicate crystals, streaks of soft, black, crumbly basalt mixed with fresher, harder basalt fragments.
- 1025' - 1029' : Gray to black, endurated, weathered BASALT with fresh basalt fragments and altered greenish yellow clay veins. @ 1027' - weathered basalt with green weathered (olivine or pyroxene ?) crystals.
- 1029' + : Dark gray to black, very hard, somewhat weathered, fractured BASALT.
- END OF CORE**

NOTE: Below 1029' 6" - Boring was made with tri-cone mud drilling to a total depth of 1095'. Cuttings of black basalt were mixed with material from the overlying section in all samples recovered. Drilling rate was extremely slow (1.5'/hr.) to approximately 1060' and increased significantly below to 1095'.

LITHOLOGY THICKNESSES AND PERCENTAGES

(Layers greater than 6" thick)

<u>Lithology</u>	<u>Total thickness</u>	<u>Ave. Thickness</u>	<u>Percentage</u>
SAND	192.2'(58m)	3.2'	20.4%
SILT	389' (120m)		41.4%
CLAY	269' (m)		28.6%

MTD-1 Portland Airport Deep Hole
1N 2E 6caaa Elevation Approx. 23' TD 1523'

This drill hole was cored with HQ wireline from 391' - 455', 473' - 474', and 724' - 841'. The rest of the hole was drilled with a mud rotary, tri-cone bit. Sample descriptions outside of the above intervals are from drill cuttings. Described by the author.

- 0' - 5': Dark brown, soft, clayey SILT. @5" - Greenish gray to brown, v. sticky, v. fine sandy, clayey SILT with organic material.
- 5' - 15': Gray brown, subangular to subrounded, poorly sorted, coarse - v. coarse SAND and GRAVEL with abundant wood chips.
- 15' - 25': Dark green gray with red and black, subangular to subrounded, loose, poorly sorted, fine to v. coarse, lithic rich, quartz bearing SAND with few wood chips. Lithics include basalt and granitic material.
- 25' - 35': As Above (AA) - dominantly medium grained.
- 35' - 37': Gray to brown, v. fine sandy, clayey SILT.
- 37' - 40': Dark green gray with red and black, subangular to subrounded, loose, poorly sorted, fine - v. coarse, lithic rich, quartz bearing SAND with few wood chips. Lithics include basalt and granitic material.
- 40' - 45': AA - with wood chips.
- 45' - 55': Gray, black, red, and green, subangular to subrounded, loose, micaceous, moderately sorted, medium - coarse lithic rich SAND with wood. Lithics include andesite, granite, granodiorite, and basalt.
- 55' - 60': AA - with lots of wood.
- 60' - 70': AA - with much less wood and some silt sized material.
- 70' - 90': Gray, angular to subrounded, loose, well sorted, micaceous, fine - medium, arkosic, lithic, quartz bearing SAND with scattered coarse grains.
- 90' - 95': Medium gray, angular to round, loose, poorly sorted, fine - v. coarse, arkosic, lithic, quartz bearing SAND.
- 95' - 100': Gray, angular to subrounded, loose, well sorted, micaceous, fine - medium, arkosic, lithic, quartz bearing SAND with scattered coarse grains.

- 100' - 135': Pale yellow brown, angular to subrounded, loose to slightly compacted (v. friable), slightly micaceous, moderately sorted, v. fine - v. coarse (mostly medium), arkosic, lithic, quartz bearing SAND.
- 135' - 145': White, dark gray, subangular to rounded, loose, moderately well sorted, coarse SAND to small GRAVEL consisting predominantly of pumice with some black basalt and lots of wood chips.
- 145' - 155': White, dark gray, subangular to subrounded, micaceous, poorly sorted, silty, fine - coarse, lithic SAND including pumice, tuff, scoria, black basalt, & gabbro(?) with wood.
- 155' - 165': Pale yellow brown, angular to subrounded, loose to slightly compacted (v. friable), slightly micaceous, moderately sorted, v. fine - v. coarse (mostly medium), arkosic, lithic, quartz bearing SAND.
- 165' - 185': White, dark gray, subangular to subrounded, loose, micaceous, moderately sorted, fine - medium, lithic SAND with occasional coarse pumice grains.
@ 180' - 182' - wood chips.
- 185' - 195': Dark gray, micaceous, subangular to rounded, moderately sorted, v. coarse SAND to GRAVEL (up to 6 cm.) consisting dominantly of basalt with minor plutonic lithics and lots of wood.
- 195' - 205': Pale yellow brown, angular to subrounded, loose to slightly compacted (v. friable), slightly micaceous, moderately sorted, v. fine - v. coarse (mostly medium), arkosic, lithic, quartz bearing SAND to rounded basaltic GRAVEL.
- 205' - 225': Dark gray, micaceous, subangular to rounded, moderately sorted, v. coarse SAND to GRAVEL (up to 6 cm.) consisting dominantly of basalt with minor plutonic lithics and lots of wood.
- 225' - 245': Pale yellow brown, angular to subrounded, loose to slightly compacted (v. friable), slightly micaceous, moderately sorted, v. fine - v. coarse (mostly medium), arkosic, lithic, quartz bearing SAND.
- 245' - 250': White, dark gray, angular to subrounded, micaceous, loose, moderately sorted, fine - coarse, arkosic, lithic SAND.

- 250' - 279': Dark gray, black, red, white, angular chips of dominantly basaltic with subordinate granitic GRAVEL, COBBLES, and BOULDERS.
- 279' - 290': Brown, gray, micaceous, clayey SILT with basalt chips probably from above.
- 290' - 295': Gray, subangular to subrounded, micaceous, moderately sorted, silty, clayey, fine, basaltic SAND.
- 295' - 310': Gray, angular to rounded, moderately sorted, fine SAND to GRAVEL consisting dominantly of basalt and clayey SILT. @ 305' - micaceous, silty CLAY material noted mixed with sand.
- 310' - 320': Gray, micaceous, v. fine sandy, clayey SILT.
- 320' - 325': Gray, subangular to subrounded, moderately sorted, loose, medium - coarse SAND with occasional basaltic GRAVEL.
- 325' - 358': Green, gray, white, red, angular to rounded (quartz & basalt more angular), micaceous, moderately sorted, v. coarse SAND to GRAVEL consisting of various granitic and basaltic material, quartz, and sandstone. Gravel up to 5 cm. @ 353' - COBBLES and BOULDERS noted from hard drilling and angular basalt chips.
- 358' - 391': Gray to gray green, micaceous, v. fine sandy, clayey SILT. @ 375' - scattered occasional medium SAND. @ 385' - trace of wood.

CORE SAMPLES From 391' to 474'

- 391' - 394': Medium blue gray, oxidizing to green gray, micaceous (15%), massive, silty CLAY.
- 394' - 397': Medium gray to green gray, blocky, micaceous (5%), massive, somewhat plastic, sticky, slightly silty CLAY.
- 397' - 402': Medium gray with mottled white and light brown, blocky, slightly micaceous, massive, stiff, nonplastic, slightly silty CLAY. Slickensides noted @ 398' 8". Clay becomes more micaceous, mottled with more light brown @ 400'.

- 402' - 403': As Above (AA) - Clay laminated with irregular or wavy lenses of white and light brown-orange (Fe+3 staining) clay with traces of organic matter and ashy? white spots (< 1mm dia.). silt (10%) - also medium green gray, purer clay drape microlaminae.
- 403' - 405': Light to medium brown, blocky, micaceous, silty CLAY with purer clay clasts and rounded clasts of v. fine to fine sandy SILT up to 1 cm. dia. The silt clasts also have clay streaks. Also round (botryoidal?) spots of white powdery material surrounding hard, translucent cores.
- 405' - 405' 2": Mixed lenses of moderate brown, subrounded - rounded, moderately sorted, silty, v. fine-fine, lithic (dominant), quartz bearing SAND with occasional medium sized grains, interlayered with dusky brown, CLAY.
- 405' 2" - 405' 6": Dark gray, micaceous, silty CLAY with traces of scattered fine sand.
- 405' 6" - 406': Dark gray, micaceous, v. fine sandy, clayey SILT.
- 406' - 417' 3": Dark gray, angular - subrounded, well-sorted, micaceous, somewhat endurated (especially bt. 411' - 415'), friable, v. fine-fine, quartz bearing, basalt rich SAND with interlayered clay drapes only a few mm. thick. - Sand become medium grained @ 409'.
- 417' 3" - 418': AA- sand becomes v. fine grained with some clay and silt.
- 418' - 418' 5": Brownish black, micaceous, clayey SILT.
- 418' 5" - 427': Light gray, micaceous, endurated, friable, faintly parallel laminated, v.fine sandy, SILTSTONE. @ 421' - soft, clayey SILT. @ 425' + - back to sandy SILT with 2 to 4 cm lenses of light green gray, angular to subrounded, micaceous, clean, silty, v. fine SAND with a hint of cross-bedding.
- 427' - 428' 5": SAND - AA
- 428' 5" - 435': Light green gray, angular to subrounded, micaceous, well sorted, v.fine to fine, arkosic, quartz bearing, lithic (black basalt) SAND with interbedded layers of v. fine sandy SILT up to 8cm thick.
- 435' - 440': No core recovered,

440' - 443' 2": Pale olive, angular to subrounded, micaceous, moderately well sorted, cross-bedded, fine to medium, arkosic, quartz bearing, SAND with occasional coarse grains and interbedded clay drapes 5-7m thick.

443' 2" - 444': Pale olive to green gray, micaceous, slightly clayey, v. fine sandy SILT with scattered fine to medium lithic grains and wood material. @ 443' 8" - color changes to gray brown.

444' - 445': Dark green gray, micaceous, silty CLAY.

445' - 454': Light olive gray, micaceous, angular to subangular, v. friable, well sorted, silty, v. fine, arkosic, quartz bearing SAND with few black lithic basalt grains. Sand coarsens downward to v. fine-fine. @ 448' - Clay stringers noted. @ 452'+ - scattered organic matter noted.

454' - 456' 4": Light brown gray, angular to subrounded, micaceous, well sorted, organic bearing, silty, v. fine SAND. Becomes fine grained @ 456'+.

456' 4" - 473': No core recovered. Drill cuttings only in this interval.

456' - 459' 6": Grayish orange, angular to subrounded, micaceous, moderately sorted, v. friable, fine to coarse, arkosic, basaltic SAND with minor quartz. Basalt grains more subrounded and larger than plagioclase.

461' - 463': Dark gray to black, angular (quartz) to subrounded, moderately well sorted, v. friable, upper medium to coarse, basaltic SAND with minor quartz and plagioclase.

463' - 466': AA - except cobble sized black basalt with vesicles (up to 5 cm.).

466' - 473': Dark gray to black, angular to subangular, v. loose, poorly sorted, fine to gravel, basaltic SAND with minor quartz and muscovite, and trace organic matter (wood?).

473' - 474': **Core 2" - 3" long.** Dusky yellow brown, subangular to well rounded, poorly sorted, fine to coarse, arkosic, quartz bearing SAND to COBBLE (> 5cm.) sized, black, basalt fragments.

Back to drill cuttings.

474' - 478': AA - mostly gravel sized material.

478' - 481': AA - occasional cobble sized material.

481' - 488': Black and white, angular to subrounded, poorly sorted, micaceous, v. friable, fine to gravel, arkosic, basaltic SAND with 30%-40% basalt and occasional light green and red brown lithic material.

488' - 493': Black with white, angular to subrounded, v. poorly sorted, fine to large gravel, basaltic, quartz bearing, lithic SAND - GRAVEL.

493' - 507': AA - occasional cobble sized basalt.

NOTE: Drill cuttings samples from this depth and below are widely scattered and sample bags are marked with only one depth. Field log descriptions will be substituted where necessary.

507' - 514': No sample. Field log indicates more SAND and GRAVEL as above.

514' - 519': Black and white, angular to rounded, loose, moderately sorted, coarse - v. coarse SAND to GRAVEL or larger consisting dominantly of basalt chips (up to 1.5 cm.) and subordinate andesite and granitic material.

519' - 533': Black, green, white, red brown, angular to rounded, loose, moderately sorted, v. coarse SAND to GRAVEL consisting of massive black basalt, vesicular basalt, pumice, quartz, and other lithic material. @ 531' - lots of wood.

533' - 566': No sample. Field log indicates black, medium to coarse, micaceous, SAND with minor blue gray CLAY and rare GRAVEL.

566' - 575': Yellowish gray, micaceous, v. fine sandy, clayey SILT.

575' - 581': No sample. Field log indicates coarse to v. coarse SAND and minor blue gray CLAY.

581' - 585': Yellow gray, micaceous, silty CLAY with scattered v. coarse sand to gravel (from above?).

585' - 601': No sample. Field log indicates CLAY as above with scattered sand.

601' - 606': Sample mixed with yellow gray, micaceous, clayey SILT and dark gray, white, angular to subrounded, loose, moderately sorted, medium - v. coarse, lithic (mostly basalt), quartz bearing SAND.

606' - 629': No sample. Field log indicates black, coarse SAND.

