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The Terroir of Pinot Noir Wine in the Willamette Valley, Oregon – A Broad
Analysis of Vineyard Soils, Grape Juice and Wine Chemistry

by

Kathryn Nora Barnard

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

Doctor of Philosophy
in
Environmental Sciences and Resources: Geology

Dissertation Committee:
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Portland State University
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Abstract

Terroir is determined by a combination of factors in the vineyard including the grape varietal, geology and soil, soil hydrology, physiography, and climate. Although most studies have examined regional differences in wine flavors and associated provenance of wine based on chemistry, few have examined the chemistry of the soil and the ability to trace that chemistry to grape juice and, finally, to the wine. This dissertation examines what soil physical and chemical differences specific to this region might influence grape juice chemistry and wine chemistry.

Wine-grapes in the Willamette Valley, Oregon, are grown on three major soil parent materials: volcanic, marine sediments, and loess/volcanic. Winemakers have observed differences in the flavor of Pinot Noir wine made from grapes grown on these different parent materials. This dissertation examines differences in the soil properties and elemental chemistry of the soil parent materials at various vineyards to document their effect on wine chemistry as a step towards understanding differences in flavor. All aspects of the terroir are controlled by carefully selecting vineyards with similar exposure and elevation, the same grape varietal and wine making techniques, and only the soils vary. The hypothesis is that the chemistry of the grape juice and wine reflect the soil in which the grapes were grown and that the three parent materials have soils that can be distinguished by their physical and chemical characteristics.

Soil pits were excavated in 20 vineyards, soil properties were described in the field, and soil samples were later analyzed in the laboratory particle size, organic matter, color, pH, cation exchange capacity (ammonium acetate method), clay mineralogy (x-ray diffraction), and elemental chemistry (ICP-MS/AES). X-ray fluorescence was used to examine the pisolites. ICP-MS/AES was used for elemental analysis of grape juice and wines produced from these vineyards. Principal component analysis was used to compare soil physical and chemical characteristics, grape juice and wine chemistry.

The physical characteristics of soils from all the three parent materials indicate: they are old (>50,000 years) based on their high clay content, low cation exchange capacity, red colors, and high Fe and Al content. These features indicate enough time has passed to reduce organic matter and other cations at depth, leave behind insoluble Fe and Al, and develop pedogenic clays. In my study region, volcanic and marine sediment soils are more developed with slightly lower acidity than the loess/volcanic soils. A new finding for this region is the presence of pisolites (Fe/Mg concretions) in the volcanic and the loess/volcanic soils, but absent in the marine sediment soils. Winemakers hypothesized that pisolites were present only in loess soils and influenced wine flavor in some way.

Volcanic soils have the highest P, S, Fe, Co, Mn, and V concentrations and the lowest As and Sr values. Marine sediment soils have higher Cl and Sr and lower P, Co, Mn, Ba, and V concentrations than volcanic soils. Loess soils have the highest values of

K and Mg and are similar to volcanic soils with higher P and V values and similar to marine sediment soils with higher Sr values. The main elements found to be significant in determining one parent material from another are V and Mn (volcanic soils), Mg and K (loess soils), and Sr (marine sediment or loess soils). Sr is slightly higher in grape juice and wine from vines grown on marine sediment parent material compared to volcanic and loess parent material, whereas Mn is higher in the juice and wine from grapes grown in volcanic parent material. P, S, Fe, Co, V, Cl, Ba, Mg, and K did not maintain their relative concentration levels from soil to grape juice to wine. The principal component analysis shows that soil and wine chemistry differs between parent material, but is inconclusive for grape juice chemistry.

Dedication

To Seth D. Boss

1983-2010

Knowing that you and I will always have a bond as strong as the bows we climbed, as constant as the flowing creeks we crossed, as deep as the waters we navigated, and as eternal as the darkness in which we both desperately grasped for the light, I surrender this effort to your memory. Your death, as much as your life, gave me the courage to discover my brokenness and begin the arduous journey of healing and growth. Without you I would have surely fallen and your spirit would not have been there to help me up. This work is dedicated to you, Seth, my best friend and partner in crime in this life and the next.

RIP

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I thank the wineries and vineyards in the Willamette Valley for allowing access and having patience for results they are eager to utilize: Elk Cove Vineyards, Willakenzie Estate Winery, Chehalem, Lange Estate Winery and Vineyards, Rex Hill, and Ken Wright Cellars. Many thanks to APEX Laboratories, Dr. Reed Glasmann of Willamette Geological Services, Oregon State University, and Washington State University for their lab analyses. I am grateful for the support of the Erath Family Foundation for funding much of the outside lab work, and to the NSF Cascades to Coast GK-12 Program for financial support and connecting me to many in the Portland community with whom I can share my knowledge and grow. I also want to thank Cooper Mountain Vineyards, Gilles de Domingo, Barbara Gross, and Dr. Robert Gross for their support, knowledge, and a love for organic and biodynamic farming.

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Chapter One – Introduction

Terroir is a French term referring to the environmental conditions in which grapes are grown and the unique taste of wine created by these conditions. In reference to wine, terroir is the way the soil, geology, climate and grape type create unique flavors due to location (Robert, 2008). Research in terroir spreads across many disciplines. A geologist's perspective of terroir is one of physical characteristics of a site that are measureable. The question of how soil influences wine flavor has pointed the role of soil chemistry. Certain elemental concentrations in the soil prove to be a reliable fingerprinting technique for discerning wine of one region from another (Almeida and Vasconcelos, 2003; Coetzee et al., 2005; Di Paola-Narajo et al., 2011; Fabani et al., 2010; Gozávez et al., 2009; Greenough et al., 2005; Kment et al., 2005 and Taylor et al., 2006). In this study, chemistry of soil samples, grape juice, and wine all coming from a single location are analyzed in order to determine if there is a chemical fingerprint tying the wine from the Willamette Valley to the different soils used to grow grapes. This study also focuses on the physical soil properties of the different soils used to grow grapes in this region as well as the chemical properties.

Burns (2012) states that there are seven different factors that affect the end flavor of wine and that these factors can be measured and used to help explain the terroir of an area. The factors include the type of grape (varietal), the bedrock geology and resulting soils, the climate, the soil hydrology, and the physiography of the site (slope, aspect, and

elevation). In his publication, Burns (2012) stresses that terroir (the combination of the soil, geology, climate, and topography on the flavor of wine) is a combination of measurable variables that contribute to wine flavor. In the Willamette Valley there are specific regions that are known for producing wine of different flavors. Therefore, specific questions have developed in regards to how the geology affects the physical properties of vineyard soils. Pisolites (concretions) are present in vineyard soils in the Willamette Valley, but what affect do they have on soil characteristics and chemistry? What macronutrients, micronutrients, and trace elements are present in vineyard soils in the Willamette Valley, and is there a correlation between soil chemistry, soil physical properties, and geology? Do grapevines incorporate the elements found in vineyard soils into the grape juice in the same ratio as found in the soils, and can chemistry be used to create a fingerprint for wines produced on different soils in the Willamette Valley?

These questions are addressed in this dissertation. Using “transparent” grapes, which are thin-skinned and more easily influenced by variations in terroir that could affect flavor than other grape varieties, the soil physical and chemical properties are presented here to commence research into this topic. The three transparent grapes varieties that are most useful in terroir studies, because you can taste the flavor variation attributed to vineyard location, are Pinot Noir, Riesling, and Chardonnay (Burns, 2012). In this study the focus is on Pinot Noir wine because it makes up 88% of winegrapes

grown in the Willamette Valley (USDA, 2012). Over 12,560 acres of Pinot Noir are planted in Oregon with a value over 53.8 million dollars in 2011 (USDA, 2012).

Oregon ranks third in the United States in number of wineries after California and Washington, and fifth in volume of wine produced after California, New York, Washington, and Pennsylvania (Table 1) (ttb.gov, 2015). Its modern wine industry has been active since 1961, when pioneers planted the first vinifera grapes. There are now over 676 (winesnw.com, 2015) wineries in Oregon, many of them located within one of the 17 wine regions known as American Viticultural Areas (AVA) the largest of these AVAs is the Willamette Valley, the focus of this dissertation (Hodgen, 2011). The northern portion of the Willamette Valley AVA includes six smaller sub-AVAs: The Chehalem Mountains, Ribbon Ridge, Yamhill-Carlton, Dundee Hills, McMinnville, and Eola-Amity Hills AVAs that were delineated based on geology, soils, and a distinct difference in wine flavors produced from them (i.e. terroir) (Figure 1).

Table 1. Statistics on wine production in 2014 from the Department of the Treasury, Alcohol and Tobacco Tax and Trade Bureau (TTB) by volume in gallons, compiled by the author (ttb.gov, 2015)

Bulk Wine Gallons by State	Still Wine	Effervescent Wines	Other	Total Production	Percent
CALIFORNIA	709,647,220	26,647,879	24,895,572	761,190,671	85.09%
NEW YORK	34,616,418	2,212,257	499,666	37,328,341	4.17%
WASHINGTON	34,011,480	483,473	12,775	34,507,728	3.86%
PENNSYLVANIA	15,479,868	7,629	1,183	15,488,680	1.73%
OREGON	11,698,997	67,798	11,315	11,778,110	1.32%
All Other States	29,759,971	514,659	601,536	30,876,166	3.48%

Figure 1. Oregon's 17 (Elkton AVA, the 17th, not shown) wine regions or American Viticulture Areas (AVA), many of which are located within a larger AVA and are termed Sub-AVAs (<http://essentialnorthwestwines.com/oregon-wine/>).

The three major soil series groups that are used for growing Pinot Noir winegrapes in the Willamette Valley of Oregon are the Jory (Oregon's State Soil), the Willakenzie, and the Laurelwood soil series (Burns, 2012). These soils develop on different bedrock and parent material and vary slightly in their age and horizon development (Moore, 2002). Parent material for the soil includes material added over time like Quaternary eolian or windblown silt (loess). The Laurelwood soil series has

loess overlying volcanic bedrock parent material while the Jory soil series has volcanic parent material and the Willakenzie soil series has marine sediment parent material. The winemakers in the Willamette Valley have noticed variation in the flavor of their Pinot Noir wine produced from vines on each of these soil groups. This observation led us to find out what it is that separates and defines these soil groups, and these differences form the basis of this study.

Objective of This Study

My hypothesis is that the physical and chemical differences in the soil can be tested and compared to the grape juice and wine chemistry to determine the contribution of soil to the terroir of this region. Using Pinot Noir, which is a thin-skinned and “transparent” grape whose flavor is easily affected by the location where it is grown, a natural laboratory exists in the Willamette Valley, one where if wine-making techniques are kept constant when comparing soil, grape juice, and wine from each winery then the main variation between the wines is the soil type the grapes are grown on (Burns, 2012). In order to find out what makes these soils different from one another, I started by sampling and analyzing the soil characteristics, soil chemistry, soil mineralogy, and then the grape and wine chemistry.

First, the differences in physical characteristics based on field descriptions of the soils were analyzed. This was followed by laboratory analysis of the physical characteristics, elemental concentrations, and the clay mineralogy of the soils. The

differences expected between soil parent materials are more horizon development (i.e. red colors) in the volcanic and marine sediment soils than the loess/volcanic soils. It is also expected that the volcanic and marine sediment soils will have higher clay percentage and a clay mineral assemblage of minerals that take more time to develop than the loess/volcanic soils. Pisolites are expected in the loess/volcanic soils and not in the others. The chemistry of the different soils based on parent material should reflect the available trace elements in the bedrock as well as differences based on depletion of macronutrients and micronutrients over time. Therefore, the volcanic and marine sediment soil should have different chemical fingerprints. The elemental concentrations in grape juice from the vines next to each soil pit, and the elemental concentrations of the finished wine from the vineyard block that contained the soil pit should reflect the soil chemistry. No other studies have attempted to track the elemental composition of the wine to the soil through the grape juice. This study was designed to fill this gap and take a closer look at what elements the vine is taking up from the soil that can be traced to the finished wine.

In general, wine-makers determined that the tannin, fruit flavors, and mouthfeel were so different between soil types that a cause for these differences was desired. Experimental constants include the macro-climate, grape varietal (Pinot Noir) and winemaking techniques (same winemaker for the three different soil types) (Burns, 2012). The macro-climate is controlled because all sample sites are located just south of

Salem to Portland, referred to as the northern Willamette Valley, and all sites are located on southeast to southwest facing slopes. Winemakers taking part in this study have agreed to process the fruit from the different soil types as consistently as possible and wine samples were taken before blending with other blocks. Therefore, the winemaking processes for each winery are constant, though winemaking techniques may vary between winemakers cooperating in this study. Further research into this variable, winemaking effects on flavor, is needed in the Willamette Valley.

Study Area

Different types of bedrock and parent material have created three different groups of soils that affect the flavor of wine in the Willamette Valley (Moore, 2005). Therefore, the vineyards selected for this study are located throughout the Willamette Valley on various types of geologic bedrock and parent material. The geomorphic surfaces above approximately 90 meters (300 feet) elevation, or the valley sides, are the result of the uplift of volcanic rock or marine sediments. The lower elevations are mostly Missoula Flood sediments or alluvial terraces. In some instances, loess was accumulated to the slopes of volcanic rock, creating a unique soil that has both volcanic rock and weathered loess as parent material. The weathered loess, in this case, dominates the soil properties.

This study used current vineyard locations on three different types of parent material: volcanic, marine sediment, and loess on volcanic bedrock. Soil pit locations

were determined by the participating wineries, with the understanding that the purpose of this study is to compare soils and wine from soils that form on these three types of parent material. The current viticulture boundaries in the Willamette Valley partially follow these geologic boundaries (Figure 2). The Dundee Hills AVA is mostly volcanic parent material, and the majority of soils used for winegrapes there are Jory or closely related soil series. The Yamhill-Carlton District AVA is mostly marine sediment parent material, and the majority of soils used for winegrapes there are Willakenzie or closely related soil series. The Chehalem Mountains AVA is mostly loess on volcanic parent material, and the majority of soils used for winegrapes there are Laurelwood or closely related soil series. This study describes and compares the soils formed on these three parent materials.

The wineries that participated in this study were chosen based on their interest in the flavor differences they saw in wines produced from these different soils. These vineyards are separated into the three main soil series and parent material (Table 2). I could also separate the vineyards in the study by AVA (Dundee Hills, Yamhill-Carlton, and Chehalem Mountains) that are generally associated with the three different geologies and soil series. This study included vineyards in other Sub-AVAs (Ribbon Ridge and McMinnville) as well as two vineyards located in the general Willamette Valley AVA.

Figure 2. Geologic map of the Willamette Valley sub-AVAs (black outline) (Jones et al., 2010) in the Willamette Valley AVA based on geologic map compilation data (Madin, 2009).

Table 2. Vineyard sites organized by parent material with main soil series in parentheses.

Participating Winery	Parent Material (Soil Series) Vineyard Name			
	Volcanic (Jory)	Marine Sediment (Willakenzie)	Loess/volcanic (Laurelwood)	Other Parent Material
Elk Cove	Clay Court	Roosevelt	Five Mountain	-
Willakenzie	The Jory Hills	Aliette	-	Terres Basses
Chehalem	Stoller	Ridgecrest	Corral Creek	-
Lange	Estate	Yamhill & Freedom Hill	-	-
Rex Hill	Sims	-	Estate	Jacob-Hart
Ken Wright	Nysa	Abbott Claim & Freedom Hill	-	Meredith Mitchell

Limitations

The terroir of the Willamette Valley is also influenced by its climate, within each AVA and within each vineyard, and the winemaking and grape-growing techniques that are employed while growing the grapes and making the wine. The many variables that were documented during this research include the variation in the macroclimate between sampling years (2011 and 2012) as well as the different clones of Pinot Noir, rootstock that may or may not have been employed, trellis type and row direction, as well as farming techniques including cover crop usage, pruning, spraying, differences in soil biota, and organic or biodynamic practices. Wine-making techniques are held constant by each winery to determine differences in wine chemistry between the soils that they employ. Comparing wine chemistry between wineries does not control for various wine-

making techniques. The inability to control all these variables make evident that further study is needed. At this time, these variables were documented, but an attempt to understand their direct influence on wine flavor are research questions for another project and were not undertaken in this dissertation as I am trying to decipher the differences in the physical and chemical properties of the soils.

Chapter Two – Background

Implications of Research

Sequin (1986) hypothesized that terroir has an effect on the end flavor of wine. It is not substantiated, though, what exactly about the terroir influences the flavor of the wine. It is thought that in the northern Willamette Valley, the physical and chemical soil properties may control the variation in wine flavor (Burns, 2012). Therefore, a thorough study of the chemistry of distinct soils in comparison to the juice and wine produced from those soils may shed some light on the subject. A connection between macronutrient, micronutrient and trace elements in the soil, grape juice and wine is established here as well as the impacts of soil chemistry on wine chemistry in this region. More research based on this study may discover the impacts that soil has on wine flavor. Sensory tests were carried out after this study on the wines from the vineyards from which I collected soils. If there is a correlation between soil chemistry and the wine, sensory analysis may also show connection between the soil and the flavor of the wine.

In 1999, Simon J. Haynes wrote the first in the eleven paper series “Geology and Wine” published in Geoscience Canada which was later compiled, in addition to a few new papers, in 2006 and published by the Geological Society of Canada. Haynes (2006a) defines the factors that affect terroir into five groups. These groups are meteorological, physiographic, petrologic, geologic and viticultural factors. In short, climate, topography, soils, geology, and vineyard techniques affect the quality and taste of wine. These factors

form complex interrelationships that are included in concept of terroir. In the New World, it is very common to address one or two of these factors at a time, with the geology, and topography usually ignored (Haynes, 2006a). Haynes (2006b) focused his research in the Niagara Peninsula in Ontario, Canada and proposed that designated *appellations* (similar to AVA in the U.S. and previously designated by climate only) should be subdivided based on significant differences in geology, landform physiography, soils types, and groundwater flow. Washington, Oregon, and California are very prolific in wine production, and studies in these states have stressed the importance of many factors that influence the distinct terroir that are found there.

Terroir-based studies have been performed on geology and wine in the Umpqua Valley of Oregon (Jones et al., 2006), the Okanagan and Similkameen Valleys of British Columbia (Bowen et al., 2006), the Red Mountain Appellation (Busacca & Meinert, 2003; Meinert & Busacca, 2006a), the Walla Walla Valley Appellation in Washington (Busacca & Meinert, 2003; Meinert & Busacca, 2006b), and in the Coastal Region of South Africa (Bargmann, 2006). These studies have attempted to find correlations, trends, and connections between wine and the physical aspects of the land on which it was produced. All aforementioned studies refer to the areas where grapes of a certain quality are grown as terroir. In these papers, it is understood that geologic bedrock is the parent material for the soil, controlling composition and texture, and ultimately controls the topography of a region through weathering (Haynes, 2006b).

According to Haynes (2006a) the terroir that contributes to quality wine from a specific area includes factors of physical geology, petrology, and hydrogeology. To be more specific, these factors are elevation, types of landform, azimuth to the sun, slope aspect, and gradient, mineralogy, texture, porosity, and geochemistry, surface water and groundwater flow rate, direction and chemistry. It seems only appropriate that geoscientists be involved with viticulture and that the delineation of AVAs be based on geology, soils, and even soil chemistry (Barnard, 2009). Since the AVAs in the Willamette Valley are already separated by geology and soils, this study will fill the gap where soil chemistry is involved and provide further insight into *how* terroir affects the flavor of wine.

Terroir

The interest in the connection between geology and wine was sparked in the 1990's by the book *Terroir: The Role of Geology, Climate, and Culture in the Making of French Wines* (Wilson, 1998). In this book, Wilson explains the historic and cultural aspects of French winemaking and how quality wines have a connection with certain soils and the bedrock geology that lies underneath. According to the French dictionary, *Le Petit Robert*, the word "terroir" has many definitions, all of which can be molded together to help one understand the relationship between terroir and wine (Robert et al., 2008). The word terroir is rooted in the word territory, which refers to land that is used for diverse activities by the rural community. This territory possesses certain

homogeneous physical properties (soil, geology, drainage, etc.) which are suitable for certain agricultural products. Specifically, the nature of the soil is thought to be communicated through the character of certain products, most notably with wine. Wine, according to its terroir, will have a particular taste that is associated with the soil, geology, topography, and climate where the vineyard is located. Because of this, terroir refers to a certain region, province, or countryside that has a cultural tradition of producing wine (or other agricultural products like cheese or meat) that has certain characteristics that reflect the place of origin (Barnard, 2009). It is the “taste of the place”.

Although this concept seems subjective, many studies have used wine flavors and chemical composition to explain differences between terroirs. This dissertation attempts to fill in the gap between the soil and the finished wine. The actual uptake of elements from the soil to the vine is not well understood and testing the grapes before they undergo fermentation is a crucial part in the connection between the soil and the flavor of the wine. There are many papers that address terroir and taste or chemistry (Table 3). These publications use various methodologies to analyze chemical compounds in wines and in the vineyard soils in order to compare the wine with its terroir. Other studies use organized sensory tests to compare the flavor of wines to their terroir. This list is not exhaustive, as there are many new publications from the last ten years of research in this area of geology, soils, climate, and wine. Researchers have also performed elemental

Table 3. Publications that address terroir using sensory characteristics of wines from different geographic locations.

Author	Paper Title
Arrhenius et al., 1996	Chemical markers for aroma of <i>Vitis vinifera</i> var. chardonnay regional wines
Fischer et al., 1999	The impact of geographic origin, vintage and wine estate on sensory properties of <i>Vitis vinifera</i> cv. Riesling wines
Douglas et al., 2001	Canadian terroir: characterization of Riesling wines from the Niagara Peninsula
Sabon et al., 2002	Determination of volatile compounds in Grenache wines in relation with different terroirs in the Rhone Valley
Kontkanen et al., 2005	Canadian terroir: sensory characterization of Bordeaux-style red wine varieties in the Niagara Peninsula
Schlosser et al., 2005	Canadian terroir: sensory characterization of chardonnay in the Niagara Peninsula
Eggers et al., 2006	Classification of British Columbia's Okanagan chardonnay wines by origin using volatile components
Andrés-De Prado et al., 2007	Effect of soil type on wines produced from <i>Vitis vinifera</i> L. Cv. Grenache in commercial vineyards
West et al., 2007	Geography and vintage predicted by a novel GIS model of wine $\delta^{18}\text{O}$
Vilanova et al., 2007	Effect of terroir on the volatiles of <i>Vitis vinifera</i> cv. Albariño
Vilanova et al., 2009	Volatile composition of wines from cvs. Blanco Lexítimo, Agudelo and Serradelo (<i>Vitis vinifera</i>) grown in Betazos (NW Spain)
Tomasino et al., 2012b	Regional differentiation of New Zealand Pinot Noir wine by professionals using canonical variate analysis

analysis on wine from different vineyards in order to establish a way of fingerprinting wines to establish their location of origin (Almeida and Vasconcelos, 2003; Arvanitoyannis et al., 1999; Baxter et al., 1996; Coetzee et al., 2005; Di Paola-Narajo et al., 2011; Eggers et al., 2006; Fabani et al., 2010; Galgano et al., 2008; Greenough et al., 2005; Latorre et al., 1994; Saurina, 2010; Taylor et al., 2006; and Theil et al., 2004).

Most of these studies were able to make use of trace element analysis to discriminate and separate wines by region.

Greenough et al. (2005) concluded that climate had a great effect on trace element solubility and uptake by the vines. The increase in photosynthesis, by increasing temperature, would therefore increase water uptake by the vines and increase the trace element concentration in the grapes. The clay mineralogy and amount of clay in the soil might also have an impact on the concentration of trace elements available for the vine to take up. Greenough et al. (2005) also discovered a higher concentration of some metals in red wines compared to white wines. This time the red wine stays with the skins during fermentation, increases the concentration of Rb, Cs, Sr, Ba, and Mo in solution, therefore red wines have higher concentrations of these elements over white wines (Greenough et al., 2005). This is because the red wines are made by allowing for the grape juice to remain in contact with the skins, seeds, and other parts of the crushed grape and these elements can be released into solution during this time. White wines are only in contact with the skins for a short amount of time, limiting the contact with parts of the plants that may have more of these elements and minimizing their content in the juice. In order to control this variation based on wine type in this study, the wine used from every vineyard was Pinot Noir. The issue remains that each clone, rootstock, microclimate, and winemaking techniques may still impact the amount of trace elements taken up by the vine and incorporated into the wine.

Taylor et al. (2006) tested the correlation between trace elements in soils and wines, finding the concentration of elements in wines clustered based on location within the Okanagan Valley. This is an indication that vineyard soils, geology, and climate have an effect on the concentration of trace elements that end up in the wine produced from that vineyard. The correlation between the actual wine chemistry and soil chemistry was not strong, suggesting that wine making techniques change the trace elements in the final product and their concentrations because of precipitation, co-precipitation, filtering, and contamination from equipment. For example, the barrels, pipes, and tanks that are used may contribute trace elements to the wine that are not actually found in the soils. The winemaking equipment used for all samples in this study was not controlled, but the winemaking equipment used for all wines from each winery were, so comparison between wines from different soils can be completed.

Terroir and Soils

Terroir in France, according to Seguin (1986), can be described and delineated based on soil alone. His quick method of characterizing separate terroir uses the physical, chemical, and physicochemical analysis of the soil and subsoil. His studies concluded that the only soil parameter that is generally associated with quality wine is calcium carbonate (CaCO_3), which affects pH and nutrient uptake (Seguin, 1986). According to most university viticulture research and extensions in the United States, nitrogen-rich land usually produces unsatisfactory grapes because too many nutrients can increase the

vines' sensitivity to rot and the fruit from deep, fertile soils and large, leafy vines is not as complex as from vines that are stressed nutritionally (Dami et al., 2005). High quality wines are produced from soils that are stony, with very little clay, or from soils that are clayey and have very few pebbles (Dami et al., 2005). The variety in types of soils that are found to produce high quality wines suggests that something else in the soil, besides gravel and clay, influences wine quality. Because of the human influences on soil, which include fertilization, irrigation, and mechanical manipulations (i.e. plowing and ripping), the usable soils can vary greatly. It is well understood that the best soils, are well-drained, well-aerated, and contain no restrictive layers, like a caliché, hardpan, or fragipan (Dami et al., 2005).

The best soil is characterized by having a high degree of macroporosity (Seguin, 1986) causing rainfall to percolate quickly and allow for air in the soil for the roots of the vines. The vines require some clay in the soil mixed with organic matter, sand, and silt so that the roots can easily penetrate it (Seguin, 1986). The best soils are meters deep, with no restrictive layers, allowing for the roots to penetrate and reach the available water and nutrients (Dami et al., 2005). The soil texture (sand, silt, clay ratio) and structure (visual description of the packing of soil particles in situ) is important and ultimately controls internal drainage. More sand in the soil results in quicker drainage and the need for deeper soil thickness. The regions with quality soils in France have soil structure, porosity, and permeability that allow for root development and regulation of water supply

to the vine. These physical properties of the soil will ultimately limit the effects of climatic destruction from either heavy rainfall or drought by allowing for the vines to neither be suffocated by too much water nor dry out from the lack (Seguin, 1986).

Willamette Valley Geology

The geology of the Willamette Valley is the main influence on the soil development. The bedrock, subsequent weathering, and geomorphic processes determine the topography of an area. Chemical nutrients are liberated from the bedrock as it is weathered into soil, making them available for the grape vine. Physical characteristics of the soil like depth, particle size, and drainage greatly affect the quality of the grapes (Andrés-de Prado et al., 2007; Berry, 1990; Burns, 2012; Busacca and Meinert, 2003; Haynes, 2006a; Haynes 2006b; Joyce, 2004; Moore, 2005; White, 2009; and Wilson, 1998).

The geology of Western Oregon consists of bedrock that ranges in age from about 52 million years ago to present. The western Cascades make up the eastern edge of the Willamette valley and are composed of lava flows, tuff, and alluvial sediments of the now buried volcanic arc. The Coast Range flanks the Willamette Valley to the west. These marine sediments were deposited over millions of years during the Paleogene and Neogene periods are now uplifted and form the Coast Range due to continued subduction off the coast of Oregon and the down-warping of the Willamette Valley. The Coast

Range also includes volcanic and intrusive rocks of the Siletz volcanics from uplifted seafloor rock (Madin, 2009).

About 17 to 15 million years ago, the Columbia River Basalts were deposited as lava flowed from hot spot vents in eastern Washington and Oregon toward the ocean. These basalt flows covered much of the state and are exposed in the Willamette Valley. The ancient rivers in the last 15 million years ago deposited sands and gravels in the Willamette Valley, and these sediments are now referred to as the Troutdale Formation. The Cascade Range is only a few million years old and young volcanoes, referred to as the Boring Lavas, penetrate the Troutdale Formation in the valley forming many of the uplands in the urbanized area around Portland (Moore, 2002; Madin, 2009). This is not commonly where vineyards are located but is included in the description of the Willamette Valley geology in order to provide context and explain map units.

From 15,000 to 18,000 years ago, the Willamette Valley was affected by cataclysmic floods referred to as the Missoula Floods (Allen et al., 2009; Atwater, 1984; Bretz, 1969; DOGAMI, 2015; Moore, 2002; and Peterson et al., 2011). These deposited many rhythmites, graded beds of sand and silt, that represent each flooding event, in the valley bottom up to around 91.5 meters (300 feet) above sea level (Moore, 2002). These events are named the Missoula Floods after the glacial Lake Missoula that breached its ice dam and scoured eastern Washington's Channeled Scablands and flowed down the Columbia River Gorge (Allen et al., 2009; Atwater, 1984; Bretz, 1969; and Peterson et

al., 2011). It has also been shown that there were many floods that occurred before the Missoula Floods referred to as the ancient cataclysmic floods (2.6 million to 18,000 years ago) that may have deposited sediment in the Willamette Valley (Medley, 2012).

The major geologic events important to this study are the deposition and subsequent uplift of marine sediments in the Coast Range, the volcanic rocks of the Columbia River Basalt flows, and the Missoula Floods and other ancient flood deposits. Following the flood deposits, loess from the valley bottoms was deposited on the hillsides through eolian transport, which adds parent material to soils that were already developing on the volcanic rocks there. For this study, the geological units that exist in the Willamette Valley are separated into four groups as parent material for the soils. These are volcanic rock, marine sediments, loess and volcanic rock, and Missoula Flood sediments (Table 4).

Table 4. Major geologic units in the northern Willamette Valley.

Parent Material or Bedrock	Geologic Units	Includes
Volcanic	Columbia River Basalt Group (CRB)	Grand Ronde Basalt and Wanapum Basalt
Marine Sediments	Yaquina-Pittsburg Bluff Fm., Keasey Fm., Spencer Fm., Yamhill Fm., Scotts Mills Fm., Nestucca Fm.	Sandstone, siltstone, and mudstone
Loess	No Unit (Overlies Volcanic CRB)	Quaternary eolian silt
Flood Sediments	Missoula Flood Deposits	Silt, sands, and gravels

The current Sub-AVAs in the Willamette Valley AVA were delineated based on broad geologic differences (Figure 3). In general, the Chehalem Mountains and Dundee Hills AVAs are delineated by the Columbia River Basalt (CRB) bedrock and the soils that formed on this parent material. The addition of loess to various parts of these two AVAs further separates the soils that form in this area. The loess dominates as the parent material in the Chehalem Mountains, hence a different Sub-AVA. The Yamhill-Carlton AVA is outlined around the Coast Range marine sedimentary bedrock, and the soils that develop on this parent material are physically and chemically different from soils that develop on the Columbia River Basalts.

Soils and Geology

Wilson (1998) noticed that the Alsace and Haut-Beaujolais regions of France were mostly underlain by acidic and sandy soils on granite type bedrock. Most of the other regions were on carbonate bedrock that creates alkaline soils with good soil structure and have active calcium carbonate that favors moisture retention (Wilson, 1998). He claims that grapevine roots can obtain great depths to avoid drought, and that the most popular soils had no caliché, or hardpan, and a granular structure with approximately 25% sand. Higher clay content and abundant rock fragments or pebbles were also commonly found within the *AOC* boundaries compared to directly outside them. The sloping bedrock, created by the uplift and deformation from mountain building, helps drainage, and the fractures in the bedrock contribute to an increase in

Figure 3. Preliminary geologic map produced by the USGS showing how the new Sub-AVAs of the northern Willamette Valley are outlined based on bedrock geology types. Ty – Tertiary Yamhill Formation, Tdb – Tertiary Diabase intrusions, Tes – Tertiary Spencer Formation, Tk – Tertiary Keasey Formation, Tpe – Tertiary Pittsburg Bluff Formation, Tsd – Tertiary Scappoose Formation, CRB – Columbia River Basalt (Wells, 2006).

water storage. Therefore, the vigor of the grape vines is closely related, through porosity and permeability, to bedrock geology and soil type. Wilson (1998) emphasizes the importance of soils to the complexity of regional terroir studies.

In a previous study, GIS revealed 23 soils were being used for wine-grape growing purposes (Table 5) in the northern Willamette Valley (Starr-Peace, 2005). The most common was the Jory soil series, which forms on volcanic parent material and is an Ultisol, which is defined as “a highly weathered leached red or reddish-yellow acid soil with a clay-rich B horizon (subsoil), occurring in warm, humid climates” (Soil Survey Staff, 1999). The second most common was the Willakenzie soil series, which forms on marine sediments and is an Alfisol, which is defined as “a soil of an order comprising leached basic or slightly acid soils with a clay-enriched B horizon (subsoil)” (Soil Survey Staff, 1999). The third most common is the Laurelwood soil series, which forms on loess and volcanic parent material and is also an Alfisol. The other soils have Missoula Floods parent material (only 10%) or are similar to the first three based on parent material (Starr-Peace, 2005 and Burns, 2012).

In the Willamette Valley the Columbia River Basalt, volcanic rocks, underlie the Jory soil series (called the Nekia soil series where it is thin). The uplifted marine sedimentary rocks of the Oregon Coast Range underlie the Willakenzie soil series and its

Table 5. Distribution of soils in the vineyards in the northern Willamette Valley (Starr-Peace, 2005, and Burns, 2012)

Soil series	Parent Material	Order	Acres
Jory	Basalt	Ultisol	1,504
Willakenzie	Marine sediments	Alfisol	1,245
Laurelwood	Basalt [& Old loess]	Alfisol	825
Yamhill	Basalt	Mollisol	333
Woodburn	Missoula Floods	Alfisol	298
Nekia	Basalt	Ultisol	195
Cornelius	Old loess	Alfisol	141
Saum	Basalt	Inceptisol	126
Bellpine	Marine sediments	Ultisol	118
Willamette	Missoula Floods	Mollisol	110
Dupee	Marine sediments	Alfisol	58
Peavine	Marine sediments	Ultisol	50
Helvetia	Mixed	Mollisol	45
Cascade	Young loess	Inceptisol	31
Wellsdale	Marine sediments	Alfisol	31
Steiwer	Marine sediments	Mollisol	28
Carlton	Missoula Floods	Mollisol	25
Amity	Missoula Floods	Mollisol	24
Melbourne	Marine sediments	Alfisol	18
Aloha	Missoula Floods	Inceptisol	15
Hazelair	Missoula Floods	Mollisol	12
Chehalem	Mixed	Mollisol	10
Dayton	Missoula Floods	Alfisol	6

cousins (Goodin, Wellsdale, Melbourne, Dupee, and Bellpine). The areas that consist of underlying Columbia River Basalt but also have loess deposits underlie the Laurelwood soil series (Figure 4). At elevations below approximately 90 meters (300 feet), the Missoula Flood sediments underlie the Woodburn Soil Series and its soil series cousins

(Amity, Aloha, Concord, Dayton, and Willamette). In general, the soil order is determined by many factors including color, clay percent, depth, base saturation, and pH, and these orders can develop on any sort of parent material based on climate, time, biota, and other variables.

Climate

The climate has an effect on wine at many levels. Firstly, regional climate determines which varieties can grow at a given site. In a cool-climate region with a xeric moisture regime (dry in the late growing season), like the northern Willamette Valley (Jones et al., 2012), the best varieties include Pinot Noir, Pinot Gris, Pinot Blanc, Chardonnay, Riesling, Gewürztraminer and Müller Thurgau. Warm-climate regions (Jones et al., 2012) like the Walla Walla area in Washington or the AVAs in southern Oregon can grow grapes that require more growing degree days (GDD). These varieties include Merlot, Cabernet Sauvignon, Zinfandel, Cabernet Franc, Sauvignon Blanc, Tempranillo, and others (Jones et al., 2012). GDD are calculated by taking the average temperature for each day and then subtracting the base of 50 °F or 10 °C (Equation 1). Cumulative GDD are calculated by adding any GDD for that season above zero. Grapes will ripen when a certain number of GDD are reached, depending on the variety. This is the reason that Pinot Noir is the preferred variety for the Willamette Valley; it matures in areas with lower GDD's.

Figure 4. A general soil series map highlighting the Willakenzie, Jory, Woodburn and Laurelwood soils from the NRCS soil data (Soil Survey Staff, 2010b) with the sub-AVAs in the Willamette Valley AVA outlined (Jones et al., 2010).

Equation 1. Growing degree days (GDD) where $T_{\max}$ = daily maximum temperature, $T_{\min}$ = daily minimum temperature, and $T_0 = 50^{\circ}\text{F}$ or 10°C .

$$GDD = \left(\frac{T_{\max} + T_{\min}}{2} \right) - T_0 \quad (1)$$

In addition to the climate variability that occurs because of latitude, topography has a major role in the microclimate in a vineyard. At this scale, a hill's slope can have variable growing degree days because of the tendency for cool air to sink to the lower elevations and slow the ripening process (Wilson, 1998). The microclimates in a vineyard are based on the variable sun exposure that is controlled by the aspect and slope, the primary wind direction, and its relation to vine row orientation, and elevation differences.

Oregon's American Viticulture Areas

An AVA is an area designated by the US Department of Treasury - Alcohol and Tobacco Tax and Trade Bureau (ATTTB) that has a history of wine making and applied for the label (TTB, 2007). The geographic "pedigree" of a wine is labeled with its origin, and the wine must meet certain federal and state requirements. An AVA is one type of *appellation*, and a vintage labeled with the AVA origin must have used 85% of the grapes from inside the AVA boundary (see US Code of Federal Regulations 27 CFR). According to Pomeroy (1989) the geological and pedological nature of an area determines the delineation of an *appellation* and the terroir for that specific wine. The close relationship that exists between the bedrock geology, soil texture and structure, stoniness, depth and chemical composition (Barham, 2002). From this, the description of current

AVAs, the justification of their boundaries, and creation of new AVAs should be based, at least partly, on the geology, soil, and topography of the vineyards in that region (Barham, 2002; Haynes, 2006b; and Barnard, 2009).

An AVA can range in size and in the concentration of vineyards within their boundaries. AVAs may cover up to 3 states, and if the AVA is to be on the vintage, 100% of the grapes must be grown in the labeled states. A bottle can be labeled from a state appellation, different than a designated AVA, if at least 75% of the grapes are grown within the state (TTB, 2007). An AVA does not guarantee the quality of any wine like the French AOC does but guarantees from where a substantial portion of the grapes originated. The boundaries of an AVA usually follow rivers, township and county lines, mountain ranges and valleys, or even power lines and roads. Most AVA boundaries in the United States were not drawn with consideration of soil and geology, and many are now being separated into sub-*appellations* because, when taken into account, these physical parameters are connected to the growing requirements of certain grape varieties (Haynes, 2006b).

Oregon is split up into 17 AVAs (Figure 1), some of which include areas in Idaho or Washington like the Snake River Valley, Walla Walla, Columbia Valley, and the Columbia Gorge AVAs. The Southern Oregon AVA is split into five separate AVAs called the Umpqua Valley, which includes Red Hills Douglas County and Elkton AVAs,

and the Applegate Valley AVA which is in the middle of the Rogue Valley AVA. The Willamette Valley AVA includes six smaller sub-AVAs (Figure 5). Of these six, the Chehalem Mountains AVA is the most northern and closest to the city of Portland. The other sub-AVAs, from the north to south, are the Ribbon Ridge, Yamhill-Carlton, Dundee Hills, McMinnville, and Eola-Amity Hills (Moore, 2002). These AVAs were all delineated based on the geology and soils that influence the variation in wine that is produced in each location (Burns, 2012; Moore, 2002).

The Chehalem Mountains AVA consists mostly of upraised Miocene age Grand Ronde Basalt of the Columbia River Basalt Group bedrock overlain by a layer of weathered loess (Figure 2). Most of the loess is “older loess” deposited on the north east side of Chehalem Mountain that was blown up from the Tualatin Valley floor after ancient floods, older than the Missoula Floods, and the soils are more weathered than Missoula Flood loess (Burns, 2012). The southern part of the Chehalem Mountain AVA is mapped as having Jory or Willakenzie soils.

One sample is in the Chehalem Mountain AVA, Elk Cove’s Clay Court Vineyard, which is clearly a Jory soil and two sample sites on the southwest side of the Chehalem Mountains that are located on the ancient landslide complex and potentially overlying Coast Range marine sediments and incorporating volcanic rocks of the Columbia River basalt group. The Ribbon Ridge and Yamhill-Carlton AVAs consist of marine

sedimentary rocks from the Oligocene age Yaquina-Pittsburg Bluff Group and Eocene age Spencer Formation and Yamhill Formations. The Dundee AVA consists of the Grand Ronde Basalt without the layer of loess. The Eola-Amity Hills are mostly Grand Ronde Basalt with marine sedimentary rocks of the Keasey or Pittsburg Bluff Formations on the western side. The McMinnville AVA is mostly marine sedimentary rocks of the Nestucca or Yamhill Formations with pockets of basalt and diabase of Lee's Falls (Madin, 2009).

Chemistry

The chemistry of vineyard soils is important to know for the health and growth of the plant, but also because some believe the flavors in wine are somehow connected to the amount of certain elements in the soil. These elements can be separated into a few groups. Macronutrients derived from air and water include carbon (C), hydrogen (H), and oxygen (O). Primary macronutrients to sustain plant life include phosphorus (P), potassium (K) and nitrogen (N) and secondary macronutrients include sulfur (S), calcium (Ca), magnesium (Mg), chloride (Cl), and silicon (Si) (White, 2003; White, 2009; and Burns, 2012). Also needed to sustain plant life, but in lesser quantities, are micronutrients which include iron (Fe), molybdenum (Mo), boron (B), copper (Cu), manganese (Mn), sodium (Na), zinc (Zn), and aluminum (Al). There are other elements found in soils that are not considered nutrients and I will refer to them as trace elements throughout this study. These trace elements include arsenic (As), barium (Ba), beryllium (Be), cadmium

Figure 5. The Willamette Valley American Viticultural Area (AVA) outline and the northern Willamette Valley Sub-AVAs (Jones et al., 2010).

(Cd), chromium (Cr), cobalt (Co), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), strontium (Sr), and vanadium (V) (White, 2003; White, 2009; and Burns, 2012).

Studies that successfully determined a correlation between trace elements found in wine and region of origin used an ICP-MS, or similar equipment, to determine trace element concentrations and a “fingerprint” for each wine region was established. It has been shown that inorganic chemical patterns in wine are a reflection of the local geochemical composition of the soil and are highly influenced by the bioavailability of these compounds (Greenough et al., 1997). Wine authenticity can be identified using organic constituents, metal composition or by stable isotopes (Almeida et al., 2002; Álvarez et al., 2007; Arvanitoyannis et al., 1999; Augagneur and Medina, 1996; Castiñeira-Gómez et al., 2004; Coetzee et al., 2005; Eschnauer et al., 1989; Frías et al., 2003; Louw et al., 2009; and Pohl, 2007).

In some cases, Li and Rb or Mg has been shown as a useful tool to discriminate wines from different Spanish regions (Galgano et al., 2008 and Gonzalvez et al., 2009). Mg was also shown to be a statistically significant element when connecting the vineyard soil to the wine produced from it in both Czech (Kment et al., 2005) and Argentinean wines (Fabani et al., 2009 and Fabani et al., 2010). Kment et al. (2005) analyzed wine samples in the Czech Republic with ICP-MS after microwave digestion to determine Ag, Al, As, Ba, Be, Cd, Co, Cr, Cs, Cu, Li, Ni, Pb, Rb, Sr, Sb, Tl, U, V and Zn. From this

research, many correlations were determined between elements based on the plants ability to take them up or because of their existence coming from the same source. The most statistically significant correlation between soil chemistry and wine chemistry was found for Mg suggesting that it is the most reliable element that can be traced from the soil to wine chemistry (Kment et al., 2005).

In the study conducted by Di Paola-Naranjo et al. (2011), the analysis of elements was carried out using ICP-MS for all elements except Na, which was measured using flame atomic absorption spectrometry (FAAS). The results of this analysis found a significant correlation between the wine and soil Ba, K, La, B, V, Cd, and Ca from the regions tested in Argentina. The overall soil-plant interaction is so complex that the relationship between the elemental composition of the soil and the wine is hard enough to distinguish without the complicating factors of wine making and processing (Taylor et al., 2003). In the study performed on Okanagan and Niagara regions, Sr and Rb seem to be the most useful elements when distinguishing wine produced in the two regions because the soil Sr concentrations also differed. This result has been seen in many other studies including those by Baxter et al. (1996), Szentmihalyi et al. (2000), and others suggesting that multielement analyses using ICP-MS are useful in determining wine fingerprints and provenance.

The amount of these elements in the wine is greatly determined by the solubility of the element in the soil (Perk, 2006). Other factors that might impact the amount of these elements in wine include agricultural practices, climate changes (drought), and winemaking techniques as well as the type of grape since plant uptake might vary between varieties. In a study of multiple elements in soil, grapes, juice along the many stages of fermentation, and the final wine, Almeida and Vasconcelos (2003) used ICP-MS and AAS to find elemental concentrations. Conclusions showed that Cd, Cr, Cu, Fe, Ni, Pb, V, and Zn were all added to the grape juice during the winemaking process. Most concentrations of other elements were similar or even lower in the final product than in the grape juice prepared in the factory. This is attributed to precipitation or co-precipitation in sediments of some elements and organic complexing agents like polyphenols and tannins for others (Almeida and Vasconcelos; 2003). This suggests that the presence of these elements may cause the precipitation of some polyphenols and tannins, and therefore affects the end flavor of the wine. This study also determined, from collecting soil samples every two months and analyzing them that the elemental concentrations did not vary seasonally, and therefore any month could be used when comparing soil and wine concentrations. Although there are lower concentrations of the elements in the final product than in the soil, a significant correlation between all elements except Al, Fe, and Ca was found (Almeida and Vasconcelos, 2003).

Grape Juice Chemistry

The chemistry of grape juice should mimic the chemistry of the soil on which the grapes were grown since some elements in the soil are taken up by the grapevine and incorporated in the grapes themselves. With enough water in the soil, the vines will be able to take up macro and micronutrients and incorporate them into various parts of the plant. Elements such as B, Cu, Fe, Mn, Mo, Ni, and Zn are all involved in many metabolic and cellular functions including protein stabilization and enzyme activation and should be present in the berry clusters (Yang., 2010). Fe will be present in the highest levels in the berry skin, pulp, and seeds and Sr, Mn, Zn, B, and Cu will also be present but at much lower concentrations (Yang, 2010). Therefore, the more of these elements are present in the soils on which these vines are grown, the more there will be in the grapes produced on those vines depending on how long the grape juice is in contact with the seeds, skins, pulp, and stems.

Wine Chemistry

Similar to the juice chemistry, the wine chemistry should mimic the soil chemistry with the exception of contamination from wine making techniques. Pinot Noir, as a red wine, should have concentrations of trace elements that are similar to the juice and soil chemistry since the wine is in contact with the skins, seeds, and pulp for a time and therefore is able to release the trace elements that are incorporated in those tissues (Yang, 2010). This mimicry will enable us to use the trace elements to create regional

fingerprints for the Willamette Valley wine chemistry (Taylor et al., 2003, Coetzee et al., 2005, Galgano et al., 2008). The input of various yeasts, wine treatments, and use of different types of oak will either diminish or increase some of these trace elements in amounts that are unknown at this time.

Chapter Three – Methods

Selection of Sites

Six wineries were chosen with the three soil groups to keep the factors affecting the wines constant as much as possible. Two wineries had all three soil groups (Elk Cove Vineyards and Chehalem), three had volcanic and marine soil groups (Willakenzie Estate, Lange Estate Winery and Vineyards, and Ken Wright Cellars) and Rex Hill had volcanic and loess/volcanic soil groups (Table 2). In order to compare physical and chemical differences in soils, the samples were collected by hand during the summers of 2011 and 2012 from twenty different vineyard sites (Figure 6). I am able to compare grape juice and wine chemistry made by the same winemaker but from grapes grown on the different soils. Winemakers allowed for me to collect grape samples directly from the vineyards within a week of their scheduled harvesting. Wine samples were collected by the winemakers before blending with other parts of the vineyard or before blending with other vineyards in order to associate the wine chemistry with the grape and soil chemistry.

According to prior research, Burns (2012) found that the three most used soil series in the northern Willamette Valley are the Jory, Willakenzie, and Laurelwood soils (Table 5). During the summers of 2011 and 2012, twenty soils were sampled belonging to

Figure 6. Soil pit locations in the northern Willamette Valley, Oregon provided by six different wineries with AVA boundaries shown (Jones et al., 2010).

these six different wineries (Table 6 and Table 7). It was determined that, out of the 20 soils sampled, six do not belong to the Willakenzie, Jory, or Laurelwood series and three of those six are close “cousins.” The Bellpine Series is a close “cousin” to the Willakenzie and the Nekia series is a close “cousin” to the Jory (Moore, 2002; Burns, 2012). Two soil pits were later designated as Witham series (Terres Basses) and Dixonville series (Jacob-Hart Block 1). One soil pit (Meredith Mitchell) was located in the McMinnville AVA and is mapped as Yamhill Series while Jacob-Hart Block 5 is mapped as Yamhill but is not likely to belong to that group and is more likely to be a part of the Steiwer series. This information belies the need to not only use current soil maps when looking for a vineyard soil, but also the need for site specific soil sampling since they maps are inaccurate at this scales in this instance.

Soil Physical Characteristics

Soil pits were dug using a pick axe and shovels until the pit was about one cubic meter in size. A soil auger was then used until refusal or the end of the auger (another meter depth) in order to collect deep samples and complete the soil profile. At each soil pit a full description of horizons was done in the field according to the procedures outlined in Birkeland (1999). This description includes depth of the horizon, dry soil color using the Munsell Soil Color Chart, structure, hardness/friability, stickiness and plasticity, soil texture, horizon boundary, pores and clay films, and any other notable observations like roots, concretions, and signs of krotovina (animal burrows) or other

Table 6. Sample ID and parent material information for the vineyards sampled in 2011.

Sample ID	Winery	Vineyard	Parent Material	Bedrock Mapped	NRCS Mapped Soil Series	AVA	Elevation (feet)
ECCC	Elk Cove Vineyards	Clay Court	Volcanic	Columbia River Basalt	Jory	Chehalem Mountains	610
ECRV	Elk Cove Vineyards	Roosevelt	Marine Sediments	Spencer Formation	Goodin-Melbourne complex (Willakenzie)	Yamhill-Carlton District	620
ECFM	Elk Cove Vineyards	Five Mountain	Loess/volcanic	Columbia River Basalt	Laurelwood	Chehalem Mountains	360
WEJH	Willakenzie Estate	The Jory Hills	Volcanic	Columbia River Basalt	Jory	Dundee	490
WEA	Willakenzie Estate	Aliette	Marine Sediments	Spencer Formation	Melbourne-Goodin complex (Willakenzie)	Yamhill-Carlton District	600
WETB	Willakenzie Estate	Terres Basses	Missoula Flood Sediments	Yamhill Formation	Witham	Yamhill-Carlton District	290
CWS	Chehalem	Stoller	Volcanic	Columbia River Basalt	Jory	Dundee	480
CWR	Chehalem	Ridgecrest	Marine Sediments	Pittsburg Bluff Formation	Wellsdale (Willakenzie)	Ribbon Ridge	640
CWCC	Chehalem	Corral Creek	Loess/volcanic	Columbia River Basalt	Laurelwood	Chehalem Mountains	370

Table 7. Sample ID and parent material information for the vineyards sampled in 2012.

Sample ID	Winery	Vineyard	Parent Material	Bedrock Mapped	NRCS Mapped Soil Series	AVA	Elevation (feet)
LEM	Lange Estate Winery and Vineyards	Estate Mia North	Volcanic	Columbia River Basalt	Jory-Gelderman	Dundee	720
LEY	Lange Estate Winery and Vineyards	Yamhill	Marine Sediments	Spencer Formation	Wellsdale-Willakenzie-Dupee complex (Willakenzie)	Yamhill-Carlton District	450
LEFH	Lange Estate Winery and Vineyards	Freedom Hill	Marine Sediments	Spencer Formation	Bellpine (Willakenzie)	Willamette Valley	340
RHS	Rex Hill	Sims	Volcanic	Columbia River Basalt	Jory	Dundee	660
RH12	Rex Hill	Estate Block 12	Loess/volcanic	Columbia River Basalt	Laurelwood	Chehalem Mountains	310
RHJH1	Rex Hill	Jacob Hart Block 1	Landslide	Scappoose Formation	Dixonville	Chehalem Mountains	320
RHJH5	Rex Hill	Jacob Hart Block 5	Landslide	Scappoose Formation	Dixonville	Chehalem Mountains	380
KWN	Ken Wright Cellars	Nysa	Volcanic	Columbia River Basalt	Jory	Dundee	710
KWAC	Ken Wright Cellars	Abbott Claim	Marine Sediments	Spencer Formation	Wellsdale-Willakenzie-Dupee complex (Willakenzie)	Yamhill-Carlton District	480
KWFH	Ken Wright Cellars	Freedom Hill	Marine Sediments	Spencer Formation	Bellpine (Willakenzie)	Willamette Valley	470
KWM	Ken Wright Cellars	Meredith Mitchell Martha Block	Coast Range Volcanic	Diabase Intrusions	Witzel-Dixonville	McMinnville	670

bioturbation. Field descriptions were carried out by me and my advisor, Dr. Burns, with various field assistants. The field documents were organized so that no part of the soil description was overlooked. Each horizon was sampled with ½ liter of soil in Ziploc® Brand bags to be taken back to the lab for further analysis. Pits were filled and sod replaced in order to limit visibility of the hole and effect on vine roots. Vines immediately adjacent to the pit were flagged in order to find them to collect grape berry clusters at harvest for elemental analysis. Photos were taken of each site of the vineyard and the soil pit as well as the GPS location and elevation. Vineyard managers and winery owners/winemakers were also asked the clone, rootstock, and age of vines (Table 8).

I used Buntley-Westin (Buntley and Westin, 1965) color index to determine the level of soil profile development and relative age of the soils. This index utilizes the rubification (color) of the dry soil to determine the level of soil profile development that has occurred. The air dried lab samples are given colors using the Munsell Soil Color Charts, and this information is used to determine the relative age of the soils. The index is based on the idea that the soils get redder with age, and the higher the index number, the older the soil is (Birkeland, 1999). A Buntley-Westin value larger than 10 indicates the soil is at least 5000 years old and values larger than 15 indicate soils greater than 10,000 years old (Miller and Birkeland, 1974). Grain size analysis determined the percentage of

gravel, sand, silt, and clay that contributes to the soil as a whole using the pipette method (Gee and Bauder, 1986).

Table 8. Winery and vineyard name for each sample location with the year the vines were planted, clone, and rootstock used (ND – No Data).

Sample ID	Year	Clone	Rootstock
ECCC	2001	Dijon 777	RG
ECRV	1994	Pommard	Own-rooted
ECFM	1993	Dijon 777/115/Pommard	101-14
WEJH	2002	Dijon 115	101-14
WEA	1992	Pommard	5C
WETB	1997	Dijon 113/115	3309
CWS	1995	Pommard	3309C
CWR	1985	Pommard	Own-rooted
CWCC	1985	Pommard	Own-rooted
LEM	2004	Dijon 777	3309
LEY	1986	Pommard	Own-rooted
LEFH	2002	Dijon 777	44-53
RHS	2000	Pommard	3309
RH12	1982	Dijon 777	108 Chardonnay
RHJH1	1989	Wädenswil	Own-rooted
RHJH5	2001	Pommard	Own-rooted
KWN	1990	Pommard	Own-rooted
KWAC	2001	Dijon 777	101-14
KWFH	2002	Wädenswil	4453
KWM	1988	Pommard	Own-rooted

Soil Chemistry

Soil pH was assessed in the lab using the Hanna Instruments bench top 211 pH meter. A 1:1 (soil:deionized water) sample of soil was prepared by taking 20 gram sample from each horizon and mixing with 20 ml of de-ionized water in order to fully submerge the probe (Soil Survey Staff, 1975). Three samples from each horizon were taken and the mean calculated. Organic matter was determined by loss on ignition using the methods adapted from Lim and Jackson (1982) and the Method of Soil Analysis used in the Soil Testing Laboratory at Oregon State University (Horneck et al., 1989).

I analyzed the macronutrients (P, K, Ca, Mg, S, and Cl), micronutrients (Fe, Mn, Mo, Cu, Zn, Na, and Al) and other trace elements (As, Ba, Be, Cd, Cr, Co, Pb, Hg, Ni, Se, Sr, and V) (Perk, 2006; White, 2009; and Burns, 2012) in soil samples, grape juice, and wine produced from these vineyard soils in the northern Willamette Valley. C, H, O, and N were not analyzed because these elements vary greatly based on time of day or year of sampling and vineyard management practices. Because of lab limitations, B was not measured even though it is an important micronutrient. Al and Na are micronutrients and Co and Ni are trace elements that were added to this analysis even though not considered by White (2009) to be significant to wines. The physiography (elevation, slope, aspect) at each site was documented during sample collection and the age of the vine, rootstock used, vineyard management techniques, and other information was

gathered from the vineyard managers and owners. The amalgamation of these data provides a base for further study into the terroir of the Willamette Valley, Oregon.

Soil bulk chemistry was completed by Apex Laboratories (Tigard, Oregon) using three different methods after completing microwave digestion following method 3051A (EPA, 2007a). Soils were digested and acid-preserved prior to analysis (EPA, 1998; EPA, 2007a; EPA, 2007b: and EPA, 2007c). Chloride (Cl) content of the soils was measured using Ion Chromatography method 9056A (EPA, 2007c). In order to measure elemental concentrations of many orders of magnitude, both ICP-MS and inductively coupled atomic emission spectrometry (ICP-AES) were used. Al, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, V and Zn were measured using ICP-MS method 6020A (EPA, 1998). ICP-AES was used to determine trace elements including Al, Ca, Fe, Mg, P, K, Na, Sr, and S using method 6010C (EPA, 2007b). This method also requires acid digestion prior to analysis. The lab utilized both ICP-MS and ICP-AES for some elements including Al, Ca, Fe, Mg, and K, because some samples had higher concentrations than the ICP-MS allowed. This method is not a total digestion technique for most samples, but it is a strong acid digestion that will dissolve almost all elements that could become “environmentally available” (EPA, 2007a). The digestion of soil samples utilized nitric acid (HNO₃) and hydrogen peroxide (H₂O₂). Trace elements analyzed using 6010C were digested with an addition of hydrochloric acid (HCl) (EPA, 2007a).

Most elements were measured using method 6020A after digestion, with a determination of sub- $\mu\text{g/L}$ (ppb) in digests (EPA, 1998). Trace elements were measured using method 6010C after digestion (EPA, 2007b). Chloride was measured using method 9056A (EPA, 2007c). Dilutions were performed and appropriate factors were applied to sample values. The accuracy of the results returned by Apex Laboratories is summarized in Appendix C. The methods used for QAQC at Apex Laboratories include calibration every morning and control samples are run every ten samples. Blanks should return a ND, or non-detect, to ensure no cross-contamination in the analytical methodology. Then known amounts are analyzed to check for analytical accuracy.

All blanks for the ion chromatography resulted in ND. The accuracy of the ion chromatography shows a recovery percent (%REC) between 91% and 101% for spikes of Cl between 39.3 mg/kg and 40.0 mg/kg with a %REC limit between 90 and 110% and a relative percent difference (RPD) between 0.2% and 4% with a RPD limit of 15% for multiple batches. Similar results were reported for the ICP-MS where all blanks resulted in ND and spikes were done for each element. For example, the Ca spike was 5000 mg/kg and the result was 4890 mg/kg, a 98% REC with REC limits between 80% and 120%. The RPD value for Cr was 0.08, well within the laboratory's QAQC RPD limit of 40%. The spike recovery and/or RPD was outside acceptance limits only 12 times and spike recovery and/or RPD was outside control limits due to high concentration of analyte present in the sample 31 times during QAQC. The original batch QC sample was

reanalyzed in most cases. A matrix interference was suspected twice for CWS V and Se and a serial dilution fail or matrix interference may have occurred once in the WETB Al analyses. For more details, refer to Appendix C.

Grape Juice and Wine Chemistry

Grape juice and wine samples were analyzed for the same bulk elemental composition as the soils by Apex Laboratories LLC in Tigard, Oregon using ICP-MS (EPA method 6020A) and ICP-AES (EPA method 6010C). Whole berry clusters from vines immediately adjacent to the soil pits were collected at harvest in the fall of 2011 and 2012. The grapes were frozen until all were collected and then approximately 150 ml of whole berries were delivered to APEX Laboratories for analysis. Whole berries were crushed, and the juice was acid digested prior to analysis using EPA method 3051a (EPA, 2007a). Wine was analyzed using the same methods as the juice. Both the grape juice and wine were analyzed by APEX Laboratories in the same manner as the soil samples using ICP-MS and ICP-AES as well as ion chromatography for the Cl. Quality control data is located in Appendix C.

Samples of wine from the soil pit block were collected from the wineries before the wine from that block could be blended with others. Vineyards are usually broken up into smaller blocks by varietal, clone, or to provide space for tractors to navigate through the vineyard. These blocks usually consist of a small amount of rows that can be

harvested and grouped together. Extra vintages from Chehalem and others from the same vineyards were also analyzed to look for trends in wine chemistry relating to vintage. There were 21 wine samples in total from the six different wineries. Approximately 150 ml of each wine was collected from the wine bottle when opened for sensory analysis. The wine samples were taken immediately to Apex Laboratories at the end of the day. Some wines were sampled and analyzed multiple times for the same elements, therefore the mean concentration and standard deviation using both sets of results for these sites is reported in the results section.

Clay Mineralogy

After pipette analysis was completed and the exact texture of the soil can be obtained from percentages of sand, silt and clay, 50 ml of sample was drawn from the graduated cylinder from the upper 30 cm of the column and placed in a cup to settle and allow some of the water to evaporate. This sample contains only the clay fraction and was analyzed using the x-ray diffraction (XRD) by Dr. Reed Glasmann at the Willamette Geological Service (Philomath, Oregon). Clays were Mg-saturated by rinsing several times with 0.5N MgCl_2 , then rinsed with distilled water. Clays were then K-saturated by washing several times with 1.0M KCl, then rinsed with 50% methanol solution. The Mg-saturated slides were analyzed after air drying, then solvated with ethylene glycol and re-scanned. The K-saturated slides were analyzed after air drying then rescanned after 6 hours in an 110C oven. The scan conditions were shortened to try to limit re-hydration

during analysis, but some minor re-expansion of smectitic clays was found in the patterns (Appendix B).

Data Analysis

These data were then analyzed using XLSTAT for Microsoft Excel 365. Principal Component Analysis (PCA) was used to find correlations between soil physical characteristics and soil chemistry, grape juice chemistry, and wine chemistry. All vineyard sites were included. Soil physical and chemical characteristics included in the analysis were clay percent, silt percent, and sand percent from grain size analysis, Buntley & Westin soil color index, depth to Bt horizon, depth to bedrock, organic matter, pH, CEC, and elemental analysis of the 25 elements using ICP-MS, ICP-AES, and ion chromatography (Al, As, Ba, Be, Cd, Ca, Cl, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, P, K, Se, Na, Sr, S, V, and Zn). Grape juice chemistry included 9 elements detected in the grape juice (K, Na, Sr, P, Mg, Mn, Ca, Cu, and Zn). Wine chemistry included 15 elements detected in the wine (Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, Ni, P, K, Na, Sr, S, and Zn). Pearson type PCA was used for all data.

Chapter Four – Elk Cove Vineyards Results

Volcanic Parent Material – Clay Court Vineyard, Block E

Physical Characteristics

The Clay Court Vineyard (ECCC), owned and operated by Elk Cove Vineyards, is located in Sherwood, Oregon. This vineyard is on basaltic rocks of the Columbia River Basalt group on a hillcrest of a south facing slope of 0 to 1 degrees with vine rows running north and south (Lat. 45.325479 N, Long. -122.834909 W). The soil pit location is at 611 feet (186 meters) elevation between rows 60 and 61. The soil is mapped as the Jory soil series (Figure 7) and is located in the Chehalem Mountains AVA. According to the vineyard manager, the spacing between rows was planted with permanent cover four years prior to sampling (2007). The vines are Pinot Noir Dijon 777 clone planted in 2001 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto RG rootstock (Table 8).

The Jory soil is characterized as a Xeric Palehumult. The soil pit is 150+ cm deep, and I did not reach the parent material or refusal at that depth (Table 9). The basalt parent material is small chips and gravel (10%) in the Bt2 horizon from 115 to 150 cm depth. Percent sand decreases with depth from 10% to 5% from Ap to Bt3 horizon at 150 cm. Dry colors for the Ap horizon are dark yellowish brown (10 YR 4/4), the Bt1 and Bt2 are both brown (7.5 YR 4/4), and the Bt3 is dark reddish brown (5 YR 3/4) (Figure 8).

Figure 7. Soil map of Elk Cove Vineyards, Clay Court Vineyard Block E. Pit location marked. 45C - Jory silty clay loam, 8 to 15 percent slopes. 45B - Jory silty clay loam, 2 to 8 percent slopes. 45D - Jory silty clay loam, 15 to 30 percent slopes (NRCS, 2014).

Structures throughout the soil profile are medium subangular blocky with some granular texture in the Ap horizon. The Ap horizon is slightly sticky and slightly plastic, but the Bt1 is very sticky and very plastic due to a jump in clay percent from 22% in the Ap to 46%, 50%, and 57% in the Bt1, Bt2, and Bt3, respectively. Texture of the Ap horizon is silt loam, the Bt1 and Bt2 are silty clay, and Bt3 is clay. Clay films located on ped faces, increase in number from Bt1 to Bt3 (common and dominant). Pisolites are found abundantly throughout the profile. The pH decreases from 6.4 in the Ap horizon to 5.0 with depth. Organic matter (OM) ranges from 9-12% for this profile. The CEC is highest in the Ap horizon and decreases with depth (Table 9).

Table 9. Elk Cove Vineyards, Clay Court Vineyard Block E field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-15	Ap	10.1	66.6	22.3	0.0	SiL
15-90	Bt1	5.3	45.2	46.1	0.0	SiC
90-115	Bt2	8.4	40.3	49.7	0.0	SiC
115-150+	Bt3	4.7	37.7	57.2	0.0	C
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-15	Ap	10YR 4/4	2, m, gr to sbk	10	6.4	31.2
15-90	Bt1	7.5YR 4/4	2, m, sbk	9.0	5.6	16.1
90-115	Bt2	7.5YR 4/4	1, m, sbk	11	5.3	16.8
115-150+	Bt3	5YR 3/4	2, m, sbk	12	5.0	14.4

Figure 8. Sample soil pit at Elk Cove Vineyards, Clay Court Vineyard Block E. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Clay Court Vineyard soil pit was separated into four horizons. Maximum concentrations are shown in bold in the following tables of macronutrients, micronutrients, trace, and other elements (Table 10). The macronutrient concentration of K, Ca, Mg, and S all decrease with depth. The concentrations of Mg, Ca, and K are highest in the Ap horizon. P concentrations are highest in the in the Bt3 horizon and variable in the rest of the profile with the lowest concentration is in the Bt1 horizon. S only registered at detectable levels in the top two horizons, the Ap and Bt1 horizons.

The micronutrient concentrations measured in the soil horizons from the Clay Court Vineyard vary greatly with the maximum in the A horizon and variability with depth or the maximum in the Bt3 horizon after increasing with depth. Fe concentrations increase with depth. Al decreased with depth with a slight bulge in the Bt2 horizon. Co concentrations are highest in the Bt1 horizon and then decrease with depth whereas Cu values are variable with the maximum in the Bt3 horizon. Mn also decreases then has a bulge in the Bt3 horizon. Mo was only measured above detection limits in the Bt3 horizon. Na decreases with depth and a bulge in the Bt2 horizon. Ni decreases with depth and Zn is highest in the Ap horizon. Trace element concentrations for the Clay Court Vineyard range in magnitude with some values increasing with depth and some decreasing. As, Ba, Cd, and Se all decrease with depth with a bulge in the Bt2 or Bt3 horizon. Be has no trend and the maximum concentration is in the Bt1 horizon. Cr and V

both increase with depth. Se was only detected in the Ap horizon. Pb concentrations are highest in the Bt1 horizon and decrease with depth.

Table 10. Macronutrient, micronutrient, and trace element concentrations (all values in mg/kg) for the Elk Cove Vineyard, Clay Court Vineyard, Block E soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-15)	1220	591	2420	1910	191	ND				
Bt1 (15-90)	954	408	1060	1140	155	ND				
Bt2 (90-115)	1240	245	606	594	ND	ND				
Bt3 (115-150+)	1740	221	446	427	ND	ND				
Mean	1290	366	1130	1020	173	ND				
SD	328	171	897	668	25.5	ND				
Maximum	1740	591	2420	1910	191	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-15)	35500	18200	18.1	15.3	1730	ND	206	8.36	46.5	
Bt1 (15-90)	37700	16900	27.9	14.9	1060	ND	185	6.17	25.1	
Bt2 (90-115)	45100	17500	23.1	16.8	1040	ND	210	4.33	22.8	
Bt3 (115-150+)	61800	16500	18.9	18.2	1260	0.692	178	3.29	26.8	
Mean	45000	17300	22.0	16.3	1270	0.692	195	5.54	30.3	
SD	11900	741	4.50	1.51	321	0	15.6	2.23	10.9	
Maximum	61800	18200	27.9	18.2	1730	0.692	210	8.36	46.5	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-15)	2.78	190	0.778	0.267	24.3	ND	10.7	0.733	13.2	114
Bt1 (15-90)	1.66	69.4	0.828	0.197	26.8	ND	10.9	ND	12.3	118
Bt2 (90-115)	1.87	74.3	0.778	0.178	21.3	0.0448	9.94	ND	8.76	136
Bt3 (115-150+)	2.08	77.8	0.817	0.260	30.0	0.0393	9.40	ND	7.38	178
Mean	2.10	103	0.800	0.226	25.6	0.0421	10.2	0.733	10.4	137
SD	0.486	58.2	0.0261	0.0447	3.70	0.00389	0.693	0	2.78	29.3
Maximum	2.78	190	0.828	0.267	30.0	0.0448	10.9	0.733	13.2	178

Grape Juice Chemistry

It is interesting to note that the grape juice samples were void of many elements as seen in Table 11. All 24 elements (same as the soils) were analyzed for in the grape juice from grapes collected adjacent to the soil pits. K, Na, Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites. The majority of these elements were found to be non-detectable using this method, therefore only the elements found in any sample are shown in Table 11. The concentrations of K and Na in the Clay Court grape juice are 530 mg/kg and 161 mg/kg, respectively. Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.973 mg/kg, which is the 6th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg.

Table 11. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Elk Cove Vineyards, Clay Court Vineyard, Block E (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.973	ND	530	161	ND	ND	ND	ND	ND

Wine Chemistry

Elk Cove Vineyards supplied a 350 ml sample of unblended wine from the 2011 vintage of Clay Court Vineyard wine. This sample was meant to be analyzed for elemental concentrations along with the 2011 vintage of a purchased bottle of Clay Court wine assuming the bottle of wine was a blend of more blocks within the vineyard than the

sample collected. Results of this analysis show reduction and contamination of certain elements that must have taken place during the winemaking process (Table 12). Also, in comparison to the grape juice analysis, many more elements are detectable, suggesting that there is an addition of elements during the winemaking, either from the extended contact with skins, seeds, and stems, or from the winemaking equipment or process.

The 14 elements that were measured at detectable levels in either the sample or the bottle of wine include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn. Macronutrient concentrations are highest for K at 458 mg/kg in the bottle and 413 mg/kg in the sample. P is higher in the bottle at 99.3 mg/kg than the sample at 46.7 mg/kg. Mg and Ca are the opposite with higher concentrations in the sample than in the bottle. S concentrations are similar at 52.7 mg/kg in the bottle and 50.4 mg/kg in the sample. The amount of Na in the wine is an order of magnitude less than that found in the grape juice, and Sr concentrations are consistent for all three.

Eight micronutrients and trace elements were measured in the wine sample and/or bottle. Ba concentrations are higher in the bottle (0.592 mg/kg) than the sample (0.292 mg/kg). Similarly, Zn increases from 0.096 mg/kg in the sample to 0.204 mg/kg in the bottle. Some elements only found in the bottle of finished wine and not in the wine sample include Co (0.0262 mg/kg), Cu (0.12 mg/kg), and Pb (0.0598 mg/kg). Mn is 1.38

mg/kg in the sample and 1.19 mg/kg in the bottle while Fe concentrations are almost identical at 1.06 mg/kg in the sample and 1.05 mg/kg in the bottle.

Table 12. Elemental concentrations measured by ICP-MS in the 2011 Elk Cove Vineyards, Clay Court Vineyard and a 350 ml sample of unblended wine from the same vineyard and vintage (ND – Non-detectable).