629' - 630': Yellow gray, micaceous, silty CLAY.

630' - 692': No sample. Field log indicates black, coarse SAND and blue gray CLAY to approximately 670' with a conglomeratic layer @ 645'. Below 670', black, fine - coarse SAND with wood @ 678'.

692' - 714': Black, angular to rounded, micaceous, moderately sorted, loose, v. coarse SAND to GRAVEL consisting of dominantly basalt with minor quartz, mica, and glass. @ 713' - basalt chips up to 1 cm. - may be from cobbles - also lots of glass and some scoria.

CORE SAMPLES FROM 714' - 841'

714' - 724': Core sample not recovered. Field log indicates SAND.

724' - 726': Black, subangular to subrounded, endurated, but friable, faintly cross laminated, well sorted, medium, basaltic SANDSTONE with olive green glass shards and trace quartz. Basalt material is a rough cinder type. Rounded basalt gravel (up to 3 cm.) at the top of the interval.

726' - 736': No core recovered.

736' - 745': AA - quartz content increases with depth (10%-15%) @ 737'. @738' - core is not as endurated as above and cross laminations are better defined.
@ 740' - Sand becomes v. loose and coarse grained. Glass still present.

745' - 776': No core recovered. Drill cuttings only.

746' - 766': Black, subangular to subrounded, well sorted, medium (a few coarse), basaltic, vitreous SAND with minor quartz and trace mica.

766' - 776': Black, rounded, basalt COBBLES up to 7cm.

BACK TO CORE SAMPLES.

776' - 778': Pale yellow to medium blue gray, angular to subrounded, massive, micaceous, moderately well sorted, silty, v. fine-fine, arkosic, quartz bearing, lithic SAND with 5% clay and trace organic matter (wood).
@ 777' - An 8 cm. thick v. loose, angular to subrounded, moderately well sorted, medium to coarse, arkosic, quart bearing SAND.

778' - 780': Pale yellow brown, angular to subrounded, loose, moderately well sorted, medium to coarse, arkosic, quartz bearing SAND. @ 779' 8" - 4-6cm. thick lens of pale yellow brown, angular to subrounded, micaceous, v. fine silty clayey, arkosic SAND.

780' - 782': No core recovered.

782' - 782' 3": Black and white, subangular to subrounded, loose, moderately well sorted, medium to coarse, quartz bearing (20%), arkosic (40%), lithic (40%) SAND with black basalt.

782' 3" - 786': Medium gray, micaceous, cross laminated, lithic rich v. fine sandy SILT with organic matter.

786' - 811': No core recovered. Drill cuttings @ 800'.

800': Yellow gray, angular to subrounded, moderately sorted, micaceous, fine to v. coarse, arkosic, quartz bearing SAND with basalt, pumice, and other lithic material.

811' - 821': Olive gray, angular to subrounded, micaceous, loose, moderately well sorted, medium to coarse, arkosic, quartz bearing, lithic (black basalt rich) SAND. Grain size variations with depth from medium to small rounded gravel from 819' - 821'.

821' - 831': NO core recovered.

831' - 831' 2": Black, loose, rounded basalt GRAVEL (up to 8 cm. dia.).

831' 2" - 835': Grayish olive, incompetent, micaceous, silty CLAY.

835' - 841': Olive gray, micaceous, clayey, v. fine sandy SILT, grading to a clayey SILT @ 836'. @ 837" - back to v. fine sandy SILT.

841' - Very small sample - core broken into pieces. Pale olive, micaceous, angular to subangular, moderately sorted, v. fine, silty SAND with pockets of medium quartz bearing, arkosic, basaltic SAND.

NO CORE BELOW 841' Only scattered drill cutting descriptions to TD.

- 864' - 872': Black, white, red brown, angular to rounded (rare), moderately sorted, micaceous, loose, v. coarse SAND to GRAVEL with dominant basalt and subordinate quartz, granitic lithic material, and pumice. @ 872' - about 10% yellow gray, micaceous, silty CLAY fragments.
- 873' - 876': Yellow gray, black, angular to rounded, moderately sorted, medium - v. coarse, arkosic, lithic, quartz bearing SAND.
- 876' - 900': Blue, oxidized to pale yellow, micaceous, silty CLAY with minor organic matter (wood).
- 900' - 917': Medium blue gray, v. sticky. plastic, silty CLAY to clayey SILT - almost 50% of each with scattered patches of v. fine sandy SILT.
- 917' - 958': Medium gray, micaceous, blocky, non plastic, silty CLAY with mottled white, v. fine sandy, clayey SILT lenses.
- 958' - 1004': Medium gray to grayish green, micaceous, slightly silty CLAY with trace scattered lenses of clayey SILT. **Only sample in this interval is @ 958'.**
- 1004' - 1124': Blue gray to light gray, micaceous, silty CLAY with common white, gray green, lenses of v. fine sandy, micaceous SILT and white clayey SILT. @ 1093' - minor coarse sand noted. **Only sample in this interval @ 1004'.** Field log notes scattered coarse SAND(from above?) from 1105' to 1124'.
- 1124' - 1184': Mixed, yellow gray, micaceous, clayey SILT and white to medium gray, silty CLAY (most common). @ 1131' - minor coarse sand noted. @ 1174' to 1180' - scattered wood chips present. **Only sample in this interval is @ 1124'.**
- 1184' - 1204': No samples. Field log indicates coarse SAND and CLAY with wood @ 1200' - 1202'. Sand is up to 30% mica @ 1204'.
- 1204' - 1209': No samples. Field log indicates predominant clay with lenses of black, micaceous, coarse SAND.
- 1209' - 1230': No samples. Field log indicates Black, micaceous, coarse SAND and blue CLAY with minor wood @ 1217'.

- 1230' - 1241': Black, angular to subrounded, loose, moderately sorted, v. coarse SAND to GRAVEL consisting dominantly of basalt and glass, trace wood, and lots of white clayey SILT and gray silty CLAY (from above?).
- 1241' - 1244': Medium brown to gray and white, silty CLAY.
- 1244' - 1256': Gray, silty CLAY with lenses of basalt SAND and white silty CLAY with organic stringers.
- 1256' - 1311': Blue gray, oxidized to gray green, micaceous, silty CLAY with white silty CLAY with scattered, thin lenses of coarse SAND below 1281'. No sample below 1256' in this interval. Only sample in this interval is @ 1256'.
- 1311' - 1314': Light brown, white, gray, micaceous, clayey, v. fine sandy SILT.
- 1314' - 1331': Yellow gray, micaceous, silty CLAY with white, micaceous clayey SILT @ 1321' and light brown, v. fine sandy, clayey SILT @ 1323'.
- 1331' - 1338': Brown gray, micaceous, silty CLAY with light brown Fe+3 staining.
- 1338' - 1361': Yellow brown mottled with light gray and medium gray, v. sticky, plastic, slightly silty CLAY with widely scattered, highly weathered, sand sized basalt beginning @ 1352'.
- 1361' - 1376': Bright ochre CLAY with light gray to black clay clasts (from above?) and round, gravel sized, basaltic nodules.
- 1376' - 1389': Red brown,, v. sticky, plastic CLAY with some ochre and silty to v. fine sand particles.
- 1389' - 1399': Mixed red brown, orange, yellow, gray, and white, silty CLAY and highly weathered basalt fragments.
- 1399' - 1420': Light brown, silty CLAY with highly weathered plagioclase crystals and basalt fragments.
- 1420' - 1436': Light brown, highly weathered BASALT. - **Top Of Columbia River Basalt.**
- 1436' - 1442': Black, hard BASALT chips and mixed samples from above.

- 1442' - 1456': Black, hard BASALT - vesicular and crystalline texture is distinguishable.
- 1456' - 1459': Weathered and fresh BASALT with lots of brown gray to medium gray, silty CLAY and red brown CLAY.
- 1459' - 1480': Black, fresh, hard BASALT.
- 1480' - 1483': Light brown, black, angular to subrounded, moderately well sorted, loose, fine - medium, quartz bearing, basaltic, arkosic SAND with black basalt chips. Drilling rate much faster and lose of drilling mud to formation.
- 1483' - 1488': Black, white, light brown, angular to rounded, upper v. coarse SAND to mostly GRAVEL consisting of chips of massive and vesicular basalt, rounded basalt, granitic material, and quartz.
- 1493' - 1515': Black, angular BASALT chips and subrounded basalt grains present.
- 1515' - 1523': Black, hard, angular chips of BASALT.

Total Depth: 1523' (464.2 m)

Recorded 10-93
by Doyle Wilson

B44

APPENDIX C

HBD-1 GRAIN SIZE ANALYSIS RESULTS

Appendix C: HBD-1, recent stream, and other boring grain size analyses for sands, silts, and clays.

DEPTH(FT)	Lithology	Total Mass (g)	SIEVES					
			V. Coarse (g)			Coarse (g)		
			(#18)	% V. Coarse	(#35)	% Coarse	Medium (g) (#60)	% Medium
34'	Silt	52.40	<0.01	0.00	0.01	0.02	0.04	0.08
73'	Silt	55.70	none	0.00	0.03	0.05	0.02	0.04
90'	Sand	79.72	none	0.00	<0.01	0.00	0.80	1.00
141'	Sand	75.00	none	0.00	0.42	0.56	7.02	9.36
162'	Clay	51.19	<0.01	0.00	0.05	0.10	0.21	0.41
166'	Clay	54.00	none	0.00	<0.01	0.00	0.07	0.13
226'	Sand	82.40	1.66	2.01	0.78	0.95	1.54	1.87
249'	Clay	56.20	<0.01	0.00	<0.01	0.00	<0.01	0.00
300'	Sand	78.60	1.61	2.05	1.03	1.31	4.73	6.02
314'	Clay	50.39	0.01	0.02	0.29	0.58	1.00	1.98
385'	Sand	79.10	<0.01	0.00	1.01	1.28	10.51	13.29
385'a	Sand	50.00	<0.01	0.00	1.04	2.08	6.05	12.10
420'	Silt	54.48	0.10	0.18	0.12	0.22	0.41	0.75
448'	Sand	77.22	0.11	0.14	1.01	1.31	15.17	19.65
484'	Sand	100.36	1.29	1.29	7.21	7.18	38.70	38.56
499'	Clay	58.00	none	0.00	0.05	0.09	2.95	5.09
537'	Sand	75.19	1.95	2.59	6.67	8.87	11.75	15.63
565'	Silt	75.23	0.46	0.61	0.13	0.17	0.35	0.47
579'	Clay	51.90	0.05	0.10	<0.01	0.00	0.01	0.02
609' 8"	Sand	86.11	6.48	7.53	13.01	15.11	14.05	16.32
632'	Silt	52.14	<0.01	0.00	<0.01	0.00	<0.01	0.00
640'	Silt	76.29	0.01	0.01	0.14	0.18	1.19	1.56
677'	Clay	52.61	none	0.00	0.26	0.49	0.59	1.12
683'	Silt	74.30	<0.01	0.00	<0.01	0.00	0.25	0.34

Appendix C: HBD-1, recent stream, and other boring grain size analyses for sands, silts, and clays.

DEPTH (FT)	Lithology	Total Mass (g)	V. Coarse (g)	% V. Coarse	Coarse (g)	% Coarse	Medium (g)	% Medium
693'	Sand	75.00	1.02	1.36	2.00	2.67	7.10	9.47
714'	Sand	53.82	0.07	0.13	0.70	1.30	14.19	26.37
734'	Sand	84.75	0.46	0.54	1.02	1.20	16.09	18.99
760'	Sand/Silt	50.10	0.71		2.21		2.89	
769'	Clay	55.20	none	0.00	<0.01	0.00	<0.01	0.00
777'	Clay	51.13	none	0.00	0.01	0.02	0.05	0.10
833'	Clay	51.49	none	0.00	<0.01	0.00	<0.01	0.00
836'	Silt	50.17	none	0.00	0.01	0.02	0.05	0.10
846'	Silt	75.37	none	0.00	0.06	0.08	0.09	0.12
877'	Sand	75.27	0.02	0.03	0.09	0.12	1.12	1.49
898'	Silt	52.64	<0.01	0.00	0.20	0.38	0.80	1.52
926'	Clay	51.29	0.01	0.02	<0.01	0.00	0.01	0.02
929'	Silt	77.34	none	0.00	<0.01	0.00	0.09	0.12
932'	Sand	60.01	0.95	1.58	1.00	1.67	2.62	4.37
939'	Clay	51.10	<0.01	0.00	0.04	0.08	0.03	0.06
WFDC		50.10	<0.01	0.00	1.02	2.04	4.82	9.62
Tualatin River		50.02	0.08	0.16	2.54	5.08	17.57	35.13
EFDC		50.36	2.23	4.43	17.63	35.01	13.91	27.62
McFee Cr.		50.30	0.39	0.78	1.00	1.99	1.75	3.48
Gales Cr.		50.02	0.35	0.70	3.43	6.86	24.61	49.20
McKay Cr.		50.00	0.74	1.48	1.48	2.96	2.70	5.40
Rock Cr.		50.27	0.82	1.63	1.12	2.23	1.30	2.59
EB-1(55')	Sand	62.51	<0.01	0.00	0.21	0.34	9.05	14.48
TRB-1 (56')	Sand	64.03	none	0.00	<0.01	0.00	1.56	2.44
BVD-6 (55')	Sand	65.55	0.06	0.09	3.91	5.96	20.11	30.68
Leis. (338')	Sand	50.42	4.10	8.13	10.30	20.43	14.43	28.62
Scholl (85-90')	Sand	55.88			8.31	14.87	9.00	16.11

Appendix C: HBD-1, recent stream, and other boring grain size analyses for sands, silts, and clays.