Element	2011 Wine Sample (mg/kg)	2011 Bottle (mg/kg)	Element	2011 Wine Sample (mg/kg)	2011 Bottle (mg/kg)
Al	ND	ND	Mn	1.38	1.19
As	ND	ND	Hg	ND	ND
Ba	0.292	0.592	Mo	ND	ND
Be	ND	ND	Ni	ND	ND
Cd	ND	ND	P	46.7	99.3
Ca	37.5	28.8	K	413	458
Cr	ND	ND	Se	ND	ND
Co	ND	0.0262	Na	2.72	4.92
Cu	ND	0.12	Sr	0.99	0.973
Fe	1.06	1.05	S	50.4	52.7
Pb	ND	0.0598	V	ND	ND
Mg	53.4	39	Zn	0.096	0.204

Clay Mineralogy

The clay mineralogy of the Clay Court Vineyard soil pit was determined from a sample of clay taken from the Bt2 horizon. The results show the sample contains moderate amounts of disordered kaolinite with minor amounts of halloysite, abundant illite and chlorite along with moderate amounts of hydroxy interlayered smectite. The smectite resisted expansion due to the development of chlorite and interlayered sheets of Fe and Al. Cristobalite is found in minor amounts and moderate amounts of goethite are

in this sample. The amount of illite in this sample suggests a contribution of loess over time since the parent material is volcanic. The kaolinite, cristobalite, and goethite suggest an older soil.

Marine Sediment Parent Material – Roosevelt Estate Vineyard

Physical Characteristics

Elk Cove Vineyards produce wine from their estate vineyards in Gaston, Oregon. These vineyards are located on rolling hills of the Coast Range marine sedimentary rocks (Figure 2). Roosevelt Estate Vineyard is located directly south of the tasting room (Lat. 45.414466 N, Long. -123.185770 W) and winery at the summit of a west to southwest facing slope ranging from 0-1 degrees with vine rows running northeast to south west. The soil pit location is at 623 feet (190 meters) elevation between rows 8 and 9, and the soils are mapped as the Willakenzie soil series in the past and now is mapped as the Goodin – Melbourne complex (a subset of the previously mapped Willakenzie soil series) (Figure 9). According to the vineyard manager, the area in between rows in this vineyard was planted with cover crop two years prior to sampling (2009) and has been farmed organically since 2004 (Appendix D). The vines are Pinot Noir Pommard clone planted in 1993 and are trellised as unilateral cordon in vertical shoot position. The vines are own-rooted (Table 8).

Figure 9. Soil map of Elk Cove Vineyards, Roosevelt Estate Vineyard. Pit location marked. 2771E – Goodin-Melbourne complex, 2 to 30 percent slopes. 2763F – Willakenzie-Sitton complex, 30 to 75 percent slopes, 2769C – Melbourne-Witham complex, hummocky, 2 to 25 percent slopes (NRCS, 2015). Previously mapped as WeC – Willakenzie silty clay loam, 2 to 12 slopes (NRCS, 2014).

The Goodin – Melbourne soil is characterized as an Ultic Haploxeralf – Ultic Palexeralf. The soil pit was 161 cm deep with friable sandstone parent material at the bottom. The bedrock and parent material belong to the Pittsburg Bluff Sandstone (Figure 2). The sandstone parent material strongly influences the soil at 110 cm depth, recognizable in a texture change, determined in the lab, from silty clay in Bt3 to silty clay loam in the Bt4, C1, C2, and Cr horizons (Figure 10). Percent sand increases from 2% to

20% from Bt4 to C1 at 110 cm. The pH decreases with depth from 5.4 to 4.7. CEC decreases from the surface horizon and then increases with depth and OM ranges from 6.7% to 15%.

Dry colors also change from brown (7.5 YR 4/4) to yellow (10 YR 7/6) and yellowish brown (10 YR 5/6) from Bt3 to C1. Structures throughout the soil profile are medium subangular blocky. The Ap horizon is nonsticky and non-plastic, but the Bt horizons are all very sticky and very plastic. Clay films increase in number from Bt1 to Bt3 and are located on ped faces and in the interstitial pores. Clay percent increases with depth from Ap (18%) to Bt2 (60%) and Bt3 (55%), then decreases as more sand is introduced with depth. The C horizons contain 28% to 37% clay. Krotovina exist in Ap horizon, and large roots from the vines are visible at depth. The presence of muscovite mica and quartz sand coincides with the sandstone parent material and bedrock being marine sediments. There are no pisolites in this soil.

Soil Chemistry

The Roosevelt Vineyard soil pit is separated into nine horizons, including three C-horizons that are of friable sandstone parent material. The macronutrients (Ca, Mg, K, P, and S) for this soil pit exhibit some trends with depth (Table 14). In general, all macronutrients decrease with depth. P and K have maximum concentrations in the Ap horizon and decrease with depth. P has a slight bulge in the Bt3 horizon and again in the

Table 13. Elk Cove Vineyards, Roosevelt Estate Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-15	Ap	7.6	76.3	18.2	0.0	SiL
15-25	AB	6.0	69.8	24.8	0.0	SiL
25-36	Bt1	4.8	64.6	31.4	0.0	SiCL
36-64	Bt2	2.6	39.5	60.3	0.0	C
64-84	Bt3	1.2	38.4	55.0	0.0	SiC
84-110	Bt4	1.6	55.8	37.4	0.0	SiCL
110-144	C1	19.7	40.4	31.0	0.2	SiCL
144-161	C2	11.8	41.7	37.0	0.1	SiCL
161+	Cr	4.7	61.2	28.4	0.8	SiCL
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-15	Ap	10YR 5/3	2, m, sbk	9.3	5.4	18.5
15-25	AB	7.5YR 5/3	2, m, sbk	6.9	5.5	15.4
25-36	Bt1	10YR 5/4	2, m, sbk	6.7	5.4	16.9
36-64	Bt2	7.5YR 4/4	2, m, sbk	12	5.4	20.7
64-84	Bt3	7.5YR 4/4	2, m, sbk	15	5.1	
84-110	Bt4	10YR 7/6 2.5Y 8/4	2, m, sbk	13	4.9	
110-144	C1	10YR 7/8 10YR 8/4	m, f, sbk	14	4.9	
144-161	C2	10YR 5/6	m/sg	15	4.9	
161+	Cr	2.5Y 8/3 10YR 6/6	m/sg	13	4.7

Figure 10. Sample soil pit at Elk Cove Vineyards, Roosevelt Estate Vineyard. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

C1 horizon. The Ca concentration in the soil decreases with depth with a bulge in the Bt2 horizon to a maximum concentration of Ca for the profile. Mg is variable with depth but generally decreases with bulges in the Bt1 and Bt3 horizons. S only registered at detectable levels in the Ap and AB horizons. This is most likely to be the result of added S, not naturally derived. The majority of the profile had non-detectable concentrations of Cl with the exception of the Ap horizon and the parent material at depth.

Micronutrient concentrations in the Roosevelt Vineyard soil pit were also analyzed for each horizon to show the trends with depth. Fe concentrations increase with depth to the Bt3 horizon. After a notable decrease in the Bt4 horizon, the Fe concentrations again increase, reaching a maximum in the C2 horizon. Al concentrations increase to the Bt3 horizon and then decrease with depth. Co decreases with depth with a bulge in the AB horizon. Cu increases with depth with a bulge in the AB horizon. Mo concentrations are not detectable at this site. Mn concentrations were the highest in the Ap horizon and decrease with depth with slightly bulges in both Bt3 and C2 horizons. Na and Ni decrease with depth with a bulge in the in the Bt1 horizon. Zn has little trend, but generally decreases with depth with bulges in the Bt1, Bt3 and C2 horizons.

Some of the trace and other elements increase with depth and some decrease with depth in the Roosevelt Vineyard soil pit (Table 15). As has three bulges in the Bt1, Bt3, and the maximum concentration in the C1 horizon. Ba decreases with depth. Be increases

Table 14. Macronutrient and micronutrient concentrations (all values in mg/kg) for the Elk Cove Vineyards, Roosevelt Estate soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl
Ap (0-15)	637	841	1720	1600	158	29.8
AB (15-25)	565	766	1370	1690	101	ND
Bt1 (25-36)	478	730	1470	1950	ND	ND
Bt2 (36-64)	329	447	1760	1790	ND	ND
Bt3 (64-84)	389	458	1700	1840	ND	ND
Bt4 (84-110)	241	267	1030	1340	ND	ND
C1 (110-144)	319	299	587	1190	ND	11.7
C2 (144-161)	289	291	445	1180	ND	ND
Cr (161+)	249	280	456	1100	ND	17.3
<i>Mean</i>	<i>388</i>	<i>487</i>	<i>1170</i>	<i>1520</i>	<i>130</i>	<i>19.6</i>
<i>SD</i>	<i>142</i>	<i>232</i>	<i>554</i>	<i>322</i>	<i>40.3</i>	<i>9.27</i>
<i>Maximum</i>	<i>637</i>	<i>841</i>	<i>1760</i>	<i>1950</i>	<i>158</i>	<i>29.8</i>

Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn
Ap (0-15)	18800	9840	11.8	8.29	971	ND	213	5.33	33.3
AB (15-25)	19800	10800	13.2	7.76	903	ND	209	5.95	30.7
Bt1 (25-36)	22100	13400	12.7	9.79	550	ND	223	6.45	30.9
Bt2 (36-64)	28100	18200	3.05	14.7	95.5	ND	199	4.11	19.8
Bt3 (64-84)	31700	20500	3.54	14.9	107	ND	204	4.72	21.6
Bt4 (84-110)	15900	19400	1.47	14.1	8.18	ND	194	1.72	13.5
C1 (110-144)	31000	17900	1.35	18.2	11.5	ND	178	1.76	11.5
C2 (144-161)	43600	17300	1.46	22.2	24.3	ND	165	1.81	14.0
Cr (161+)	21700	19400	1.46	18.3	16.6	ND	168	1.43	11.4
<i>Mean</i>	<i>25900</i>	<i>16300</i>	<i>5.56</i>	<i>14.2</i>	<i>299</i>	<i>ND</i>	<i>195</i>	<i>3.70</i>	<i>20.7</i>
<i>SD</i>	<i>8640</i>	<i>3940</i>	<i>5.32</i>	<i>4.92</i>	<i>400</i>	<i>ND</i>	<i>20.4</i>	<i>2.03</i>	<i>8.89</i>
<i>Maximum</i>	<i>43600</i>	<i>20500</i>	<i>13.2</i>	<i>22.2</i>	<i>971</i>	<i>ND</i>	<i>223</i>	<i>6.45</i>	<i>33.3</i>

to the Bt2 horizon then decreases with depth. Cd concentrations are highest in the Ap horizon then decrease. Cr increases to the Bt3 horizon and then decreases. Hg is measured in the Bt2 through C1 horizons at very low quantities. Pb decreases with depth

with a bulge in the Bt3 horizon and parent material. Se was only detected in the Bt3, Bt4, and C1 horizons and the highest concentration in the C1 horizon. There is a bulge in Sr concentration in the Bt2, Bt3, and Bt4 horizons, the Ap horizon and parent material have similar values. V also has a bulge in the Bt3 horizon at then decreases to the Cr horizon.

Table 15. Trace element concentrations and other elements tested (all values in mg/kg) for the Elk Cove Vineyards, Roosevelt Estate soil pit (ND – Non-detectable).

Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-15)	3.87	205	0.510	0.174	14.2	ND	8.68	ND	17.2	42.1
AB (15-25)	3.48	187	0.572	ND	14.8	ND	7.85	ND	14.5	45.2
Bt1 (25-36)	4.31	147	0.621	ND	16.7	ND	7.78	ND	15.7	50.8
Bt2 (36-64)	3.04	86.6	0.661	0.107	20.0	0.0417	7.70	ND	22.9	56.3
Bt3 (64-84)	4.97	87.2	0.631	0.120	21.6	0.0408	7.96	0.521	23.0	60.0
Bt4 (84-110)	4.65	43.6	0.654	0.121	15.0	0.0511	5.92	0.543	22.3	30.6
C1 (110-144)	6.17	39.5	0.546	0.117	17.7	0.0506	6.86	0.673	17.7	38.3
C2 (144-161)	4.44	32.3	0.468	ND	17.6	ND	7.04	ND	15.1	30.4
Cr (161+)	4.68	37.1	0.448	0.109	13.1	ND	6.64	ND	16.6	26.7
Mean	4.40	96.1	0.568	0.125	16.7	0.0461	7.38	0.579	18.3	42.3
SD	0.907	67.4	0.0799	0.0248	2.79	0.00556	0.835	0.0821	3.45	11.9
Maximum	6.17	205	0.661	0.174	21.6	0.0511	8.68	0.673	23.0	60.0

Grape Juice Chemistry

Grape juice from clusters of grapes collected from vines adjacent to the soil pit were analyzed for the same 24 elements as the soils. The majority of these elements are non-detectable using this method, therefore only the elements found in any sample are shown in Table 16. The highest elemental concentration measured in the Roosevelt Vineyard grape juice is K at 1240 mg/kg. P is also detected at 361 mg/kg and Na is 144

mg/kg. Sr, one of only three elements to be detected in all 20 grape juice samples, has a concentration of 0.852 mg/kg in this sample. It is the 7th highest concentration where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg (Table 105).

Table 16. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Elk Cove Vineyards, Roosevelt Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.852	361	1240	144	ND	ND	ND	ND	ND

Wine Chemistry

Elk Cove Vineyards provided a 350 ml sample of the wine produced from each vineyard in 2011. The unblended wine was stored until sensory analysis could take place during the winter of 2014. At that time, a bottle of Elk Cove Roosevelt Vineyard Pinot Noir 2011 was purchased in order to complete the sensory analysis. Therefore, samples were taken of both the unblended wine and the finished bottle for chemical analysis (Table 17). As noted in the previous chapter on the Clay Court results, the concentrations of certain elements are similar between the sample and the finished bottle, while others have increased or decreased as a reflection of contamination or precipitation and removal during winemaking.

The 14 elements that are detected in the Roosevelt Vineyard wine include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn. Ba concentration increased from the sample to the wine from the bottle. Ca concentrations were consistent between the sample

and the bottle. Co was detected in the finished wine and was below detection limits in the sample. Cu concentration increased from the sample to the finished bottle. Other elements that increased in concentration from the sample to the finished wine include Pb, Sr, P, Na, and Zn. S concentrations were similar from sample to bottle and Mg, Mn, and K all decreased from sample to finished wine.

Table 17. Elemental concentrations measured by ICP-MS in the 2011 Elk Cove Vineyards, Roosevelt Vineyard wine and a 350 ml sample of unblended wine from the same vineyard and vintage (ND – Non-detectable).

Element	2011 Wine Sample (mg/kg)	2011 Bottle (mg/kg)	Element	2011 Wine Sample (mg/kg)	2011 Bottle (mg/kg)
Al	ND	ND	Mn	1.09	0.996
As	ND	ND	Hg	ND	ND
Ba	0.268	0.754	Mo	ND	ND
Be	ND	ND	Ni	ND	ND
Cd	ND	ND	P	443	560
Ca	46.1	53.8	K	829	752
Cr	ND	ND	Se	ND	ND
Co	ND	0.0255	Sr	0.915	1.07
Cu	0.046	0.12	Na	2.59	4.10
Fe	0.738	0.684	S	76.8	74.6
Pb	ND	0.061	V	ND	ND
Mg	85.7	58.9	Zn	0.0785	0.126

Clay Mineralogy

The clays mineral assemblage for Elk Cove Vineyards, Roosevelt Estate soil were analyzed from the Bt2 horizon. This horizon was chosen because it had the highest clay percentage based on my lab analysis. The results based on x-ray diffraction (Appendix B)

included minor fully expansive smectite clay and a trace amount of mica. The clays also include moderate chlorite intergrade, minor amounts of disordered kaolinite and possibly a minor amount of dehydrated halloysite. Vermiculite was not present in this sample and minor amounts of illite were present. Quartz is the main silica phase with only trace amounts of cristobalite. Weak development of hydroxy interlayered clays and no vermiculite/chlorite intergrade were present. Minor goethite was present suggesting an older soil with the illite portion being a result of weathering of mica in the parent material and not from an eolian loess component.

Loess and Volcanic Parent Material – Five Mountain Vineyard

Physical Characteristics

Five Mountain Vineyard is owned and operated by Elk Cove Vineyards and located in Cornelius, Oregon. These vineyards are located on basaltic rocks of the Columbia River Basalt group with ancient weathered loess on top of the basalt. The soil pit location was at 362 feet (110 meters) elevation between rows 27 and 28, and the soil is mapped as Laurelwood soil series (Figure 11). Five Mountain Vineyard is located on midslope of a slightly south facing slope with vine rows running north and south (Lat. 45.448694 N, Long. -123.036566 W). According to the vineyard manager, this vineyard was cultivated with permanent grass cover in 2010 and utilizes sustainable farming practices (Appendix D). The vines are Pinot Noir Dijon 115 clone planted in 1996 and

are trellised as bilateral cordon in vertical shoot position with 5 foot by 9 foot (1.5 meters by 2.75 meters) spacing. The vines are grafted onto 101-14 rootstock (Table 8).

Figure 11. Soil map of Elk Cove Vineyards, Five Mountain Vineyard. Pit location marked. 28C - Laurelwood silt loam, 7 to 12 percent slopes. 28B - Laurelwood silt loam, 3 to 7 percent slopes. 28E - Laurelwood silt loam, 20 to 30 percent slopes (NRCS, 2014).

The Laurelwood soil is characterized as an Ultic Haploxeralf. The soil pit was 171+ cm deep, and I did not reach the parent material or refusal at that depth. The bedrock is part of the Columbia River Basalt group with an addition of loess (Figure 2). The CEC decreases with depth and OM ranges from 5.1% to 9.2% (Table 18). The pH of

this soil profile decreases with depth from 5.7 to 5.5 with a bulge in the Bt1 horizon to 6.0. The silt content of this soil pit ranges from 47% (Bt3) to 63% (Ap) depending on the horizon. Percent sand decreases with depth from 23% to 7% from Ap to Bt3 at 114 cm.

Table 18. Elk Cove Vineyards, Five Mountain Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-30	Ap	23.0	63.2	12.1	2.9	SiL
30-61	Bt1	4.7	58.5	32.8	0.0	SiCL
61-114	Bt2	3.8	61.8	31.7	0.0	SiCL
114-171+	Bt3	7.0	46.8	38.9	0.7	C

Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-30	Ap	10YR 5/4	1, f, sbk	7.9	5.7	18.6
30-61	Bt1	10YR 5/4	2, m, sbk	5.1	6.0	14.2
61-114	Bt2	10YR 5/4	2, m, sbk	5.5	5.8	14.9
114-171+	Bt3	10YR 4/4	2, m, sbk	9.2	5.5	13.8

Dry colors for the Ap, Bt1 and Bt2 horizons are yellowish brown (10 YR 5/4), and Bt3 is dark yellowish brown (10 YR 4/4). Structure throughout the soil profile is medium subangular blocky (Figure 12). The Ap horizon is slightly sticky and slightly plastic, but the Bt1 is very sticky and very plastic due to a jump in clay percent from 12% in the Ap to 33%, 32%, and 39% in Bt1, Bt2, and Bt3, respectively. Clay films, located

Figure 12. Sample soil pit at Elk Cove Vineyards, Five Mountain Vineyard. A – View of sample location, facing west. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

on ped faces, are the most common and dominant in the Bt1 horizon while the Bt2 and Bt3 horizons only have few faint clay films on the ped faces. Pisolites are found abundantly throughout the profile and can be seen in the Ap horizon.

Soil Chemistry

Four horizons were designated in the Five Mountain Vineyard soil pit. The maximum concentration of P and S are in the Ap horizon while concentrations of the other macronutrients increased with depth, then decreased in the deepest horizon (Table 19). P decreases with depth, the maximum concentration in the Ap horizon and a bulge in the Bt3 horizon. K concentration bulges in the Bt1 horizon. Ca and Mg both increase with depth and the maximum concentration is in the Bt2 horizon. S was only detected in the Ap horizon at the surface.

The micronutrient concentrations were measured in the four soil horizons from the Five Vineyard. Fe concentrations are highest in the deepest horizon, Bt3, and Al increased with depth from the Ap horizon the Bt2 horizon. A non-detectable concentration in the Bt3 horizon for Al was not expected and may be due to instrument error since it is unlikely that there was such a significant decrease in Al from the Bt2 to Bt3 horizon to cause it to be unmeasurable. Mo is non-detectable. Co concentrations increase with depth from the Bt3 horizon. Cu values increase from the surface horizons to the Bt2 horizon. Mn decreases with depth. Na decreases with depth and a bulge in the Bt3

horizon and the maximum concentration in the Ap horizon. Ni concentrations slightly bulge with depth from the Ap horizon to the Bt2 horizon. Zn is highest in the Ap horizon and decreases with depth.

Table 19. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Elk Cove Vineyards, Five Mountain Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-30)	1550	998	1420	2000	176	ND				
Bt1 (30-61)	669	1430	1480	3210	ND	ND				
Bt2 (61-114)	508	1420	1560	3380	ND	ND				
Bt3 (114-171+)	572	396	988	927	ND	ND				
Mean	825	1060	1360	2380	176	ND				
SD	488	487	256	1150	0	ND				
Maximum	1550	1430	1560	3380	176	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-30)	19400	14300	11.1	12.5	1330	ND	220	9.12	56.9	
Bt1 (30-61)	27000	20900	14.8	12.5	476	ND	187	10.2	43.5	
Bt2 (61-114)	31200	20900	14.4	15.3	491	ND	154	10.5	42.6	
Bt3 (114-171+)	35400	ND	20.1	13.6	515	ND	188	5.37	28.3	
Mean	28300	18700	15.1	13.5	703	ND	187	8.80	42.8	
SD	6820	3810	3.72	1.32	418	ND	26.9	2.36	11.7	
Maximum	35400	20900	20.1	15.3	1330	ND	220	10.5	56.9	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-30)	2.49	244	0.540	0.244	14.9	0.0426	8.85	ND	10.7	54.1
Bt1 (30-61)	3.51	107	0.683	0.163	20.5	ND	8.44	ND	19.2	84.6
Bt2 (61-114)	3.31	106	0.754	0.218	24.1	ND	9.15	ND	20.1	95.3
Bt3 (114-171+)	0.86	75.4	0.827	0.229	24.1	ND	8.68	ND	15.3	127
Mean	2.54	133	0.701	0.214	20.9	0.0426	8.78	ND	16.3	90.3
SD	1.21	75.4	0.122	0.0353	4.35	0	0.299	ND	4.29	30.1
Maximum	3.51	244	0.827	0.244	24.1	0.0426	9.15	ND	20.1	127

The trace and other elements were also measured in the Five Mountain Vineyard soil pit. Hg was only detectable in the Ap horizon and Se was below detection limits throughout the profile. The maximum concentration of As in the profile is in the Bt1 horizon. Ba decreases with depth. Be concentrations increase with depth. Cd concentrations are highest in the Ap horizon and the concentration decreases in the Bt1 horizon but increases. Cr increases with depth. Pb concentrations are consistent from the surface horizons to depth. There is a bulge in Sr concentration in the Bt1 and Bt2 horizons. V bulges in the Bt3 horizon.

Grape Juice Chemistry

Grape juice was obtained by crushing a sample of the grapes collected from vines immediately adjacent to the soil pit at the time of harvest. All 24 of the elements were analyzed, but the elements measured in the grape juice from Five Mountain Vineyard were scarce. They include Sr, P, K, Na, and Mn. Only the elements found in any of the 20 grape juice samples are shown in Table 20. The highest elemental concentration measured in the Five Mountain grape juice is K at 1340 mg/kg. P is also detected at 232 mg/kg and Na is 145 mg/kg. Mn is also measured at 2.14 mg/kg, one of the four vineyards (The Jory Hills, Stoller, and Sims Vineyards) where Mn is measured in the grape juice. Sr, one of only three elements detected in all 20 grape juice samples, has a concentration of 1.02 mg/kg in this sample. It is the 5th highest concentration where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg (Table 105).

Table 20. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Elk Cove Vineyards, Five Mountain Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	1.02	232	1340	145	ND	2.04	ND	ND	ND

Wine Chemistry

Two bottles of the Five Mountain Vineyard wine were used during the sensory analysis, therefore each bottle of wine was sampled and sent to the lab for analysis along with the wine sample from 350 ml bottle given to me before blending occurred. There is only a slight difference between the values for elements found in the sample and in the finished bottles of wine, but the bottles of wine were most similar. The 14 elements that are detected in the Five Mountain wine include Ba, Ca, Cu, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn. The mean and standard deviation calculations for the elemental concentrations of these two bottles and one sample reveal that only P increased significantly from the sample to the finished wine from 180 mg/kg to 280 mg/kg and 282 mg/kg.

Almost all other elements increased slightly from sample to bottle with the exception of the concentration of Ba, which decreased from 0.576 mg/kg in the sample to 0.414 and 0.404 mg/kg in the bottle and zine which decreased from 0.222 mg/kg in the sample to 0.172 mg/kg in the bottles. Ca increased from 31.1 mg/kg to 49.4 mg/kg, Fe increased from 0.63 mg/kg to 0.858 mg/kg, and Mg increased from 58.6 mg/kg to 66.6 mg/kg. Na concentration in the sample was below detection limits, while it registered at

4.34 mg/kg in one bottle. Sr concentrations were fairly constant from sample to bottle, ranging only from 0.774 mg/kg in one bottle to 0.8 mg/kg in the other and the sample was 0.779 mg/kg. S increased slightly from 55.1 mg/kg to 68.1 mg/kg in one bottle.

Table 21. Elemental concentrations measured by ICP-MS in the 2011 Elk Cove Vineyards, Five Mountain Vineyard wine (two bottles purchased and analyzed), and a 350 ml sample of unblended wine from the same vineyard and vintage (ND – Non-detectable, *denotes mean of samples from two different bottles).

Element	2011 Wine Sample (mg/kg)	2011 Bottle* (mg/kg)	Element	2011 Wine Sample (mg/kg)	2011 Bottle* (mg/kg)
Al	ND	ND	Mn	1.03	0.964
As	ND	ND	Hg	ND	ND
Ba	0.576	0.409	Mo	ND	ND
Be	ND	ND	Ni	ND	ND
Cd	ND	ND	P	180	281
Ca	31.1	48.0	K	828	811
Cr	ND	ND	Se	ND	ND
Co	ND	ND	Na	ND	4.12
Cu	0.0805	0.0975	Sr	0.779	0.787
Fe	0.63	0.844	S	55.1	65.6
Pb	ND	ND	V	ND	ND
Mg	58.6	63.0	Zn	0.222	0.172

Clay Mineralogy

The Elk Cove, Five Mountain (loess/volcanic parent material) clays were very similar to the Clay Court (volcanic parent material) sample. The clay mineralogy was determined from the Bt3 horizon for this site. These two sites are both located in the Chehalem Mountain AVA at opposite ends, with Five Mountain in the northwest and Clay Court to the east. The original thought during the site selection was that Clay Court

did not have an eolian loess component. The Five Mountain sample includes minor disordered kaolinite with dehydrated halloysite, moderate illite, and hydroxy interlayered smectite. The smectite was resistant to collapse because of Fe and Al as well as chlorite interlayers. This suggests moderate weathering or a mix of soil age based on constant input of loess as with the Clay Court sample. The quartz phase also included minor cristobalite, and the Fe phase was a mix of goethite and traces of hematite.

Chapter Five – Willakenzie Estate Winery Results

Volcanic Parent Material – The Jory Hills Vineyard, Block 50c

Physical Characteristics

The Jory Hills Vineyard is owned and operated by Willakenzie Estate Winery and located in Dundee, Oregon. This vineyard is planted on volcanic basalt bedrock, part of the Columbia River Basalt Group (Figure 2), and the soils are mapped as the Jory soil series but is more similar to a Nekia soil series because of the shallow bedrock. The Jory Hills Vineyard soil pit is located on the midslope of an east facing slope with vine rows running east and west (Lat. 45.287902 N, Long. -123.030467 W). The soil pit location was at 493 feet (150 meters) elevation between rows 69 and 70 (Figure 13). The vines are Pinot Noir Dijon 115 clone planted in 2002 and are trellised as bilateral cordon in vertical shoot position. The vines here were grafted onto 101-14 rootstock (Table 8).

The Jory soil is characterized as a Xeric Palehumult, and the Nekia soil is a Xeric Haplohumult. The soil pit was 43+ cm deep with refusal caused by greater than 75% rock fragments. The bedrock and parent material is the Columbia River Basalt Group (Figure 2). The silt content of this soil pit remains fairly constant with depth ranging from 46% (Ap) to 38% (Bt2). Dry color for the Ap and Bt1 horizons are brown (7.5 YR 4/4), Bt2 and Bt3 are yellowish red (5 YR 4/6).

Figure 13. Soil map of Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c. Pit location marked. 2711D – Jory silty clay loam, 12 to 20 percent slopes. 2711E – Jory silty clay loam, 20 to 30 percent slopes. 2780C – Jory-Gelderman silty clay loams, 2 to 12 percent slopes (NRCS, 2015).

Textures are silty clay loam and silty clay at depth. Structures for the soil profile are weak, very fine to medium subangular blocky (Figure 14). The Ap horizon is sticky and plastic, and the Bt1 and Bt2 horizons are very sticky and very plastic. Clay percent increases with depth from 34% in the Ap to 46% in Bt2. Clay films located on ped faces are common and distinct in the Bt1 and Bt2 horizons. Pisolites are common throughout the soil profile, and most abundant in the Ap horizon. Even though this soil is mapped as the Jory soil series, this soil pit was very shallow to bedrock and technically is classified

as the Nekia soil series. For this study it has been grouped with the Jory Series since they are the same with the exception of depth to bedrock. I could have dug the pit one row over and found Jory soil. The pH decreases with depth and the CEC slightly increases in the Bt1 horizon. OM ranges from 9.8% to 10.7% (Table 22).

Table 22. Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-18	Ap	17.4	46.0	34.1	0.9	SiCL
18-33	Bt1	16.4	44.5	37.4	0.8	SiCL
33-43	Bt2	7.8	37.9	46.5	0.6	SiC
43+	Cr	11.1	41.4	40.6	28.2	SiC
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-18	Ap	7.5YR 4/4	1, f, sbk	10.7	5.6	14.4
18-33	Bt1	7.5YR 4/4	1, m, sbk	9.8	5.5	15.4
33-43	Bt2	5YR 4/6	1, vf, sbk	10.4	5.2	14.6
43+	Cr	5YR 4/6

Figure 14. Sample soil pit at Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c. A – View of sample location, facing southwest. B - Picture of the face of the soil pit with horizon depths and boundaries marked.

Soil Chemistry

The Jory Hills Vineyard soil pit was separated into four horizons and the macronutrient (P, K, C, Mg, and S) concentrations are reported below (Table 10). This soil pit is one of the shallowest in this study at only 43 cm. The maximum concentrations of K, Ca, and Mg are in the Ap horizon. K, Ca, and Mg decrease with depth. There is little trend in P concentrations. The maximum concentration of P is in the Bt1 horizon, and there is little trend in this profile for this element. Cl is only detected in the two lower horizons, the Bt2 and Cr horizons.

The micronutrient concentrations measured in the soil horizons from the Jory Hills Vineyard mostly reach a maximum concentration in the Bt1 horizon. Fe and Al bulge in the Bt2 horizon, decreasing with depth. Co, Cu, Mn, Ni and Zn have a bulge in the Bt1 horizon. Na increases with depth. Mo is below detections limits. Trace element concentrations, with maximum concentrations are shown in bold, for The Jory Hills Vineyard are reported. Ba, Be, Cr, Sr, and V have variable concentrations throughout the profile with the maximum concentration in the Cr horizon. Hg and Se are below detection limits. As and Pb both are highest in the Ap and Bt1 horizons and decrease with depth. Cd decreases with depth with the maximum concentration in the Ap horizon.

Table 23. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Willakenzie Estate Winery, The Jory Hills Vineyard, Block 50c soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-18)	1530	685	1110	951	182	ND				
Bt1 (18-33)	1580	510	994	922	196	ND				
Bt2 (33-43)	1140	111	375	188	194	10.0				
Cr (43+)	1560	60.3	302	79.5	274	17.6				
Mean	1450	342	695	535	212	13.8				
SD	209	305	416	466	42.1	5.37				
Maximum	1580	685	1110	951	274	17.6				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-18)	55800	17900	23.0	18.0	2060	ND	160	6.61	47.1	
Bt1 (18-33)	55300	18000	28.4	19.8	2580	ND	171	6.76	47.9	
Bt2 (33-43)	60000	19100	12.8	19.5	524	ND	175	5.81	24.9	
Cr (43+)	48100	10900	22.8	13.1	380	ND	206	1.73	22.4	
Mean	54800	16500	21.8	17.6	1390	ND	178	5.23	35.6	
SD	4940	3760	6.51	3.10	1100	ND	19.7	2.37	13.8	
Maximum	60000	19100	28.4	19.8	2580	ND	206	6.76	47.9	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-18)	1.59	202	0.781	0.346	24.1	ND	11.4	ND	14.7	153
Bt1 (18-33)	1.62	195	0.808	0.308	23.3	ND	11.4	ND	13.4	150
Bt2 (33-43)	0.566	168	0.734	0.252	29.0	ND	7.31	ND	5.87	127
Cr (43+)	ND	430	0.910	0.219	31.8	ND	8.57	ND	15.4	195
Mean	1.26	249	0.808	0.281	27.1	ND	9.67	ND	12.3	156
SD	0.600	122	0.0744	0.0567	4.05	ND	2.06	ND	4.39	28.3
Maximum	1.62	430	0.910	0.346	31.8	ND	11.4	ND	15.4	195

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study, as seen in Table 24. All 24 elements were analyzed for in the grape juice from grapes collected adjacent to the soil pits. These elements include Al,

As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, P, K, Se, Na, Sr, S, V, and Zn. K, Na, and Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites. The concentrations of K and Na in The Jory Hills grape juice are 1150 mg/kg and 141 mg/kg, respectively. Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.506 mg/kg, which is the 18th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 275 mg/kg and Mn is measured as 2.14 mg/kg for this sample. Mn is measured only in grape juice from The Jory Hills, Five Mountain, Stoller, and Sims Vineyards.

Table 24. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Willakenzie Estate Winery, The Jory Hills Vineyard, Block 50c (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.506	275	1150	141	ND	2.14	ND	ND	ND

Wine Chemistry

Willakenzie Estate Winery provided a 750 ml sample of the wine produced from each vineyard in 2011. The unblended wine was stored until sensory analysis could take place during the winter of 2014. As noted in the previous results chapter of Elk Cove Vineyards, the concentrations of many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that

were detected in The Jory Hills wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 25).

Table 25. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2011 Willakenzie Estate Winery, The Jory Hills Vineyard (ND – Non-detectable).

Element	2011 Wine Sample (mg/kg)	Element	2011 Wine Sample (mg/kg)
Al	ND	Mn	1.3
As	ND	Hg	ND
Ba	0.464	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	187
Ca	51.6	K	818
Cr	ND	Se	ND
Co	0.031	Na	4.5
Cu	0.0272	Sr	0.954
Fe	0.645	S	72.7
Pb	0.0615	V	ND
Mg	40.6	Zn	0.164

The highest concentrations include K (818 mg/kg), P (187 mg/kg), S (72.7 mg/kg), Ca (51.6 mg/kg), and Mg (40.6 mg/kg). Na concentration is 4.5 mg/kg for this wine sample and Mn is 1.3 mg/kg. Concentrations in descending order for the rest of the elements tested are Sr (0.954 mg/kg), Fe (0.645 mg/kg), Ba (0.464 mg/kg), and Zn (0.164 mg/kg). Trace amounts of Pb (0.0615 mg/kg), Co (0.0272 mg/kg), and Cu (0.031 mg/kg) were also measured in The Jory Hills wine sample.

Clay Mineralogy

The Jory Hills clay mineral assemblage from the Bt2 horizon is similar to the Elk Cove, Five Mountain (loess/volcanic parent material) and Chehalem, Stoller Vineyards (volcanic parent material). Moderate kaolinite and minor dehydrated halloysite are the main clays present. There is minor illite in this sample and minor chlorite intergrade clays are present but are non-expansive. Vermiculite is not present. There are minor amounts of cristobalite, and abundant goethite as the main Fe phase with minor gibbsite.

Marine Sediment Parent Material – Aliette Vineyard, Block 2b

Physical Characteristics

Aliette Vineyard is owned and operated by Willakenzie Estate Winery and also located in Yamhill, Oregon. This vineyard is planted on sandstone bedrock associated with the marine sedimentary rocks of the Coast Range. This sandstone is most likely the Spencer Formation (Figure 2), and the soil is Melbourne – Goodin soil series (previously mapped as Willakenzie soil series). Aliette Vineyard is located on the upland of a south facing slope with vine rows running north and south (Lat. 45.364343 N, Long. - 123.133329 W). The soil pit location was at 604 feet (185 meters) elevation between rows 35 and 36 (Figure 15). According to the vineyard manager, this vineyard has permanent fescue cover between rows. The vines are Pinot Noir Pommard clone planted in 1992 and are trellised as bilateral cordon in vertical shoot position. The vines here were grafted onto 5C rootstock (Table 8).

Figure 15. Soil map of Willakenzie Estate Winery, Alette Vineyard Block 2b. Pit location marked. 2770C – Melbourne-Goodin silt loams, 2 to 12 percent slopes. 2770D – Melbourne-Goodin silt loams, 12 to 20 percent slopes. 2770E – Melbourne-Goodin silt loams, 20 to 30 percent slopes. 2770F – Melbourne-Goodin silt loams, 30 to 60 percent slopes. 2763F – Willakenzie-Sitton complex, 30 to 75 percent slopes (NRCS, 2015). Previously mapped as WeC - Willakenzie silty clay loam, 2 to 12 percent slopes (NRCS, 2014).

The Melbourne – Goodin soil is characterized as an Ultic Palexeralf – Ultic Haploxeralf. The soil pit was 150+ cm deep without refusal. The silt content of this soil pit decreases with depth from 42% (Ap) to 23% (Bt3). The pH is consistent at 5.8. CEC decreases with depth with a bulge in the Bt1 horizon. OM ranges from 5.9% to 9.4% (Table 26). Textures are loam, clay loam, and clay at depth. Structures for the soil profile

are moderate medium subangular blocky. The Ap horizon is slightly sticky and slightly plastic, and all Bt horizons are very sticky and very plastic. Clay percent increases with depth from 18% in the Ap to 47% in Bt3. Clay films located on ped faces are few to common and faint to distinct in the AB, Bt1, Bt2, and Bt3 horizons. The presence of

Table 26. Willakenzie Estate Winery, Aliette Vineyard Block 2b field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-26	A	38.8	42.0	18.0	0.0	L
26-35	AB	40.0	38.7	21.6	0.0	L
35-100	Bt1	28.7	32.7	38.4	0.0	CL
100-150	Bt2	29.4	24.4	43.4	0.2	C
150+	Bt3	28.5	22.6	47.1	0.0	C

Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-26	A	10YR 5/4	2, m, sbk	8.0	5.9	15.9
26-35	AB	10YR 5/4	2, m, sbk	5.9	5.8	12.9
35-100	Bt1	10YR 4/6	2, m, sbk	7.3	5.8	17.5
100-150	Bt2	7.5YR 4/6	2, m, sbk	7.4	5.8	14.9
150+	Bt3	5YR 4/6	2, m, sbk	9.4	5.8	

muscovite mica and quartz sand in the lower horizons originates from the sandstone and siltstone bedrock here. There are no pisolites in this profile. Dry colors for the A/E and AB is yellowish brown (10 YR 5/4), Bt1 is dark yellowish brown (10 YR 4/6) and Bt2 and Bt3 were both strong brown (7.5 YR 4/6 and 5 YR 4/6) (Figure 16).

Figure 16. Sample soil pit at Willakenzie Estate Winery, Aliette Vineyard Block 2b. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Aliette Vineyard soil pit was separated into five horizons and each was analyzed for the macronutrient concentrations (Table 27). The maximum concentrations of P, Ca, and S are in the Ap horizon. P decreases with depth with a slight bulge in the Bt2 horizon. K concentration is highest in the AB horizon and then decreases with depth. Ca decreases with depth and has a slight bulge in the Bt1 horizon. Mg increases from the surface to the Bt1 horizon then decreases before reaching a maximum in the Bt3 horizon. S is highest in the A/E horizon then decreases with depth and until it is not detected in the Bt2 horizon.

The micronutrient concentrations measured in the five soil horizons from the Aliette Vineyard are highest in the Ap horizon or in the Bt1 horizon. Fe concentration increases with the maximum in the Bt3 horizon. Al increases with depth similarly to Fe. Co concentration is highest in the Bt1 horizon. Cu values are variable with the highest in the A/E horizon. Mn constantly decreases with depth. Na and Zn decrease with depth with a bulge in the Bt2 horizon. Ni is highest in the Bt1 horizon. Mo is non-detectable in the profile. Trace element concentrations for the five horizons of the Aliette Vineyard are reported. As, Pb, and V concentrations are highest in the Bt1 horizon. Ba, Cd, and Sr all have maximum concentrations in the A/E horizon, decrease with depth, and then have a bulge at the bottom of the profile. Be and Cr increase with depth. Hg and Se were not detected in the profile.

Table 27. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Willakenzie Estate Winery, Alette Vineyard, Block 2b soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
A/E (0-26)	594	1020	2240	1020	245	ND				
AB (26-35)	497	1030	1290	1220	128	ND				
Bt1 (35-100)	413	667	1340	1250	99.8	ND				
Bt2 (100-150)	445	542	1190	960	ND	ND				
Bt3 (150+)	477	586	1160	1390	ND	ND				
Mean	485	769	1440	1170	158	ND				
SD	68.7	238	451	176	77.0	ND				
Maximum	594	1030	2240	1390	245	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
A/E (0-26)	17500	6600	9.63	17.0	751	ND	188	5.42	33.8	
AB (26-35)	20300	8340	9.74	10.1	717	ND	148	6.4	31	
Bt1 (35-100)	29500	14400	12.0	16.9	337	ND	145	7.0	29.8	
Bt2 (100-150)	27600	11700	3.54	12.3	116	ND	161	4.79	22.7	
Bt3 (150+)	32000	14400	2.59	12.2	69.6	ND	155	6.13	26.7	
Mean	25400	11100	7.50	13.7	398	ND	159	5.95	28.8	
SD	6200	3540	4.17	3.09	323	ND	17.2	0.861	4.26	
Maximum	32000	14400	12.0	17.0	751	ND	188	7.0	33.8	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
A/E (0-26)	3.46	125	0.389	0.233	12.6	ND	6.30	ND	18.4	34.0
AB (26-35)	3.62	124	0.471	ND	14.5	ND	6.44	ND	9.81	39.1
Bt1 (35-100)	4.92	65.4	0.589	0.116	17.7	ND	8.89	ND	13.1	59.4
Bt2 (100-150)	2.86	74.3	0.682	0.119	17.2	ND	6.65	ND	14.2	50.9
Bt3 (150+)	3.67	92.5	0.711	0.138	19.4	ND	6.84	ND	17.4	55.0
Mean	3.71	96.2	0.568	0.152	16.3	ND	7.02	ND	14.6	47.7
SD	0.751	27.6	0.137	0.0552	2.71	ND	1.06	ND	3.45	10.7
Maximum	4.92	125	0.711	0.233	19.4	ND	8.89	ND	18.4	59.4

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study (Table 28). All 24 elements, the same as were tested in the soil samples, were analyzed for in the grape juice from grapes collected adjacent to the soil pits. The concentrations of K and Na in Aliette Vineyard grape juice are 1680 mg/kg and 158 mg/kg, respectively. Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.716 mg/kg, which is the 11th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 267 mg/kg for these grapes.

Table 28. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Willakenzie Estate Winery, Aliette Vineyard, Block 2b (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.716	267	1680	158	ND	ND	ND	ND	ND

Wine Chemistry

Willakenzie Estate Winery provided a 750 ml sample of the wine produced from the Aliette Vineyard in 2011. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in Aliette Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 29). The highest concentrations in descending order

include K (835 mg/kg), P (222 mg/kg), S (71.3 mg/kg), Ca (55.8 mg/kg), and Mg (47.9 mg/kg). Na concentration is 4.45 mg/kg for this wine sample and Mn is 0.995 mg/kg. Concentrations for the rest of the elements, also in descending order, are Sr (1.21 mg/kg), Fe (0.768 mg/kg), Ba (0.439 mg/kg), and Zn (0.333 mg/kg). Trace amounts of Pb (0.061 mg/kg), Co (0.0258 mg/kg), and Cu (0.102 mg/kg) were also measured in the Aliette Vineyard wine sample.

Table 29. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2011 Willakenzie Estate Winery, Aliette Vineyard (ND – Non-detectable).

Element	2011 Wine Sample (mg/kg)	Element	2011 Wine Sample (mg/kg)
Al	ND	Mn	0.995
As	ND	Hg	ND
Ba	0.439	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	222
Ca	55.8	K	835
Cr	ND	Se	ND
Co	0.0258	Na	4.45
Cu	0.102	Sr	1.21
Fe	0.768	S	71.3
Pb	0.061	V	ND
Mg	47.9	Zn	0.333

Clay Mineralogy

The Aliette Vineyard clay mineralogy were determined using the Bt3 horizon. This site is the least illitic of the samples from Elk Cove Vineyards, Chehalem, and Willakenzie Estate with most of the clays present being kaolinite and vermiculite with a

well-developed chlorite intergrade. There is no dehydrated halloysite present. Trace amounts of mica and illite are present, moderate amounts of chlorite, vermiculite, and kaolinite. Cristobalite is also present in this profile and minor amounts of goethite and gibbsite.

Missoula Flood Sediment over Shale Parent Material – Terres Basses Vineyard

Physical Characteristics

Terres Basses Vineyard, owned and operated by Willakenzie Estate Winery, is located in Yamhill, Oregon. This vineyard is located on presumably shale, associated with the marine sedimentary rocks of the Coast Range (Figure 2). I located a thin layer of Missoula Flood sediments overlying the shale bedrock at this site. This shale layer may be part of the Yamhill or Spencer Formation. Terres Basses Vineyard is located on foot slope of a slightly west-northwest facing slope with vine rows running north and south (Lat. 45.357946 N, Long. -123.144353 W). The soil pit location was at 293 feet (90 meters) elevation between rows 91 and 92, and the soil is mapped as the Witham (previously Hazelair) soil series (Figure 17). According to the vineyard manager, this vineyard was cultivated, needs some irrigation, and is usually the first to ripen in the fall.

Figure 17. Soil map of Willakenzie Estate Winery, Terres Basses Vineyard. Pit location marked. 2798D – Witham silty clay loam, hummocky, 2 to 25 percent slopes with 2769C – Melbourne-Witham complex and 2825C – Hazelair-Witham complex surrounding (NRCS, 2015). Previously mapped as HcD - Hazelair silty clay loam, 7 to 20 percent slopes (NRCS, 2014).

The vines are Pinot Noir Dijon 113 and 115 clones planted in 1997 and are trellised as single cordon in vertical shoot position with 10 to 12 buds per vine preserved at pruning.

The vines are grafted onto 3309 rootstocks (Table 8).

The Witham soil is characterized as a Vertic Haploxeroll, the only Mollisol in this study. The soil pit was 118+ cm deep reaching parent material at 102 cm depth without

refusal. The bedrock is part of the Coast Range marine sedimentary rocks (Figure 2). The silt content of this soil pit decreases with depth from 47% (Ap) to 23% (Bg2). The pH ranges from 5.3 to 5.9 with no trend while CEC seems to increase with depth and OM ranges from 6.9% to 10.8% (Table 30). Textures for this profile are silty clay loam, silty clay and clay. The soil profile structures are mostly fine to medium subangular blocky.

Table 30. Willakenzie Estate Winery, Terres Basses Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-25	A	15.4	46.7	31.0	0.0	SiCL
25-36	AB	15.2	43.2	36.2	0.0	SiCL
36-65	Bg1	14.0	31.6	41.8	0.1	SiC
65-86	Bg2	21.6	23.3	47.9	1.2	C
86-102	Cg					
102-118+	R					

Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-25	A	10YR 5/3	1, m, g to sbk	9.0	5.4	25.3
25-36	AB	10YR 5/3	1, m, sbk	6.9	5.9	23.1
36-65	Bg1	10YR 5/3 5YR 4/6	2, m, sbk	7.9	5.3	38.1
65-86	Bg2	10YR 5/3 5YR 5/6	2, m, sbk	10.8	5.4	34.6
86-102	Cg		1, f, sbk	10.8	5.7	
102-118+	R			9.0	5.4	

The Ap horizon is very sticky and very plastic, and this trend persists through the profile. Clay percent increases with depth from 31% in the Ap to 48% in Bg2. Clay films located on ped faces, and interstitial pores are common and distinct in the Bg1 and Bg2 horizons. These horizons also portray mottling (redoximorphic features) within 20 inches of the surface suggesting somewhat poorly drained soil. The presence of quartz sand in the lower horizons coincides with the shale bedrock being associated with the sandstone and siltstones of the Coast Range marine sedimentary rocks. There are no pisolites in this profile. Dry colors for the Ap, AB and Bg1 and Bg2 horizons are brown (10 YR 5/3) with yellowish red (5 YR 4/6) secondary colors (Figure 18).

Soil Chemistry

The Terres Basses Vineyard soil pit was separated into six horizons, and samples of each horizon were sent for elemental analysis (Table 31). The maximum concentrations of P, K, and S are in the Ap horizon and the maximum concentrations of Ca and Mg were measured at depth in the parent material or R horizon. P, K, and S decrease with depth and bulge in the Cg horizon. Ca and Mg increase with depth with the highest concentration in the R horizon.

Figure 18. Sample soil pit at Willakenzie Estate Winery, Terres Basses Vineyard. A – View of sample location, facing southwest. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Table 31. Macronutrient concentrations (all values in mg/kg) for the Willakenzie Estate Winery, Terres Basses Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
A (0-25)	758	970	3410	1400	270	ND				
AB (25-36)	674	894	2860	1600	174	ND				
Bg1 (36-65)	318	676	3990	2370	ND	ND				
Bg2 (65-86)	295	647	4260	2380	ND	ND				
Cg (86-102)	645	673	5620	3310	105	ND				
R (118+)	534	688	6050	3330	ND	ND				
Mean	537	758	4370	2400	183	ND				
SD	193	138	1240	817	82.9	ND				
Maximum	758	970	6050	3330	270	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
A (0-25)	24500	7400	20.5	34.9	849	ND	172	10.2	42.6	
AB (25-36)	27100	8810	24.4	36.8	821	ND	185	11.0	40.4	
Bg1 (36-65)	26300	14100	5.24	32.3	151	ND	108	7.57	29.9	
Bg2 (65-86)	23400	15400	6.82	38.1	280	ND	127	9.34	33.5	
Cg (86-102)	28600	18400	11.1	64.4	200	ND	216	16.3	58.7	
R (118+)	23000	18100	9.53	50.4	194	ND	289	15.9	56.9	
Mean	25500	13700	12.9	42.8	416	ND	183	11.7	43.7	
SD	2210	4650	7.75	12.3	327	ND	65.1	3.58	11.9	
Maximum	28600	18400	24.4	64.4	849	ND	289	16.3	58.7	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
A (0-25)	8.97	157	0.654	0.120	11.1	ND	9.00	ND	36.3	54.3
AB (25-36)	8.93	153	0.691	ND	12.7	ND	8.89	0.638	35.5	58.5
Bg1 (36-65)	6.07	117	0.438	ND	12.8	ND	7.28	0.531	47.0	49.1
Bg2 (65-86)	4.40	156	0.600	ND	10.7	ND	6.03	ND	49.1	45.1
Cg (86-102)	4.29	250	0.748	0.128	12.6	ND	5.14	0.512	75.2	35.4
R (118+)	3.83	226	0.570	0.132	12.1	ND	5.27	ND	81.5	30.3
Mean	6.08	177	0.617	0.1	12.0	ND	6.94	0.560	54.1	45.5
SD	2.35	50.5	0.108	0.006	0.894	ND	1.73	0.068	19.7	10.9
Maximum	8.97	250	0.748	0.132	12.8	ND	9.00	0.638	81.5	58.5

The trends in the micronutrient concentrations measured in the six soil horizons from the Terres Basses Vineyard are highly variable. Fe, Ni, Zn and Cu are variable with the maximum concentration in the Cg horizon. Al increases with depth and is highest in the Cg horizon as well. Na, is variable with a maximum in the R horizon. Mn is highest in the A horizon and variable with depth, decreasing mostly. Co bulges in the AB horizon and is variable with depth. Mo is non-detectable. Trace element concentrations for the six horizons of the Terres Basses Vineyard were also analyzed. As and Pb both decrease with depth and the maximum is in the A horizon. Sr and Cd increase with depth and the maximum is in the R horizon. Ba and Be are variable with depth and the maximum is in the Cg horizon. Se and V bulge in the AB horizon and Cr bulges in the Bg1 horizon. Hg is non-detectable.

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study (Table 32). All 24 elements, the same as were tested in the soil samples, were analyzed for in the grape juice from grapes collected adjacent to the soil pits. The concentrations of K and Na in the Terres Basses Vineyard grape juice are 1940 mg/kg and 159 mg/kg, respectively. This is the highest reported level of K in all 20 grape samples (Table 105). Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.739 mg/kg, which is the 10th highest concentration of Sr for the 20 vineyard samples. Mean Sr concentration for all grape juice samples from

the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 324 mg/kg for these grapes.

Table 32. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Willakenzie Estate Winery, Terres Basses Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.739	324	1940	159	ND	ND	ND	ND	ND

Wine Chemistry

The Terres Basses Vineyard sample was also collected and used in the sensory analysis. Two samples of the same bottle were sent to measure the concentrations of the same 24 elements tested in the soil samples. Again, many elemental concentrations were below detection limits. The 15 elements that were detected in the Terres Basses wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, Ni, P, K, Na, Sr, S, and Zn (Table 33). The concentration of K in the wine is 908 mg/kg, P is 207 mg/kg, S is 90.7 mg/kg, Ca is 50.5 mg/kg, and Mg is 52.7 mg/kg. Na concentration is 4.04 mg/kg for this location and Mn is 2.56 mg/kg. Concentrations in descending order for the rest of the elements tested are Sr (1.15 mg/kg), Fe (1.07 mg/kg), Ba (0.419 mg/kg), and Zn (0.208 mg/kg). Trace amounts of Cu (0.127 mg/kg), Pb (0.0890 mg/kg), Co (0.0315 mg/kg), and Ni (0.026 mg/kg) were also measured in the Terres Basses wine.

Table 33. Elemental concentrations measured twice by ICP-MS of the same 750 ml unblended wine sample from the 2011 Willakenzie Estate Winery, Terres Basses Vineyard (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2011 Wine Sample* (mg/kg)	Element	2011 Wine Sample* (mg/kg)
Al	ND	Mn	2.56
As	ND	Hg	ND
Ba	0.419	Mo	ND
Be	ND	Ni	0.026
Cd	ND	P	207
Ca	50.5	K	908
Cr	ND	Se	ND
Co	0.0315	Na	4.04
Cu	0.127	Sr	1.15
Fe	1.07	S	90.7
Pb	0.0890	V	ND
Mg	52.7	Zn	0.208

Clay Mineralogy

My Terres Basses location is located on Missoula Flood deposits and is highly smectitic. Clay mineralogy was determined from the Bg1 horizon. Only traces of mica exist and no interlayer chlorite layers are present. Trace amounts of kaolinite and minor vermiculite as well as Fe oxides suggest a wetter site. The Bg soil horizons in the profile corroborate this, suggesting that this site is poorly drained, leaving most Fe in the reduced phase instead of oxidized. Only minor amounts of quartz are found in the sample and no cristobalite.

Chapter Six – Chehalem Results

Volcanic Parent Material – Stoller Vineyard

Physical Characteristics

Stoller Vineyard is owned by Bill Stoller of Stoller Family Estate and located in Dayton, Oregon. This vineyard is planted on volcanic basalt bedrock, part of the Columbia River Basalt Group. The Stoller Vineyard soil pit is located on the midslope of a southeast facing slope with vine rows running north and south (Lat. 45.248827 N, Long. -123.072347 W). The soil pit location was at 475 feet (145 meters) elevation between rows 67 and 68 and is mapped as the Jory soil series (Figure 19). The vines are Pinot Noir Pommard clone planted in 1995 and are trellised as bilateral cordon in vertical shoot position.

The Jory soil is characterized as a Xeric Palehumult. The soil pit was 135 cm deep with refusal at the Columbia River Basalt bedrock and parent material (Figure 2). The silt content of this soil pit remains fairly constant with depth ranging from 58% (Bt3) to 64% (Bt1). Dry color for all horizons is dark yellowish brown (10 YR 4/4) (Figure 20). Textures are silt loam throughout the profile. Structures for the soil profile are strong fine subangular blocky in the Ap horizon grading to weak fine subangular blocky in Bt2. The Bt3 horizon has less than 10 percent coarse fragments and structure is weak, fine loose single grain to subangular blocky. The Ap horizon is slightly sticky and slightly plastic,

Figure 19. Soil map of Chehalem, Stoller Vineyards. Pit location marked. 2711D – Jory silty clay loam, 12 to 20 percent slopes. 2711 E – Jory silty clay loam, 20 to 30 percent slopes. 2780C – Jory-Gelderman silty clay loams, 2 to 12 percent slopes (NRCS, 2015). Previously mapped as JrC – Jory clay loam, 7 to 12 percent slopes (NRCS, 2014).

the Bt1 and Bt2 horizons are very sticky and very plastic, and the Bt3 horizon is slightly sticky and slightly plastic. Clay percent increases with depth from 18% in the Ap to 24% in Bt1 and 27% in Bt3. Clay films located on ped faces are few and faint in the Bt1 and Bt2 horizons. Pisolites are few and fine but throughout the soil profile. The CEC and OM both decrease with depth with OM ranging from 9.8% to 13.8%. The pH decreases with depth from 5.6 to 5.4 (Table 34).

Table 34. Chehalem, Stoller Vineyards field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-10	Ap	15.0	62.4	17.7	0.0	SiL
10-60	Bt1	11.8	64.4	24.0	0.0	SiL
60-100	Bt2	12.2	61.6	25.6	0.0	SiL
100-135	Bt3	13.9	57.9	27.0	0.0	SiL
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-10	Ap	10YR 4/4	3, f, sbk	13.8	5.6	23.5
10-60	Bt1	10YR 4/4	2, f, sbk	10.4	5.4	18.7
60-100	Bt2	10YR 4/4	1, f, sbk	9.9	5.4	17.0
100-135	Bt3	10YR 4/4	sg to 1, f, sbk	9.8	5.5	16.5

Figure 20. Sample soil pit at Chehalem, Stoller Vineyards. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked.

Soil Chemistry

The Stoller Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 35). The maximum concentrations of P, K, Ca, and S are in the Ap horizon, and the maximum concentrations of Mg is at depth in the Bt3 horizon. P, K, Ca, and S decrease with depth. Mg constantly increases with depth. Cl is only detected in the Ap horizon. The micronutrient concentrations measured in the four soil horizons from the Stoller Vineyard are all highest in the Ap horizon, within the top 10 cm. Fe, Al, Co, Cu, Mn, Ni, and Zn have the highest concentration in the Ap horizon, decrease with depths and have small bulges exhibited in the Bt2 horizon. Mo is only detected in the Ap horizon. Na has the highest value in the Ap horizon and the lowest in the Bt1 and then increases with depth below that horizon. Trace element concentrations were also measured for the four horizons of the Stoller Vineyard. Highest values are in the Ap horizon for all elements except Be, Hg, and Sr. As, Cd, Cr, Pb, and V are highest in the Ap horizon and decrease with depth with bulges in the Bt2 horizon. Be is highest in the Bt2 horizon and Sr is highest in the Bt3 horizon.

Grape Juice Chemistry

All 24 elements, the same as were tested in the soil samples, were analyzed for the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study (Table 36). K, Na, and Sr are the only elements found in all 20 grape juice samples, and P is

Table 35. Macronutrient concentrations (all values in mg/kg) for the Chehalem, Stoller Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-10)	2380	1800	2570	1300	309	17.7				
Bt1 (10-60)	1150	1090	1400	1390	148	ND				
Bt2 (60-100)	1060	1030	1250	1620	122	ND				
Bt3 (100-135)	922	745	1260	1850	125	ND				
Mean	1380	1170	1620	1540	176	17.7				
SD	675	449	637	247	89.4	0				
Maximum	2380	1800	2570	1850	309	17.7				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-10)	60500	19500	60.3	33.4	3190	0.612	201	7.25	111	
Bt1 (10-60)	50300	18300	35.6	15.6	1810	ND	174	6.12	78.4	
Bt2 (60-100)	55600	19500	42.7	16.2	2050	ND	184	6.79	82.8	
Bt3 (100-135)	43400	18100	29.4	13.7	1470	ND	199	5.99	74.7	
Mean	32500	18900	42.0	19.7	2130	0.612	190	6.54	86.7	
SD	7330	755	13.4	9.18	746	0	12.8	0.590	16.5	
Maximum	60500	19500	60.3	33.4	3190	0.612	201	7.25	111	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-10)	2.40	310	1.49	0.558	18.3	ND	15.3	0.569	14.9	219
Bt1 (10-60)	1.63	204	1.45	0.370	16.6	ND	10.7	ND	10.8	185
Bt2 (60-100)	1.69	208	1.52	0.391	17.3	ND	11.7	ND	14.5	191
Bt3 (100-135)	1.29	217	1.31	0.355	15.5	ND	10.6	ND	16.8	159
Mean	1.75	235	1.44	0.419	16.9	ND	12.1	0.569	14.3	189
SD	0.466	50.5	0.0929	0.0942	1.18	ND	2.21	0	2.51	24.6
Maximum	2.40	310	1.52	0.558	18.3	ND	15.3	0.569	16.8	219

detected in 15 of the 20 sites. The concentrations of K and Na in the Stoller Vineyard grape juice are 1400 mg/kg and 153 mg/kg, respectively. Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.633 mg/kg, which is the 17th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr

concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 213 mg/kg and Mn is 4.56 mg/kg for these grapes. This is the highest concentration of Mn, which is only found in four vineyards including Stoller, Five Mountain, The Jory Hills, and Sims Vineyards.

Table 36. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Chehalem, Stoller Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.633	213	1400	153	ND	4.56	ND	ND	ND

Wine Chemistry

Chehalem provided a 750 ml sample of the wine produced from the Stoller Vineyard in 2011. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in Stoller Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 37). K and P concentrations are the highest at 785 mg/kg and 233 mg/kg, respectively. S is 75.1 mg/kg, Ca is 52.3 mg/kg, Mg is 50.1 mg/kg, and Na is 17.5 mg/kg for this wine. In much lower amounts, Mn is reported at 1.70 mg/kg and Fe at 1.64 mg/kg. In descending order, Sr concentration is 0.698 mg/kg, Zn is 0.436 mg/kg, and Ba is 0.408 mg/kg. Trace amounts of Pb (0.0815 mg/kg), Cu (0.0704 mg/kg), and Co (0.0282 mg/kg) are also detected in the Stoller Vineyard wine sample.

Table 37. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2011 vintage of Chehalem, Stoller Vineyard (ND – Non-detectable, * denotes mean of three samples from the same bottle).

Element	2011 Wine Sample* (mg/kg)	Element	2011 Wine Sample* (mg/kg)
Al	ND	Mn	1.70
As	ND	Hg	ND
Ba	0.408	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	233
Ca	52.3	K	785
Cr	ND	Se	ND
Co	0.0282	Na	17.5
Cu	0.0704	Sr	0.698
Fe	1.64	S	75.1
Pb	0.0815	V	ND
Mg	50.1	Zn	0.436

Chehalem also contributed multiple vintages of each vineyard to this study in order to look further into the possible influence of climate on the uptake of elements from the soil. The 2007, 2008, and 2009 vintages of the Stoller Vineyard site are shown in (Table 38). In brief comparison, the 2007 vintage has higher concentrations of Ba, Cu, Mn, and Na. The 2008 vintage has the highest concentration of Fe, S, and Co but the lowest concentration of Mg and Ca. The bottle of the 2009 vintage has the highest concentration of Ca and K, but the lowest concentration of Ba, Cu, Fe, Mn, Na, and Sr. Further analysis needs to be completed in order to determine if these differences are significant. Direct comparison of vineyard climate to the uptake of elements should be done in the future.

Table 38. Elemental concentrations measured by ICP-MS of multiple vintages of Chehalem, Stoller Vineyard wine (ND – Non-detectable).

Element	2007 Bottle (mg/kg)	2008 Bottle (mg/kg)	2009 Bottle (mg/kg)
Al	ND	ND	ND
As	ND	ND	ND
Ba	0.557	0.393	0.358
Be	ND	ND	ND
Cd	ND	ND	ND
Ca	49	32.5	51.6
Cr	ND	ND	ND
Co	ND	0.0358	ND
Cu	0.298	0.213	0.14
Fe	2.68	2.82	1.7
Pb	ND	0.0812	0.0475
Mg	71.5	46.8	60.8
Mn	2.12	1.95	1.91
Hg	ND	ND	ND
Mo	ND	ND	ND
Ni	ND	ND	ND
P	327	289	319
K	774	710	860
Se	ND	ND	ND
Na	3.93	3.87	3.32
Sr	0.858	0.812	0.732
S	68.4	88.1	77.4
V	ND	ND	ND
Zn	0.702	0.55	0.356

Clay Mineralogy

The Stoller Vineyard soil contains a similar clay mineral assemblage as Elk Cove Five Mountain (loess/volcanic parent material) and Willakenzie Estate Jory Hills Vineyards (volcanic parent material). The clay mineralogy was determined from the Bt3

horizon. There is moderate cristobalite and goethite as the main Fe phase at this site. Clays include moderate illite, kaolinite, and halloysite. Minor hydroxy interlayered smectite, which may contain chlorite, is also present. The clays also included some mica, suggesting a loess addition.

Marine Sediment Parent Material – Ridgecrest Vineyard

Physical Characteristics

The site at Ridgecrest Vineyard is owned by Chehalem and located in Newberg, Oregon. This vineyard is planted on sandstone of the Coast Range marine sediments (Figure 2). The Ridgecrest Vineyard soil pit is located on the midslope of an east facing slope with vine rows running north and south (Lat. 45.367757 N, Long. -123.079108 W). The soil pit location was at 638 feet (195 meters) elevation between rows 23 and 24 and is mapped as Wellsdale (previously Willakenzie) soil series (Figure 21). The vines are Pinot Noir Pommard clone planted in 1985 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto Chardonnay Dijon clone rootstock (Table 8).

The Wellsdale soil is characterized as an Aquultic Haploxeralf. The soil pit was 220+ cm deep without refusal and 20 cm of C horizon was collected using an auger. The C1 and C2 horizons were sandstone of the Coast Range marine sediments (Figure 2). Sand percent increased from 23% in the Ap horizon to 47% in the C2 horizon (Table 39).

Figure 21. Soil map of Chehalem, Ridgecrest Vineyard. Pit location marked. 2779C – Wellsdale loam, 2 to 12 percent slopes. 2779D – Wellsdale loam, 12 to 20 percent slopes. 2779E – Wellsdale loam, 20 to 30 percent slopes. 2770F – Melbourne-Goodin silt loams, 30 to 60 percent slopes (NRCS, 2015). Previously mapped as WeC - Willakenzie silty clay loam, 2 to 12 percent slopes (NRCS, 2014).

The pH decreases with depth from 5.5 in the Ap horizon to 5.0. CEC decreases from the Ap horizon but bulges in the Bt2 horizon and OM ranges from 3.9% to 16.1%. Dry color for the upper horizons (Ap, Bt1 and Bt2) is yellowish brown and dark yellowish brown (10 YR 5/4 and 10 YR 4/4). The C horizons portrayed two colors of sand/silt, one strong brown (7.5 YR 5/6) and light yellowish brown (2.5 Y 7/4) (Figure 22). Textures are silt loam in the Ap horizon, Bt2 is clay loam, and the C horizons are loam. Structures for the upper horizons of the soil profile are weak to moderate, fine subangular blocky, and the C

horizons are single grain. The Bt2, C1 and C2 horizons have 10% coarse fragments of sandstone bedrock. The Ap horizon is nonsticky and non-plastic, the Bt1 and Bt2 horizons are sticky and plastic. Clay percent increases with depth from 14% in the Ap to 29% in Bt2 but then decreases to 14% in the C2 horizon. Common, faint clay films are located on ped faces in the Bt1 horizon. The soil contains muscovite mica and quartz sand. There are no pisolites in this profile.

Table 39. Chehalem, Ridgecrest Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-25	Ap	23.2	59.6	13.7	0.0	SiL
25-65	Bt1	20.9	56.3	21.4	0.0	SiL
65-115	Bt2	25.8	42.6	29.0	0.0	CL
115-200	C1	43.0	35.7	10.4	0.1	L
200-220+	C2	46.6	31.3	13.5	0.1	L
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-25	Ap	10YR 5/4	1, f, gr	3.9	5.5	14.8
25-65	Bt1	10YR 4/4	2, f, sbk	6.0	5.6	11.2
65-115	Bt2	10YR 5/4	2, f, sbk	8.6	5.3	19.1
115-200	C1	7.5YR 5/6 2.5Y 7/4	sg	16.1	5.1	
200-220+	C2	7.5YR 5/8 2.5Y 6/4	sg	15.5	5.0

Figure 22. Sample soil pit at Chehalem, Ridgecrest Vineyard. A – View of sample location, facing east. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Ridgecrest Vineyard soil pit was separated into six horizons, and samples of each horizon were sent for analysis (Table 40). This is one of the deepest soil pits reaching the R horizon at depths greater than 220 cm. P and K decrease with depth. Ca and Mg increase with depth. S is only detected in the Ap horizon. The micronutrient concentrations measured in the six soil horizons from the Ridgecrest Vineyard have varying trends. Co, Fe, and Al increase with depth to the C1 horizon, then decrease. Cu and Mn are highest at the top of the profile and decrease with depth. Na, Ni and Zn are variable with the highest concentrations at the bottom of the profile. Trace element concentrations vary for the six horizons of the Ridgecrest Vineyard (Table 40). As and Se are highest in the Ap horizon at the top of the profile and decrease with depth with a bulge in the R horizon for As. Ba, Be, Cd, Cr, Pb, and V are all highest in the R horizon as well. Disregarding the R horizon, Ba and Cd decrease with depth with a bulge in the C1 horizon. Be, Sr, and V increases with depth. Cr and Pb decrease with depth.

Grape Juice Chemistry

As previously stated, 24 elements (same as the soil samples) were analyzed in the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study and only

Table 40. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Chehalem, Ridgecrest Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-25)	713	902	1290	1590	174	ND				
Bt1 (25-65)	528	711	965	1690	ND	ND				
Bt2 (65-115)	378	525	1350	1720	ND	ND				
C1 (115-200)	260	182	2960	2840	ND	ND				
C2 (200-220)	324	115	3050	2510	ND	ND				
R (220+)	1040	307	1060	930	ND	ND				
Mean	541	457	1780	1880	174	ND				
SD	294	311	961	688	0	ND				
Maximum	1040	902	3050	2840	174	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-25)	27000	13700	17.7	19.2	1470	ND	196	6.21	44.3	
Bt1 (25-65)	28600	14700	18.6	12.7	1160	ND	172	6.57	41.8	
Bt2 (65-115)	29900	14500	20.7	10.9	698	ND	183	4.31	36.4	
C1 (115-200)	49000	36000	24.6	11.9	522	ND	219	6.56	82.7	
C2 (200-220)	44800	34400	18.4	13.3	302	ND	215	5.72	78.6	
R (220+)	34100	22600	14.3	17.4	240	ND	267	15.9	85.8	
Mean	35600	22700	19.1	14.2	732	ND	209	7.55	61.6	
SD	9190	10300	3.42	3.30	490	ND	33.8	4.18	23.0	
Maximum	49000	36000	24.6	19.2	1470	ND	267	15.9	85.8	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-25)	2.34	170	0.708	0.219	16.2	ND	9.58	0.594	14.1	74.3
Bt1 (25-65)	2.22	128	0.699	0.180	16.1	ND	8.50	0.572	11.4	80.1
Bt2 (65-115)	1.31	97.9	0.719	0.177	13.7	ND	8.68	ND	16.8	86.8
C1 (115-200)	0.389	267	0.758	0.277	7.32	ND	5.47	ND	43.1	97.6
C2 (200-220)	0.43	250	0.796	0.258	6.18	ND	6.61	ND	46.2	107
R (220+)	1.34	328	1.220	0.916	23.8	ND	16.2	0.568	11.1	127
Mean	1.34	207	0.817	0.338	13.9	ND	9.17	0.578	23.8	95.5
SD	0.838	89.0	0.201	0.286	6.50	ND	3.76	0.014	16.3	19.4
Maximum	2.34	328	1.220	0.916	23.8	ND	16.2	0.594	46.2	127

elements found in any grape sample are show in Table 41. The concentrations of K and Na in the Ridgecrest Vineyard grape juice are 851 mg/kg and 155 mg/kg, respectively. This is one of the lowest concentrations of K in all 20 of the grape samples. Sr concentrations are measured as 1.1 mg/kg, which is the 4th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P and Mn concentrations are both below detection limits for these grapes.

Table 41. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Chehalem, Ridgecrest Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	1.1	ND	851	155	ND	ND	ND	ND	ND

Wine Chemistry

Chehalem provided a 750 ml sample of the wine produced from the Ridgecrest Vineyard in 2011. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in Ridgecrest Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 42). K and P concentrations are the highest at 673 mg/kg and 364 mg/kg, respectively. S is 86.0 mg/kg, Ca is 61.6 mg/kg, Mg is 61.5 mg/kg, and Na is 9.94 mg/kg for this wine. In much lower amounts, Fe concentration is 2.14 mg/kg and Mn is reported at 1.31 mg/kg. The concentration of Sr is 1.19 mg/kg, Zn is 1.09 mg/kg,

Ba is 0.288 mg/kg, and Cu is 0.162 mg/kg. Trace amounts of Pb (0.0622 mg/kg) and Co (0.030 mg/kg) are also detected in the Stoller Vineyard wine sample.