DEPTH (FT)	SIEVES				Total Sand(g)	% Total Sand	Total Silt	Total Clay
	Fine (g) (#120)	% Fine	V. Fine (g) (#230)	% V. Fine				
34'	0.11	0.21	0.22	0.42	0.38	0.73	79%	20%
73'	0.12	0.22	0.67	1.20	0.84	1.51	66%	33%
90'	3.20	4.01	7.28	9.13	11.28	14.15	63%	23%
141'	14.95	19.93	10.42	13.89	32.81	43.75	44%	12%
162'	1.21	2.36	3.11	6.08	4.58	8.95	66.70%	25%
166'	0.34	0.63	1.89	3.50	2.30	4.26	37.70%	58.30%
226'	15.01	18.22	14.41	17.49	33.40	40.53	49%	10%
249'	<0.01	0.00	0.11	0.20	0.11	0.20	55%	45%
300'	16.85	21.44	8.00	10.18	32.22	40.99	40%	18.50%
314'	4.53	8.99	7.10	14.09	12.93	25.66	29.3%??	45%??
385'	27.58	34.87	9.67	12.23	48.77	61.66	Flocculated	
385'a	14.67	29.34	6.10	12.20	27.86	55.72	30%	15%
420'	4.71	8.65	8.90	16.34	14.24	26.14	44%	30%
448'	12.37	16.02	5.15	6.67	33.81	43.78	40%	17%
484'	24.36	24.27	4.69	4.67	76.25	75.98	26%	2%
499'	1.00	1.72	0.33	0.57	4.33	7.47	52%	40%
537'	14.08	18.73	9.90	13.17	44.35	58.98	36%	5%
565'	2.87	3.81	9.47	12.59	13.28	17.65	65%	17%
579'	0.05	0.10	0.04	0.08	0.15	0.29	71.20%	29.50%
609' 8"	7.70	8.94	5.18	6.02	46.42	53.91	43.10%	3%
632'	0.05	0.10	0.08	0.15	0.13	0.25	90.30%	9.50%
640'	4.87	6.38	13.56	17.77	19.77	25.91	65%	9%
677'	0.72	1.37	0.70	1.33	2.27	4.31	55%	39%
683'	2.77	3.73	10.90	14.67	13.92	18.73	51.30%	30%

Appendix C: HBD-1, recent stream, and other boring grain size analyses for sands, silts, and clays.

<u>DEPTH(FT)</u>	<u>Fine (g)</u>	<u>% Fine</u>	<u>V. Fine (g)</u>	<u>% V. Fine</u>	<u>Total Sand(g)</u>	<u>% Total Sand</u>	<u>Total Silt</u>	<u>Total Clay</u>
693'	13.88	18.51	13.83	18.44	37.83	50.44	34.50%	14.50%
714'	11.71	21.76	6.20	11.52	32.87	61.07	29%	10%
734'	26.70	31.50	9.56	11.28	53.83	63.52	28%	8%
760'	5.70		4.43		15.94	31.82		
769'	<0.01	0.00	<0.01	0.00	0.00	0.00	48%	52%
777'	0.19	0.37	1.01	1.98	1.26	2.46	53%	45%
833'	0.01	0.02	0.02	0.04	0.03	0.06	64%	36%
836'	0.89	1.77	3.75	7.47	4.70	9.37	66%	25%
846'	3.61	4.79	11.43	15.17	15.19	20.15	69.90%	10%
877'	18.45	24.51	17.45	23.18	37.13	49.33	43%	8%
898'	4.00	7.60	7.67	14.57	12.67	24.07	52%	24%
926'	0.05	0.10	0.46	0.90	0.53	1.03	64%	36%
929'	5.37	6.94	19.55	25.28	25.01	32.34	57%	11%
932'	9.28	15.46	7.72	12.86	21.57	35.94	48%	16%
939'	0.03	0.06	0.09	0.18	0.19	0.37	45%	55%
WFDC	22.22	44.35	14.25	28.44	42.31	84.45		
Tualatin Riv	20.40	40.78	6.61	13.21	47.20	94.36		
EFDC	7.87	15.63	5.49	10.90	47.13	93.59		
McFee Cr.	2.40	4.77	5.84	11.61	11.38	22.62		
Gales Cr.	11.72	23.43	3.60	7.20	43.71	87.39		
McKay Cr.	7.41	14.82	10.88	21.76	23.21	46.42		
Rock Cr.	1.12	2.23	0.95	1.89	5.31	10.56		
EB-1(55')	17.74	28.38	9.79	15.66	36.79	58.85		
TRB-1 (56')	29.61	46.24	14.80	23.11	45.97	71.79		
BVD-6 (55')	14.61	22.29	5.46	8.33	44.15	67.35		
Leis. (338')	16.48	32.69	4.23	8.39	49.54	98.25		
Scholl (85-9	15.69	28.08	8.00	14.32	41.00	73.37		

APPENDIX C: HBD-1 and other borings grain size analyses for sands, silts, and clays continued.

DEPTH (FT)	HYDROMETER READINGS											
	30 sec			1 min			2 min			6 min		
	Grain Size	Cum. %	Grain Size	Grain Size	Cum. %	Grain Size	Grain Size	Cum. %	Grain Size	Grain Size	Cum. %	Grain Size
34'	0.0546	3.63	0.0396	0.0396	7.44	0.0290	0.0179	15.08	0.0179	30.34	0.0104	45.61
73'	0.0569	16.52	0.0412	0.0412	21.01	0.0304	0.0188	29.98	0.0188	46.14	0.0107	56.01
90'	0.0518	30.38	0.0391	0.0391	37.91	0.0294	0.0186	46.69	0.0186	59.86	0.0107	69.27
141'	0.0660	62.67	0.0473	0.0473	65.33	0.0343	0.0200	70.00	0.0200	74.67	0.0113	78.67
162'	0.0628	31.63	0.0451	0.0451	35.53	0.0320	0.0193	39.44	0.0193	49.21	0.0110	59.95
166'	0.0592	22.22	0.0423	0.0423	24.07	0.0302	0.0180	26.85	0.0180	31.48	0.0100	35.19
226'	0.0660	66.02	0.0473	0.0473	68.45	0.0343	0.0201	72.69	0.0201	77.55	0.0113	80.58
249'	0.0582	21.71	0.0414	0.0414	23.49	0.0296	0.0174	25.27	0.0174	27.94	0.0098	35.05
300'	0.0623	54.20	0.0447	0.0447	56.11	0.0320	0.0189	58.65	0.0189	63.10	0.0106	67.56
314'	0.0553	1.77	0.0393	0.0393	2.76	0.0280	0.0165	4.74	0.0165	8.71	0.0095	20.62
385'	0.0693	73.45	0.0496	0.0496	75.98	0.0355	0.0207	78.51	0.0207	81.04	0.0116	85.46
385a	0.0696	60.00	0.0496	0.0496	62.00	0.0353	0.0206	65.00	0.0206	68.00	0.0114	72.00
420'	0.0634	38.51	0.0455	0.0455	41.26	0.0326	0.0193	45.85	0.0193	52.28	0.0107	55.95
448'	0.0646	59.85	0.0463	0.0463	61.80	0.0333	0.0195	65.03	0.0195	68.27	0.0108	70.86
484'	0.0748	92.03	0.0532	0.0532	93.03	0.0378	0.0219	94.02	0.0219	95.52	0.0121	96.01
499'	0.0559	17.24	0.0400	0.0400	18.97	0.0288	0.0173	21.55	0.0173	29.31	0.0098	37.93
537'	0.0683	69.41	0.0492	0.0492	73.40	0.0355	0.0210	77.39	0.0210	82.71	0.0117	86.70
565'	0.0576	40.18	0.0423	0.0423	45.50	0.0316	0.0193	54.81	0.0193	64.77	0.0109	71.42
579'	0.0631	34.49	0.0451	0.0451	36.42	0.0323	0.0189	37.38	0.0189	42.20	0.0106	51.83
609' 8"	0.0704	79.10	0.0505	0.0505	81.42	0.0361	0.0212	83.74	0.0212	87.23	0.0118	90.13
632'	0.0674	52.05	0.0483	0.0483	55.89	0.0351	0.0209	63.56	0.0209	73.15	0.0117	79.86
640'	0.0613	50.19	0.0463	0.0463	61.99	0.0341	0.0207	69.85	0.0207	79.68	0.0115	84.27
677'	0.0613	27.77	0.0438	0.0438	30.62	0.0313	0.0184	32.52	0.0184	37.27	0.0104	43.93

Appendix C: HBD-1 and other borings grain size analyses for sands, silts, and clays continued.

DEPTH (FT)	HYDROMETER READINGS											
	30 sec		1 min		2 min		6 min		20 min			
	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %
714	0.0712	69.34	0.0507	72.13	0.0361	73.99	0.0211	70.27	0.0117	83.28		
734	0.0701	77.58	0.0498	78.76	0.0355	79.94	0.0209	83.48	0.0115	84.66		
769'	0.0586	22.10	0.0416	23.01	0.0294	23.01	0.0171	23.91	0.0095	25.72		
777'	0.0598	19.81	0.0425	21.77	0.0304	23.72	0.0181	31.55	0.0101	36.44		
833'	0.0643	38.82	0.0461	39.79	0.0324	40.77	0.0189	43.68	0.0105	46.59		
836'	0.0631	32.23	0.0455	37.21	0.0330	44.19	0.0196	53.16	0.0100	59.14		
846'	0.0613	49.58	0.0449	54.89	0.0329	62.19	0.0199	70.81	0.0113	79.43		
877'	0.0660	62.80	0.0477	66.79	0.0343	70.11	0.0205	77.41	0.0114	81.40		
898'	0.0657	45.86	0.0473	49.66	0.0340	54.41	0.0199	59.16	0.0111	63.91		
926'	0.0610	24.94	0.0434	25.91	0.0307	26.89	0.0184	35.66	0.0101	42.48		
929'	0.0663	64.44	0.0473	66.38	0.0341	70.26	0.0203	76.73	0.0114	81.90		
932'	0.0666	55.01	0.0475	57.51	0.0343	62.51	0.0202	68.34	0.0113	72.50		
939'	0.0556	5.09	0.0396	6.07	0.0283	8.02	0.0166	11.94	0.0095	21.72		
EB-1(55')	0.0722	77.60	0.0516	80.80	0.0370	84.00	0.0215	86.40	0.0119	88.80		
TRB-1 (56')	0.0715	75.01	0.0511	78.14	0.0366	82.04	0.0214	85.16	0.0119	88.29		
BVD-6 (55')	0.0720	77.88	0.0514	80.93	0.0366	82.46	0.0214	84.74	0.0117	86.27		

Appendix C: HBD-1 and other borings grain size analyses for sands, silts, and clays continued.

DEPTH (FT)	HYDROMETER READINGS									
	1 hour		3 hours		16 hours		1 day		3 days	
	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %
34'	0.0064	60.88	0.0038	73.28	0.0016	83.78	0.0014	83.78	0.0008	87.60
73'	0.0062	60.50	0.0037	64.09	0.0016	68.58	0.0013	69.48	0.0007	70.38
90'	0.0063	73.66	0.0037	76.79	0.0014	76.79	0.0013	78.05	0.0008	77.42
141'	0.0066	82.00	0.0039	86.00	0.0016	88.67	0.0014	89.33	0.0008	90.67
162'	0.0065	67.77	0.0038	70.70	0.0015	77.53	0.0014	77.53	0.0008	80.46
166'	0.0058	37.04	0.0034	41.67	0.0014	41.67	0.0012	43.52	0.0007	40.74
226'	0.0066	84.22	0.0039	87.86	0.0016	90.29	0.0014	90.29	0.0008	95.15
249'	0.0058	42.17	0.0035	51.07	0.0015	59.07	0.0013	59.96	0.0008	63.52
300'	0.0062	70.74	0.0037	76.46	0.0016	84.10	0.0014	86.64	0.0008	91.73
314'	0.0056	23.60	0.0034	39.47	0.0014	63.29	0.0013	65.27	0.0008	72.22
385'	0.0068	87.99	0.0041	99.37	0.0016	100.00	0.0015	100.00	0.0008	100.00
385a	0.0067	75.00	0.0022	78.00	0.0016	83.00	0.0014	83.00	0.0008	84.00
420'	0.0063	59.62	0.0037	63.29	0.0016	70.63	0.0013	71.55	0.0008	75.22
448'	0.0064	76.04	0.0038	81.22	0.0016	82.52	0.0014	83.16	0.0008	85.11
484'	0.0070	97.01	0.0040	97.01	0.0017	98.51	0.0014	99.00	0.0008	99.50
499'	0.0059	44.83	0.0035	53.45	0.0015	62.93	0.0013	64.66	0.0008	70.69
537'	0.0068	90.03	0.0040	92.69	0.0016	95.35	0.0014	95.35	0.0008	96.01
565'	0.0064	75.41	0.0038	80.06	0.0016	84.05	0.0014	85.38	0.0008	86.71
579'	0.0064	62.43	0.0037	67.24	0.0015	73.99	0.0014	74.95	0.0008	78.81
609' 8"	0.0069	94.77	0.0040	95.94	0.0016	97.10	0.0014	98.26	0.0008	98.84
632'	0.0068	85.62	0.0040	88.49	0.0015	90.41	0.0014	92.33	0.0008	92.33
640'	0.0068	87.55	0.0040	90.17	0.0016	91.48	0.0014	92.79	0.0008	93.45
677'	0.0061	49.63	0.0036	56.28	0.0005	62.93	0.0013	65.79	0.0008	69.59

Appendix C: HBD-1 and other borings grain size analyses for sands, silts, and clays continued.