Table 42. Elemental concentrations measured by ICP-MS of three samples of the same 750 ml unblended wine sample from the 2011 vintage of Chehalem, Ridgecrest Vineyard (ND – Non-detectable, * denotes mean of three samples from the same bottle).

Element	2011 Wine Sample* (mg/kg)	Element	2011 Wine Sample* (mg/kg)
Al	ND	Mn	1.31
As	ND	Hg	ND
Ba	0.288	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	364
Ca	61.6	K	673
Cr	ND	Se	ND
Co	0.030	Na	9.94
Cu	0.162	Sr	1.19
Fe	2.14	S	86.0
Pb	0.0622	V	ND
Mg	61.5	Zn	1.09

Chehalem also contributed multiple vintages of each vineyard to this study in order to look further into the possible influence of climate on the uptake of elements from the soil. The 2007 and 2008 vintages of the Ridgecrest Vineyard site are shown in (Table 43). In brief comparison, the 2007 vintage has higher concentrations of Ba, Ca, Co, Cu, Fe, Pb, P, Na, Sr, S, and Zn. The Ca, Na, Sr, S, Zn are very similar to the concentrations in the 2008 vintage. The 2008 vintage has the higher concentrations of Mg, Mn, and K than the 2007 vintage. Further analysis needs to be completed in order to determine if these differences are significant.

Table 43. Elemental concentrations measured by ICP-MS of multiple vintages of Chehalem, Ridgecrest Vineyard wine (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2007 Bottle (mg/kg)	2008 Bottle* (mg/kg)	Element	2007 Bottle (mg/kg)	2008 Bottle* (mg/kg)
Al	ND	ND	Mn	1.34	1.58
As	ND	ND	Hg	ND	ND
Ba	0.366	0.262	Mo	ND	ND
Be	ND	ND	Ni	ND	ND
Cd	ND	ND	P	326	208
Ca	40.5	39.7	K	700	723
Cr	ND	ND	Se	ND	ND
Co	0.0345	ND	Na	8.54	8.32
Cu	0.553	0.377	Sr	1.49	1.40
Fe	3.84	2.77	S	106	99.4
Pb	0.0822	ND	V	ND	ND
Mg	49.5	90.0	Zn	0.644	0.618

Clay Mineralogy

The Ridgecrest Vineyard soil includes moderate to abundant illite in the clay fraction of the Bt2 horizon. This is mostly likely from the weathering of the mica in the parent material, recorded visually during grain size analysis. Minor amounts of hydroxy interlayered smectite and dehydrated halloysite and moderate amounts of highly disordered kaolinite are also present. The minor chloritic intergrade has moderate expansion and little mixed layered chlorite with trace vermiculite. Minor amounts of cristobalite and goethite are present.

Loess and Volcanic Parent Material – Corral Creek Vineyard

Physical Characteristics

Corral Creek Vineyard is owned by Chehalem and located in Newberg, Oregon. This vineyard is planted on basalt of the Columbia River Basalt Group, (Figure 2), and the soils are part of the Laurelwood soil series (Figure 23). The Corral Creek Vineyard soil pit is located on the midslope of a northwest facing slope with vine rows running slightly northwest and southeast (Lat. 45.312503 N, Long. -122.916342 W). The soil pit location was at 373 feet (114 meters) elevation between rows 2 and 3. The vines are Pinot Noir Pommard clone planted in 1983 and are trellised as bilateral cordon in vertical shoot position.

The Laurelwood soil is characterized as an Ultic Haploxeralf. The soil pit was 65+ cm deep with refusal. The Cr and R horizons contained fractured basalt bedrock. The pH for the pit is around 5.8, and OM ranges from 5.9% to 6.9%. CEC is very high at 42.2 meq/100 g in the Ap horizon and abruptly drops to 19.5 meq/100 g in the Bt horizon (Table 44). The silt content of this soil pit decreases with depth as sand and clay percent increase. Silt percent is 68% in the Ap horizon and decreases to 49% percent in the Cr horizon. Dry colors for the entire profile are brown (10 YR 4/3 and 7.5 YR 4/4) (Figure 24). Textures are silt loam in the Ap horizon and silty clay loam with depth. Structures are moderate medium subangular blocky in the Bt horizon. The Cr horizon contains 50% coarse fragments of basalt bedrock, and the R horizon has greater than 75% rock

Figure 23. Soil map of Chehalem, Corral Creek Vineyard Mid North Block. Pit location marked. 2712D – Laurelwood silt loam 12 to 20 percent slopes. 2712 E – Laurelwood silt loam, 20 to 30 percent slopes. 2712 F – Laurelwood silt loam, 30 to 60 percent slopes. 2712C – Laurelwood silt loam, 2 to 12 percent slopes. 2310C – Woodburn silt loam, 2 to 12 percent slopes. 2301A – Amity silt loam, 0 to 3 percent slopes (NRCS, 2015). Previously mapped as LuD – Laurelwood silt loam (NRCS, 2014).

Table 44. Chehalem, Corral Creek Vineyards Mid North Block field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-35	Ap	6.9	67.6	18.2	0.0	SiL
35-55	Bt	6.9	53.4	36.7	0.0	SiCL
55-65	Cr	14.8	49.2	34.6	5.0	SiCL
65+	R					
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-35	Ap	10YR 4/3	m to 1, f, sbk	6.7	5.7	42.2
35-55	Bt	7.5YR 4/4	2, m, sbk	5.9	5.9	19.5
55-65	Cr	7.5YR 5/4		6.9	5.7	
65+	R					

fragments. Clay percent increases with depth from 18% in the Ap to 37% in the Bt horizon. Very few to common faint to distinct clay films are located on ped faces and interstitial pores of the Ap, Bt and Cr horizons. The soil contains few, fine to medium pisolites in both Ap and Bt horizons.

Soil Chemistry

The Corral Creek Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 45). K decreases with depth. S is only detected in the Ap horizon. P and Ca concentrations are variable, decreasing from the Ap then increasing to a maximum in the R horizon. Mg concentration bulges in the Bt

Figure 24. Sample soil pit at Chehalem, Corral Creek Vineyard Mid North Block. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked.

Table 45. Macronutrient concentrations (all values in mg/kg) for the Chehalem, Corral Creek Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl
Ap (0-35)	1280	1560	1630	2640	148	ND
Bt (35-55)	699	1150	1440	2930	ND	ND
Cr (55-65)	830	1020	1570	2730	ND	ND
R (65+)	1310	393	2100	1100	ND	ND
Mean	1030	1030	1690	2350	148	ND
SD	311	483	288	842	0	ND
Maximum	1310	1560	2100	2930	148	0

Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn
Ap (0-35)	32000	19200	17.2	17.3	1210	ND	214	9.69	66.0
Bt (35-55)	31600	21600	14.8	12.9	556	ND	217	9.5	43.0
Cr (55-65)	37600	25500	19.7	15.3	715	ND	225	13.1	44.6
R (65+)	37300	36400	12.1	28.8	176	ND	281	35.3	63.4
Mean	34600	25700	16.0	18.6	664	ND	234	16.9	54.3
SD	3270	7600	3.25	7.05	428	ND	31.5	12.4	12.1
Maximum	37600	36400	19.7	28.8	1210	0	281	35.3	66.0

Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-35)	3.02	222	0.645	0.222	18.2	ND	10.7	ND	19.2	106
Bt (35-55)	2.80	134	0.743	0.180	19.8	ND	9.09	ND	19.2	98.9
Cr (55-65)	2.56	240	0.979	0.372	20.6	ND	10.2	ND	22.5	111
R (65+)	0.948	669	1.02	0.741	19.1	ND	12.5	0.686	34.1	87.3
Mean	2.33	316	0.847	0.379	19.4	ND	10.6	0.686	23.8	101
SD	0.942	240	0.182	0.255	1.02	ND	1.42	0	7.07	10.3
Maximum	3.02	669	1.02	0.741	20.6	ND	12.5	0.686	34.1	111

horizon and decreases in the R horizon. The micronutrient concentrations measured in the four soil horizons from the Corral Creek Vineyard have varying trends. Al, Na, Ni, and Cu increase with depth with the highest in the R horizon. Fe and Co concentrations bulge in the Cr horizon. Mn decreases with depth. Zn decreases from the surface but then

increases in the R horizon. Trace element concentrations for the four horizons of the Corral Creek Vineyard are reported. Be and Sr increase with depth and the highest concentration is in the R horizon. Ba, Cd, and Pb concentrations vary with depth but are highest also in the R horizon. Se was only detected in the R horizon. Cr and V increase to a bulge in concentration in the Cr horizon then decrease. As decreases with depth.

Grape Juice Chemistry

The 24 elements (same as the soil samples) were analyzed in the grape juice from grapes collected adjacent to the soil pits had concentrations of many elements that are below detection limits in this study, and only elements found in any grape sample are shown in (Table 46). The concentrations of K and Na in the Corral Creek Vineyard grape juice are 1530 mg/kg and 159 mg/kg, respectively. Sr concentrations are measured as 0.711 mg/kg, which is the 12th highest concentration of Sr, equal to Lange Estate Mia Vineyard, for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 303 mg/kg for these grapes.

Table 46. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Chehalem, Corral Creek Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.711	303	1530	159	ND	ND	ND	ND	ND

Wine Chemistry

Chehalem provided a 750 ml wine sample from the Corral Creek Vineyard in 2011. Many of the 24 elements tested in the wine were below detection limits. The 14 elements that were detected in Corral Creek Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 47). K and P concentrations are the highest at 808 mg/kg and 467 mg/kg, respectively. S is 87.7 mg/kg, Ca is 57.2 mg/kg, Mg is 54.1 mg/kg, and Na is 8.91 mg/kg for this wine. In much lower amounts, the concentration of Fe is 2.13 mg/kg and Mn is 0.865 mg/kg. The concentration of Sr is 0.880 mg/kg, Zn is 0.567 mg/kg, Ba is 0.298 mg/kg, and Cu is 0.116 mg/kg. Trace amounts of Pb (0.0845 mg/kg) and Co (0.0312 mg/kg) are also detected.

Table 47. Elemental concentrations measured by ICP-MS of three samples of the same 750 ml unblended wine from the 2011 vintage of Chehalem, Corral Creek Vineyard wine (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2011 Wine Sample* (mg/kg)	Element	2011 Wine Sample* (mg/kg)
Al	ND	Mn	0.865
As	ND	Hg	ND
Ba	0.298	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	467
Ca	57.2	K	808
Cr	ND	Se	ND
Co	0.0312	Na	8.91
Cu	0.116	Sr	0.880
Fe	2.13	S	87.7
Pb	0.0845	V	ND
Mg	54.1	Zn	0.567

Chehalem also contributed multiple vintages of each vineyard to this study to look further into the possible influence of climate on the uptake of elements from the soil. The 2008 and 2009 vintages of the Corral Creek Vineyard site are shown in (Table 48). In brief comparison, the 2008 vintage has higher concentrations of Ba, Cu, Fe, Mg, Mn, and Sr. The Mn and Sr concentrations are very similar to the concentrations in the 2009 vintage. The 2009 vintage has the higher concentrations of Ca, P, K, Na, S, and Zn than the 2008 vintage. Further analysis needs to be completed in order to determine if these differences are significant.

Table 48. Elemental concentrations measured by ICP-MS of multiple vintages of Chehalem, Corral Creek Vineyard wine (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2008 Bottle* (mg/kg)	2009 Bottle (mg/kg)	Element	2008 Bottle* (mg/kg)	2009 Bottle (mg/kg)
Al	ND	ND	Mn	1.10	0.926
As	ND	ND	Hg	ND	ND
Ba	0.469	0.272	Mo	ND	ND
Be	ND	ND	Ni	ND	ND
Cd	ND	ND	P	246	384
Ca	39.4	49	K	771	828
Cr	ND	ND	Se	ND	ND
Co	ND	ND	Na	4.87	5.32
Cu	0.171	0.102	Sr	1.08	0.992
Fe	2.68	2.18	S	75.9	84.8
Pb	ND	ND	V	ND	ND
Mg	82.6	68.2	Zn	0.416	0.478

Clay Mineralogy

The Bt horizon of the Corral Creek Vineyard provides the clay mineralogy for the profile. This site is described as having the most illite clay compared to the other Chehalem, Elk Cove, and Willakenzie samples. Moderate amounts of mica are present as well as minor chlorite and vermiculite interlayers. Moderate kaolinite in the sample is accompanied by trace amounts of smectite and halloysite. Minor cristobalite is also present and gibbsite with just trace amounts of goethite. The variety of clay minerals at this site, suggest a mix of parent material and ages of soil development.

Chapter Seven – Lange Estate Winery and Vineyards Results

Volcanic Parent Material – Estate Vineyard, Mia Block North

Physical Characteristics

The Mia Block Vineyard, owned and operated by Lange Estate, is located in Dundee, Oregon. These vineyards are located on basaltic rocks of the Columbia River Basalt group. Mia Block Vineyard is located on the midslope of a south facing slope with vine rows running north and south (Lat. 45.294480 N, Long. -123.043289 W). The soil pit location was at 719 feet (220 meters) elevation between rows 15 and 16, and the soil is mapped as the Jory – Gelderman (previously Jory) soil series (Figure 25). According to the vineyard manager, this vineyard is cultivated every other year. The vines are Pinot Noir Dijon 777 clone planted in 2004 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto 3309 rootstocks (Table 8).

The Jory – Gelderman soil is characterized as a Xeric Palehumult – Xeric Haplohumult. The soil pit was 195+ cm deep, and I did not reach the parent material or refusal at that depth. Percent silt decreases from 61% in Ap to 47% in A/B but then increases again in the Bt1 horizon to 57% and then decreases again to 42% in the Bt2 and Bt3 horizons. Dry color of brown (7.5 YR 4/3) is also constant throughout (Figure 26). Structure throughout the soil profile is moderate to strong, medium subangular blocky with some granular texture in the Ap horizon and platy structure in Bt2. The Ap horizon

Figure 25. Soil map of Lange Estate Winery and Vineyards, Estate Vineyard Mia North Block. Pit location marked. 2780C – Jory-Gelderman silty clay loams, 2 to 12 percent slopes. 2711D – Jory silty clay loam, 12 to 20 percent slopes. 2711F – Jory silty clay loam, 30 to 60 percent slopes (NRCS, 2015). Previously mapped as JrC – Jory clay loam, 7 to 12 percent slopes (NRCS, 2014).

is slightly sticky and slightly plastic, but Bt1 is sticky and plastic, and the Bt2 and Bt3 are very sticky and very plastic due to a jump in clay percent from 19% in the Ap to 46% and 43% in Bt2 and Bt3, respectively. Clay films, located on ped faces and interstitial pores, increase in number from A/B (very few and faint) to Bt3 (many and dominant). Pisolites are found abundantly throughout the profile. The OM, pH and CEC decrease with depth

for this profile. The pH ranges from 5.3 to 5.8, CEC ranges from 15.6 to 22.6, and OM ranges from 7.8% to 10.7% (Table 49).

Table 49. Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-20	Ap	18.5	60.7	19.4	2.1	SiL
20-50	A/B	18.3	46.6	26.2	0.5	SiL
50-80	Bt1	17.7	57.4	24.1	1.0	SiL
80-140	Bt2	6.9	42.2	46.2	0.0	SiC
140-195+	Bt3	8.2	42.3	43.5	0.3	SiC
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-20	Ap	7.5YR 4/3	2, m, gr to sbk	10.7	5.6	22.6
20-50	A/B	7.5YR 4/3	2, m, sbk	9.8	5.8	22.4
50-80	Bt1	7.5YR 4/3	3, m, sbk	8.3	5.8	18.9
80-140	Bt2	7.5YR 4/4	3, m, pl to sbk	7.8	5.5	15.6
140-195+	Bt3	7.5YR 4/4	3, m, sbk	8.6	5.3	17.8

Soil Chemistry

The Lange Estate Vineyard, Mia Block soil pit was separated into five horizons, and samples of each horizon were sent for analysis (Table 50). This is one of the deepest soil pits in the project without reaching the parent material even at 195 cm. P and Ca have bulges in the A/B horizon. K concentration is highest in the Ap horizon and decreases

Figure 26. Sample soil pit at Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

with depth. Mg reaches a maximum in the Bt1 and Bt2 horizons. S decreases with depth from a maximum concentration in the Ap horizon. The micronutrient concentrations measured in the five soil horizons from the Lange Estate Vineyard, Mia Block also have few trends. Fe concentration is highest in the Ap horizon and then bulges in the Bt1 horizon. Al, Co, Mn, Ni and Zn all bulge in the Bt1 horizon. Cu is highest in the A/B horizon. Na is highest at depth in the Bt3 horizon after variable concentrations through the profile. Trace element concentrations for the five horizons of the Lange Estate Vineyard, Mia Block are also reported. Sr, Se, As and Ba all decrease with depth. V, Be, and Cr decrease with depth with a bulge in the Bt1 horizon. Cd and Pb decrease with depth with a bulge in the A/B horizon.

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study and are not listed in Table 51. All 24 elements, the same as were tested in the soil samples, were analyzed in the grape juice from grapes collected adjacent to the soil pits. K, Na, and Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites. The concentrations of K and Na in the Stoller Vineyard grape juice are 1730 mg/kg and 162 mg/kg, respectively. Sr concentrations are measured as 0.711 mg/kg, which is the 12th highest concentration, equal to Chehalem Corral Creek Vineyard, of Sr for the 20 vineyard samples (Table 105). P concentration is 248 mg/kg for this grape sample.

Table 50. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Lange Estate Winery and Vineyards, Estate Vineyard, Mia Block North soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-20)	1680	936	1620	1090	270	ND				
A/B (20-50)	1750	891	1790	1450	240	ND				
Bt1 (50-80)	1650	743	1030	1590	152	ND				
Bt2 (80-140)	878	491	972	1590	ND	ND				
Bt3 (140-195+)	1010	373	849	1220	ND	ND				
Mean	1390	687	1250	1390	221	ND				
SD	415	247	423	225	61.3	ND				
Maximum	1750	936	1790	1590	270	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-20)	45700	19000	20.0	19.3	2480	ND	173	8.97	63.1	
A/B (20-50)	39600	15200	21.1	22.3	2490	ND	130	6.69	50.6	
Bt1 (50-80)	44100	19300	21.1	17.0	2560	ND	189	9.25	63.1	
Bt2 (80-140)	42200	17300	14.0	15.9	796	ND	177	7.34	39.5	
Bt3 (140-195+)	43600	15900	20.4	17.5	1150	ND	199	6.11	33.4	
Mean	43000	17300	19.3	18.4	1900	ND	174	7.67	49.9	
SD	2290	1820	3.01	2.50	852	ND	26.4	1.39	13.5	
Maximum	45700	19300	21.1	22.3	2560	ND	199	9.25	63.1	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-20)	2.75	281	0.770	0.292	26.6	ND	12.1	0.604	24.8	139
A/B (20-50)	2.12	265	0.695	0.301	21.8	ND	12.4	0.581	23.0	119
Bt1 (50-80)	2.25	229	0.757	0.289	25.7	ND	11.5	0.508	16.2	130
Bt2 (80-140)	1.49	110	0.696	0.203	23.8	ND	10.0	ND	15.3	122
Bt3 (140-195+)	1.18	87.2	0.670	0.231	22.0	ND	10.7	ND	13.3	125
Mean	1.96	194	0.718	0.263	24.0	ND	11.3	0.564	18.5	127
SD	0.625	89.9	0.0434	0.0435	2.15	ND	0.991	0.050	5.06	7.84
Maximum	2.75	281	0.770	0.301	26.6	ND	12.4	0.604	24.8	139

Table 51. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Lange Estate, Estate Vineyard Mia Block North (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.711	248	1730	162	ND	ND	ND	ND	ND

Wine Chemistry

Lange Estate Winery and Vineyards provided a 750 ml sample of the wine produced from the Estate Vineyard, Mia Block in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in Estate Vineyard, Mia Block wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 52). K and P concentrations are the highest at 739 mg/kg and 168 mg/kg, respectively. S is 108 mg/kg, Mg is 73.3 mg/kg, Ca is 28.5 mg/kg, and Na is 10.2 mg/kg for this wine. In much lower amounts, the concentration of Mn is 2.30 mg/kg and Fe is 1.75 mg/kg. The concentration of Sr is 1.04 mg/kg, Ba is 0.462 mg/kg, Zn is 0.274 mg/kg, and Cu is 0.141 mg/kg. Trace amounts of Pb (0.0892 mg/kg) and Co (0.0330 mg/kg) are also detected in the Estate Vineyard, Mia Block wine sample.

Clay Mineralogy

The Mia Block clay mineral assemblage was determined from the Bt3 horizon. It is considered very similar to the Lange Yamhill (marine sediment parent material), Rex Hill Sims (volcanic parent material), and Ken Wright Abbot Claim Vineyards (marine sediment parent material). This soil is dominated by disordered kaolinite with trace

amounts of halloysite, illite, hydroxy-interlayered smectite-vermiculite and chloritic-intergrade clays. Moderate goethite and minor amounts of gibbsite are present. Hydroxy interlayered material is composed of highly pillared clays with lots of hydroxy Al-Fe interlayer material.

Table 52. Elemental concentrations measured twice by ICP-MS of the same 750 ml unblended wine sample from the 2012 Lange Estate Winery, Mia Block North Vineyard (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2012 Wine Sample* (mg/kg)	Element	2012 Wine Sample* (mg/kg)
Al	ND	Mn	2.30
As	ND	Hg	ND
Ba	0.462	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	168
Ca	28.5	K	739
Cr	ND	Se	ND
Co	0.0330	Na	10.2
Cu	0.141	Sr	1.04
Fe	1.75	S	108
Pb	0.0892	V	ND
Mg	73.3	Zn	0.274

Marine Sediment Parent Material – Yamhill Vineyard

Physical Characteristics

Yamhill Vineyard, owned and operated by Ralph Stein, is located in Yamhill, Oregon. These vineyards are located on Coast Range marine sediments. Yamhill Vineyard is located on the summit of a south facing slope with vine rows running north and south (Lat. 45.324441 N, Long. -123.150227 W). The soil pit location was at 453

Figure 27. Soil map of Lange Estate Winery and Vineyards, Yamhill Vineyard. Pit location marked. 2760C – Wellsdale-Willakenzie-Dupee complex, 2 to 12 percent slopes. 2762D – Willakenzie-Wellsdale complex, 12 to 20 percent slopes. 2762E – Willakenzie-Wellsdale complex, 20 to 30 percent slopes. 2761E – Wellsdale-Willakenzie complex, 20 to 30 percent slopes (NRCS, 2015). Previously mapped as WeC – Willakenzie silty clay loam, 2 to 12 percent slopes (NRCS, 2014).

feet (138 meters) elevation between rows 9 and 10, and the soil is mapped as the Wellsdale complex soil series (Figure 27). According to the vineyard owner, this vineyard suffers from phylloxera (*Dactylosphaera vitifoliae*) and has produced small clusters of grapes since planted. The impact of phylloxera on the roots of the vines, restricting nutrients, may also influence the uptake of trace elements. The vines are Pinot

Noir Pommard clone planted in 1986 and are trellised as bilateral cordon in vertical shoot position. The vines are most likely own-rooted (Table 8).

Table 53. Lange Estate Winery and Vineyards, Yamhill Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-26	Ap	39.6	43.8	18.2	0.1	L
26-42	Bt1	32.6	36.3	30.7	0.0	CL
42-75	Bt2	30.3	32.4	37.0	0.0	CL
75-110	Bg	41.2	30.3	26.6	1.9	CL
110-160	Cr1	58.6	27.1	13.1	0.0	SL
160-200+	Cr2	56.2	30.2	11.7	0.0	SL
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-26	Ap	10YR 5/4	2, f, gr to sbk	5.7	5.8	14.0
26-42	Bt1	10YR 6/4	2, m, sbk	5.1	5.5	15.3
42-75	Bt2	7.5YR 5/6 7.5YR 5/4	2, m, sbk	6.2	5.3	17.8
75-110	Bg	5YR 6/6 5YR 7/3	1, c/f, pl to sbk	8.7	4.9	26.1
110-160	Cr1	10YR 7/4	sg to 1, f, sbk	8.5	5.0	
160-200+	Cr2	10YR 7/4	sg to 1, f, sbk	8.4	5.1	

The Wellsdale complex soil is characterized as an Aquultic Haploxeralf. The soil pit was 200+ cm deep, and I did not reach the parent material or refusal at that depth. Percent sand varies from 30% in the Bt2 horizon to 59% in Cr1 and 40% in Ap. The pH decreases with depth from 5.8 to 4.9. CEC increases with depth and OM ranges from

5.1% to 8.7% (Table 53). Dry colors for the Ap horizon are yellowish brown (10 YR 5/4). The Bt2 horizon is strong brown (7.5 YR 5/6), and the Bg horizon is multicolored with brown (7.5 YR 5/4) dominant with reddish yellow (5 YR 6/6) and pink (5 YR 7/3) speckling (Figure 28). Textures include loam, clay loam and sandy loam with depth. Structure is medium subangular blocky with some granular texture in the Ap, Cr1 and Cr2 horizons. The Bt1 is very sticky and very plastic due to a jump in clay percent from 18% in the Ap to 31% in the Bt1 and 37% percent in the Bt2 horizon. Clay films located on ped faces are common and dominant in the Bt1 and Bt2 horizons. The soil contains muscovite mica and quartz sand, and no pisolites are found in the profile.

Soil Chemistry

The Yamhill Vineyard soil pit was separated into six horizons, and samples of each horizon were sent for analysis (Table 54). This is one of the deepest soil pits, reaching weathered parent material (Cr1 horizon) at 110 cm but continuing through the friable material to 200 cm. The maximum concentration of most macronutrients is in the Cr2 horizon. Ca concentration bulges in the Bg horizon and Mg bulges in the Bt1 horizon. S is only detected in the Ap horizon. Cl is only detected in the Cr1 horizon. The micronutrient concentrations measured in the six soil horizons from the Yamhill Vineyard also have few trends. Na, Ni, Zn, and Cu concentrations are highest in the Cr2 horizon but bulge in the Bt1 horizon. Mn is highest in the Ap horizon with a bulge in the Bt2 horizon.

Figure 28. Sample soil pit at Lange Estate Winery and Vineyards, Yamhill Vineyard. A – View of sample location, facing northwest. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Table 54. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Lange Estate Winery and Vineyards, Yamhill Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-26)	367	839	1120	1020	154	ND				
Bt1 (26-42)	318	1280	805	2920	ND	ND				
Bt2 (42-75)	367	1020	1260	1450	ND	ND				
Bg (75-110)	382	909	1300	1490	ND	ND				
Cr1 (110-160)	351	1760	836	4090	ND	11.1				
Cr2 (160-200+)	415	1790	1500	4670	ND	ND				
Mean	367	1270	1140	2610	154	11.1				
SD	32.2	422	274	1530	0	0				
Maximum	415	1790	1500	4670	154	11.1				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-26)	14500	5760	8.46	10.3	549	ND	178	3.83	23.5	
Bt1 (26-42)	27200	12800	4.49	12.9	126	ND	204	6.33	38.0	
Bt2 (42-75)	24700	10400	8.83	11.3	326	ND	184	5.31	25.7	
Bg (75-110)	27000	11000	10.2	11.6	304	ND	168	5.31	26.5	
Cr1 (110-160)	27600	13200	4.54	14.7	136	ND	183	8.02	48.5	
Cr2 (160-200+)	36900	12300	5.36	16.9	191	ND	222	11.9	53.5	
Mean	26300	10900	6.98	13.0	272	ND	190	6.78	36.0	
SD	7170	2740	2.48	2.46	159	ND	19.7	2.86	12.8	
Maximum	36900	13200	10.2	16.9	549	ND	222	11.9	53.5	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-26)	2.07	92.5	0.342	0.101	12.5	ND	6.92	ND	12.3	32.1
Bt1 (26-42)	2.24	87.3	0.543	ND	20.3	ND	7.26	ND	22.6	43.5
Bt2 (42-75)	2.68	93.5	0.535	ND	19.4	ND	6.76	ND	15.9	51.9
Bg (75-110)	2.88	87	0.586	ND	19.5	ND	7.88	ND	17.9	55.5
Cr1 (110-160)	3.41	102	0.620	ND	19.5	ND	6.09	ND	23.7	38.2
Cr2 (160-200+)	3.38	116	0.855	0.119	21.4	ND	6.00	0.517	36.9	37.9
Mean	2.78	96.4	0.580	0.110	18.8	ND	6.82	0.517	21.6	43.2
SD	0.561	11.0	0.166	0.013	3.16	ND	0.712	0	8.63	8.98
Maximum	3.41	116	0.855	0.119	21.4	ND	7.88	0.517	36.9	55.5

Co bulges in the Bg horizon. Fe and Al are highest in the Cr2 and Cr1 horizons, respectively, both with small bulges in the Bt1 horizon. Yamhill Vineyard trace element concentrations were also determined for the six horizons. Ba, Be, Cr, and Sr have variable concentrations with the maximum concentration in the Cr2 horizon. Se was only detected in the Cr2 horizon. Cd was detected in the Ap horizon and at slightly higher concentrations in the Cr2 horizon. Pb concentration is variable with the maximum in the Bg horizon. As increases with depth with the highest in the Cr1 horizon.

Grape Juice Chemistry

The same 24 elements that were tested in the soil samples were analyzed in the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study and are not listed in Table 55. The concentrations of K and Na in the Yamhill Vineyard grape juice are 1220 mg/kg and 141 mg/kg, respectively. Sr concentrations are measured as 1.41 mg/kg, which is the highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 243 mg/kg for this grape sample. This is the only grape sample with detectable levels of Mg (111 mg/kg) and one of two samples, along with Ken Wright Nysa Vineyard, with detectable levels of Ca (115 mg/kg) in the grapes.

Table 55. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Lange Estate, Yamhill Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	1.41	243	1220	141	111	ND	115	ND	ND

Wine Chemistry

Lange Estate Winery and Vineyards provided a 750 ml sample of the wine produced from the Yamhill Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 11 elements that were detected in Yamhill Vineyard wine sample include Ba, Ca, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 56). Co, Cu, and Pb were not detected in this sample while they are commonly detected in other wine samples in this study. K and P concentrations are the highest at 743 mg/kg and 206 mg/kg, respectively. S is 74.2 mg/kg, Mg is 94.4 mg/kg, Ca is 31.7 mg/kg, and Na is 4.85 mg/kg for this wine. In much lower amounts, the concentration of Mn is 2.36 mg/kg and Fe is 1.42 mg/kg. The concentration of Sr is 1.62 mg/kg, Ba is 0.54 mg/kg, and Zn is 0.334 mg/kg.

Clay Mineralogy

As stated previously, the Yamhill Vineyard clays are considered very similar to the Lange Estate (volcanic parent material), Rex Hill Sims (volcanic parent material), and Ken Wright Abbot Claim Vineyards (marine sediment parent material). The mineralogy is determined from the Bt2 horizon of this profile. This soil is dominated by disordered kaolinite, indicating strong weathered material. Trace amounts of mica, illite, chlorite,

smectite, and halloysite are present. The smectite-vermiculite, chloritic intergrade clays are present in trace amounts as well. Moderate amounts of goethite are present as the main Fe phase.

Table 56. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Lange Estate Winery, Yamhill Vineyard (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	2.36
As	ND	Hg	ND
Ba	0.54	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	206
Ca	31.7	K	743
Cr	ND	Se	ND
Co	ND	Na	4.85
Cu	ND	Sr	1.62
Fe	1.42	S	74.2
Pb	ND	V	ND
Mg	94.4	Zn	0.334

Marine Sediment Parent Material – Freedom Hill Vineyard

Physical Characteristics

The Freedom Hill Vineyard, owned and operated by Dan and Helen Dusschee, is located near Monmouth and Dallas, Oregon. These vineyards are located on marine sedimentary rocks of the Coast Range. Lange's Freedom Hill Vineyard soil is located on the midslope of an east facing slope of 0 to 1 degrees with vine rows running north and south (Lat. 44.877285 N, Long. -123.286436 W). The soil pit location was at 344 feet

(105 meters) elevation between rows 116 and 117, and the soil is mapped as the Bellpine soil series (Figure 29). The vines are Pinot Noir Dijon 777 clone planted in 2002 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto 44-53 rootstock (Table 8).

Figure 29. Soil map of Lange Estate Winery and Vineyards, Freedom Hill Vineyard. Pit location marked. 8C – Bellpine silty clay loam, 3 to 12 percent slopes. 36C – Jory silty clay loam, 2 to 12 percent slopes. 36D – Jory silty clay loam, 12 to 20 percent slopes (NRCS, 2015). Two sites were analyzed at the Freedom Hill Vineyard; one for Lange and one for Ken Wright.

The Bellpine soil is classified as a Xeric Haplohumult. The soil pit was 157+ cm deep, and I did reach the sandy parent material but not refusal at that depth. The bedrock is part of the Coast Range marine sediments (Figure 2). Less than 10% of the Bt horizon consisted of coarse fragments of sandstone parent material. Percent sand decreases with depth from 20% to 15% from Ap to Bt, but then increases to 63% percent in the Cr2 horizon. Dry colors for the Ap horizon are brown (10 YR 5/4), the Bt is yellowish brown (10 YR 6/4) and the Cr1 and Cr2 horizons are multi-colored from pale yellow (2.5 Y 8/2) to yellowish red (5 YR 4/6) to dark yellowish brown (10 YR 4/6) (Figure 30).

Structure of the Ap and Bt horizons are subangular blocky, and the Cr1 and Cr2 horizons have strong medium platy structure. The Bt1 horizon is sticky and plastic, and the Cr horizons are nonsticky and nonplastic. Clay percent is highest in the Bt horizon at 29% but decreases with depth to 12% in the Cr2 horizon. Clay films are located on ped faces in the Ap and Bt horizons and are few to common and dominant. The soil contains muscovite mica and quartz sand and no pisolites are found in the profile. The CEC increases with depth from 18.9 meq/100 g. OM ranges from 5.3% to 8.4% and pH decreases from 5.4 to 5.1 with depth (Table 57).

Soil Chemistry

The Lange Freedom Hill Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 58). P and S are highest in the Ap

horizon. S is detected at the surface and in the Cr2 horizon. Ca and Mg increase to a bulge in the Cr1 horizon. K bulges in the Bt horizon. P decreases with depth, but increases in the Cr2 horizon to close to the maximum value for the profile. Cl is non-detectable throughout the profile.

Table 57. Lange Estate Winery and Vineyards, Freedom Hill Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-34	Ap	20.3	56.0	22.1	0.0	SiL
34-63	Bt	15.5	54.1	29.1	1.6	SiCL
63-102	Cr1	18.3	51.4	23.3	8.1	SiL
102-157+	Cr2	62.6	23.8	12.1	3.5	SL
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-34	Ap	10YR 5/4	2, vf, sbk	7.6	5.4	18.9
34-63	Bt	10YR 6/4	2, m, sbk	8.4	5.3	20.2
63-102	Cr1	10YR 6/4 5YR 4/6 10YR 4/4	m to 3, m, pl	6.4	5.2	
102-157+	Cr2	10YR 4/6 2.5Y 8/2	m to 3, m, pl	5.3	5.1

Figure 30. Sample soil pit at Lange Estate Winery and Vineyards, Freedom Hill Vineyard. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Table 58. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Lange Estate Winery and Vineyards, Freedom Hill Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-34)	672	683	1190	1170	159	ND				
Bt (34-63)	545	828	1200	1670	104	ND				
Cr1 (63-102)	292	617	2260	2260	ND	ND				
Cr2 (102-157+)	651	580	1220	1860	130	ND				
Mean	540	677	1470	1740	131	ND				
SD	174	109	528	453	27.5	ND				
Maximum	672	828	2260	2260	159	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-34)	29600	8150	11.7	13.8	584	ND	189	5.77	35.8	
Bt (34-63)	38700	11300	16.0	18.0	513	0.589	ND	9.67	36.7	
Cr1 (63-102)	26000	11200	3.46	19.2	96.7	ND	ND	6.10	28.4	
Cr2 (102-157+)	29000	7980	9.87	17.0	220	0.678	107	4.15	22.8	
Mean	30800	9660	10.3	17.0	353	0.634	148	6.42	30.9	
SD	5480	1840	5.21	2.32	233	0.0629	58.0	2.33	6.57	
Maximum	38700	11300	16.0	19.2	584	0.678	189	9.67	36.7	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-34)	6.81	91.4	0.728	0.148	22.6	ND	11.0	ND	14.6	50.8
Bt (34-63)	11.2	85.5	0.888	0.120	27.3	ND	11.9	ND	17.8	68.8
Cr1 (63-102)	9.32	70.1	0.557	ND	18.0	ND	6.94	ND	38.6	40.8
Cr2 (102-157+)	11.8	55.5	0.719	ND	12.3	0.0412	6.07	ND	26.3	28.6
Mean	9.78	75.6	0.723	0.134	20.1	0.0412	8.98	ND	24.3	47.3
SD	2.25	16.1	0.135	0.0198	6.41	0	2.90	ND	10.7	17.0
Maximum	11.8	91.4	0.888	0.148	27.3	0.0412	11.9	ND	38.6	68.8

The micronutrient concentrations measured in the four soil horizons from the Freedom Hill Vineyard also have few trends. Fe, Al, Co, Ni and zinc bulge in the Bt horizon. Mn decreases with depth, then increases in the Cr2 horizon. Cu bulges in the Cr1 horizon. Mo is detected in the Bt and Cr2 horizons, with the highest concentration in the

Cr2 horizon. Na is highest in the Ap horizon. Lange Freedom Hill Vineyard trace element concentrations were also determined for the four horizons. Cd and Ba decrease with depth. Hg was only detected in the Cr2 horizon. Be, V, Pb and Cr all bulge in the Bt horizon. As is variable with the maximum concentration in the Cr2 horizon. Sr bulges in the Cr1 horizon. Se is non-detectable in this profile.

Grape Juice Chemistry

The soil samples were analyzed for the same 24 elements that were tested in the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study and are not listed in Table 59. The concentrations of K and Na in the Freedom Hill Vineyard grape juice are 1380 mg/kg and 150 mg/kg, respectively. Sr concentrations are measured as 0.697 mg/kg, which is the 14th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 266 mg/kg for this grape sample. These are the only 4 elements detected in the grape juice from this sample.

Table 59. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Lange Estate, Freedom Hill Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.697	266	1380	150	ND	ND	ND	ND	ND

Wine Chemistry

Lange Estate Winery and Vineyards provided a 750 ml sample of the wine produced from the Freedom Hill Vineyard in 2012. The 14 elements that were detected in Freedom Hill Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 60). K and P concentrations are the highest at 676 mg/kg and 199 mg/kg, respectively. S is 72.1 mg/kg, Mg is 51.6 mg/kg, Ca is 27.6 mg/kg, and Na is 4.3 mg/kg for this wine. The concentration of Mn is 1.25 mg/kg and Fe is 0.966 mg/kg. The concentration of Sr is 1.05 mg/kg, Ba is 0.577 mg/kg, and Zn is 0.118 mg/kg. Trace amounts of Cu (0.0865 mg/kg), Pb (0.0782 mg/kg) and Co (0.029 mg/kg) are also detected in the Freedom Hill Vineyard wine sample.

Table 60. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Lange Estate Winery, Freedom Hill Vineyard (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.25
As	ND	Hg	ND
Ba	0.577	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	199
Ca	27.6	K	676
Cr	ND	Se	ND
Co	0.029	Na	4.3
Cu	0.0865	Sr	1.05
Fe	0.966	S	72.1
Pb	0.0782	V	ND
Mg	51.6	Zn	0.118

Clay Mineralogy

The Lange Freedom Hill and Ken Wright Freedom Hill are essentially the same when looking at the clay minerals. The Lange Freedom Hill clays were determined from the Bt horizon. These two soils are separated by approximately 500 meters of vineyard at this estate. The expansive clay in the sample is moderately interlayered by Al and Fe oxides which shows moderate weathering. The soil contains trace amounts of mica and illite. The trace amount of chlorite is weakly developed. Minor hydroxy-interlayered smectite and vermiculite are also present with minor amounts of kaolinite. Cristobalite is also in this sample in minor amounts. The main Fe oxide is goethite and is well ordered and expressed.

Chapter Eight – Rex Hill Results

Volcanic Parent Material – Sims Vineyard, Block 2

Physical Characteristics

Sims Vineyard is located in Dundee, Oregon. This vineyard is located on basaltic rocks of the Columbia River Basalt group. Sims Vineyard soil is located on the midslope of a south facing slope with vine rows running north and south (Lat. 45.280286 N, Long. -123.042398 W). The soil pit location was at 656 feet (200 meters) elevation between rows 72 and 73, and the soil is mapped as the Jory soil series (Figure 31). According to the vineyard manager, this vineyard was cultivated with permanent fescue blend cover crop and is certified LIVE, Organic and Biodynamic (Appendix D). The vines are Pinot Noir Pommard clone planted in 2000 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto 3309 rootstocks (Table 8).

The Jory soil is classified as a Xeric Palehumult. The soil pit was 130+ cm deep, and I did reach the parent material but not refusal at that depth. The basalt parent material is found as small chips and gravel (less than 10%) in the Bt2 and Bt3 horizons at depths greater than 50 cm. Dry colors for the entire profile are brown (10 YR 4/4) and strong brown (10 YR 4/6) (Figure 32). Structures throughout the soil profile are moderate, medium subangular blocky with some fine granular texture in the Ap horizon. The Ap horizon is slightly sticky and slightly plastic, but the Bt horizons are all sticky

Figure 31. Soil map for Rex Hill, Sims Vineyard Block 2. Pit location marked. 2711D – Jory silty clay loam, 12 to 20 percent slopes. 2711E – Jory silty clay loam, 20 to 30 percent slopes (NRCS, 2015). Previously JrD - Jory clay loam, 12 to 20 percent slopes (NRCS, 2014).

and plastic due to a jump in clay from 28% in the Ap to 53%, 48%, and 48% in Bt1, Bt2, and Bt3, respectively. Clay films are located on ped faces throughout the profile. They are mostly in the Bt1 horizon (many prominent) but are also in the Bt2 and Bt3 horizons (common dominant to faint). Pisolites are found abundantly throughout the profile. The pH decreases with depth with a bulge in the Bt1 horizon. CEC also decreases with depth with a similar bulge in the Bt2 horizon. OM ranges from 10.3% to 11.9% (Table 61).

Table 61. Rex Hill, Sims Vineyard Block 2 field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-12	Ap	22.2	47.9	28.1	0.4	CL
12-50	Bt1	11.8	35.5	53.4	2.3	C
50-84	Bt2	13.7	34.4	48.4	0.3	C
84-130+	Bt3	18.8	29.9	48.5	0.0	C
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-12	Ap	7.5YR 4/4	2, f, gr to sbk	11.9	5.2	20.2
12-50	Bt1	7.5YR 4/6	2, m, sbk	10.3	5.4	15.0
50-84	Bt2	7.5YR 4/4	2, m, sbk	10.9	5.6	20.0
84-130+	Bt3	7.5YR 4/4	1, m, sbk	10.5	5.0	16.9

Soil Chemistry

The Sims Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 62). The maximum concentrations of K, Mg, and S are in the Ap horizon. K, Mg, and S decrease with depth. Ca increases with depth and bulges in the Bt2 horizon. P is bimodal with a max in the Bt3 horizon and the Ap horizon. The micronutrient concentrations measured in the four soil horizons from the Sims Vineyard have few trends but some elements decrease with depth and then increase again in the deepest horizon. Fe and Co are highest in the Bt3 horizon and the second highest in the Ap horizon. Al, Cu, Mn, Ni, and Zn decrease with depth and then increase again in the Bt3 horizon. Na is highest in the Bt3 horizon with similar values in the Ap horizon.

Figure 32. Sample soil pit at Rex Hill, Sims Vineyard Block 2. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Table 62. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Rex Hill, Sims Vineyard, Block 2 soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S					
Ap (0-12)	1530	515	585	907	213					
Bt1 (12-50)	913	208	871	596	116					
Bt2 (50-84)	843	101	892	428	ND					
Bt3 (84-130+)	1560	80.7	661	431	ND					
Mean	1212	226	752	591	165					
SD	386	200	153	225	69					
Maximum	1560	515	892	907	213					
Horizon (cm)	Fe	Al	Cl	Co	Cu	Mn	Mo	Na	Ni	Zn
Ap (0-12)	62300	17800	ND	36.4	20.6	2510	ND	178	6.49	53.9
Bt1 (12-50)	50400	15400	ND	34.9	14.0	1250	ND	161	4.78	34.1
Bt2 (50-84)	38400	11300	ND	26.0	9.3	1090	ND	165	2.80	24.2
Bt3 (84-130+)	65300	16900	ND	41.2	19.7	1890	ND	184	3.35	34.7
Mean	54100	15350	ND	34.6	15.9	1685	ND	172	4.36	36.7
SD	12286	2876	ND	6.35	5.27	650	ND	11	1.65	12.4
Maximum	65300	17800	ND	41.2	20.6	2510	ND	184	6.49	53.9
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-12)	1.72	127	1.05	0.475	23.1	ND	12.0	0.759	5.95	171
Bt1 (12-50)	0.666	168	0.772	0.296	18.3	ND	10.1	ND	11.1	143
Bt2 (50-84)	ND	72.1	0.597	0.347	12.6	ND	6.89	0.501	10.5	101
Bt3 (84-130+)	0.447	55.5	0.884	0.416	13.7	ND	8.06	ND	7.90	125
Mean	0.944	106	0.826	0.384	16.9	ND	9.26	0.630	8.9	135
SD	0.681	51.6	0.191	0.078	4.80	ND	2.26	ND	2.4	30
Maximum	1.72	168	1.05	0.475	23.1	ND	12.0	0.759	11.1	171

Cl and Mo were non-detectable in this profile. Sims Vineyard trace element concentrations were also determined for the four horizons. As and Se are highest in the Ap horizon and decrease with depth. Be, V, Pb, and Cr decrease with depth and then increase in the Bt3 horizon. Ba decreases with depth with a bulge in the Bt1 horizon. Sr

also bulges in the Bt1 horizon but has little other trend. Cd is highest in the Ap horizon, decreases to the Bt1 horizon, then increases with depth.

Grape Juice Chemistry

The same 24 elements that were tested in the soil samples were analyzed in the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study and are not listed in Table 63. K, Na, and Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites. The concentrations of K and Na in the Sims Vineyard grape juice are 747 mg/kg (one of the lowest concentrations of K) and 142 mg/kg, respectively. Sr concentrations are measured as 0.645 mg/kg, which is the 16th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is non-detectable and Mn concentration is 2.02 mg/kg for this grape sample. Mn is only found in four vineyards, including Stoller (volcanic parent material), Five Mountain (loess/volcanic parent material), The Jory Hills (volcanic parent material), and Sims Vineyards (volcanic parent material).

Table 63 Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Rex Hill, Sims Vineyard, Block 2 (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.645	ND	747	142	ND	2.02	ND	ND	ND

Wine Chemistry

Rex Hill provided a 750 ml sample of the wine produced from the Sims Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 12 elements that were detected in Sims Vineyard wine sample include Ba, Ca, Cu, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 64). Co and Pb were not detected in this wine, though they were detected in trace amounts in other wine samples in this study. K and P concentrations are the highest at 453 mg/kg and 186 mg/kg, respectively. S is 115 mg/kg, Mg is 79.9 mg/kg, Ca is 35.1 mg/kg, and Na is 5.52 mg/kg for this wine. The concentrations of both Mn and Fe are 2.36 mg/kg. The concentration of Sr is 0.965 mg/kg, Ba is 0.369 mg/kg, and Zn is 0.343 mg/kg. Trace amounts of Cu (0.0473 mg/kg) are detected in the Sims Vineyard wine sample.

Clay Mineralogy

As stated previously, the Sims Vineyard clay mineral assemblage, determined from the Bt1 horizon, is very similar to the Lange Estate (volcanic parent material), Lange Yamhill (marine sediment parent material), and Ken Wright Abbot Claim (marine sediment parent material) Vineyards. This soil is dominated by moderate amounts of disordered kaolinite with trace amounts of halloysite, chlorite, and smectite. Goethite is moderate, and minor amounts of gibbsite are present. These soils are indicative of deeply weathered material.

Table 64. Elemental concentrations measured twice by ICP-MS of the same 750 ml unblended wine sample from the 2012 Rex Hill, Sims Vineyard (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2012 Wine Sample* (mg/kg)	Element	2012 Wine Sample* (mg/kg)
Al	ND	Mn	2.36
As	ND	Hg	ND
Ba	0.369	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	186
Ca	35.1	K	453
Cr	ND	Se	ND
Co	ND	Na	5.52
Cu	0.0473	Sr	0.965
Fe	2.36	S	115
Pb	ND	V	ND
Mg	79.9	Zn	0.343

Loess and Volcanic Parent Material – Estate Vineyard, Block 12

Physical Characteristics

The Rex Hill Estate Vineyard Block 12, owned and operated by Rex Hill, is located in Newberg, Oregon. This vineyard is located on basaltic rocks of the Columbia River Basalt group. Block 12 soil pit is located on the midslope of a southeast facing slope with vine rows running north and south (Lat. 45.313974 N, Long. -122.918974 W). The soil pit location was at 611 feet (186 meters) elevation between rows 60 and 61, and the soil is mapped as the Laurelwood soil series (Figure 33). According to the vineyard manager, this vineyard is LIVE certified (Appendix D). The vines are Pinot Noir Dijon

Figure 33. Soil map of Rex Hill, Estate Vineyard Block 12. Pit location marked. 2712C – Laurelwood silt loam, 2 to 12 percent slopes. 2712D – Laurelwood silt loam, 12 to 20 percent slopes. 2712E – Laurelwood silt loam, 20 to 30 percent slopes (NRCS, 2015). Previously mapped as YhD – Yamhill silt loam, moderately shallow, 7 to 20 percent slopes and LuC – Laurelwood silt loam, 3 to 12 percent slopes (NRCS, 2014).

777 clone planted in 1982 and are trellised as bilateral cordon in vertical shoot position.

The vines are grafted onto 108 Chardonnay rootstock (Table 8).

The Laurelwood soil is characterized as an Ultic Haploxeralf. The soil pit was 130 cm deep at refusal. The basalt parent material is found as small chips and gravel (10%) in the Bt2 horizon from 100 to 130 cm depth. Dry colors for the Ap horizon are brown (10

YR 5/3), Bt1 and Bt2 are both yellowish brown (10 YR 5/4), and Bt2 also has yellowish red (5 YR 5/8) (Figure 34). Textures are silt loam for the Ap horizon and silty clay loam and silt loam for the Bt horizons. Structures throughout the soil profile are strong medium subangular blocky with some finer texture in the Ap horizon. The Bt1 and Bt2 horizons are very sticky and very plastic due to a jump in clay from 14% in the Ap to 33% in the Bt1 horizon. Clay films located on ped faces, increase in number from Ap (few and dominant) to Bt1 (many and prominent). Pisolites are found abundantly throughout the profile. The pH decreases with depth but CEC is highest in the Bt2 horizon. OM ranges from 4.7% to 8.0% (Table 65).

Table 65. Rex Hill, Estate Vineyard Block 12 field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-25	Ap	11.0	74.0	14.4	0.1	SiL
25-100	Bt1	4.5	62.3	32.6	0.0	SiCL
100-130	Bt2	26.6	54.2	17.0	10.1	SiL
130+	R					
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-25	Ap	10YR 5/3	2, f, sbk	8.0	5.8	17.8
25-100	Bt1	10YR 5/4	3, m, sbk	4.7	5.6	15.9
100-130	Bt2	10YR 5/4 5YR 5/8	3, m, sbk	7.0	5.4	23.2
130+	R

Figure 34. Sample soil pit at Rex Hill, Estate Vineyard Block 12. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Rex Hill Estate Vineyard, Block 12 soil pit was separated into three horizons, and samples of each horizon were sent for analysis (Table 66). The maximum concentrations of K and S are in the Ap horizon and they decrease with depth. K and Mg both decrease with depth with a bulge in the Bt1 horizon. Ca is highest in the Bt2

Table 66. Macronutrient, micronutrient and trace elements concentrations (all values in mg/kg) for the Rex Hill, Estate Vineyard, Block 12 soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl
Ap (0-25)	1730	1450	1660	2360	193	ND
Bt1 (25-100)	774	1560	1300	3100	ND	ND
Bt2 (100-130)	761	652	1680	2060	117	ND
Mean	1088	1221	1547	2507	155	ND
SD	556	496	214	535	54	ND
Maximum	1730	1560	1680	3100	193	ND

Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn
Ap (0-25)	22200	12100	14.8	12.0	1530	ND	199	9.62	63.1
Bt1 (25-100)	25300	13500	14.9	14.2	595	ND	184	10.2	45.5
Bt2 (100-130)	41000	15700	22.3	16.8	885	ND	201	8.47	42.6
Mean	29500	13767	17.3	14.3	1003	ND	195	9.43	50.4
SD	10079	1815	4.30	2.40	479	ND	9.3	0.88	11.1
Maximum	41000	15700	22.3	16.8	1530	ND	201	10.2	63.1

Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-25)	12.2	246	0.614	0.277	15.9	ND	47.1	ND	20.5	63
Bt1 (25-100)	3.58	115	0.665	0.147	19.6	ND	10.6	ND	17.5	76
Bt2 (100-130)	1.70	169	0.975	0.226	20.5	ND	8.7	ND	28.2	130
Mean	5.83	177	0.751	0.217	18.7	ND	22.1	ND	22.1	90
SD	5.60	65.8	0.195	0.066	2.4	ND	21.6	ND	5.5	35
Maximum	12.2	246	0.975	0.277	20.5	ND	47.1	ND	28.2	130

horizon, but has a similarly high concentration in the Ap horizon. Most of the micronutrient concentrations measured in the three soil horizons from the Rex Hill Estate Vineyard, Block 12 increase with depth. Fe, Al, Co, and Cu all increase with depth. Mn decreases from a maximum concentration in the Ap horizon to the Bt1 horizon, but then increases again. Na has no trend, though the highest concentration is at depth. Ni concentration bulges in the Bt1 horizon. Mo is non-detectable in this profile. There are some trends in trace element concentrations for the three horizons of the Rex Hill Estate Vineyard, Block 12. As and Pb both decrease in concentration from the Ap horizon. Be, Cr, and V increase with depth and the highest concentration is in the Bt2 horizon. Ba and Cd decrease from a maximum in the Ap horizon, but then increase in the Bt2 horizon. Sr is highest in the Bt2 horizon. Hg and Se are non-detectable in this profile.

Grape Juice Chemistry

The same 24 elements that were tested in the soil samples were analyzed in the grape juice from grapes collected adjacent to the soil pits. The grape juice samples have concentrations of many elements that are below detection limits in this study and are not listed in Table 67. The concentrations of K and Na in the Rex Hill Estate Vineyard grape juice are 1600 mg/kg and 139 mg/kg, respectively. Sr concentrations are measured as 0.696 mg/kg, which is the 15th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites

is 0.805 ± 0.261 mg/kg. P concentration is 361 mg/kg and Mn concentration is non-detectable for this grape sample.

Table 67. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Rex Hill, Estate Vineyard, Block 12 (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.696	361	1600	139	ND	ND	ND	ND	ND

Wine Chemistry

Rex Hill provided a 750 ml sample of the wine produced from the Estate Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 12 elements that were detected in the Rex Hill Estate Vineyard wine sample include Ba, Ca, Cu, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 68). Co and Pb were not detected in this wine, though they were detected in trace amounts in other wine samples in this study. K and P concentrations are the highest at 713 mg/kg and 447 mg/kg, respectively. S is 97 mg/kg, Mg is 80.4 mg/kg, Ca is 42.9 mg/kg, and Na is 7.74 mg/kg for this wine. The concentration of Fe is 1.11 mg/kg and Mn is 1.06 mg/kg. The concentration of Sr is 1.18 mg/kg, Ba is 0.406 mg/kg, and Zn is 0.394 mg/kg. Trace amounts of Cu (0.081 mg/kg) are detected in the Estate Vineyard wine sample.

Clay Mineralogy

The Rex Hill Estate Vineyard clay mineralogy is determined from the Bt1 horizon. This soil is abundantly illitic as a result of a huge loess input. It has moderate amounts of mica present that is unweathered. The clay minerals also include moderate amounts of chloritic intergrade, hydroxy interlayered vermiculite, and minor amounts of mixed layer kaolinite with vermiculite or smectite. Trace amounts of halloysite are present as well as cristobalite. Very little goethite has developed, which aligns with this as a younger soil with less development than other sites.

Table 68. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Rex Hill, Estate Vineyard, Block 12 (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.06
As	ND	Hg	ND
Ba	0.406	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	447
Ca	42.9	K	713
Cr	ND	Se	ND
Co	ND	Na	7.74
Cu	0.081	Sr	1.18
Fe	1.11	S	97
Pb	ND	V	ND
Mg	80.4	Zn	0.394

Volcanic Landslide Parent Material – Jacob-Hart Vineyard, Block 1

Physical Characteristics

The Jacob-Hart Vineyard, owned and operated by Rex Hill, is located in Newberg, Oregon. These vineyards are located on a landslide complex that contains basaltic rocks of the Columbia River Basalt group. Jacob-Hart Block 1 is located at the toe of this ancient landslide and is on a south facing slope with vine rows running north and south (Lat. 45.337304 N, Long. -123.021697 W). The soil pit location was at 315 feet (96 meters) elevation between rows 11 and 12, and the soil is mapped as the Dixonville (previously Steiwer) soil series (Figure 35). According to the vineyard manager, this vineyard is too rocky for tractor tilling, and there is phylloxera (*Dactylosphaera vitifoliae*) near the oak trees on the edge of the vineyard. The vines are Pinot Noir Wädenswil clone planted in 1989 and are trellised as bilateral cordon in vertical shoot position. The vines are own-rooted (Table 8).

The Dixonville soil is characterized as a Pachic Ultic Argixeroll. The soil pit was 185+ cm deep, and the gravel of the parent material was at the surface as well as at depth for this pit. The basalt parent material is found as rock fragments in the Ap and in the Bt horizon (less than 10%), but the Cr horizon is 75% basalt rock fragments. Dry colors are brown (10 YR 5/3) (Figure 36). Texture ranges from silt loam to silty clay loam and clay loam with depth. Structures throughout the soil profile are medium subangular blocky.

Figure 35. Soil map of Rex Hill, Jacob-Hart Vineyard Block 1. Pit location marked. 2702C – Dixonville silty clay loam, 3 to 12 percent slopes. 2702D – Dixonville silty clay loam, 12 to 20 percent slopes. 2304C – Carlton silt loam, 2 to 12 percent slopes. 2793C – Witzel-Dixonville complex, 2 to 12 percent slopes (NRCS, 2015). Previously mapped as SuD – Steiwer silty clay loam, basalt substratum, 5 to 20 percent slopes (NRCS, 2014).

Clay films located on ped faces increase in number from Ap (common and distinct) to At (many and distinct). Hardly any fine pisolites are found in the profile. The pH increases with depth to 6.0 and CEC decreases with a bulge in the Bt horizon. OM also decreases at first, then increases to 11.6% at depth (Table 69).

Table 69. Rex Hill, Jacob-Hart Vineyard Block 1 field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-30	Ap	13.3	65.2	19.4	1.3	SiL
30-78	At	10.7	64.0	24.6	1.4	SiL
78-145	Bt	15.3	49.7	34.0	10.7	SiCL
145-185+	Cr	37.8	24.8	34.5	39.8	CL
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-30	Ap	10YR 5/3	2, m, sbk	8.5	5.7	20.3
30-78	At	10YR 5/3	2, m, sbk	6.0	5.7	16.3
78-145	Bt	10YR 4/3	2, m, sbk	7.7	5.7	22.3
145-185+	Cr	10YR 7/3		11.3	6.0

Figure 36. Sample soil pit at Rex Hill, Jacob-Hart Vineyard Block 1. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Jacob-Hart Vineyard, Block 1 soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 70). The maximum concentrations of P, K, and S are in the Ap horizon. K and S both decrease with depth. Mg increases with depth and has a bulge in the Bt horizon. Ca is variable, the maximum concentration in the Cr horizon. P is highest in the Ap horizon and decreases with depth with a slight bulge in the Bt horizon. Cl was only detected in the Cr horizon. The micronutrient concentrations measured in the four soil horizons from the Jacob-Hart Vineyard, Block 1 mostly decrease from the surface but then increase with depth from the At horizon. Fe and Al decrease in the At horizon then increase with depth with a maximum in the Cr horizon. Co, Cu, and Zn have maximum concentrations in the Ap horizon and decrease with depth with a bulge in the Bt or Cr horizons. Ni also decreases from the surface and the highest concentration in the Bt horizon. Mn decreases with depth. Na increases with depth with the highest concentration in the Cr horizon. Mo was non-detectable in this profile. The trace element concentrations show varying trends for the three horizons of the Jacob-Hart Vineyard, Block 1. As decreases with depth with the maximum concentration in the Ap horizon. Ba, Sr, and V increase with depth. Cd and Pb are highest in the Ap horizon with little trend. Cd decreases in the At horizon then bulges in the lower horizons. Be and Cr decrease then bulge in the Bt horizon. Hg and Se are non-detectable.

Table 70. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Rex Hill, Jacob-Hart Vineyard, Block 1 soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-30)	1040	1390	1870	2090	216	ND				
At (30-78)	542	989	1400	2150	ND	ND				
Bt (78-145)	569	616	2100	2600	107	ND				
Cr (145-185+)	500	149	2650	1220	ND	24				
<i>Mean</i>	<i>663</i>	<i>786</i>	<i>2005</i>	<i>2015</i>	<i>162</i>	<i>24</i>				
<i>SD</i>	<i>253</i>	<i>529</i>	<i>519</i>	<i>577</i>	<i>77</i>	<i>0</i>				
<i>Maximum</i>	<i>1040</i>	<i>1390</i>	<i>2650</i>	<i>2600</i>	<i>216</i>	<i>24</i>				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-30)	33000	11300	28.0	19.3	1230	ND	190	8.01	63.2	
At (30-78)	25100	9400	20.3	12.9	921	ND	189	6.89	39.0	
Bt (78-145)	35000	13500	18.7	18.2	824	ND	210	8.89	53.2	
Cr (145-185+)	51100	19500	27.6	16.7	430	ND	299	8.43	39.4	
<i>Mean</i>	<i>36050</i>	<i>13425</i>	<i>23.7</i>	<i>16.8</i>	<i>851</i>	<i>ND</i>	<i>222</i>	<i>8.06</i>	<i>48.7</i>	
<i>SD</i>	<i>10906</i>	<i>4383</i>	<i>4.84</i>	<i>2.79</i>	<i>330</i>	<i>ND</i>	<i>52</i>	<i>0.86</i>	<i>11.7</i>	
<i>Maximum</i>	<i>51100</i>	<i>19500</i>	<i>28.0</i>	<i>19.3</i>	<i>1230</i>	<i>ND</i>	<i>299</i>	<i>8.89</i>	<i>63.2</i>	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-30)	6.33	196	0.757	0.259	17.1	ND	25.9	ND	17.9	129
At (30-78)	1.73	166	0.745	0.176	15.7	ND	10.4	ND	17.9	92
Bt (78-145)	1.83	219	0.942	0.251	20.2	ND	10.3	ND	28.0	130
Cr (145-185+)	0.666	630	0.809	0.256	14.6	ND	10.7	ND	39.4	187
<i>Mean</i>	<i>2.64</i>	<i>303</i>	<i>0.813</i>	<i>0.236</i>	<i>16.9</i>	<i>ND</i>	<i>14.3</i>	<i>ND</i>	<i>25.8</i>	<i>134</i>
<i>SD</i>	<i>2.52</i>	<i>219.2</i>	<i>0.090</i>	<i>0.040</i>	<i>2.4</i>	<i>ND</i>	<i>7.7</i>	<i>ND</i>	<i>10.2</i>	<i>39</i>
<i>Maximum</i>	<i>6.33</i>	<i>630</i>	<i>0.942</i>	<i>0.259</i>	<i>20.2</i>	<i>ND</i>	<i>25.9</i>	<i>ND</i>	<i>39.4</i>	<i>187</i>

Grape Juice Chemistry

Grape juice from clusters of grapes collected from vines adjacent to the soil pit were analyzed for the same 24 elements as the soils. The majority of these elements are non-detectable using this method, therefore only the elements found in any sample are

shown in Table 71. The highest elemental concentration measured in the Jacob-Hart Vineyard Block 1 grape juice is K at 1880 mg/kg, which is the 2nd highest K concentration in all 20 grape juice samples (Table 105). P is also detected at 397 mg/kg and Na is 140 mg/kg. Sr, one of the only elements to be detected in all 20 grape juice samples, has a concentration of 1.12 mg/kg in this sample. It is the 3rd highest concentration where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg. Cu is also detected in the grape juice at 2.41 mg/kg. The Jacob-Hart Vineyard Block 1 and Block 5 are the only vineyards whose grape samples contained Cu.

Table 71. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Rex Hill, Jacob-Hart Vineyard, Block 1 (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	1.12	297	1880	140	ND	ND	ND	2.41	ND

Wine Chemistry

Rex Hill provided a 750 ml sample of the wine produced from the Jacob-Hart Vineyard, Block 1 in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in Jacob-Hart Vineyard, Block 1 wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 72). K and P concentrations are the highest at 563 mg/kg and 412 mg/kg, respectively. S is 119 mg/kg, Mg is 59.2 mg/kg, Ca is 35.2 mg/kg, and Na is 8.42 mg/kg for this wine. The concentration of Fe is 2.22 mg/kg and Mn is 1.07 mg/kg. The concentration of Sr is 1.12 mg/kg, Ba is 0.327 mg/kg, Zn is 0.338

mg/kg, and Cu is 0.111 mg/kg. Trace amounts of Pb (0.0892 mg/kg) and Co (0.0338 mg/kg) are also detected in the Jacob-Hart Vineyard, Block 1 wine sample.

Table 72. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Rex Hill, Jacob-Hart Vineyard, Block 1 (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.07
As	ND	Hg	ND
Ba	0.327	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	412
Ca	35.2	K	563
Cr	ND	Se	ND
Co	0.0338	Na	8.42
Cu	0.111	Sr	1.12
Fe	2.22	S	119
Pb	0.0892	V	ND
Mg	59.2	Zn	0.338

Clay Mineralogy

The Jacob-Hart Vineyard Block 1 and Block 5 have similar clay mineralogy, most likely because they are located less than 500 meters apart. The elevation of the site differs by 20 meters with Block 1 at the lower elevation. The clay mineralogy for both sites is determined by the Bt horizon from each soil pit. Moderate amounts of non hydroxy-interlayered smectite dominates the sample. The Block 1 clays have less smectite and slightly more hydroxy interlayering than the Block 5 sample. Both sites have no mica or illite. The clays include trace amounts of disordered kaolinite, vermiculite, and goethite

as the main Fe phase. No kaolinite/smectite, chlorite/vermiculite, smectite/chlorite interlayers, or chlorite intergrade are present in this sample.

Volcanic Landslide Parent Material – Jacob-Hart Vineyard, Block 5

Physical Characteristics

The Jacob-Hart Vineyard, owned and operated by Rex Hill, is located in Newberg, Oregon. These vineyards are located on a landslide complex that contains basaltic rocks of the Columbia River Basalt group. Jacob-Hart Block 5 is located at the summit of this ancient landslide and is on a south facing slope with vine rows running north and south (Lat. 45.340408 N, Long. -123.019881 W). The soil pit location was at 377 feet (115 meters) elevation between rows 24 and 25, and the soil is mapped as the Dixonville (previously Yamhill) soil series (Figure 37). According to the vineyard manager, Jacob-Hart is LIVE, Organic, and biodynamically farmed (Appendix D). The vines are Pinot Noir Pommard clone planted in 2001 and are trellised as bilateral cordon in vertical shoot position. The vines are mostly likely also own-rooted like Block 1 (Table 8).

The Dixonville soil is characterized as a Pachic Ultic Argixeroll. The soil pit was 138+ cm deep, and I did not reach refusal at that depth. The basalt parent material is found as rock fragments in the Apr (12%) and in the Bt and Btg horizons (less than 10%). The OM ranges from 9.0% to 9.8% and pH decreases with depth from 6.1 to 5.7.

Figure 37. Soil map of Rex Hill, Jacob-Hart Vineyard Block 5. Pit location marked. 2702C – Dixonville silty clay loam, 3 to 12 percent slopes. 2702D – Dixonville silty clay loam, 12 to 20 percent slopes. 2304C – Carlton silt loam, 2 to 12 percent slopes. 2793C – Witzel-Dixonville complex, 2 to 12 percent slopes (NRCS, 2015). Previously mapped as SuD – Steiwer silty clay loam, basalt substratum, 5 to 20 percent slopes (NRCS, 2014).

CEC increases with depth (Table 73). Dry colors for the Apr is brown (10 YR 4/3), Bt is brown (10 YR 4/3) and Btg has two colors dark yellowish brown (10 YR 4/4) and light brownish gray (10 YR 6/2) redoximorphic features (Figure 38). Textures include silt loam, silty clay, and clay in the Btg. Structures are moderate medium subangular blocky. Clay films located on ped faces, increase in number from Apr (common and faint) to Bt (many and distinct). Few fine pisolites are found throughout the profile.

Soil Chemistry

The Jacob-Hart Vineyard, Block 5 soil pit was separated into three horizons, and samples of each horizon were sent for analysis (Table 74). The maximum concentrations of P, K, and S are in the Apr horizon. P and K decrease with depth. Ca concentration

Table 73. Rex Hill, Jacob-Hart Vineyard Block 5 field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-60	Apr	14.9	54.3	25.5	1.7	SiL
60-80	Bt	16.6	38.8	42.9	0.0	SiC
80-138+	Btg	21.5	34.8	41.6	5.2	C
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-60	Apr	10YR 4/3	m to 2, m, sbk	9.0	6.1	28.2
60-80	Bt	10YR 4/3	2, m, sbk	9.8	5.9	32.9
80-138+	Btg	10YR 4/4	2, m, sbk	9.5	5.7	35.1
		10YR 6/2

Figure 38. Sample soil pit at Rex Hill, Jacob-Hart Vineyard Block 5. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Table 74. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Rex Hill, Jacob-Hart Vineyard, Block 5 soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl
Apr (0-60)	515	718	3110	1560	152	ND
Bt (60-80)	348	286	3640	2020	ND	ND
Btg (80-138+)	314	206	3580	2030	ND	ND
<i>Mean</i>	<i>392</i>	<i>403</i>	<i>3443</i>	<i>1870</i>	<i>152</i>	<i>ND</i>
<i>SD</i>	<i>108</i>	<i>275</i>	<i>290</i>	<i>269</i>	<i>0</i>	<i>ND</i>
<i>Maximum</i>	<i>515</i>	<i>718</i>	<i>3640</i>	<i>2030</i>	<i>152</i>	<i>ND</i>

Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn
Apr (0-60)	40600	11500	39.4	14.3	1490	ND	172	4.96	64.1
Bt (60-80)	42800	14900	37.1	14.5	1290	ND	212	5.18	59.1
Btg (80-138+)	46000	14500	67.4	15.8	2350	ND	193	8.03	62.1
<i>Mean</i>	<i>43133</i>	<i>13633</i>	<i>48.0</i>	<i>14.9</i>	<i>1710</i>	<i>ND</i>	<i>192</i>	<i>6.06</i>	<i>61.8</i>
<i>SD</i>	<i>2715</i>	<i>1858</i>	<i>16.9</i>	<i>0.81</i>	<i>563</i>	<i>ND</i>	<i>20</i>	<i>1.71</i>	<i>2.5</i>
<i>Maximum</i>	<i>46000</i>	<i>14900</i>	<i>67.4</i>	<i>15.8</i>	<i>2350</i>	<i>ND</i>	<i>212</i>	<i>8.03</i>	<i>64.1</i>

Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Apr (0-60)	1.04	201	1.02	0.413	13.0	ND	9.89	0.776	29.7	187
Bt (60-80)	0.826	191	1.04	0.275	13.4	ND	9.66	ND	35.6	186
Btg (80-138+)	0.945	290	1.15	0.346	12.0	0.0418	9.50	0.722	36.0	185
<i>Mean</i>	<i>0.937</i>	<i>227</i>	<i>1.07</i>	<i>0.345</i>	<i>12.8</i>	<i>0.0418</i>	<i>9.68</i>	<i>0.749</i>	<i>33.8</i>	<i>186</i>
<i>SD</i>	<i>0.107</i>	<i>54.5</i>	<i>0.07</i>	<i>0.069</i>	<i>0.72</i>	<i>ND</i>	<i>0.20</i>	<i>0.038</i>	<i>3.53</i>	<i>1</i>
<i>Maximum</i>	<i>1.04</i>	<i>290</i>	<i>1.15</i>	<i>0.413</i>	<i>13.4</i>	<i>0.0418</i>	<i>9.89</i>	<i>0.776</i>	<i>36.0</i>	<i>187</i>

bulges in the Bt horizon. Mg increases with depth and the highest concentration is in the Btg horizon. S is only detected at the surface. The micronutrient concentrations measured in the three soil horizons from the Jacob-Hart Vineyard, Block 5 mostly increase with depth. Fe, Cu, Ni and Co increase with depth and the maximum concentration is in the Btg horizon. Al and Na both bulge in the Bt horizon. Zn is highest in the Ap horizon and is variable with depth. Mn is highest in the Btg horizon and variable above. Mo is non-

detectable. The trace element concentrations for the three horizons of the Jacob-Hart Vineyard, Block 5 have little trend. Be and Sr both increase with depth and the maximum concentration is in the Btg horizon. Ba is variable with the highest in the Btg horizon. Hg was only detected in the Btg horizon. V and Pb decrease with depth and the highest is in the Apr horizon. As, Se, and Cd are variable with depth but are also highest in the Apr horizon. Cr decreases with a bulge in the Bt horizon.