DEPTH (FT)	HYDROMETER READINGS											
	1 hour			3 hours			16 hours			1 day		
	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %	Grain Size	Cum. %
714	0.0068	86.06	0.0040	87.92	0.0017	88.85	0.0014	89.78	0.0008	90.71		
734	0.0067	88.79	0.0039	89.97	0.0017	92.92	0.0014	92.92	0.0008	94.10		
769'	0.0056	31.16	0.0034	40.22	0.0015	52.90	0.0013	56.52	0.0007	61.05		
777'	0.0059	41.33	0.0035	49.15	0.0016	56.97	0.0013	58.93	0.0007	62.84		
833'	0.0062	54.36	0.0037	59.22	0.0014	66.01	0.0013	66.98	0.0008	71.84		
836'	0.0065	65.12	0.0038	71.10	0.0017	77.08	0.0013	78.07	0.0008	81.06		
846'	0.0066	83.42	0.0039	87.40	0.0015	90.05	0.0014	91.38	0.0008	92.70		
877'	0.0067	85.39	0.0039	89.37	0.0017	92.69	0.0014	93.36	0.0008	94.69		
898'	0.0065	67.71	0.0038	72.45	0.0016	76.25	0.0014	78.15	0.0008	81.00		
926'	0.0061	50.28	0.0036	57.11	0.0016	65.88	0.0013	65.88	0.0008	70.75		
929'	0.0066	83.84	0.0039	87.07	0.0015	89.66	0.0014	90.30	0.0008	90.95		
932'	0.0065	78.34	0.0039	81.67	0.0016	85.00	0.0013	85.00	0.0008	88.34		
939'	0.0057	32.49	0.0034	39.33	0.0014	48.14	0.0013	50.10	0.0007	53.03		
EB-1(55')	0.0047	88.80	0.0040	90.40	0.0016	92.80	0.0014	92.80	0.0008	92.80		
TRB-1 (56')	0.0069	89.85	0.0040	90.63	0.0016	92.97	0.0014	92.97	0.0008	92.97		
BVD-6 (55')	0.0068	87.80	0.0040	89.32	0.0016	90.08	0.0014	90.08	0.0008	91.61		

APPENDIX D

XRD CLAY MINERAL TYPES IN HBD-1 SAMPLES

APPENDIX D**HBD-1 Clay Samples - X-ray Diffraction Semi-Quantitative Identification
COARSE CLAY SIZE : 2 - 0.2 microns****HBD-1 34' Blue gray, micaceous, v. fine sandy, clayey SILT.**

- 1) Smectite - 50%
- 2) Kaolinite - 30%
- 3) Illite/Micas - 20%
- 4) Clay sized Quartz and Feldspars

HBD-1 166'

- 1) Smectite - 90%
- 2) Kaolinite - 10%
- 3) Clay sized Quartz and Feldspars

HBD-1 249': Blue gray, micaceous, silty CLAY to clayey SILT.

- 1) Smectite - 70%
- 2) Kaolinite - 20%
- 3) Probable Illite/Smectite or Micas mixed layer phase - (10.04 ang.). - 10%
- 4) Clay sized Feldspars (mostly Plagioclase with some K-Feldspar) and Quartz are also present.

HBD-1 313' 6": Gray green to dark gray with olive brown, dense, ashy??, silty CLAY.

- 1) Smectite - 80%
- 2) Kaolinite - 5%
- 3) Possible Illite/Smectite or Micas mixed layer phase.- 15%
- 4) Clay sized Plagioclase (3.2 ang.) and Quartz (3.36 and 4.267 ang.).

HBD-1 352': Dark brown gray, micaceous, silty CLAY.

- 1) Ca (?) Smectite - (14.967 - 12.988 ang.) - glycerated (16.352 ang.). - 90%
- 2) Kaolinite - (12.31, 24.87 ang. and amorphous @ 600 C) - 10%
- 3) Probable Illite/Smectite mixed layer phase. - (10.0 - 10.27 ang. & possible 3.36 ang.)
- 4) Clay sized Plagioclase (3.2 ang.) and Quartz (3.36 & 4.3 ang.).

HBD-1 545': Blue gray, micaceous, incompetent slightly sticky, clayey SILT.

- 1) Probable Illite/Smectite mixed layer phase - (10.04 ang.).
- 2) Kaolinite
- 3) Mg++ Glycerated sample shows a low, broad Smectite peak - (19.6 -19.1 ang.) Clay may be Na, Mg, Al - Smectite
- 4) Clay sized Plagioclase and Quartz.

HBD-1 710'

- 1) Smectite - 30%
- 2) Kaolinite - 60%
- 3) Illite/Micas - 10%
- 4) Clay sized Plagioclase and Quartz.

HBD-1 769': Mottled blue gray-light brown, very incompetent, silty CLAY.

- 1) Smectite - 90%
- 2) Kaolinite - (small peak @ 7.3 ang.). - 5%
- 3) Possible Illite/Smectite mixed layer phase (v. small peak @ 10 ang.). - 5%
- 4) Clay sized Plagioclase and Quartz.

HBD-1 859'

- 1) Smectite - 90%
- 2) Kaolinite - 10%
- 3) Clay sized Quartz and Plagioclase

HBD-1 910': Light brown - blue gray, sticky, silty CLAY.

- 1) Smectite - 75%
- 2) Kaolinite - 20%
- 3) Possible Illite/Smectite mixed layer phase (small peak @ 10.0 ang.). - 5%
- 4) Clay sized Plagioclase and Quartz.

HBD-1 942'

- 1) Kaolinite - 90%
- 2) Illite/Micas - 10%
- 3) Quartz and Feldspar(Plagioclase)

Figure D1: An example of X-ray diffraction peaks from sample HBD-1 249' used to identify clay mineral types. Smectites generally show broad peaks at low angles and kaolinite and illite clays are depicted by sharp, narrow peaks at slightly higher peaks.

APPENDIX E

HEAVY MINERAL ANALYSIS RESULTS

Appendix E: Heavy mineral counts of fine to very fine sands from Tualatin Valley and Portland Region.

SAMPLE NAME	TOTAL	Augite	Augite %	Hyperssthene	Hyperssthene %	Hornblende	Hornblende %	Blue-Green	Blue-Green
Recent Stream Sands	COUNT							Hornblende	Hornblende %
Tualatin River #120	350	270	77.14	5	1.43	1	0.29		
Gales Creek #1 #120	300	237	79.00	9	3.00				
Gales Creek #2 #120	325	221	68.00	4	1.23				
E. Fork Dairy Cr. #1 #120	329	33	10.03	44	13.37	83	25.23	1	0.30
E. Fork Dairy Cr. #2 #120	226	55	24.34	33	14.60	58	25.66		
Rock Creek #1 #120	353	39	11.05	46	13.03	90	25.50	4	1.13
McFee Creek #1 #120	388	93	23.97	32	8.25	89	22.94		
W. Fork Dairy Cr. #1 #120	436	72	16.51	22	5.05	178	40.83	5	1.15
W. Fork Dairy Cr. #2 #120	454	125	27.53	54	11.89	175	38.55	13	2.86
McKay Creek #1 #120	484	18	3.72	37	7.64	195	40.29	2	0.41
Columbia River #120	432	133	30.79	152	35.19	88	20.37	15	3.47
Hillsboro Airport (HBD-1) Sands									
HBD-1 34' #230	598	185	30.94	75	12.54	217	36.29	15	2.51
HBD-1 73' #230	569	139	24.43	14	2.46	179	31.46	17	2.99
HBD-1 141' #120	450	366	81.33			47	10.44	6	1.33
HBD-1 226' #120	533	161	30.21	5	0.94	74	13.88	3	0.56
HBD-1 300' #230	507	53	10.45	18	3.55	200	39.45	7	1.38
HBD-1 385' #120	291	80	27.49	2	0.69	87	29.90	16	5.50
HBD-1 415' #120	537	192	35.75	7	1.30	160	29.80	26	4.84
HBD-1 484' #230	573	126	21.99	11	1.92	271	47.29	23	4.01
HBD-1 537' #120	589	382	64.86	4	0.68	45	7.64	11	1.87
HBD-1 651' #120	485	143	29.48	8	1.65	237	48.87	32	6.60
HBD-1 734' #120	481	155	32.22	7	1.46	202	42.00	32	6.65
HBD-1 846' #230	416	21	5.05	5	1.20	321	77.16	7	1.68
HBD-1 877' #230	391	80	20.46	12	3.07	180	46.04	37	9.46
HBD-1 898' #230	435	141	32.41	17	3.91	131	30.11	6	1.38
HBD-1 929' #120	409	63	15.40	5	1.22	256	62.59	28	6.85

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	TOTAL	Augite	Augite %	Hyperssthene	Hyperssthene %	Hornblende	Hornblende %	Blue-Green	Blue-Green
Tualatin Valley Borings	COUNT							Hornblende	Hornblende %
EB-1 55' #120	308	292	94.81	0	0.00	15	4.87	1	0.32
DOGAMI BVD-2 102' #120	301	22	7.31	2	0.66	277			
DOGAMI BVD-2 102' #230	300	33	11.00	1	0.33	266			
DOGAMI BVD-5 75' #120	300	194	64.67	77	25.67	27	9.00	5	1.67
DOGAMI BVD-5 75' #230	318	231	72.64	58	18.24	23	7.23	6	1.89
DOGAMI BVD-6 24' #120	542	281	51.85	163	30.07	71	13.10	4	0.74
DOGAMI BVD-6 55'-60' #120	531	457	86.06	12	2.26	54	10.17	2	0.38
DOGAMI LOD-3 20'-23' #230	538	149	27.70	43	7.99	305	56.69	17	3.16
DOGAMI LOD-3 155'	353	121	34.28	80	22.66	152	43.06		
DOGAMI LOD-4 125'	210	65	30.95	3	1.43	142	67.62		
ODOT Brookwood 30' #230	320	110	34.38	1	0.31	196	61.25	13	4.06
ODOT Brookwood 70' #230	306	60	19.61	27	8.82	215	70.26	19	6.21
ODOT Hwy47 42' #230	300	81	27.00	16	5.33	184	61.33	20	6.67
ODOT TRB-1 28' #120	353	242	68.56	26	7.37	85	24.08		
ODOT TRB-1 55' #120	424	409	96.46	1	0.24	14	3.30	0	0.00
ODOT TRB-1 101' #120	350	346	98.86	0	0.00	4	1.14		
ODOT TRB-1 148' #120	351	313	89.17	0	0.00	38	10.83		

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	TOTAL	Augite	Augite %	Hyperssthene	Hyperssthene %	Hornblende	Hornblende %	Blue-Green Hornblende	Blue-Green Hornblende %
Tualatin Valley Water Well	COUNT								
Bich Well 30' #120	314	161	51.27	70	22.29	78	24.84	5	1.59
Bich Well 30' #230	309	199	64.40	21	6.80	87	28.16	3	0.97
Carter Well 40' #120	303	114	37.62	41	13.53	140	46.20	9	2.97
Carter Well 40' #230	300	94	31.33	15	5.00	211	70.33	10	3.33
Carter Well 160' #120	502	438	87.25	1	0.20	66	13.15		
Carter Well 200' #120	501	464	92.61	4	0.80	38	7.58		
Carter Well 260' #120	500	449	89.80	2	0.40	53	10.60		
Childress Well 180' #120	500	496	99.20	1	0.20	3	0.60		
Claremont Well 140' #120	721	104	14.42	5	0.69	46	6.38	0	0.00
Claremont Well 200' #120	507	116	22.88	6	1.18	309	60.95	3	0.59
Claremont Well 340' #120	316	27	8.54	5	1.58	234	74.05		
Gillenwater Well 105'-115'	513	496	96.69	4	0.78	7	1.36		
Leisigang Well 338' #120	410	77	18.78	23	5.61	232	56.59	20	4.88
Waibel Well 180'-205' #120	500	493	98.60	1	0.20	6	1.20		
Waibel Well 180'-205' #230	500	473	94.60	4	0.80	22	4.40	1	0.20
Scholl's Well 85' #120	375	354	94.40	7	1.87	10	2.67	1	0.27
Tualatin Valley Outcrop									
COSTCO Site C #120	515	377	73.20	80	15.53	47	9.13	11	2.14
Portland Basin and Northern Willamette Valley Sands									
Carus Rd. Well 1035' #120	401	182	45.39	210	52.37	10	2.49	1	0.25
Carus Rd. Well 1120' #120	515	0	0.00	7	1.36	156	30.29	3	0.58
GDFB Well 830' #120-230	312	5	1.60	7	2.24	300	96.15		
GDFB Well 1210' #230	320	12	3.75	271	84.69	37	11.56		
DOGAMI MTD-1 411' #120	559	450	80.50	90	16.10	14	2.50	1	0.18
DOGAMI MTD-1 432 #230	344	2	0.58	9	2.62	283	82.27	50	14.53
DOGAMI MTD-1 811' #120	633	149	23.54	189	29.86	205	32.39	25	3.95
Sandy River Mudstone	387	6	1.55	4	1.03	365	94.32	12	3.10