Grape Juice Chemistry

Grape juice from clusters of grapes collected from vines adjacent to the soil pit were analyzed for the same 24 elements as the soils. The majority of these elements are non-detectable using this method, therefore only the elements found in any sample are shown in Table 75. The highest elemental concentration measured in the Jacob-Hart Vineyard Block 5 grape juice is K at 1500 mg/kg. P is also detected at 272 mg/kg and Na is 131 mg/kg. Sr, one of the only elements to be detected in all 20 grape juice samples, has a concentration of 0.447 mg/kg in this sample. It is the 19th highest concentration (second lowest) where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg (Table 105). Cu is also detected in the grape juice at 4.19 mg/kg. The Jacob-Hart Vineyard Block 1 and Block 5 are the only vineyards whose grape samples contained Cu. The grape juice from this site also contains Zn (2.2 mg/kg), the only juice to have detectable amounts of this element.

Table 75. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Rex Hill, Jacob-Hart Vineyard, Block 5 (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.447	272	1500	131	ND	ND	ND	4.19	2.2

Wine Chemistry

Rex Hill provided a 750 ml sample of the wine produced from the Jacob-Hart Vineyard, Block 1 in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 13 elements that were detected in Jacob-Hart Vineyard, Block 5 wine sample include Ba, Ca, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 76). Co was not detected in this sample even though it is detected in most other wine samples in this study. K and P concentrations are the highest at 745 mg/kg and 368 mg/kg, respectively. S is 145 mg/kg, Mg is 85.4 mg/kg, Ca is 54.5 mg/kg, and Na is 7.93 mg/kg for this wine. The concentration of Mn is 1.78 mg/kg and Fe is 1.23 mg/kg. The concentration of Sr is 0.769 mg/kg, Zn is 0.453 mg/kg, Cu is 0.303 mg/kg, and Ba is 0.177 mg/kg. Trace amounts of Pb (0.0678 mg/kg) is also detected in the Jacob-Hart Vineyard, Block 5 wine sample.

Clay Mineralogy

As stated previously, the Jacob-Hart Vineyard Block 1 and Block 5 are similar and are also located less than 500 meters apart. The elevation of the site differs by 20 meters with Block 5 at the higher elevation. The clay mineralogy for both sites is determined by the Bt horizon from each soil pit. Moderate non hydroxy-interlayered

smectite dominates the sample. The Block 5 clays have more smectite and less hydroxy interlayering than the Block 1 sample. Both sites have no mica or illite. The clays include lots of disordered kaolinite, vermiculite, and goethite as the main Fe phase. No kaolinite/smectite, chlorite/vermiculite, smectite/chlorite interlayers, or chlorite intergrade are present in this sample.

Table 76. Elemental concentrations measured twice by ICP-MS of the same 750 ml unblended wine sample from the 2012 Rex Hill, Jacob-Hart Vineyard, Block 5 (ND – Non-detectable, * denotes mean of two samples from the same bottle).

Element	2012 Wine Sample* (mg/kg)	Element	2012 Wine Sample* (mg/kg)
Al	ND	Mn	1.78
As	ND	Hg	ND
Ba	0.177	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	368
Ca	54.5	K	745
Cr	ND	Se	ND
Co	ND	Na	7.93
Cu	0.303	Sr	0.769
Fe	1.23	S	145
Pb	0.0678	V	ND
Mg	85.4	Zn	0.453

Chapter Nine – Ken Wright Cellars Results

Volcanic Parent Material – Nysa Vineyard, Midblock

Physical Characteristics

The Nysa Vineyard, owned and operated by Michael Mega, is located in Dayton, Oregon. This vineyard is located on basaltic rocks of the Columbia River Basalt group. Nysa Vineyard is located on the summit of an east facing slope with vine rows running just slightly off north and south (Lat. 45.265995 N, Long. -123.048344 W). The soil pit location was at 712 feet (217 meters) elevation between rows 24 and 25, and the soil is mapped as the Jory soil series (Figure 39). According to the vineyard owner, this vineyard is highly stressed because of phylloxera (*Dactylosphaera vitifoliae*). The vines are Pinot Noir Pommard clone planted in 1990 and are trellised as unilateral cordon very close to the ground in vertical shoot position. The vines are own-rooted (Table 8).

The Jory soil is characterized as a Xeric Palehumult. The soil pit was 150+ cm deep, and I did reach the parent material but not refusal at that depth. The bedrock is part of the Columbia River Basalt Group (Figure 2). The basalt parent material is found as small chips and gravel (20%) in the Bt1 horizon from 35 to 80 cm depth and then increases to 70% in the Bt2 horizon from 80 to 118 cm and greater than 75% in the Cr horizon from 118 to 150+ cm. Percent silt decreases with depth from 53% in the Ap

Figure 39. Soil map for Ken Wright Cellars, Nysa Vineyard Midblock. Pit location marked. 2711D – Jory silty clay loam, 12 to 20 percent slopes. 2711E – Jory silty clay loam, 20 to 30 percent slopes. 2780C Jory-Gelderman silty clay loams, 2 to 12 percent slopes (NRCS, 2015). Previously mapped as JrD - Jory clay loam, 12 to 20 percent slopes (NRCS, 2014).

horizon to 33% in the Cr horizon. Dry colors for the Ap, Bt1 and Bt2 horizons brown (7.5 YR 4/3) (Figure 40). Textures are silt loam, silty clay loam, clay loam, and loam with depth. Structures are strong, medium subangular blocky. The Ap horizon is slightly sticky and slightly plastic, but the Bt1 is sticky and plastic due to a jump in clay from 21% in the Ap to 39% in the Bt1 horizon. Clay films located on ped faces, decrease in number from the Ap (many and prominent) to the Bt2 (few and dominant). Hardly any fine pisolites are found throughout the profile. The pH remains consistent at 5.4 or 5.5 throughout the profile. CEC decreases with depth then bulges in the Bt2 horizon. OM ranges from 9.2% to 12.9%.

Table 77. Ken Wright Cellars, Nysa Vineyard Midblock field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-35	Ap	24.9	52.7	20.7	1.2	SiL
35-80	Bt1	15.4	44.1	38.9	0.1	SiCL
80-118	Bt2	26.3	35.4	35.2	23.1	CL
118-150+	Cr	48.6	33.5	16.2	21.7	L
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-35	Ap	7.5YR 4/3	3, m, sbk	10.6	5.4	20.2
35-80	Bt1	7.5YR 4/4	3, m, sbk	9.2	5.5	17.8
80-118	Bt2	7.5YR 4/4	1, m, sbk	10.0	5.5	21.7
118-150+	Cr	2.5Y 7/4 10YR 6/6	sg to 1, f, sbk	12.9	5.4

Figure 40. Sample soil pit at Ken Wright Cellars, Nysa Vineyard Midblock. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Nysa Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 78). The maximum concentration of P is in the AP horizon and decreases with depth. The P concentration then increases in the Cr horizon. K decreases with depth with the maximum in the AP horizon. Ca is essentially the same throughout the profile with a maximum in the Bt2 horizon. Mg is highest in the Bt1 horizon and decreases below. S is only detected in the AP and Bt1 horizons.

The micronutrient concentrations measured in the four soil horizons from the Nysa Vineyard mostly decrease with depth. Mn decreases with depth with the maximum concentration in the Ap horizon. Fe, Co, Cu, Ni, and Zn decrease with depth with a bulge in the Cr horizon. Al decreases with depth with the maximum concentration in the Cr horizon. Na increases with depth. Mo is non-detectable in the profile. The trace element concentrations for the four horizons of the Nysa Vineyard have little variation with depth (Table 78). Ba and Sr decrease with depth but reach a maximum concentration in the Cr horizon. As, Cd, and Se are highest in the Ap horizon and decrease without much trend in subsequent horizons. Cr and V bulge in in the Bt1 horizon and decrease with depth compared to the surface. Be is the same throughout the profile. Pb is highest in the Ap horizon and decreases with depth. Hg was non-detectable.

Table 78. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Ken Wright Cellars, Nysa Vineyard, and Midblock soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-35)	2200	1030	1150	1410	212	ND				
Bt1 (35-80)	1530	744	1150	1550	107	ND				
Bt2 (80-118)	1060	433	1160	1140	ND	ND				
Cr (118-150+)	1530	ND	1120	757	ND	ND				
<i>Mean</i>	<i>1580</i>	<i>736</i>	<i>1150</i>	<i>1210</i>	<i>160</i>	<i>ND</i>				
<i>SD</i>	<i>469</i>	<i>299</i>	<i>17</i>	<i>349</i>	<i>74.2</i>	<i>ND</i>				
<i>Maximum</i>	<i>2200</i>	<i>1030</i>	<i>1160</i>	<i>1550</i>	<i>212</i>	<i>ND</i>				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-35)	60100	23000	34.7	20.3	2590	ND	147	7.20	60.4	
Bt1 (35-80)	47500	22600	25.5	17.1	1280	ND	175	6.51	46.8	
Bt2 (80-118)	44300	18700	19.0	11.3	603	ND	189	4.84	32.6	
Cr (118-150+)	52900	23100	27.1	14.1	530	ND	216	6.71	49.5	
<i>Mean</i>	<i>51200</i>	<i>21900</i>	<i>26.6</i>	<i>15.7</i>	<i>1250</i>	<i>ND</i>	<i>182</i>	<i>6.32</i>	<i>47.3</i>	
<i>SD</i>	<i>6910</i>	<i>2110</i>	<i>6.45</i>	<i>3.87</i>	<i>955</i>	<i>ND</i>	<i>28.7</i>	<i>1.03</i>	<i>11.4</i>	
<i>Maximum</i>	<i>60100</i>	<i>23100</i>	<i>34.7</i>	<i>20.3</i>	<i>2590</i>	<i>ND</i>	<i>216</i>	<i>7.20</i>	<i>60.4</i>	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-35)	1.61	275	1.05	0.787	19.7	ND	11.6	0.909	15.1	148
Bt1 (35-80)	1.01	142	1.00	0.587	22.0	ND	9.13	0.576	14.9	150
Bt2 (80-118)	ND	171	1.04	0.591	14.6	ND	6.87	0.581	11.9	116
Cr (118-150+)	ND	467	1.05	0.572	6.84	ND	4.0	0.604	23.2	119
<i>Mean</i>	<i>1.31</i>	<i>264</i>	<i>1.04</i>	<i>0.634</i>	<i>15.8</i>	<i>ND</i>	<i>7.90</i>	<i>0.668</i>	<i>16.3</i>	<i>133</i>
<i>SD</i>	<i>0.424</i>	<i>147</i>	<i>0.0238</i>	<i>0.102</i>	<i>6.72</i>	<i>ND</i>	<i>3.24</i>	<i>ND</i>	<i>4.84</i>	<i>18.2</i>
<i>Maximum</i>	<i>1.61</i>	<i>467</i>	<i>1.05</i>	<i>0.787</i>	<i>22.0</i>	<i>ND</i>	<i>11.6</i>	<i>0.909</i>	<i>23.2</i>	<i>150</i>

Grape Juice Chemistry

Grape juice from clusters of grapes collected from vines adjacent to the soil pit were analyzed for the same 24 elements as the soils. The majority of these elements are non-detectable using this method, therefore only the elements found in any sample are

shown in Table 79. K, Na, and Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites. The highest elemental concentration measured in the Nysa Vineyard grape juice is K at 1500 mg/kg. P is also detected at 272 mg/kg and Na is 131 mg/kg. Sr, one of the only elements to be detected in all 20 grape juice samples, has a concentration of 1.14 mg/kg in this sample (Table 105). It is the 2nd highest concentration, after Yamhill Vineyard, where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg. Ca is also detected in this sample at 102 mg/kg. This is one of only two samples, the other being Yamhill Vineyard, that has detectable levels of Ca in the grape juice from these vineyards.

Table 79. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Ken Wright Cellars, Nysa Vineyard, Midblock (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	1.14	257	1070	138	ND	ND	102	ND	ND

Wine Chemistry

Ken Wright provided a 750 ml sample of the wine produced from the Nysa Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in the Nysa Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 80). K and P concentrations are the highest at 917 mg/kg and 542 mg/kg, respectively. S is 106 mg/kg, Mg is 65.7 mg/kg, Ca is 37.4 mg/kg, and Na is 4.5 mg/kg for this wine. The concentration of Mn is 1.67 mg/kg and Fe is 1.58 mg/kg.

The concentration of Sr is 1.09 mg/kg, Zn is 0.747 mg/kg, and Ba is 0.584 mg/kg. Trace amounts of Cu (0.0742 mg/kg), Pb (0.0678 mg/kg), and Co (0.027 mg/kg) are also detected in the Nysa Vineyard wine sample.

Table 80. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Ken Wright, Nysa Vineyard (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.67
As	ND	Hg	ND
Ba	0.584	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	542
Ca	37.4	K	917
Cr	ND	Se	ND
Co	0.027	Na	4.5
Cu	0.0742	Sr	1.09
Fe	1.58	S	106
Pb	0.0678	V	ND
Mg	65.7	Zn	0.747

Clay Mineralogy

The Nysa Vineyard clays indicate more weathering than some of the others samples. This is suggested from the clay mineralogy determined from the Bt1 horizon. The clay minerals are mainly chlorite intergrade and kaolinite with minor amounts of halloysite. Goethite is the main Fe phase and is moderately pronounced. Illite, vermiculite, and smectite are present in minor to trace amounts.

Marine Sediment Parent Material – Abbott Claim Vineyard

Physical Characteristics

Abbott Claim Vineyard, owned and operated by Ken Wright Cellars, is located in Carlton, Oregon. This vineyard is located on marine sedimentary rocks of the Coast Range. The Abbott Claim Vineyard soil pit is located on the shoulder of a south facing slope with vine rows running north and south (Lat. 45.291616 N, Long. -123.116963 W). The soil pit location was at 476 feet (145 meters) elevation, and the soil is mapped as the Wellsdale – Willakenzie – Dupee complex (previously Willakenzie) soil series (Figure 41). According to the vineyard manager, this vineyard was ripped about 2 feet (0.61 m) deep in 2000. The vines are Pinot Noir Dijon 777 clone planted in 2001 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto 101-14 rootstock (Table 8).

The Wellsdale – Willakenzie – Dupee soil is characterized as an Aquultic Haploxeralf. The soil pit was 215+ cm deep, and I did reach the parent material but not refusal at that depth. The bedrock is part of the Spencer Formation of the Coast Range marine sediments (Figure 2). The pH decreases with depth from 6.4 in the Ap horizon. OM ranges from 6.5% to 9.4% and CEC is highest in the Bt1 horizon at 20.5 meq/100 g (Table 81). The sandstone parent material is found with depth to highly influence the texture of the soil. Clay percent is highest in the Bt horizon at 47% while percent sand increases in the Bw and Cr1 horizons from 51% to 58%.

Figure 41. Soil map for Ken Wright Cellars, Abbott Claim Vineyard. Pit location marked. 2760C – Wellsdale-Willakenzie-Dupee complex, 2 to 12 percent slopes. 2760D – Wellsdale-Willakenzie-Dupee complex, 2 to 12 percent slopes. 2762D – Willakenzie-Wellsdale complex, 12 to 20 percent slopes (NRCS, 2015). Previously mapped as WeC – Willakenzie silty clay loam, 2 to 12 percent slopes (NRCS, 2014).

Dry colors for the Ap horizon are yellowish brown (10 YR 5/4), Bt is strong brown (7.5 YR 5/6) and Bw is reddish yellow (7.5 YR 6/6). The parent material is multi-colored in the Cr1 and Cr2 horizons including pale yellow (2.5 Y 8/2), strong brown (7.5 YR 4/6), and reddish yellow (7.5 YR 7/6) (Figure 42). The soil profile structure includes weak fine subangular blocky in the Ap horizon and moderate medium subangular block in the Bt with the Bw, Cr1, and Cr2 horizons having more single grain fine structure.

Texture is loam in the Ap horizon, clay in the Bt horizon and sandy clay loam, sandy loam, and loam with depth. Clay films are located on ped faces in the Bt horizon and are common and dominant. This soil contains abundant muscovite mica and quartz sand. There are no pisolites found in this profile.

Table 81. Ken Wright Cellars, Abbott Claim Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-24	Ap	38.1	44.1	18.1	0.0	L
24-70	Bt1	27.8	24.5	47.0	0.0	C
70-140	Bw	51.4	27.4	21.7	0.0	SCL
140-150	Cr1	57.6	28.9	14.6	0.0	SL
150-215+	Cr2	40.2	34.3	22.4	0.9	L
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-24	Ap	10YR 5/4	1, f, sbk	6.5	6.4	11.7
24-70	Bt1	7.5YR 5/6	2, m, sbk	9.2	5.6	20.5
		7.5YR 4/4				
70-140	Bw	7.5YR 6/6	sg to 1, f, sbk	8.2	4.9	9.7
		7.5YR 8/6				
140-150	Cr1	7.5YR 4/6	sg to f, gr	9.4	4.7	
		2.5Y 8/2				
150-215+	Cr2	7.5YR 7/6	sg to f, gr	6.3	4.8	
		10YR 8/4

Figure 42. Sample soil pit at Ken Wright Cellars, Abbott Claim Vineyard. A – View of sample location, facing north. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Soil Chemistry

The Abbott Claim Vineyard soil pit was separated into five horizons, and samples of each horizon were sent for analysis (Table 82). The maximum concentrations of P, K, Ca, and S are in the Ap horizon and the concentrations then decrease with depth. S is only detected in the Ap horizon. Mg concentrations bulge in the Bt horizon but has little trend. Cl is detected only in the Cr1 and Cr2 horizons. The micronutrient concentrations measured in the five soil horizons from the Abbott Claim Vineyard mostly decrease with depth. Zn, Ni, Mn, Cu and Co are highest in the Ap horizon, decrease with depth, and have a small bulge in the Cr1 horizon. Na is highest in the Ap horizon with no trend below. Al bulges in the Bt horizon and Fe bulges in the Cr1 horizon before dropping significantly in the Cr2 horizon. Mo is non-detectable. Trace element concentrations for the five horizons of the Abbott Claim Vineyard show some trends. Ba and Pb are highest in the Ap horizon, decrease with depth, and have a small bulge in the Cr horizon. Be, Cr, V and As are variable at depth with the highest in the Cr1 horizon. Sr concentration bulges in the Bt horizon. Cd is highest in the Ap horizon and decreases with depth. Hg and Se are non-detectable.

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study, as seen in Table 83. All 24 elements were analyzed in the

Table 82. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Ken Wright Cellars, Abbott Claim Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-24)	521	668	1610	653	135	ND				
Bt (24-70)	504	548	1270	955	ND	ND				
Bw (70-140)	303	238	428	615	ND	ND				
Cr1 (140-150)	520	400	524	879	ND	31.5				
Cr2 (150-215+)	ND	295	286	611	ND	10.0				
Mean	462	430	824	743	135	20.8				
SD	106	178	582	162	0	15.2				
Maximum	521	668	1610	955	135	31.5				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-24)	12800	6410	7.37	8.44	552	ND	141	2.42	17.8	
Bt (24-70)	25700	11800	4.45	8.13	205	ND	122	1.91	12.7	
Bw (70-140)	12600	6440	0.609	4.47	24.5	ND	132	1.14	9.12	
Cr1 (140-150)	30400	9490	0.661	8.40	49.3	ND	137	2.37	13.2	
Cr2 (150-215+)	5290	5160	0.523	2.48	21.1	ND	137	0.931	8.37	
Mean	17400	7860	2.72	6.38	170	ND	134	1.75	12.2	
SD	10400	2720	3.09	2.75	226	ND	7.33	0.690	3.77	
Maximum	30400	11800	7.37	8.44	552	ND	141	2.42	17.8	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-24)	1.99	92.2	0.309	0.192	10.5	ND	11.5	ND	7.41	35.4
Bt (24-70)	1.42	83.4	0.518	0.143	14.4	ND	10.1	ND	11.3	48.9
Bw (70-140)	2.48	52.6	0.379	ND	7.71	ND	8.11	ND	7.06	28.9
Cr1 (140-150)	8.99	41.8	0.790	0.134	17.2	ND	9.39	ND	9.68	54.9
Cr2 (150-215+)	0.69	44.1	0.222	ND	3.73	ND	6.04	ND	4.83	12.0
Mean	3.11	62.8	0.444	0.156	10.7	ND	9.03	ND	8.06	36.0
SD	3.35	23.4	0.222	0.0312	5.33	ND	2.07	ND	2.50	17.0
Maximum	8.99	92.2	0.790	0.192	17.2	ND	11.5	ND	11.3	54.9

grape juice from grapes collected adjacent to the soil pits. The concentrations of K and Na in Abbott Claim Vineyard grape juice are 1730 mg/kg and 166 mg/kg, respectively.

Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.844 mg/kg, which is the 8th highest concentration of Sr for the 20 vineyard samples (Table 105). Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P and Mn concentrations are non-detectable in this sample.

Table 83. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Ken Wright Cellars, Abbott Claim Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.844	ND	1730	166	ND	ND	ND	ND	ND

Wine Chemistry

Ken Wright provided a 750 ml sample of the wine produced from the Abbott Claim Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 14 elements that were detected in the Abbott Claim Vineyard wine sample include Ba, Ca, Co, Cu, Fe, Pb, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 84). K and P concentrations are the highest at 767 mg/kg and 403 mg/kg, respectively. S is 77.2 mg/kg, Mg is 60.4 mg/kg, Ca is 30.6 mg/kg, and Na is 5.77 mg/kg for this wine. The concentration of Mn is 1.13 mg/kg. The concentration of Zn is 0.965 mg/kg, Sr is 0.912 mg/kg, Fe is 0.517 mg/kg and Ba is 0.457 mg/kg. Trace amounts of Cu (0.075 mg/kg), Pb (0.074 mg/kg), and Co (0.0325 mg/kg) are also detected in the Abbott Claim Vineyard wine sample.

Table 84. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Ken Wright, Abbott Claim Vineyard (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.13
As	ND	Hg	ND
Ba	0.457	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	403
Ca	30.6	K	767
Cr	ND	Se	ND
Co	0.0325	Na	5.77
Cu	0.075	Sr	0.912
Fe	0.517	S	77.2
Pb	0.074	V	ND
Mg	60.4	Zn	0.965

Clay Mineralogy

The Abbot Claim clay mineral assemblage is considered very similar to the Lange Estate (volcanic parent material), Lange Yamhill (marine sediment parent material), and Rex Hill Sims (volcanic parent material) Vineyards. This soil is dominated by moderate amounts of disordered kaolinite with trace amounts of halloysite, chlorite, and smectite. Goethite is moderate, and minor amounts of gibbsite are present. These soils are indicative of deeply weathered material.

Marine Sediment Parent Material – Freedom Hill Vineyard

Physical Characteristics

The Freedom Hill Vineyard, owned and operated by Dan and Helen Dusschee, is located in between Monmouth and Dallas, Oregon. This vineyard is located on marine

sedimentary rocks of the Coast Range. Ken Wright's Freedom Hill Vineyard soil is located the midslope of a west facing slope with vine rows running north and south (Lat. 44.875343 N, Long. -123.293962 W). The soil pit location was at 466 feet (142 meters) elevation between rows 30 and 31, and the soil is mapped as the Jory soil series (Figure 43), but I determined that it is really the Bellpine soil series. The vines are Pinot Noir Wädenswil clone planted in 2002 and are trellised as bilateral cordon in vertical shoot position. The vines are grafted onto 44-53 rootstock (Table 8). The Bellpine soil is characterized as a Xeric Haplohumult. The soil pit was 75+ cm deep, and I did reach the sandy parent material but not refusal at that depth. The bedrock is the Spencer Formation of the Coast Range marine sediments (Figure 2). Approximately 75 percent of the Cr horizon consisted of coarse fragments of sandstone parent material. Dry colors for the Ap horizon are yellowish brown (10 YR 5/4), and the Bt is dark yellowish brown (10 YR 4/4) (Figure 44).

Textures are silt loam in the Ap horizon and clay loam with depth. Structure is moderate medium subangular blocky. Clay percent is highest in the Bt horizon at 33% but decreases with depth to 27% in the Cr horizon. Clay films are located on ped faces in the Ap and Bt horizons and are many and dominant. The soil contains muscovite mica and quartz sand. There are no pisolites in this profile. The pH decreases from 6.0 to 5.3 and CEC is around 20.3 meq/100 g. OM ranges from 6.6% to 7.9% (Table 85).

Figure 43. Soil map of Ken Wright Cellars, Freedom Hill Vineyard. Pit location marked. 36D – Jory silty clay loam, 12 to 20 percent slopes. 8C – Bellpine silty clay loam, 3 to 12 percent slopes. 36C – Jory silty clay loam, 2 to 12 percent slopes (NRCS, 2014). Two sites were analyzed at the Freedom Hill Vineyard; one for Lange and one for Ken Wright.

Soil Chemistry

The Freedom Hill Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 86). P concentration bulges in the Cr horizon. K decreases with depth with the maximum in the Ap horizon. Ca is variable through the profile and is significantly higher in the R horizon. Mg increases with depth and is significantly higher in the R horizon as well. S is only detected in the Ap horizon.

Table 85. Ken Wright Cellars, Freedom Hill Vineyard field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		<-----Pct.----->				
0-15	Ap	22.2	56.8	21.7	0.0	SiL
15-50	Bt	21.0	45.8	32.9	0.0	CL
50-75+	Cr	36.1	33.4	27.0	0.7	CL
	R					
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-15	Ap	10YR 5/4	2, m, sbk	7.2	6.0	20.3
15-50	Bt	10YR 4/4	2, m, sbk	6.6	5.6	21.5
50-75+	Cr	10YR 5/4	2, m, sbk	7.9	5.3	
		10YR 7/6				
	R					

The micronutrient concentrations measured in the four soil horizons from the Freedom Hill Vineyard mostly increase with depth. Al, Fe, Cu, Na, Ni and zine all increase with depth in the profile with the maximum concentration in the R horizon that is significantly higher than the horizons above. Mn concentration bulges in the Bt horizon. Co concentration also bulges in the Bt horizon and is highest in the R horizon. Mo is non-detectable. V, Sr, and Cr are highest in the R horizon after increasing with depth. Cd and Ba decrease with depth and then bulge in the R horizon. Pb bulges slightly in the Bt horizon and decreases with depth. Be and As increase with depth and bulge in the Cr horizon. Hg and Se are non-detectable in this profile.

Figure 44. Sample soil pit at Ken Wright Cellars, Freedom Hill Vineyard. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked.

Table 86. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Ken Wright Cellars, Freedom Hill Vineyard soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-15)	543	1210	2070	1790	151	ND				
Bt (15-50)	541	1060	1860	1840	ND	ND				
Cr (50-75)	614	922	2100	2270	ND	ND				
R (75+)	375	132	21700	17700	ND	ND				
Mean	518	831	6930	5900	151	ND				
SD	101	481	9850	7870	0	ND				
Maximum	614	1210	21700	17700	151	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-15)	23600	12700	13.2	14.0	819	ND	172	4.3	24.0	
Bt (15-50)	29700	13000	19.0	19.3	869	ND	165	6.4	35.4	
Cr (50-75)	33100	15800	12.6	20.8	444	ND	181	6.25	36.6	
R (75+)	59700	35100	29.5	114	628	ND	3330	24.0	87.6	
Mean	36500	19200	18.6	42.0	690	ND	962	10.2	45.9	
SD	15900	10700	7.83	48.1	194	ND	1580	9.22	28.4	
Maximum	59700	35100	29.5	114	869	ND	3330	24.0	87.6	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-15)	1.41	132	0.572	0.292	13.1	ND	9.29	ND	15.1	33.4
Bt (15-50)	4.55	123	0.680	0.110	19.2	ND	9.46	ND	17.1	57.9
Cr (50-75)	6.03	112	0.868	ND	23.9	ND	8.06	ND	23.5	57.9
R (75+)	ND	201	0.681	0.319	24.9	ND	0.956	ND	452	150
Mean	4.00	142	0.700	0.240	20.3	ND	6.94	ND	127	74.8
SD	2.36	40.2	0.123	0.114	5.39	ND	4.04	ND	217	51.4
Maximum	6.03	201	0.868	0.319	24.9	ND	9.46	ND	452	150

Grape Juice Chemistry

Grape juice from clusters of grapes collected from vines adjacent to the soil pit were analyzed for the same 24 elements as the soils. The majority of these elements are non-detectable using this method, therefore only the elements found in any sample are

shown in Table 87. The highest elemental concentration measured in the Ken Wright Freedom Hill Vineyard grape juice is K at 1160 mg/kg. P is below detection limits and Na is 126 mg/kg. Sr, one of the only elements to be detected in all 20 grape juice samples, has a concentration of 0.816 mg/kg in this sample. It is the 9th highest concentration where the mean concentration for all grape juice samples is 0.805 ± 0.261 mg/kg (Table 105). No other elements were detected in the grape juice from this site.

Table 87. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Ken Wright Cellars, Freedom Hill Vineyard (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.816	ND	1160	126	ND	ND	ND	ND	ND

Wine Chemistry

Ken Wright provided a 750 ml sample of the wine produced from the Freedom Hill Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 12 elements that were detected in the Freedom Hill Vineyard wine sample include Ba, Ca, Cu, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 88). Co and Pb, which were detected in many other wine samples in this study, were not detected in the wine sample from Freedom Hill Vineyard. K and P concentrations are the highest at 844 mg/kg and 297 mg/kg, respectively. S is 100 mg/kg, Mg is 96.8 mg/kg, Ca is 43.5 mg/kg, and Na is 5.4 mg/kg for this wine. The concentration of Mn is 1.73 mg/kg. The concentration of Sr is 1.05 mg/kg, Zn is 0.784

mg/kg, Fe is 0.544 mg/kg, and Ba is 0.47 mg/kg. Trace amounts of Cu (0.054 mg/kg) are detected in the Freedom Hill Vineyard wine sample.

Table 88. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Ken Wright, Freedom Hill Vineyard (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	1.73
As	ND	Hg	ND
Ba	0.47	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	297
Ca	43.5	K	844
Cr	ND	Se	ND
Co	ND	Na	5.4
Cu	0.054	Sr	1.05
Fe	0.544	S	100
Pb	ND	V	ND
Mg	96.8	Zn	0.784

Clay Mineralogy

The Lange Freedom Hill and Ken Wright Freedom Hill are essentially the same when looking at the clay minerals. These two soils are separated by approximately 500 meters of vineyard at this estate. The expansive clay in the sample is moderately interlayered by Al and Fe oxides which shows moderate weathering. The soil contains trace amounts of mica and illite. The trace amount of chlorite is weakly developed. Minor hydroxy-interlayered smectite and vermiculite are also present with minor amounts of

kaolinite. Cristobalite is also in this sample in minor amounts. The main Fe oxide is goethite and is well ordered and expressed.

Volcanic Parent Material – Meredith Mitchell Vineyard, Martha Block

Physical Characteristics

Meredith Mitchell Vineyard, owned and operated by Susan Meredith and Frank Mitchell, is located in McMinnville, Oregon. This vineyard is unique in that it is located on Eocene-aged basaltic or diabase rocks that are part of the Coast Range. The Meredith Mitchell Vineyard soil pit was located at the summit of a southwest facing slope with vine rows running north and south (Lat. 45.156368 N, Long. -123.291720 W). The soil pit location was at 669 feet (204 meters) elevation between rows 60 and 61, and the soil is mapped as the Witzel – Dixonville (previously Yamhill) soil series (Figure 45).

According to the vineyard owners, this vineyard was cultivated in 2010 and is farmed using LIVE Sustainable methods but is not currently certified (Appendix D). The rows at this location are 12 feet (3.6 meters) wide compared to most other vineyards that are 6 feet (1.83 meters) wide. The vines are Pinot Noir Pommard clone planted in 1988 and are trellised as bilateral cordon in hanging cane position. The vines are own-rooted (Table 8).

Figure 45. Soil map for Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block. Pit location marked. 2793C – Witzel-Dixonville complex, 2 to 12 percent slopes. 2792D – Witzel-Dixonville complex, 12 to 20 percent slopes. 2795E – Gellatly-Dixonville complex, 20 to 30 percent slopes. 2791F – Gellatly silty clay loam, 30 to 60 percent slopes (NRCS, 2015). Previously mapped as YhD – Yamhill silt loam, moderately shallow, 7 to 20 percent slopes (NRCS, 2014).

The Witzel – Dixonville soil is classified as a Lithic Ultic Haploxeroll. The soil pit was 204+ cm deep, reaching parent material but not refusal (Figure 46). The bedrock is mapped as Nestucca Formation that includes sedimentary sandstone and pillow basalt (Figure 2). The highly weathered basalt parent material is found from 121 to 204+ cm depth. The pH increases with depth to 6.7. CEC is the greatest in this profile, up to 80.0 meq/100 g in the Bt horizon. OM ranges from 10.1% at depth to 17.9% in the Ap horizon (Table 89). Coarse fragments also increase to 25% with depth. Percent sand increases with depth from 31% to 77% from Ap to Cr at 118 cm. Dry colors for the Ap and Bt horizon are dark yellowish brown (10 YR 4/4).

Table 89. Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block field and lab data.

Depth (cm)	Horizon	Total			Coarse Fragment (>2mm)	Texture Lab
		Sand (2-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)		
		←-----Pct.-----→				
0-10	Ap	30.7	53.2	13.4	0.0	L
10-72	Bt	21.3	54.1	20.2	0.5	SiL
72-121	Bw	62.4	21.2	9.3	0.0	SL
121-204+	Cr	76.9	12.1	4.4	1.1	LS
Depth (cm)	Horizon	Dry Color	Structure	Organic Matter LOI (Pct.)	pH (1:1 H ₂ O)	CEC (meq/100g)
0-10	Ap	10YR 4/4	1, f, sbk	17.9	6.0	48.5
10-72	Bt	10YR 53/4	2, m, sbk	11.2	6.0	80.0
72-121	Bw	7.5YR 4/3	2, m, sbk	11.1	6.3	61.0
121-204+	Cr	7.5YR 4/1	2, m, sbk	10.1	6.7

Figure 46. Sample soil pit at Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block. A – View of sample location, facing south. B - Picture of the face of the soil pit with horizon depths and boundaries marked. C - Soil retrieved using a hand auger with horizon depths and boundaries marked.

Textures include loam and silt loam in the Ap horizon, sandy loam, and loamy fine sand with depth. Structures of the soil profile are medium subangular blocky with single grain texture in the Bw and Cr horizons. Clay percent is highest in the Bt horizon with 20% and lowers in the Cr to 4%. Clay films are common and dominant on ped faces in the Bt horizon. There are no pisolites in this profile.

Soil Chemistry

The Meredith Mitchell Vineyard soil pit was separated into four horizons, and samples of each horizon were sent for analysis (Table 90). This is one of the deepest soil profiles in this study reaching weathered parent material at 121 cm and then coring to 204 cm because of the friability of the material. P and K decrease with depth and the maximum concentration is in the Ap horizon. Ca and Mg increase with depth with the maximum concentration in the Cr horizon. Ca increases dramatically in the Cr horizon compared to the horizons above and Mg is an order of magnitude higher for every horizon in this profile than all the other soil pits examined in this study. S is only detected at the surface and decreases with depth.

Some micronutrient concentrations measured in the four soil horizons from the Meredith Mitchell Vineyard decrease with depth and some increase with a slight bulge in the Bt or Bw horizons. Fe and Mn decrease with depth and the highest concentration is in the Ap horizon. Al increases with depth with the highest in the Cr horizon. Na decreases

Table 90. Macronutrient, micronutrient and trace element concentrations (all values in mg/kg) for the Ken Wright Cellars, Meredith Mitchell Vineyard, Martha Block soil pit (ND – Non-detectable).

Horizon (cm)	P	K	Ca	Mg	S	Cl				
Ap (0-10)	873	2330	6530	12300	292	ND				
Bt (10-72)	685	1560	6060	14100	159	ND				
Bw (72-121)	288	220	9950	22300	ND	ND				
Cr (121-204+)	304	111	21900	22300	ND	ND				
Mean	538	1060	11100	17800	226	ND				
SD	289	1080	7400	5300	94.0	ND				
Maximum	873	2330	21900	22300	292	ND				
Horizon (cm)	Fe	Al	Co	Cu	Mn	Mo	Na	Ni	Zn	
Ap (0-10)	92100	36100	46.8	110	1810	ND	1130	14.5	93.0	
Bt (10-72)	91300	37100	48.4	116	1810	ND	386	15.5	83.1	
Bw (72-121)	76300	40500	40.1	146	1380	ND	344	27.3	104	
Cr (121-204+)	67300	41200	35.4	138	1240	ND	1560	26.8	101	
Mean	81800	38700	42.7	128	1560	ND	855	21.0	95.3	
SD	12100	2500	6.04	17.2	294	ND	593	6.97	9.35	
Maximum	92100	41200	48.4	146	1810	ND	1560	27.3	104	
Horizon (cm)	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
Ap (0-10)	0.426	162	0.863	1.11	40.7	ND	3.91	ND	196	255
Bt (10-72)	0.341	179	0.954	0.912	40.1	ND	3.21	0.621	202	235
Bw (72-121)	ND	214	0.863	0.542	35.9	ND	1.35	ND	396	181
Cr (121-204+)	ND	177	0.800	0.634	29.6	ND	1.08	ND	555	221
Mean	0.384	183	0.870	0.800	36.6	ND	2.39	0.621	337	223
SD	0.0601	22.0	0.0634	0.260	5.12	ND	1.39	ND	172	31.3
Maximum	0.426	214	0.954	1.11	40.7	ND	3.91	0.621	555	255

with depth, but increases significantly from the Bw horizon to the maximum in the Cr horizon. Ni and Cu increase with depth with a bulge in the Bw horizon. Zn is variable, with a bulge in the Bw horizon as well. Co bulges in the Bt horizon and decreases with depth. Mo is non-detectable. Trace element concentrations for the four horizons of the

Meredith Mitchell Vineyard also varied greatly. As, Cr, Pb, and V decrease with depth the highest concentration in the Ap horizon. Cd decreases with depth from a maximum in the Ap horizon and a small bulge in the Cr horizon. Ba increases with depth and bulges in the Bw horizon. Be bulges in the Bt horizon and then decreases with depth. Se is only detected in the Bt horizon. Sr increases with depth. Hg was non-detectable.