Appendix E: Continued.- Heavy mineral counts

SAMPLE NAME	Opaques	Opaques %	Rock Frag.	Rock Frag %	Garnet	Garnet %	Zircon	Zircon %	Enstatite	Enstatite %
Recent Stream Sands										
Tualatin River #120	68	19.43								
Gales Creek #1 #120	41	13.67	4	1.33						
Gales Creek #2 #120	48	14.77	49	15.08						
E. Fork Dairy Cr. #1 #120	113	34.35	20	6.08			1	0.30	1	0.30
E. Fork Dairy Cr. #2 #120	44	19.47	28	12.39			1	0.44		
Rock Creek #1 #120	130	36.83	15	4.25	4	1.13	8	2.27	2	0.57
McFee Creek #1 #120	65	16.75	62	15.98	5	1.29	7	1.80		
W. Fork Dairy Cr. #1 #120	83	19.04	36	8.26	3	0.69	3	0.69	3	0.69
W. Fork Dairy Cr. #2 #120					45	9.91	12	2.64	0	0.00
McKay Creek #1 #120	212	43.80	8	1.65					3	0.62
Columbia River #120					13	3.01	1	0.23	4	0.93
Hillsboro Airport (HBD-1) Sands										
HBD-1 34' #230					10	1.67	6	1.00	4	0.67
HBD-1 73' #230					31	5.45	3	0.53		
HBD-1 141' #120					9	2.00			2	0.44
HBD-1 226' #120	87	16.32	158	29.64	1	0.19			4	0.75
HBD-1 300' #230					48	9.47	23	4.54	7	1.38
HBD-1 385' #120					20	6.87	4	1.37	3	1.03
HBD-1 415' #120					20	3.72	6	1.12	8	1.49
HBD-1 484' #230					65	11.34	13	2.27	5	0.87
HBD-1 537' #120					6	1.02			1	0.17
HBD-1 651' #120					14	2.89			1	0.21
HBD-1 734' #120					40	8.32	1	0.21	2	0.42
HBD-1 846' #230					20	4.81	2	0.48	4	0.96
HBD-1 877' #230					8	2.05			4	1.02
HBD-1 898' #230					25	5.75	17	3.91	17	3.91
HBD-1 929' #120					5	1.22			8	1.96

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Opaques	Opaques %	Rock Frag.	Rock Frag %	Garnet	Garnet %	Zircon	Zircon %	Enstatite	Enstatite %
Tualatin Valley Borings										
EB-1 55' #120										
DOGAMI BVD-2 102' #120										
DOGAMI BVD-2 102' #230										
DOGAMI BVD-5 75' #120										
DOGAMI BVD-5 75' #230										
DOGAMI BVD-6 24' #120					20	3.69				
DOGAMI BVD-6 55'-60' #120					2	0.38				
DOGAMI LOD-3 20'-23' #230					7	1.30			6	1.12
DOGAMI LOD-3 155'										
DOGAMI LOD-4 125'										
ODOT Brookwood 30' #230										
ODOT Brookwood 70' #230										
ODOT Hwy47 42' #230										
ODOT TRB-1 28' #120										
ODOT TRB-1 55' #120										
ODOT TRB-1 101' #120										
ODOT TRB-1 148' #120										

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Opaques	Opaques %	Rock Frag.	Rock Frag %	Garnet	Garnet %	Zircon	Zircon %	Enstatite	Enstatite %
Tualatin Valley Water Well Sands										
Bich Well 30' #120										
Bich Well 30' #230										
Carter Well 40' #120										
Carter Well 40' #230										
Carter Well 160' #120										
Carter Well 200' #120										
Carter Well 260' #120										
Childress Well 180' #120										
Claremont Well 140' #120	546	75.73			2	0.28	3	0.42	1	0.14
Claremont Well 200' #120					3	0.59	4	0.79	7	1.38
Claremont Well 340' #120										
Gillenwater Well 105'-115'										
Leisigang Well 338' #120					10	2.44	3	0.73		
Waibel Well 180'-205' #120										
Waibel Well 180'-205' #230										
Scholl's Well 85' #120							3	0.80		
Tualatin Valley Outcrop Sand										
COSTCO Site C #120										
Portland Basin and Northern Willamette Valley Sands										
Carus Rd. Well 1035' #120										
Carus Rd. Well 1120' #120										
GDFB Well 830' #120-230										
GDFB Well 1210' #230										
DOGAMI MTD-1 411' #120										
DOGAMI MTD-1 432 #230										
DOGAMI MTD-1 811' #120					39	6.16			4	0.63
Sandy River Mudstone										

Appendix E: Continued.- Heavy minera; counts

SAMPLE NAME	Epidote	Epidote %	Clinoziosite	Clinoziosite %	Kyanite	Kyanite %	Staurolite	Staurolite %	Diopside	Diopside %
Recent Stream Sands										
Tualatin River #120										
Gales Creek #1 #120										
Gales Creek #2 #120										
E. Fork Dairy Cr. #1 #120										
E. Fork Dairy Cr. #2 #120										
Rock Creek #1 #120	2	0.57								
McFee Creek #1 #120										
W. Fork Dairy Cr. #1 #120			1	0.23	2	0.46				
W. Fork Dairy Cr. #2 #120	7	1.54	14	3.08	0		4	0.88		
McKay Creek #1 # 120										
Columbia River #120	1	0.23	8	1.85			3	0.69		
Hillsboro Airport (HBD-1) Sands										
HBD-1 34' #230	9	1.51	44	7.36			6	1.00	14	2.34
HBD-1 73' #230	60	10.54	56	9.84	2	0.35				
HBD-1 141' #120	5	1.11			2	0.44	1	0.22	3	0.67
HBD-1 226' #120	3	0.56	8	1.50						
HBD-1 300' #230	48	9.47	88	17.36	4	0.79	7	1.38		
HBD-1 385' # 120	46	15.81	26	8.93					7	2.41
HBD-1 415 #120	83	15.46	21	3.91	3	0.56			2	0.37
HBD-1 484' #230	38	6.63	20	3.49						
HBD-1 537' #120	4	0.68								
HBD-1 651' #120	22	4.54	9	1.86	1	0.21			4	0.82
HBD-1 734' #120	25	5.20	1	0.21	1	0.21	1	0.21		
HBD-1 846' #230	19	4.57	13	3.13						
HBD-1 877 #230	26	6.65	14	3.58	2	0.51			5	1.28
HBD-1 898' #230	29	6.67	3	0.69	1	0.23	6	1.38		
HBD-1 929' #120	21	5.13	8	1.96	3	0.73	6	1.47		

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Epidote	Epidote %	Clinoziosite	Clinoziosite %	Kyanite	Kyanite %	Staurolite	Staurolite %	Diopside	Diopside %
Tualatin Valley Borings										
EB-1 55' #120										
DOGAMI BVD-2 102' #120										
DOGAMI BVD-2 102' #230										
DOGAMI BVD-5 75' #120										
DOGAMI BVD-5 75' #230										
DOGAMI BVD-6 24' #120	3	0.55								
DOGAMI BVD-6 55'-60' #120	2	0.38								
DOGAMI LOD-3 20'-23' #230	4	0.74	5	0.93						
DOGAMI LOD-3 155'										
DOGAMI LOD-4 125'										
ODOT Brookwood 30' #230										
ODOT Brookwood 70' #230										
ODOT Hwy47 42' #230										
ODOT TRB-1 28' #120										
ODOT TRB-1 55' #120										
ODOT TRB-1 101' #120										
ODOT TRB-1 148' #120										

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Epidote	Epidote %	Clinoziosite	Clinoziosite %	Kyanite	Kyanite %	Staurolite	Staurolite %	Diopside	Diopside %
Tualatin Valley Water Well Sands										
Bich Well 30' #120										
Bich Well 30' #230										
Carter Well 40' #120										
Carter Well 40' #230										
Carter Well 160' #120										
Carter Well 200' #120										
Carter Well 260' #120										
Childress Well 180' #120										
Claremont Well 140' #120			15	2.08	1	0.14				
Claremont Well 200' #120			55	10.85	2	0.39			3	0.59
Claremont Well 340' #120										
Gillenwater Well 105'-115'										
Leisigang Well 338' #120	6	1.46					5	1.22		
Waibel Well 180'-205' #120										
Waibel Well 180'-205' #230										
Scholl's Well 85' #120										
Tualatin Valley Outcrop Sand										
COSTCO Site C #120										
Portland Basin and Northern Willamette Valley Sands										
Carus Rd. Well 1035' #120										
Carus Rd. Well 1120' #120										
GDFB Well 830' #120-230										
GDFB Well 1210' #230										
DOGAMI MTD-1 411' #120	2	0.36								
DOGAMI MTD-1 432' #230										
DOGAMI MTD-1 811' #120	5	0.79	5	0.79	11	1.74	1	0.16		
Sandy River Mudstone										

Appendix E: Continued.- Heavy mineral counts

SAMPLE NAME	Actinolite	Actinolite %	Unknown	Unknown %
Recent Stream Sands				
Tualatin River #120			8	2.29
Gales Creek #1 #120			5	1.67
Gales Creek #2 #120			3	0.92
E. Fork Dairy Cr. #1 #120			14	4.26
E. Fork Dairy Cr. #2 #120			5	2.21
Rock Creek #1 #120			3	0.85
McFee Creek #1 #120			9	2.32
W. Fork Dairy Cr. #1 #120			16	3.67
W. Fork Dairy Cr. #2 #120			5	1.10
McKay Creek #1 #120			5	1.03
Columbia River #120			13	3.01
Hillsboro Airport (HBD-1) Sands				
HBD-1 34' #230	3	0.50	16	2.68
HBD-1 73' #230			46	8.08
HBD-1 141' #120			7	1.56
HBD-1 226' #120			8	0.08
HBD-1 300' #230			4	0.79
HBD-1 385' #120				
HBD-1 415 #120	3	0.56	6	1.12
HBD-1 484' #230			14	2.44
HBD-1 537' #120			137	23.26
HBD-1 651' #120	1	0.21	8	1.65
HBD-1 734' #120			7	1.46
HBD-1 846' #230			4	0.96
HBD-1 877 #230			10	2.56
HBD-1 898' #230			23	5.29
HBD-1 929' #120			6	1.47

Also 2 Chondrodite and 1 Allanite
 Also one Tourmaline and 4 Allanite
 Most unknowns are altered grains
 Also 1 diatom (spherical)

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Actinolite	Actinolite %	Unknown	Unknown %
Tualatin Valley Borings				
EB-1 55' #120				
DOGAMI BVD-2 102' #120				
DOGAMI BVD-2 102' #230				
DOGAMI BVD-5 75' #120				
DOGAMI BVD-5 75' #230				
DOGAMI BVD-6 24' #120				
DOGAMI BVD-6 55'-60' #120				
DOGAMI LOD-3 20'-23' #230	2	0.37		
DOGAMI LOD-3 155'				
DOGAMI LOD-4 125'				
ODOT Brookwood 30' #230				
ODOT Brookwood 70' #230				
ODOT Hwy47 42' #230				
ODOT TRB-1 28' #120				
ODOT TRB-1 55' #120				
ODOT TRB-1 101' #120				
ODOT TRB-1 148' #120				

Sandy SILT
-80% Opaque Minerals

Appendix E: Continued - Heavy mineral counts

SAMPLE NAME	Actinolite	Actinolite %	Unknown	Unknown %
Tualatin Valley Water Well Sands				
Bich Well 30' #120				
Bich Well 30' #230				
Carter Well 40' #120				
Carter Well 40' #230				
Carter Well 160' #120				
Carter Well 200' #120				
Carter Well 260' #120				
Childress Well 180' #120				
Claremont Well 140' #120				
Claremont Well 200' #120				
Claremont Well 340' #120				
Gillenwater Well 105'-115'				
Leisigang Well 338' #120			16	3.90
Waibel Well 180'-205' #120				
Waibel Well 180'-205' #230				
Scholl's Well 85' #120				
Tualatin Valley Outcrop Sand				
COSTCO Site C #120				
Portland Basin and Northern Willamette Valley Sands				
Carus Rd. Well 1035' #120				
Carus Rd. Well 1120' #120				
GDFB Well 830' #120-230				
GDFB Well 1210' #230				
DOGAMI MTD-1 411' #120			2	0.36
DOGAMI MTD-1 432 #230				
DOGAMI MTD-1 811' #120			1	0.16
Sandy River Mudstone				

Note: Opaques dominate
Note: Opaques dominate
Sandy SILT

Note: Sample contained mostly altered grains - 350

APPENDIX F

INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS

Appendix F: HBD-1 Instrumental Neutron Activation Analysis
(Barnes, 1995).

Depth	K%	Rb	Cs	Sr	Ba	Zr	Hf	Ta	Th	U
HBD1-60.5	1.90	59.05	2.49	333	625	224	9.44	0.55	10.59	3.4
HBD1-73	1.97	n/a	3.17	n/a	803	n/a	8.3	1.14	11.19	n/a
HBD1-84	1.64	51.31	3.06	n/a	555	332	11.09	0.68	10.78	2.8
HBD1-131	1.06	41.69	4.00	194	620	202	8.49	1.13	9.19	2.7
HBD1-176	0.93	n/a	3.17	n/a	437	n/a	5.44	1.22	6.66	n/a
HBD1-206.5	2.52	101.39	4.84	326	759	202	5.64	0.91	14.80	2.3
HBD1-230	1.55	82.95	3.31	287	753	220	6.79	3.03	9.01	4.8
HBD1-257	1.48	69.26	2.95	286	710	228	7.50	2.24	8.15	2.4
HBD1-275	n/a	n/a	3.49	n/a	555	n/a	7.8	1.25	9.38	n/a
HBD1-303.5	1.46	42.88	3.47	333	589	163	5.34	2.52	6.34	3.5
HBD1-314	2.6	n/a	9.38	n/a	920	n/a	5.95	1.07	12.78	n/a
HBD1-349	1.59	39.03	4.24	439	512	201	7.66	2.82	7.82	2.6
HBD1-405.5	2.99	50.93	3.88	639	619	323	10.40	2.29	10.40	2.3
HBD1-425	0.93	n/a	4.38	n/a	489	n/a	5.68	1.13	8.69	n/a
HBD1-436.3	1.29	54.61	3.13	388	503	198	7.60	2.01	7.40	3.6
HBD1-455	1.57	n/a	3.33	n/a	635	n/a	5.03	0.81	5.39	n/a
HBD1-468	1.37	n/a	5	n/a	491	n/a	4.45	1.05	6.53	n/a
HBD1-492.5	n/a	47.30	3.11	n/a	485	182	7.33	3.29	9.85	6.7
HBD1-507	2.04	n/a	6.93	n/a	688	n/a	7.26	1.17	10.96	n/a
HBD1-535	1.78	n/a	2.93	n/a	757	n/a	9	1.24	12.04	n/a
HBD1-545.6	1.23	57.33	3.79	198	456	200	6.69	3.33	10.00	3.8
HBD1-553	1.95	61.37	3.86	219	744	208	6.80	3.02	8.15	3.4
HBD1-565.7	1.23	48.74	3.69	n/a	547	258	6.38	3.67	7.55	3.1
HBD1-579	0.83	n/a	4.34	n/a	612	n/a	5.92	0.98	8.26	n/a
HBD1-602.3	2.22	101.36	6.98	343	675	246	6.28	2.63	12.46	3.8
HBD1-649	1.36	n/a	4.43	n/a	726	n/a	7.6	1.42	11.26	n/a
HBD1-659	n/a	35.79	4.41	403	629	371	8.25	4.11	10.19	3.8
HBD1-677	1.01	n/a	3.91	n/a	610	n/a	8.48	1.43	8.92	n/a
HBD1-714.8	1.06	35.23	2.86	466	537	203	7.37	3.42	8.13	2.6
HBD1-722	0.85	n/a	3.08	n/a	810	n/a	10.71	1.46	10.40	n/a
HBD1-755	1.49	48.60	4.27	551	727	189	5.49	2.78	7.55	3.0
HBD1-760	n/a	n/a	1.53	n/a	630	224	9.83	1.16	7.16	2.9
HBD1-763.4	2.74	44.50	2.50	200	799	293	9.84	1.13	7.13	3.3
HBD1-779	0.42	n/a	4.31	n/a	592	n/a	8.22	1.23	10.39	n/a
HBD1-790.7	1.06	45.42	3.56	n/a	553	184	9.00	3.89	10.21	3.7
HBD1-803	0.65	n/a	3.63	n/a	598	n/a	8.81	1.51	11.66	n/a
HBD1-822	n/a	39.93	3.60	n/a	680	373	9.52	5.03	10.63	3.8
HBD1-850	1.43	n/a	4.2	n/a	703	n/a	5.96	1.01	7.76	n/a
HBD1-871	1.90	93.03	5.19	489	687	171	8.13	3.17	11.00	3.8
HBD1-890	1.56	n/a	4.51	n/a	655	n/a	7.25	1.16	8.65	n/a
HBD1-912	0.83	n/a	4.87	n/a	483	n/a	7.02	1.2	10.15	n/a
HBD1-920.5	n/a	31.15	3.30	567	568	382	8.29	4.69	10.03	2.9
HBD1-930	n/a	n/a	1.77	n/a	271	293	13.38	4.23	17.79	5.5
HBD1-938.5	0.21	28.11	2.97	208	477	364	12.00	5.50	12.75	3.8

Appendix F: HBD-1 Instrumental Neutron Activation Analysis continued
(Barnes, 1995)

Depth	Zn	As	Sb	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
HBD1-60.5	59	n/a	0.66	43.8	2.5	42	7.01	1.49	0.90	2.85	0.49
HBD1-73	n/a	n/a	n/a	50.44	78.89	n/a	7.91	1.83	1.26	3.59	0.45
HBD1-84	63	4.95	n/a	44.7	91.8	46	8.37	1.92	1.15	3.24	0.56
HBD1-131	114	11.21	1.73	27.3	56.7	26	5.57	1.45	0.85	2.87	0.53
HBD1-176	n/a	n/a	n/a	29.45	56.9	n/a	6.26	1.64	n/a	3.08	0.45
HBD1-206.5	101	6.77	0.53	48.5	92.4	41	7.62	1.63	1.06	2.94	0.51
HBD1-230	108	5.24	n/a	42.8	107.8	43	9.01	2.46	1.37	4.77	0.79
HBD1-257	84	8.39	1.03	32.2	63.2	30	5.95	1.53	0.87	2.66	0.42
HBD1-275	n/a	n/a	n/a	26.09	49.81	n/a	4.85	1.12	n/a	3.07	0.35
HBD1-303.5	82	9.96	1.36	24.1	45.2	n/a	5.21	1.40	0.79	2.52	0.44
HBD1-314	n/a	n/a	n/a	96.6	190.2	n/a	18.06	4.05	2.56	6.06	0.82
HBD1-349	82	23.11	4.81	26.4	48.3	26	5.88	1.49	0.82	2.91	0.57
HBD1-405.5	71	20.22	0.94	38.2	91.3	41	6.52	1.76	0.96	2.91	0.49
HBD1-425	n/a	n/a	n/a	43.56	92.27	n/a	9.32	2.26	n/a	3.36	0.45
HBD1-436.3	70	13.26	n/a	28.4	49.9	26	5.92	1.35	0.70	2.80	0.48
HBD1-455	n/a	n/a	n/a	4353	85.42	n/a	10.64	2.48	1.34	3.28	0.43
HBD1-468	n/a	n/a	n/a	15.86	29.91	n/a	3.15	0.82	n/a	3.05	0.41
HBD1-492.5	122	6.28	n/a	26.3	65.4	28	6.62	1.99	1.09	3.31	0.62
HBD1-507	n/a	n/a	n/a	28.9	51.69	n/a	4.66	1.05	0.75	3.65	0.6
HBD1-535	n/a	n/a	n/a	43.63	87.8	n/a	8.28	1.75	0.97	3.62	0.53
HBD1-545.6	99	2.14	n/a	21.3	36.4	n/a	3.77	1.05	0.69	2.36	0.39
HBD1-553	109	5.03	2.78	32.8	66.9	64	6.96	1.83	0.98	2.93	0.56
HBD1-565.7	113	9.16	n/a	35.5	64.8	39	7.88	1.96	1.05	3.23	0.60
HBD1-579	n/a	n/a	n/a	32.22	62.67	n/a	7.15	1.82	1.09	4.27	0.53
HBD1-602.3	98	6.80	2.46	42.2	85.5	45	8.62	1.99	1.22	3.54	0.65
HBD1-649	n/a	n/a	n/a	43.47	85.4	n/a	8.78	2.37	1.51	4.28	0.64
HBD1-659	146	6.56	n/a	43.2	123.0	42	7.78	2.19	1.08	3.15	0.64
HBD1-677	n/a	n/a	n/a	21.07	43	n/a	3.88	1.05	1.07	3.56	0.45
HBD1-714.8	121	8.50	1.09	30.8	70.8	38	7.88	2.22	1.23	4.18	0.78
HBD1-722	n/a	n/a	n/a	51.83	120.7	n/a	11.31	2.67	n/a	4.55	0.6
HBD1-755	103	5.82	1.46	26.4	49.3	28	5.50	1.46	0.86	2.65	0.51
HBD1-760	64	8.30	0.95	25.7	49.1	n/a	6.79	1.18	1.01	3.93	0.55
HBD1-763.4	55	11.45	n/a	30.6	64.3	36	7.86	1.38	1.20	4.95	0.78
HBD1-779	n/a	n/a	n/a	29.3	74.49	n/a	6.82	1.81	n/a	4.13	0.58
HBD1-790.7	118	9.92	10.56	38.4	80.1	45	8.06	2.23	1.47	4.04	0.70
HBD1-803	n/a	n/a	n/a	36.13	61.85	n/a	6.73	1.74	1.39	3.74	0.55
HBD1-822	160	15.92	2.15	63.1	118.6	64	11.96	3.17	1.76	5.22	0.84
HBD1-850	n/a	n/a	n/a	55.18	60.3	n/a	7.89	1.69	1.22	3.49	0.43
HBD1-871	122	11.16	3.40	38.5	77.4	n/a	8.08	2.02	1.21	4.01	0.70
HBD1-890	n/a	n/a	n/a	18.37	33.12	n/a	3.76	0.95	0.81	3.27	0.41
HBD1-912	n/a	n/a	n/a	22.71	36.8	n/a	3.99	1.12	n/a	2.96	0.44
HBD1-920.5	156	7.91	n/a	33.8	78.8	38	8.26	2.30	1.25	4.11	0.75
HBD1-930	103	20.37	1.22	11.2	29.2	86	2.83	0.81	0.99	1.25	1.07
HBD1-938.5	182	3.18	8.33	47.8	93.6	n/a	8.64	2.28	1.06	2.73	0.53

Appendix F: MTD-1, and DOGAMI Instrumental Neutron Activation
Analyses for Willamette Silt and Neogene Sediments
(Barnes, 1995).

<u>Boring and Depth</u>	<u>Age</u>	<u>Na%</u>	<u>K%</u>	<u>Rb</u>	<u>Cs</u>	<u>Sr</u>	<u>Ba</u>	<u>Fe%</u>	<u>Sc</u>
BVD-2 93.5'	Neogene	2.54	1.03	35	1.71	316	456	4.2	17.4
BVD-3 19.6'	W. S.	1.85	1.81	65	3.36	367	670	5.5	17.2
BVD-4 36.5'	Neogene	0.35	0.82	67	3.88	614	n/a	10.39	37.3
BVD-4 59.9'	Neogene	0.11	0.35	40	3.89	277	256	6.42	22.4
BVD-4 91.4'	Neogene	0.76	1.85	77	5.62	588	n/a	3.82	14.2
BVD-5 55'	W. S.	1.9	1.98	83	4.38	359	722	4.06	14.8
BVD-6 25'	W. S.	2.33	1.57	46	1.82	452	610	4.64	13.8
BVD-6 47'	Neogene	1.36	1.24	42	3.06	493	653	5.04	20.1
LOD-1 53'	W. S.	1.8	2.01	58	2.95	421	628	2.82	10.7
LOD-3 22'	W. S.	1.61	1.88	71	3.99	300	576	5.53	11.9
LOD-4 100'	Neogene	1	1.26	40	2.59	310	609	5.38	17.3
LTD-4 11.6'	W. S.	1.87	1.84	79	3.33	348	690	3.72	12.2
DHW-330'	Eocene	1.53	1.31	73	4.24	273	579	4.34	15.7

Portland Airport MTD-1 Drill Test INNA Geochemical Data

<u>Depth</u>	<u>Na %</u>	<u>Rb</u>	<u>Cs</u>	<u>Sr</u>	<u>Ba</u>	<u>Fe%</u>	<u>Sc</u>	<u>Cr</u>	<u>Co</u>
MTD1-30	3.15	34	1.75	531	400	3.75	10.3	39	16
MTD1-50	3.44	26	108	501	344	3.26	9.9	29	14
MTD1-105	2.64	49	1.82	389	597	2.9	9.4	46	12
MTD1-155	2.64	69	2.2	464	662	2.69	9.2	35	11
MTD1-225	2.67	58	1.74	412	604	2.29	8.2	32	9
MTD1-295	1.68	n/a	2.75	334	642	3.59	11.7	51	14
MTD1-350	2.56	66	2.31	376	527	4.72	15.3	45	23
MTD1-402	0.18	48	2.33	423	338	8.46	26.3	198	22
MTD1-412	0.91	n/a	2.6	n/a	423	7.17	20.7	114	40
MTD1-466	1.9	53	1.69	260	452	3.25	10.7	77	16
MTD1-575	1.17	72	4.76	277	605	4.76	16.7	67	17
MTD1-692	2.27	34	0.66	n/a	325	6.05	21.2	127	32
MTD1-725	1.53	26	0.84	308	248	7.46	15.4	113	28
MTD1-744	2.46	28	1.44	408	337	5.5	20.3	128	23
MTD1-782	2.02	43	1.59	331	536	2.87	9.6	83	13
MTD1-840	1.55	89	4.3	224	713	4.88	12.6	69	14
MTD1-864	2.11	54	3.37	276	508	5.44	17.4	78	24
MTD1-900	1.22	89	5.18	150	643	4.15	14.4	74	18
MTD1-958	0.81	111	6.37	155	644	4.5	15.6	77	15
MTD1-1004	1.69	84	4.9	312	720	3.18	9.9	41	9
MTD1-1124	0.83	108	7.29	311	641	4.34	15.4	74	16
MTD1-1241	1.26	92	5.04	n/a	586	4.51	15.6	63	18
MTD1-1311	1	84	6.12	247	616	4.53	15.4	71	17

Appendix F: continued (Barnes, 1995).

<u>Boring and Depth</u>	<u>Cr</u>	<u>Co</u>	<u>Zr</u>	<u>Hf</u>	<u>Ta</u>	<u>Th</u>	<u>U</u>	<u>Zn</u>	<u>As</u>	<u>Sb</u>
BVD-2 93.5'	164	21	127	4.66	0.56	4.5	1.6	85	8.7	0.8
BVD-3 19.6'	134	19	335	7.39	1.12	9.3	2.2	95	16	1
BVD-4 36.5'	70	30	407	8.31	1.33	11.8	4.2	145	15	n/a
BVD-4 59.9'	71	12	340	4.44	0.54	6	1.9	99	3.4	0.7
BVD-4 91.4'	39	14	298	5.87	2.27	17.7	5	106	2	1.1
BVD-5 55'	90	17	183	7.07	1.21	11	4.3	80	11	1.4
BVD-6 25'	64	18	198	4.68	0.63	4.9	2.1	75	4.9	0.5
BVD-6 47'	82	22	319	6.72	1.12	6.7	2.3	102	8	n/a
LOD-1 53'	52	9	235	8.67	0.97	11.8	2.4	61	4.1	1.1
LOD-3 22'	53	12	310	5.92	0.75	8.3	2.9	74	3.3	1.8
LOD-4 100'	71	26	234	7	0.81	7.5	3.9	74	5	1.2
LTD-4 11.6'	60	16	276	8.37	0.96	9.7	2.7	76	7.1	0.7
DHW-330'	59	13	224	5.58	0.81	7.9	2.6	88	11	2.8

Portland Airport MTD-1 Drill Test INNA Geochemical Data

<u>Depth</u>	<u>Zr</u>	<u>Hf</u>	<u>Ta</u>	<u>Th</u>	<u>U</u>	<u>Zn</u>	<u>As</u>	<u>Sb</u>	<u>La</u>	<u>Ce</u>
MTD1-30	270	3.61	0.64	4.1	1.7	61	93.6	0.4	20	39.4
MTD1-50	182	3.72	0.65	3.3	1.1	60	9.1	20.3	n/a	35.3
MTD1-105	165	3.44	0.62	5.3	1.4	50	7.7	0.9	24	38.2
MTD1-155	n/a	3.03	0.59	4.3	1.8	63	5.8	0.7	18	34.5
MTD1-225	106	2.7	0.62	3.6	1.8	45	2.4	0.4	19	30.8
MTD1-295	181	3.67	0.79	6.2	2.1	56	4.2	1.4	26	44
MTD1-350	158	5.06	0.78	7.5	2	93	10.9	1.9	26	49
MTD1-402	280	3.42	0.56	4.6	23.5	111	12.3	13	n/a	26.6
MTD1-412	203	2.3	0.35	1.8	21.6	83	3.6	313	9.7	23.3
MTD1-466	165	2.29	0.49	3.5	2.3	111	1.9	4.1	14	25.5
MTD1-575	198	4.76	1.01	10.1	3.9	81	14.2	2.1	33	62.1
MTD1-692	187	2.8	0.47	2.5	2.3	98	4.5	2.3	13	25.1
MTD1-725	239	1.72	0.29	1.1	21.5	70	n/a	n/a	7.1	10.9
MTD1-744	168	2.44	0.39	1.6	13	92	2.8	267	11	20.4
MTD1-782	102	2.34	0.44	4.2	1.3	101	3.5	0.5	16	27.2
MTD1-840	229	5.89	1.08	10.4	3.4	78	n/a	1.1	39	716
MTD1-864	181	4.49	0.74	6.6	2.4	98	17.3	11.9	26	50.9
MTD1-900	237	4.31	1.01	11.1	3.8	91	6.9	2.4	38	65.7
MTD1-958	395	4.47	1.03	12.7	3.9	91	9	1.6	39	76.5
MTD1-1004	245	4.27	1.17	11.4	4.3	71	4.6	2.9	37	74.6
MTD1-1124	217	4.21	1.04	12.9	4.7	98	10.3	9	38	76
MTD1-1241	181	4.37	1.02	10.5	2.9	92	7.7	14	35	63.7
MTD1-1311	223	4.56	1.09	11.8	3.3	107	8.4	10.5	38	74.4

Appendix F: continued (Barnes, 1995).

<u>Boring and Depth</u>	<u>La</u>	<u>Ce</u>	<u>Nd</u>	<u>Sm</u>	<u>Eu</u>	<u>Tb</u>	<u>Yb</u>	<u>Lu</u>	<u>La/Sm</u>	<u>Ce/Sm</u>
BVD-2 93.5'	20.7	38.4	24	4.21	1.11	0.67	2.2	0.34	4.92	9.12
BVD-3 19.6'	35.8	69.1	n/a	6.32	1.51	0.94	2.9	0.42	5.66	10.93
BVD-4 36.5'	40.5	82.6	n/a	8.68	2.32	1.8	3.5	0.59	4.67	9.52
BVD-4 59.9'	13.5	22.6	n/a	2.2	0.65	0.49	1.7	0.26	6.14	10.27
BVD-4 91.4'	31.9	64.8	29	6.54	1.2	1.14	2.9	0.47	4.88	9.91
BVD-5 55'	40.4	78.4	n/a	6.73	1.56	0.98	2.9	0.47	6.00	11.65
BVD-6 25'	23	44.4	n/a	4.29	1.22	0.66	2.1	0.31	5.36	10.35
BVD-6 47'	31.4	58.1	29	6.37	1.62	0.94	3	0.43	4.93	9.12
LOD-1 53'	45.6	78.5	31	6.9	1.46	0.95	2.9	0.49	6.61	11.38
LOD-3 22'	30.4	57	n/a	5.23	1.21	0.74	2.5	0.38	5.81	10.90
LOD-4 100'	39.9	75.5	38	7.81	1.97	1.09	3.6	0.57	5.11	9.67
LTD-4 11.6'	38.1	72.6	33	5.87	1.39	0.83	2.8	0.44	6.49	12.37
DHW-330'	28.4	54.9	n/a	5.92	1.36	0.83	2.8	0.5	4.80	9.27

Portland Airport MTD-1 Drill Test INNA Geochemical Data

<u>Depth</u>	<u>Nd</u>	<u>Sm</u>	<u>Eu</u>	<u>Tb</u>	<u>Yb</u>	<u>Lu</u>	<u>La/Sm</u>
MTD1-30	16	3.73	1.1	0.51	1.44	0.21	5.44
MTD1-50	19	3.77	1.05	0.48	1.42	0.21	n/a
MTD1-105	n/a	3.91	0.91	0.54	1.76	0.24	6.16
MTD1-155	n/a	3.36	0.95	0.51	1.53	0.23	5.33
MTD1-225	13	3.22	0.83	0.42	1.4	0.2	5.81
MTD1-295	20	4.38	1.15	0.64	1.85	0.27	5.82
MTD1-350	23	5.04	1.22	0.79	2.59	0.38	5.16
MTD1-402	n/a	3.15	1.07	0.68	2.06	0.31	n/a
MTD1-412	n/a	2.89	1.13	0.58	1.96	0.26	3.36
MTD1-466	14	2.39	0.81	0.45	1.29	0.17	5.69
MTD1-575	25	5.72	1.33	0.86	2.46	0.35	5.79
MTD1-692	27	3.45	1.14	0.6	1.95	0.31	3.80
MTD1-725	n/a	2.23	0.81	0.43	1.27	0.21	3.18
MTD1-744	28	3.27	1.16	0.58	1.82	0.25	3.24
MTD1-782	n/a	3	0.8	0.43	1.45	0.19	5.20
MTD1-840	30	6.55	1.45	1.01	2.98	0.46	5.97
MTD1-864	22	5.09	1.27	0.76	2.38	0.35	5.13
MTD1-900	28	6.47	1.31	0.88	2.76	0.4	5.83
MTD1-958	34	6.7	1.37	1.05	2.91	0.41	5.78
MTD1-1004	29	6.35	1.26	0.95	3.06	0.36	5.81
MTD1-1124	35	6.74	1.47	1.03	3.01	0.43	5.68
MTD1-1241	27	6.15	1.33	0.9	2.78	0.41	5.63
MTD1-1311	33	6.43	1.43	0.98	2.74	0.44	5.89

APPENDIX G

HBD-1 AND DOGAMI SHALLOW BORING VELOCITY DATA AND SYNTHETIC SEISMOGRAMS

Appendix G: HBD-1 wave velocity data gathered by DOGAMI, 1993.

DEPTH (Meters)	Vs (m/sec)	Vp (m/sec)
12	278	1667
14	250	1538
16	282	1667
18	388	1667
20	290	1538
22	270	1667
24	242	1667
26	278	1667
28	315	1667
30	370	1667
32	288	1667
34	324	1613
36	373	1471
38	324	1667
40	339	1563
42	379	1613
44	340	1613
46	323	1563
48	334	1667
50	386	1613
52	450	1562
54	329	1667
56	420	1613
58	368	1667
60	505	1667
62	415	1515
64	415	1563
66	296	1563
68	334	1613
70	412	1563
72	467	1724
74	431	1667
76	331	1562
78	317	1562
80	403	1724
82	n/a	1667
84	382	1613
86	347	1613
88	397	1667
90	617	1724
92	621	1613
94	595	1563
96	400	1724
98	355	1613
100	310	1667
102	305	1613
104	415	1724
106	n/a	n/a

DEPTH (Meters)	Vs (m/sec)	Vp (m/sec)
108	465	1613
110	498	n/a
112	385	1429
114	457	1613
116	613	1667
118	299	n/a
120	386	1667
122	469	1613
124	685	1667
126	588	1724
128	321	1563
130	n/a	1613
132	373	1613
134	508	1786
136	571	1667
138	n/a	1613
140	347	1613
142	515	1563
144	394	1613
146	375	1667
148	n/a	1724
150	n/a	1667
152	529	1613
154	308	1667
156	452	1667
158	412	1724
160	395	1724
162	435	1724
164	467	1724
166	355	1724
168	435	1667
170	450	1613
172	439	1613
174	524	1667
176	741	1613
178	671	1515
180	699	1515
182	595	1613
184	407	1613
186	495	1724
188	405	1852
190	388	1667
192	485	1724
194	418	1667
196	361	1429
198	427	1786
200	503	1724
202	467	1613

Appendix G: Continued - HBD-1 wave velocity

DEPTH (Meters)	Vs (m/sec)	Vp (m/sec)
204	403	1613
206	365	1563
208	415	1724
210	373	1724
212	375	1471
214	331	1515
216	405	1613
218	457	1563
220	442	1563
222	559	1562
224	503	1724
226	538	1667
228	575	1667
230	578	1724
232	901	2174
234	469	1563
236	568	1667
238	581	1562
240	518	1563
242	617	1563
244	649	1613
246	637	1786
248	775	1563
250	641	1887
252	707	1587
254	760	1639
256	803	1613
258	637	1667
260	840	1818
262	781	1563
264	803	1639
266	645	1667
268	717	1538
270	926	1613
272	881	1639
274	962	1639
276	881	1613
278	893	1667
280	909	1724
282	901	1724
284	1031	1786
286	909	1613
288	935	2174
290	n/a	1786
292	1170	2564
294	602	1786
296	775	1667
298	717	1667

DEPTH (Meters)	Vs (m/sec)	Vp (m/sec)
300	775	1613
302	508	1695
304	599	1639
306	671	1613
307	662	1667
308	413	1613
309	687	1667
310	551	1754
311	649	1887
312	690	1923
313	941	2410
314	2260	4651
315	2920	5263
316	2985	5128
317	3226	5556
318	3101	5405
319	3226	5714
320	3150	5556
321	3175	5405
322	3333	5714
323	2837	5128
324	1786	3279

Appendix G: Primary wave velocity data from DOGAMI BVD shallow borings in the eastern part of the Tualatin Valley along the Hwy 217 corridor. Modified from original DOGAMI survey data, 1993-1994.

BVD2 Velocity Data			
Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)
0	556	0.0	1824.1
3	1000	9.8	3280.8
4	1000	13.1	3280.8
6	1936	19.7	6351.7
8	2500	26.2	8202.1
10	1795	32.8	5889.1
12	2000	39.4	6561.7
14	1298	45.9	4258.5
16	1600	52.5	5249.3
18	1500	59.1	4921.3
20	2200	65.6	7217.8
22	1600	72.2	5249.3
24	2417	78.7	7929.8
26	1629	85.3	5344.5
28	1785	91.9	5856.3
30	1500	98.4	4921.3
32	1613	105.0	5292.0
34	1534	111.5	5032.8
36	1534	118.1	5032.8

BVD3 Velocity Data			
Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)
0	900	0.0	2952.8
3	900	9.8	2952.8
4	900	13.1	2952.8
5	900	16.4	2952.8
6	900	19.7	2952.8
8	944	26.2	3097.1
10	7765	32.8	25475.7
12	2521	39.4	8271.0
14	1580	45.9	5183.7
16	1960	52.5	6430.4
17	22163	55.8	72713.3
18	1500	59.1	4921.3
20	2141	65.6	7024.3
22	1500	72.2	4921.3
23	1500	75.5	4921.3
24	1500	78.7	4921.3
26	1500	85.3	4921.3
27	1500	88.6	4921.3
28	2061	91.9	6761.8
30	2061	98.4	6761.8

Appendix G: Primary wave velocity data from 1993-1994 DOGAMI BVD shallow borings continued.

BVD4 Velocity Data				BVD4 Velocity Data Continued			
Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)	Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)
0	440	0.0	1443.6	57	3274	187.0	10741.5
3	440	9.8	1443.6	59	3682	193.6	12080.1
5	2030	16.4	6660.1	61	3684	200.1	12086.6
7	1338	23.0	4389.8	63	3600	206.7	11811.0
9	1671	29.5	5482.3				
11	1140	36.1	3740.2	BVD5 Velocity Data			
13	1690	42.7	5544.6	Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)
15	1774	49.2	5820.2	0	800	0.0	2624.7
17	1774	55.8	5820.2	3	800	9.8	2624.7
19	1792	62.3	5879.3	4	800	13.1	2624.7
21	1806	68.9	5925.2	6	800	19.7	2624.7
23	1814	75.5	5951.4	8	800	26.2	2624.7
25	1463	82.0	4799.9	10	800	32.8	2624.7
27	1335	88.6	4379.9	12	726	39.4	2381.9
29	1828	95.1	5997.4	14	604	45.9	1981.6
31	1832	101.7	6010.5	16	1500	52.5	4921.3
33	2093	108.3	6866.8	18	1577	59.1	5173.9
35	2085	114.8	6840.6	20	2306	75.6	7565.6
37	2098	121.4	6883.2	22	2346	72.2	7696.9
39	2447	128.0	8028.2	24	1607	78.7	5272.3
41	3254	134.5	10675.9	26	1500	85.3	5295.3
43	3560	141.1	11679.8	28	1500	91.9	4921.3
45	2939	147.6	9642.4	30	1500	98.4	4921.3
47	2942	154.2	9652.2	32	2162	105.0	7093.2
49	3350	160.8	10990.8	34	1500	111.5	4921.3
51	3586	167.3	11765.1	36	2804	118.1	9199.5
53	3770	173.9	12368.8				
55	3678	180.4	12066.9	BVD6 Velocity Data			
				Depth (m)	Vp (m/s)	Depth (ft)	Vp (ft/s)
				0	305	0.0	1000.7
				2	305	6.6	1000.7
				4	365	13.1	1197.5
				6	521	19.7	1709.3
				8	721	26.2	2365.5
				10	438	32.8	1437.0
				12	398	39.4	1305.8
				14	331	45.9	1086.0
				16	332	52.5	1089.2
				18	365	59.1	1197.5
				20	717	65.6	2352.4
				22	895	72.2	2936.4
				24	725	78.7	2378.6
				26	1500	85.3	4921.3
				28	788	91.9	2585.3
				30	732	98.4	2401.6

BVD2 PRIMARY WAVE VELOCITY PROFILE

Figure G1: Primary wave velocity/depth profile and synthetic seismogram for DOGAMI boring BVD-2.

Figure G2: Primary wave velocity/depth profile and synthetic seismogram for DOGAMI boring BVD-3.

Figure G3: Primary wave velocity/depth profile and synthetic seismogram for DOGAMI boring BVD-4.

Figure G4: Primary wave velocity/depth profile for DOGAMI boring BVD-5.

BVD6 PRIMARY WAVE VELOCITY PROFILE

bvd6 10-50 Hz. wavelet

Time Scale: 20.00 ips

Wavelet Amplitude: 50%

Figure G5: Primary wave velocity/depth profile and synthetic seismogram for DOGAMI boring BVD-6.

APPENDIX H

TUALATIN VALLEY PHOSPHORUS ANALYSIS RESULTS

Appendix H: Phosphorus values from borings in the Tualatin Valley.

Analyses performed at the Oregon Graduate Institute.

Eastern Tualatin Valley

ODOT			TRI-MET				
Boring #	Depth (feet)	P (mg/l)	Boring #	Depth (feet)	P (mg/l)		
C 102	6.5	0.032	B101	20.5	0.008		
	11.5	0.074		35.5	0.472		
	21.5	0.13		58.5	0.237		
	34.5	0.113	B750	56.5	0.597	B860	
D 115	4.9	0.077		61.5	0.75	Depth (feet)	P (mg/l)
	10.5	0.035		66.5	0.583	7.5	0.01
H 102	8.5	0.069	B804	71.5	0.438	11.5	0.06
	13.5	0.191		4	0.013	12.5	0.093
K 104	6.5	0.069		13.5	0.073	15	0.044
	11.5	0.08	B808b	16.5	0.027	20	0.2
L 103	6.5	0.087		6.5	0.016	25	0.024
	11.5	0.052		4	0.028	30	0.034
	16.5	0.157	B809	9	0.085	40	0
L 104	6.5	0.133		11.5	0.155	50	0.347
	11.5	0.051		11	0.032	55	0.494
L 105	6.5	0.051	B815	13.5	0.016	60	0.485
	11.5	0.023		16.5	0.085	60	0.503
	16.5	0.219		31.5	0.01	65	0.66
	21.5	0.009	B818	46.5	0.011	70	1.07
	31.5	0.015		6.5	0.102	72	0.418
	36.5	0.022		9	0.223	75	0.264
M 102	23.5	0.067	B827a	16.5	0.042	80	0.32
	43.5	0.057		2.5	0.055	82	0.105
	61.5	0.098		5	0.042	110	0.39
	81.5	0.106		7.5	0.082	140	0.41
	111.5	0.354		10	0.117		
	131.5	0.201		12.5	0.115		
	161.5	0.049	B831	15	0.086		
	191.5	0.025		9.5	0.054		
	201.5	0.008		12	0.238		
	241.5	0.016		18.5	0.1		
	281.5	0.012		26.5	0.051		
	301.5	0.101		30	0.011		
M 106	6.5	0.087		45	0.029		
	11.5	0.076		60	0.959		
	21.5	0.024		65	0.016		
	36.5	0.108		75	0.094		
	51.5	0.046		91.5	0.115		
	6.5	0.058	B844	16.5	0.037		
N 101	11.5	0.103		4	0.132		
	21.5	0.089		9	0.016		
N 106	18.5	0.121		16.5	0.078		
	33.5	0.027					
	43.5	0.123					
	61.5	0.095					

Appendix H: Continued - Phosphorus values from borings in the Tualatin Valley.

Central Tualatin Valley

<u>BVD-2</u>		<u>BVD-5</u>		<u>HBD-1</u>		<u>Bich</u>	
<u>Depth (feet)</u>	<u>P (mg/l)</u>	<u>Depth (feet)</u>	<u>P (mg/l)</u>	<u>Depth (feet)</u>	<u>P (mg/l)</u>	<u>Depth (feet)</u>	<u>P (mg/l)</u>
10	0.107	5	0.5	20	0.11	20	0.648
15	0.128	10	0.35	37	0.097	30	0.893
20	0.033	15	0.1	61	0.125	<u>Dremmer</u>	
25	0.094	35	0	80	0.129	<u>Depth (feet)</u>	<u>P (mg/l)</u>
30	0.018	40	0.235	101	0.447	75	0.222
35	0.031	45	0.63	121	0.447	85	0.11
40	0.151	60	0.24	139	0.736	92	0.267
45	0.149	70	0.52	164	0.026	95	0.833
50	0.057	80	0.27	180	0.512	105	0.561
55	0.212	85	0.38	202	0.186	115	0.233
65	0.191	90	0.52	223	0.242	125	0.223
70	0.254	95	0.47	240	0.81	<u>Gillenwater #1</u>	
75	0.197	100	0.49	255	0.06	<u>Depth (feet)</u>	<u>P (mg/l)</u>
80	0.217	105	0.45	280	0.231	30	0.451
90	0.164	<u>BVD-6</u>		302	3.17	50	0.023
95	0.116	<u>Depth (feet)</u>	<u>P (mg/l)</u>	316	1.54	60	0.027
100	0.311	5	0.226	340	2.62	65	0.083
105	0.347	10	0.117	360	0.016	73	0.024
115	0.406	15	0.258	380	2.58	93	0.039
120	0.261	25	0.151	406	1.51	<u>Hillsboro</u>	
<u>BVD-4</u>		24	0.107	424	0.339	<u>Depth (feet)</u>	<u>P (mg/l)</u>
<u>Depth (feet)</u>	<u>P (mg/l)</u>	50	0.136	453	0.018	15	0.068
15	0.405	55	0.069	469	0.182	36	0.032
20	1.54	65	0.018	493	0.202	36	0.173
25	0.21	70	0.025	509	0.017	65	0.036
30	0.242	75	0.019	525	0.009	70	0.077
35	0.251	90	0.039	539	0.011	80	0.039
40	0.263	95	0.041	559	0.01	90	0.004
45	0.11	100	0.016	579	0.05	111	0.319
50	0.319	<u>LOD-3</u>		600	0.167	<u>Jackson Bottom</u>	
55	0	<u>Depth (feet)</u>	<u>P (mg/l)</u>	634	0.01	<u>Depth (feet)</u>	<u>P (mg/l)</u>
60	0.22	5	0.092	647	0.01	10.5	0.094
65	0.11	10	0.102	674	0.04	15.5	0.211
70	0.16	15	0.166	689	0.015	19	0.344
75	0.28	20	0.014	709	0.416	5	0.056
80	0.2	25	0.014	723	0.064	10	0.067
85	0.29	<u>LTD-4</u>		769	0.249	15	0.071
90	0.3	<u>Depth (feet)</u>	<u>P (mg/l)</u>	789	0.009	19	0.56
95	0.73	5	0.031	811	0.108	24.5	0.174
100	0.5	10	0.464	830	0.525	5	0.056
		15	0.034	850	0.01	10	0.2
		20	0.022	870	0.157	15	0.205
				890	0.074	19	0.929
				909	0.075	22	0.574
				938	0.039		

Appendix H: Continued - Phosphorus values from borings in the Tualatin Valley

Southern Tualatin Valley	
<u>Vandomelen</u>	
<u>Depth (feet)</u>	<u>P (mg/l)</u>
56	0.172
65	0.037
75	0.072
95	0.759
115	0.11
115	0.092
125	0.094
130	0.059

Western Tualatin Valley	
<u>Cain</u>	
<u>Depth (feet)</u>	<u>P (mg/l)</u>
10	0.938
20	0.105
30	0.013
40	0.1
50	0.041
60	0.009
80	0.006
90	0.008
100	0.008
110	0.014
160	0.009
180	0.017
190	0.007
200	0.009
220	0.028
230	0.021
240	0.007
250	0.025

<u>Leisigang</u>	
<u>Depth (feet)</u>	<u>P (mg/l)</u>
118	1.07
150	1.25
165	1.48
240	0.165
250	0.078
275	0.017
290	0.032
335	0.006
440	0.014
540	0.01