Grape Juice Chemistry

The grape juice samples have concentrations of many elements that are below detection limits in this study, as seen in Table 91. All 24 elements were analyzed for in the grape juice from grapes collected adjacent to the soil pits. The concentrations of K and Na in Meredith Mitchell Vineyard grape juice are 883 mg/kg (3rd lowest) and 156 mg/kg, respectively (Table 105). Sr concentration, one of only three elements found in all grape juice samples, is measured as 0.332 mg/kg, which is the lowest concentration of Sr for the 20 vineyard samples. Mean Sr concentration for all grape juice samples from the 20 different sites is 0.805 ± 0.261 mg/kg. P concentration is 328 mg/kg and Mn concentrations are non-detectable in this sample.

Table 91. Elemental concentrations measured by ICP-MS in the grape juice from clusters collected from vines immediately adjacent to the soil pit location at Ken Wright Cellars, Meredith Mitchell Vineyard, Martha Block (ND – Non-detectable).

Element	Sr	P	K	Na	Mg	Mn	Ca	Cu	Zn
Grape Juice (mg/kg)	0.332	328	883	156	ND	ND	ND	ND	ND

Wine Chemistry

Ken Wright provided a 750 ml sample of the wine produced from the Meredith Mitchell Vineyard in 2012. Many of the 24 elements tested in the wine (same as the elements tested in the soil samples) were below detection limits. The 11 elements that were detected in the Meredith Mitchell Vineyard wine sample include Ba, Ca, Fe, Mg, Mn, P, K, Na, Sr, S, and Zn (Table 92). Co, Cu, and Pb, which were detected in many other wine samples in this study, were not detected in the wine sample from Meredith Mitchell Vineyard. K and P concentrations are the highest at 538 mg/kg and 430 mg/kg, respectively. S is 101 mg/kg, Mg is 84.9 mg/kg, Ca is 43.9 mg/kg, and Na is 4.76 mg/kg for this wine. The concentration of Fe is 1.06 mg/kg and Mn is 0.952 mg/kg. The concentration of Zn is 0.768 mg/kg, Sr is 0.681 mg/kg, and Ba is 0.188 mg/kg.

Clay Mineralogy

The Meredith Mitchell Vineyard soil sample contains a distinct clay mineral assemblage that is not similar to any other pit in this study. There are minor amounts of smectite present in this sample, and the smectite present is not strongly interlayered with Al-Fe hydroxides. Some minor vermiculite and mixed layer kaolinite/smectite is present and expansive. No chlorite or chlorite intergrade is present. Trace amounts of kaolinite and dehydrate halloysite exists in this sample. The trace amount of goethite is also not strongly developed as compared to other samples.

Table 92. Elemental concentrations measured by ICP-MS of a 750 ml unblended wine sample from the 2012 Ken Wright, Meredith Mitchell Vineyard, Martha Block (ND – Non-detectable).

Element	2012 Wine Sample (mg/kg)	Element	2012 Wine Sample (mg/kg)
Al	ND	Mn	0.952
As	ND	Hg	ND
Ba	0.188	Mo	ND
Be	ND	Ni	ND
Cd	ND	P	430
Ca	43.9	K	538
Cr	ND	Se	ND
Co	ND	Na	4.76
Cu	ND	Sr	0.681
Fe	1.06	S	101
Pb	ND	V	ND
Mg	84.9	Zn	0.768

Chapter Ten – Data Analysis

Principal Component Analysis

Principal Component Analysis (PCA) is a statistical method that converts the observations into vectors describing the variance in the data. These vectors are then placed on a new coordinate system using the first principal component and second principal coordinate to show correlations between data points in a space, allowing for correlation clusters to be observed. Because PCA does not handle data that varies greatly in magnitude, elements are analyzed according to the macronutrient, micronutrient, and trace element groups as discussed previously.

The soil horizon in each pit with the highest BW index (the most developed or “old”) was selected. Each vineyard and data for the percent clay, mean OM, depth to Cr horizon, mean pH, and CEC values were analyzed using PCA. The Meredith Mitchell vineyard is perceived as an outlier for many variables and is removed for some analyses. The null hypothesis is that there is no correlation significantly different from 0 between the variables. At least one of the correlations between the variables is significantly different from 0 for these data, and the computed p-value (0.022) is lower than the significance level ($\alpha=0.05$) in the Bartlett’s sphericity test. Therefore, the null hypothesis is rejected. The eigenvectors indicate that 69.21% of the variability is explained using the F1 (40.60%) and F2 (28.61%) vectors (Figure 47). CEC, mean pH,

and depth to Cr are related while the percent clay and mean OM are also related (indicating that the OM values in this study have been influenced by the high clay content of these soils).

Figure 47. Principal component analysis of physical characteristics of vineyard soils in this study including % Clay, Mean pH, Mean OM, Depth to Cr, and CEC in comparison to vineyard soil parent materials (Red = volcanic, Blue = marine sediments, Orange = loess/volcanic, Purple = other).

Macronutrients, CEC, and percent clay were plotted using PCA. The null hypothesis was again rejected because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The risk in this case to reject the null hypothesis that there is no correlation between the variables is lower than 0.01%. CEC is positively correlated with Ca and Mg and negatively correlated with percent clay. This result relates to the age of the soil, these soils being Ultisols and Ultic Alfisols with low CEC and high percent clay because of age and development. Vineyards are clustered based on soil parent material (Figure 48).

There is clustering of these data based on parent material. Vineyards with volcanic parent material plot together while vineyards with marine sediment parent material cluster separately. The loess/volcanic vineyards tend to plot in between the volcanic and the marine sediments. This indicates that these vineyards are influenced by both the volcanic bedrock which has similar chemistry and the loess parent material which has similar texture as the marine sediment soils. Ken Wright Meredith Mitchell vineyard is clearly an outlier, plotting nearest to CEC, Mg, and Ca. This vineyard is removed for subsequent PCA analysis. The vineyards on other parent material, Terres Basses and Jacob-Hart, plot similarly to the vineyards loess/volcanic and marine sediment parent material. The Terres Basses vineyard is located on shale from the Coast Range sediments and Missoula Flood sediments, while the Jacob-Hart vineyard is located on a landslide on the south side of Chehalem Mountains, mostly consisting of basalt bedrock.

Figure 48. PCA biplot of soil macronutrients, CEC, and percent clay. Red labels – volcanic parent material. Blue labels – marine sediment parent material. Orange labels – loess/volcanic parent material. Purple labels – other parent material.

All soil elements (macronutrients, micronutrients, and trace elements) show a similar trend when PCA is done with outliers removed (Figure 49). This plot shows a separation based on soil parent material. The null hypothesis was again rejected because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The vineyards on volcanic parent material are more dispersed based on the soil elemental

concentrations than the vineyards on marine sediment parent material. The vineyards on micronutrient concentrations in the soil, the volcanic soils cluster with Fe, Zn, Mn, and Al, while the loess/volcanic and marine sediment soils are separated from the volcanic soils by Mo, Cu, and Na (Figure 50). The null hypothesis was again rejected for the soil

Figure 49. PCA plot of macronutrients, micronutrients and trace elements. Triangles – volcanic parent material. Squares – marine sediment parent material. Circles – loess/volcanic parent material. Diamonds – other parent material (Meredith Mitchell vineyard outlier data removed).

Figure 50. PCA biplot of the soil micronutrients grouping soil parent materials by color. Red labels – volcanic parent material. Blue labels – marine sediment parent material. Orange labels – loess/volcanic parent material. Purple labels – other parent material.

micronutrients because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The eigenvectors indicate that 57.06% of the variability is explained using the F1 (34.16%) and F2 (22.90%) vectors.

The vineyard soil parent materials to the trace element concentrations in the soil, the volcanic soils cluster nearest to Ba, Cd, V, and Be, while the loess/volcanic trend

toward the As and Ni vectors (Figure 51). Marine sediment soils are separated from the volcanic soils by As and Se, and are clustered near Sr and Hg. The Jacob-Hart soils are most similar to the volcanic soil values and cluster near Se and Ba. Cr and Pb vectors lie between the volcanic and the loess/volcanic soils. The null hypothesis was again rejected

Figure 51. PCA biplot of the soil trace elements grouping soil parent materials by color. Red labels – volcanic parent material. Blue labels – marine sediment parent material. Orange labels – loess/volcanic parent material. Purple labels – other parent material.

because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The eigenvectors indicate that 53.50% of the variability is explained using the F1 (37.24%) and F2 (16.26%) vectors. The Lange Estate Freedom Hill vineyard is an outlier when looking at these plots.

The grape analysis provided very little data but the nine elements that were detected are compared using PCA to the vineyard parent materials (Figure 52). The Jacob-Hart vineyards plot with the P, K, Cu, and Zn while Yamhill, Nysa, and Ken Wright Freedom Hill plot with Ca, Mg, and Sr. One volcanic soil (Stoller) and one marine sediment soil (Aliette) plot with Na while all the rest of the vineyards, regardless of soil parent material cluster near the Mn vector. The null hypothesis was again rejected because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The eigenvectors indicate that 52.58% of the variability is explained using the F1 (28.20%) and F2 (24.39%) vectors.

Lastly, 15 elements were detected in the wine chemistry and the mean values are compared using PCA to the vineyard parent materials (Figure 53). The null hypothesis was again rejected because the computed p-value (<0.0001) is lower than the significance level ($\alpha=0.05$). The eigenvectors indicate that 42.91% of the variability is explained using the F1 (23.87%) and F2 (19.04%) vectors. Some vineyards from the marine

sediments group with Sr and Ba (LEFH and WEA) and vineyards from volcanic parent material group with Pb, Co, Ni, and K (KWN, CWS, LEM, and WEJH).

Figure 52. PCA biplot of grape chemistry by vineyard. Red labels – volcanic parent material. Blue labels – marine sediment parent material. Orange labels – loess/volcanic parent material. Purple labels – other parent material.

correlated with Ca and Mg concentrations and negatively correlated with percent clay. All marine and volcanic soils have higher percent clay and loess and other soils have lower percent clay. Volcanic soils clustered more with Cl, P and S while marine sediments mingled again with loess soils, some of which had higher K, Ca, Mg, and CEC (Figure 48). The PCA revealed that the KWMM site was an outlier in many cases.

Concerning all the elements tested, marine, volcanic, and loess soils clustered with loess in between the volcanic and marine sediments. This clearly suggests similarities in the loess soil with both the volcanic (because the bedrock of the loess soil is also volcanic) and the marine sediments. These results were only observed with KWMM removed from the data set (Figure 49). Specifically, volcanic soils clustered with higher Fe, Zn, Mn, and Al as well as Mo, and Cu. Loess soils clustered with Na and marine sediment soils are separated from the volcanic soils with lower values for all these elements (Figure 50). The clustering of trace elements is less pronounced, but the soil parent materials are still slightly clustered. Volcanic soils cluster with Cr, Pb, Be, Co, Cd, V, Ba, and Se. Marine sediments cluster with Hg, Sr, and loess soils cluster with As and Ni. Both marine sediments and loess are more similar to one another in terms of Ni, As, Sr, and Hg while loess also shows similarities with volcanic soils concerning Cr and Pb (Figure 51). Clearly, there are similarities in soil chemistry and soil physical attributes causing each soil parent material to be clustered.

There are few clear trends in the grape juice or wine chemistry as all three soil parent materials are mixed throughout the plot (Figure 52). The Rex Hill Jacob-Hart Vineyard Block 1 and Block 5 (RHJH1 and RHJH5) “other” soils both have similarly higher Zn and Cu concentrations in both grape juice and wine chemistry and had higher levels of Zn and Cu in the soils. The concentrations of Sr and Ba in the wine are correlated with a few marine sediment soils while the concentrations of Pb and Co in the wine are more correlated with volcanic soils (Figure 53).

Chapter Eleven – Discussion

Soil Physical Characteristics

This study shows that there are trends in the physical, mineral, and chemical data that distinguish the soils that form on volcanic, marine sediments, and loess/volcanic parent material from one another. Soils from vineyards planted on the volcanic bedrock and loess sediments on volcanic bedrock are more similar to one another than to soils from vineyards planted on the marine sediment bedrock. Physical characteristics used to compare the various parent material in this study include texture, structure, depth, horizons, coarse fragments, and others (Table 93). The physical characteristics, clay mineralogy, and soil chemistry results (last chapter) from this study have demonstrated the need for and provided more focused research questions for future studies.

Table 93. Comparison of physical characteristics of vineyard soils in the Willamette Valley.

Characteristic	Volcanic	Marine	Loess
Horizon Development	All have Bt Horizon	All have Bt Horizon	All have Bt Horizon
Bt Horizon Textures	SiL, SiCL, SiC, C	SiCL, CL, C	SiCL
Max Clay	57%	60%	39%
Depth to Bt	44 ± 16 cm	44 ± 13 cm	51 ± 10 cm
Depth to Bt with Max Clay	81 ± 44 cm	68 ± 40 cm	83 ± 52 cm
Cr Horizon	2/6	6/7	1/3
Coarse Fragments in the Cr Horizon	~25%	~2%	~5%
Max BW	20 ± 6.5	19 ± 7.3	13 ± 2.3
Mean Soil Acidity	5.4 ± 0.11	5.4 ± 0.25	5.7 ± 0.11
Presence of Pisolites	6/6	0/7	3/3

In general, 19 of the 20 soil pits analyzed in this study have developed a Bt horizon, the formation of which is dependent on time and moisture availability. A Bt horizon suggests a color change from the upper horizons to more red colors which is the result of oxidation occurring in a well-drained soil. Translocated clays from surface horizons have accumulated in the B horizon as fine-grained coatings on the peds and in the pore spaces. My soils with Bt horizons are old soils, as noted by the occurrence of a Bt horizon and other physical characteristics in the following discussion. The one soil without a Bt horizon was the Willakenzie Estate Terres Basses which is located on thin Missoula Flood sediments. The age of this soil must then be less than the age of the floods (approximately 15,000 years) (Allen et al., 2009) and not enough time has passed for a Bt horizon to form.

The idea that the majority of the vineyard soils examined in this study are old soils is supported also by the amount of clay present in each profile. The horizon with the maximum clay percentage for each profile based on parent material shows a major distinction between the soils on volcanic and marine sediments versus loess soils. For the soils on volcanic parent material the average maximum clay percentage is 57%. Marine sediment soil has an average maximum clay percentage of 60%. Loess soils have the least high average maximum clay percentage at 39%. This is most likely due to the input of loess and resulting higher silt percentages in the soil profile.

For all the Bt horizons in this study, the textures were determined from grain size analysis using the pipette method. The most common texture for these vineyard soils is silty clay loam in 28% of the horizons. The second most common textures were clay and silt loam in 21% of the horizons for each texture. Finally, 15% of the horizons were clay loam or silty clay in texture. Again, the accumulation of clay in these soils implies that they are old soils, and the presence of silt in almost all of the sites in this study is coming from the original loess parent material or an addition of loess over time. Many of the volcanic and all of the loess/volcanic soils are shown to contain a high percentage of silt. The many floods that brought sediment to the Willamette Valley provided silt to be blown from the valley bottoms onto the hillslopes where these sites are located. The silt in the marine sediments is coming from the sandstone and siltstone parent material directly from the Coast Range marine sediments.

Furthermore, many of the vineyard soils sampled in this study were shallow enough for the bedrock to be reached. In this study, 13 of 20 pits reached parent material. Many of these profiles were described as having a Cr or R horizon at depth. Marine sediment soil was most likely to have Cr horizon(s) sampled (six of seven pits), since the sandstone and siltstone parent material was friable and easily penetrated with the auger. Volcanic (two of six) and loess soils (one of three) were unable to reach basalt bedrock, but many contained basalt gravel at depth. Refusal at only a few sites was reached; The Jory Hills (volcanic), Stoller (volcanic), Corral Creek (loess), and Rex Hill Estate (loess)

vineyards were dug to refusal at basalt bedrock. For the most part, the vine roots were also present in the Cr horizons, especially in the marine sediments.

In addition to reaching the bedrock or a Cr horizon, nine pits had 2.9% or less coarse fragments in the A horizon. Many quality vineyards in other places in the world have very little soil accumulation and are mostly gravel at the surface (White, 2009). This difference makes the soils of the Willamette Valley distinctive in that many vineyards have very little to no gravel at the surface. In contrast half of the sites in this study, 10 pits out of the 20, had coarse fragments in the Cr horizon. The majority of these coarse fragments were highly weathered basalt fragments from the bedrock below. The Jacob-Hart vineyard contained the most gravel in the Cr horizon because this site is an ancient landslide deposit, consisting of a mix of sediment and basalt colluvium from the southwest slope of the Chehalem Mountains.

Of the 20 soil profiles, no vineyard had an O horizon present which is not uncommon for agricultural soils. An O horizon is an organic layer developed from leaves, needles, mosses, rushes, or woody material that is slightly decomposed and is mostly found in forested areas. These vineyards are well groomed and void of much debris left to decompose on the vineyard floor. The vineyard managers removed or till under the vine cuttings each season. Many have mown cover crops between vine rows and bare earth directly below the vines. Two of the profiles in this study had Bg horizons.

A Bg horizon indicates that there are periods of intense reduction in the soil meaning that it is poorly drained (Birkeland, 1999). The Bg horizon is characterized by gray colors and the presence of red mottling (redoximorphic features). The only sites in this study with Bg horizons were the Terres Basses vineyard on Missoula Flood deposits and the Yamhill vineyard on marine sediments. The cause of a Bg horizon at the Yamhill vineyard is most likely because of a clay layer within the siltstone parent material that inhibits drainage. The lack of many Bg horizons in the study indicates most vineyard soils in the study were well-drained.

An indication that these soils are old and have had plenty of time to develop is the structure of the peds. The majority of these soils had subangular blocky structure (Spohn and Giani, 2011). This structure is good for agriculture because pores and channels within the soil allow for the movement of air and fluids through the soil and creates a favorable environment for microbial activity and root growth (Barthès and Roose, 2002; Helgason et al., 2010). Structure is dependent on texture, clay, organic matter, and cementing substances like sesquioxides that coat and group the particles into aggregates (Colombo and Torrent, 1991). The presence of Fe and Al in many of the soils in this study, as well as the presence of macronutrients like Ca and Mg, will aid in the formation of aggregates and the subangular structure. Bacteria, fungi, and mycorrhizae are also very important in the formation of aggregates and the structure of the soil (Barto et al., 2010; Rillig et al., 2010). Subangular blocky structure in these vineyards promotes aeration and

soil permeability and, most likely, has a huge impact on the health of the vine and the quality of the wine. More research is needed into the role of soil structure in the vineyards of the Willamette Valley.

Pisolites (Concretions)

A major discovery in the physical characteristics is that both the volcanic and windblown soils, which form on the volcanic bedrock with the addition of loess, have concretions called pisolites (Miller, 1985) (Figure 54). These concretions were also described in 1985 in the Pre-Peoria loess in Northeastern Louisiana (Miller, 1985). I expected to find pisolites in the loess soils (mainly the Laurelwood series) because farmers have always called these “buckshot” soils, but finding them in the volcanic soils (at lower concentrations) was a surprise. The grain size of the volcanic and loess/volcanic soils have an unusually high percentage of sand-size grains in the upper horizons because of these secondary concretions of Fe and Mn similarly to the Pre-Peoria loess (Miller, 1985). These concretions are found in Alfisols and Ultisols in Louisiana, which is also the case in this study. The Pre-Peoria loess is dated at 60 to 25 Kya (Gillespie et al., 2004) suggesting that the soils with concretions in this study are likely soils on old weathered loess and not loess from the 15 Kya Missoula Flood sediment.

Therefore, many of the volcanic soils are closely related to the windblown soils in this study. These pisolites, discovered during the grain size analysis, exist in the soils that

develop on volcanic bedrock that also have a loess input. Some of the volcanic soils have pisolites, implying they also have had an addition of loess in the past. Previous to this study, pisolites were only found in the old windblown soils in the Willamette Valley. Now, I know that volcanic soils sometimes also contain pisolites and must also have a windblown component. In this study, the marine sediment soils do not contain pisolites. The marine sediment soils do, on the other hand, contain visible muscovite mica and quartz sand where the volcanic soils are more likely to have dark rock fragments in the sand fraction and no quartz.

Pisolites are subrounded in shape and are sometimes referred to as Fe-Mn concretions (Manceau, 2003). Thin sections show that these pisolites usually contain a grain of quartz, feldspar, or mica that is surrounded by layers of Fe and Mn oxides and phyllosilicates. The similarity between the minerals available in the soil and the minerals found in the pisolites indicate that they form in place and are not transported. The mechanism of formation may involve wet and dry cycles and the enrichment of Fe, Mn, and other metals that are attracted to the nucleus and deposited in concentric layers during oxidation (Manceau, 2003). This process is most common in loess soils and may have an important impact on the availability of trace metals in the soils for uptake by the vines and result in lower Fe and Mn concentrations in the bulk soil.

Figure 54. Pisolites from the Lange Estate, Mia Block (A - LEM) and Elk Cove, Five Mountain Vineyards (B - ECFM).

The pisolites were most significant in two vineyard sites in this study. The Lange Estate Vineyard, Mia Block and the Elk Cove, Five Mountain Vineyard both contain abundant pisolites throughout their profiles. I was expecting to find pisolites in the Five Mountain Vineyard, since it is one of my loess/volcanic sites, but did not expect to find pisolites in the Lange Estate, Mia Block. The pisolites were separated from the soil and powdered for X-ray diffraction at Portland State University in order to determine the mineralogy. Samples were also sent to Washington State University labs for analysis using X-ray fluorescence to determine elemental composition (Table 94). Trace elements were determined using ICP-MS (Figure 55). It is thought that the pisolites form mostly of

Fe and Mn oxides while pulling many trace elements out of the soil. If this is true, it may relate to trends in the soil chemistry data for samples containing pisolites.

Table 94. Major elements measured in pisolites from soils formed on two different parent materials in the Willamette Valley using XRF. LEM – Lange Estate Mia vineyard on volcanic parent material. ECFM – Elk Cove Five Mountain vineyard on windblown and volcanic parent material.

Normalized Major Elements (Weight %)		
Sample	LEM (Volcanic)	ECFM (Loess/volcanic)
SiO ₂	53.14	63.68
TiO ₂	2.722	1.532
Al ₂ O ₃	20.60	16.82
FeO*	16.95	9.23
MnO	0.972	0.670
MgO	0.83	1.11
CaO	0.73	1.33
Na ₂ O	1.01	1.88
K ₂ O	1.44	1.99
P ₂ O ₅	1.618	1.759
Total	100.00	100.00

The results from the XRF and ICP-MS analysis indicate that the pisolites do contain mostly silica, Al, and Fe oxides. Initial results of the x-ray diffraction also suggest the core of the pisolites is either quartz or feldspar as these peaks are the most distinguishing. The pisolites from the volcanic soil (LEM) actually have higher weight percent of Al, Fe, and Mn than the pisolites from the loess/volcanic soil (ECFM). Mg, Ca, Na, K, and P are higher weight percent in the loess soil pisolites, which correlates with the higher values of these elements in the soils of the loess pisolites (discussed in the

soil chemistry section). Trace elements are similar between pisolites from the different parent materials with the exception of Cr, V, Ba, Sr, Cu, and Zn. Cr, V, and Zn are higher in the LEM (volcanic) pisolites while Ba and Sr are higher in the ECFM (loess/volcanic) pisolites.

Figure 55. Trace elements of pisolites from soils formed on two different parent materials in the Willamette Valley using ICP-MS. LEM – Lange Estate Mia vineyard on volcanic parent material. ECFM – Elk Cove Five Mountain vineyard on windblown and volcanic parent material.

Buntley-Westin Soil Development Index

The soils in this study are mostly red soils, and this physical characteristic did vary between soils of different parent material and soil development. In general, the colors that have developed in the soils of the volcanic and loess parent material are more

likely to be brown, strong brown, or reddish brown which coincides with the Munsell notations of 7.5YR or 5YR hue. The marine sediment soils are more yellowish brown in color which coincides with Munsell notations from the 10YR hue. This may be connected to the formation of different Fe-oxides, and the age of the soils, and the color of the parent material. In most cases, the marine sediments (sandstones and siltstones) have yellowish color which then influences the color of the soil above.

The Buntley-Westin (BW) soil development index (Buntley and Westin, 1965) utilizes soil colors determined by the Munsell notations to assess soil development which is based on redness of the soil (redder the soil the older the soil). The soils analyzed are grouped by parent material with their respective B horizon Buntley-Westin soil development index (Table 95). For each soil, the hue is given a value (5YR = 5; 7.5YR = 4; 10YR = 3; 2.5Y = 2), which is multiplied by the chroma (Buntley and Westin, 1965 and Birkeland, 1999). According to Birkeland (1999), a BW Color Index greater than 15 coincides with soils greater than 10,000 years old in alpine soils (study by Miller and Birkeland, 1974).

I know that the soils in this study are older than this, possibly a half to a million years old according to geologic history. The soils are at high enough elevations to have been protected from the catastrophic flooding that occurred approximately 15,000 to 18,000 calendar years ago (Allen et al., 2009) which would have deposited sediments to

make the soils younger. Soils with volcanic parent material have a color index ranging from 12 to 30 with a mean of 20 ± 6.5 (Table 95). The soils with marine sediment parent material have BW color indices ranging from 12 to 30 with a mean of 19 ± 7.3 . These soils are very similar in age as the soils that formed on the volcanic parent material in this study. The soils of loess/volcanic parent material have similar values ranging from 12 to 16 with a mean of 13 ± 2.3 . These values are slightly lower due to the addition of loess.

Table 95. Soil development rating based on Buntley-Westin Color Index. Value is the maximum for each soil pit compared to all horizons sampled within that pit separated by parent material.

Volcanic		Marine		Loess		
ECCC	20	ECRV	18	ECFM		12
WEJH	30	WEAB	30	CWCC		16
CWS	12	CWR	12	RH12		12
LEM	16	LEY	24	<i>Mean</i>		<i>13</i>
RHS	24	KWAC	24	<i>St. Dev.</i>		<i>2.3</i>
KWN	16	LEFH	12	Other	WETB	9
		KWFH	12		RHJH1	9
<i>Mean</i>	<i>20</i>	<i>Mean</i>	<i>19</i>		RHJH5	9
<i>St. Dev.</i>	<i>6.5</i>	<i>St. Dev.</i>	<i>7.3</i>		KWM	12

These results do not demonstrate a significant difference in soil development between these three parent materials, but it does imply all these vineyards in this study comparing three different parent materials are all well developed and old soils (Figure 56). My belief going into this study was that there would be a trend in the BW values with the Jory (volcanic parent material in the Dundee AVA) greater than the Willakenzie

Figure 56. Map of the maximum Buntley & Westin color from a B horizon in each soil pit for vineyards in this study that were located in the northern Willamette Valley AVAs.

(marine sediment parent material in the Yamhill-Carlton AVA) and both greater than the Laurelwood (loess/volcanic parent material in the Chehalem Mountains AVA) soil series. These data show this trend but are not statistically significant since I have so few data points (Scott Burns, per comm., 2015). It is notable that the vineyards on Missoula Flood Deposits (WETB) and the landslide deposits (RHJH1 and RHJH5) all have a BW color index of 9. This is the lowest soil development for all of my samples and correlates with what I know about these deposits being less than 15,000 years old and the youngest

deposits in this study. The Meredith Mitchell vineyard is located on old volcanic bedrock in the Coast Range, and a value of 12 coincides with this being an older soil, similar to the other soils on marine sediments.

Organic Matter

The organic matter content of each horizon was determined using loss on ignition. Normally organic matter decreases with depth (Birkeland, 1999). The results using this method can be higher than normally seen at depth because of unusually high clay content in the soil. As the soil is heated, the moisture trapped in the clay lattice can be released, giving an incorrect value for the organic matter. As stated before, the average clay content of the volcanic soils is 57% and 60% for marine sediment soils so many of the horizons with these high amounts of clay also have high perceived percent organic matter values. Despite this issue with the deeper horizons, the organic matter in most of the A horizons are between 3% and 10%, which is within the normal range for agricultural soils which is from 2 to 10% (Birkeland, 1999). The Stoller vineyard has the highest percent organic matter in the A horizon for these vineyards at 13.8%. To compare the parent material in this study, the mean percent organic matter for the A horizon of each was calculated. The mean percent organic matter in volcanic soils is $11.3 \pm 1.3\%$. The mean percent organic matter for the A horizons of the marine sediment soil is $6.9 \pm 1.8\%$. The A horizons of the loess/volcanic soils have a mean percent organic matter of $7.5 \pm 0.7\%$ (Table 96). There is enough of a distinction to believe the volcanic soils in this study do

have higher organic matter in the surface horizons. This is most likely due to farming practices.

Table 96. Percent organic matter for the A horizon of each soil pit in this study separated by parent material. Organic matter determined using loss on ignition separated by parent material.

Volcanic		Marine		Loess	
ECCC	10.3	ECRV	9.3	ECFM 7.9	
WEJH	10.7	WEAB	8.0	CWCC 6.7	
CWS	13.8	CWAB	3.9	RH12 8.0	
LEM	10.7	LEY	5.7	Mean 7.5	
RHS	11.9	KWAC	6.5	St. Dev. 0.7	
KWN	10.6	LEFH	7.6	Other	WETB 9.0
		KWFH	7.2		RHJH1 8.5
Mean	11.3	Mean	6.9		RHJH5 9.0
St. Dev.	1.3	St. Dev.	1.8		KWM 17.9

In order to assess the variation in percent organic matter by parent material, the mean for each soil pit was calculated and mapped according to AVA (Figure 57). The Dundee AVA (mostly volcanic soils) contains the sites with the highest organic matter content. Since organic matter is impacted by farming practices, it is necessary to note that the vineyard sites in all the AVAs have cover crop strategies and regular tilling schedules. It may be that these vineyards had been tilled more recently than others which increases the organic matter in the soils. Also, as stated before, the clay content in many of the sub-horizons of volcanic soils is higher than in the other soils. This high clay content most likely is the main reason these data are also high since loss on ignition tends

to drive water out of the clays. Almost every site had increasing organic matter with depth, which is uncommon without evidence of translocation, which there is none in these sites. Organic matter translocation would leave behind OM coatings on ped faces among other visible evidence, and nothing of this kind was found. Percentages over 10% for OM at depth are not common, and a comparison of various methods (other than LOI) to clay content is needed.

Figure 57. Map showing the mean organic matter determined using loss on ignition on each horizon in each soil pit for vineyards in this study that were located in the northern Willamette Valley AVAs.

Soil Acidity

The pH values ranged from 4.7 to 6.7 for all 87 horizons tested in this study with a mean of 5.5 ± 0.4 . The maximum soil pH of 6.7 was recorded in the Ken Wright Meredith Mitchell vineyard. This is correlated to the high organic matter, CEC, and Ca content in this vineyard as compared to the other sites. The most acidic horizon was the Cr1 horizon of the Ken Wright Abbott Claim vineyard with a pH of 4.7. The minimum mean pH for soils with volcanic parent material is 5.2 ± 0.2 , and the overall mean is 5.4 ± 0.1 (Table 97).

Table 97. Minimum soil pH for each vineyard site according to parent material.

Volcanic		Marine		Loess		
ECCC	5.0	ECRV	4.7	ECFM	5.5	
WEJH	5.2	WEAB	5.8	CWCC	5.7	
CWS	5.4	CWAB	5.0	RH12	5.6	
LEM	5.3	LEY	4.9	Mean	5.6	
RHS	5.0	KWAC	4.7	St. Dev.	0.1	
KWN	5.4	LEFH	5.1	Other	WETB	5.3
		KWFH	5.3		RHJH1	5.7
Mean	5.2	Mean	5.1		RHJH5	5.7
St. Dev.	0.2	St. Dev.	0.4		KWM	6.0

The minimum mean pH for soils with marine sediment parent material is 5.1 ± 0.4 , and the overall mean is 5.4 ± 0.3 . Loess soils tend to have slightly higher pH with a minimum mean at 5.6 ± 0.1 and an overall mean at 5.7 ± 0.1 . This is due to the input of young loess which also supplies nutrients to the soils. The majority of soil pits in this

study have pH values that decrease with depth, usually from the moderately acid range (5.6 to 6.0) to strongly acid (5.1 to 5.5). This was expected since these are old soils with low nutrients. Four soil pits were very consistent with depth considering pH. These were Ken Wright Nysa vineyard, Willakenzie Estate Aliette vineyard, and Chehalem Corral Creek vineyard. These vineyards all have low pH because they are located on old soils.

A moderately low acidic soil is commonly used for quality vineyard sites. If the pH becomes too acidic or too alkaline, various key nutrients can become insoluble and unavailable to the plants (White, 2009). The soil pH has an important influence on the availability of nutrients and on the growth of different kinds of plants. If the soil pH is too low the N, P and K are tied up in the soil and not available to plants. Ca and Mg, which are essential plant nutrients, may be absent or deficient in low pH soils. Low pH also increases the toxicity of Al, Fe and Mn. Non-toxic elements like S, Ca, Mg, and Mo will be available for plant uptake at the correct pH. The decomposition of organic matter improves soil structure and is also impacted by the pH. If soil pH is too low, the activity of soil organisms that break down organic matter is reduced (White, 2009). Proper soil pH increases microorganism activity which produces improved soil tilth (aggregation and readiness for crops), aeration and drainage. This in turn allows for better use of nutrients, increased root development, and drought tolerance.

Cation Exchange Capacity

Cation exchange capacity can sometimes be estimated if the dominant clay minerals in the soil are known. The value of CEC relates to the elements that are available for uptake by the vine. From White (2003) kaolinite clays will have low CEC (3 to 20 meq/100g), illite (10 to 40 meq/100g), smectite (80 to 120 meq/100g) and vermiculite will have the highest CEC (100-150 meq/100g). In this study, volcanic soils have a mean CEC of 22.5 meq/100 g while the marine soils have a mean of 20.8 meq/100 g. The loess soils have a slightly higher mean CEC at 28.0 meq/100 g. All the sites in this study have very low CEC which correlates with the clay mineralogy since many sites are dominated by kaolinite and illite clay. The volcanic and marine sediments have slightly lower CEC than the loess/volcanic parent material. These low values also indicate that all soils in this study are old soils.

Table 98. Maximum CEC (meq/100g) for each soil pit by parent material.

Volcanic		Marine		Loess		
ECCC	31.2	ECRV	20.7	ECFM		18.6
WEJH	15.4	WEAB	17.5	CWCC		42.2
CWS	23.5	CWAB	19.1	RH12		23.2
LEM	22.6	LEY	26.1	Mean		28.0
RHS	20.2	KWAC	20.5	St. Dev.		12.5
KWN	21.7	LEFH	20.2	Other	WETB	38.1
		KWFH	21.5		RHJH1	22.3
Mean	22.5	Mean	20.8		RHJH5	35.1
St. Dev.	5.2	St. Dev.	2.7		KWM	80.0

With the exception of the Chehalem Corral Creek vineyard (loess soil) that has a CEC of 42.2 meq/100 g, all other vineyards range from approximately 10 to 23 meq/100 g (Figure 58). The marine sediment soils contain the most smectite clays, which generally means high CEC, but these data suggest that the method used was not satisfactory or that the percent of smectite clays in those soils are not high enough to influence the CEC. The higher CEC for the Corral Creek vineyard may be the result of the loess contribution of cations except for the fact that this vineyard is directly across the street from the Rex Hill Estate vineyard (loess soil) where the CEC is 23.2 meq/100 g. This indicates an addition of cations to the soil as amendments by the vineyard manager resulting in higher CEC. This one vineyard increased the mean CEC for loess soils and, if taken out and regarded as an outlier, the loess soils would have similar values as the volcanic and marine soils in this study. One notable CEC value at 80.0 meq/100 g belongs to the Ken Wright Meredith Mitchell vineyard (old volcanic soil). This soil had visible calcium carbonate deposits in the parent material and a higher pH. This, together with the higher concentration of Ca, coincides with the higher CEC value.

Clay Mineralogy

Characterization of clay minerals as a product of weathering is important because they may best reflect the long-term effects of the chemical and leaching environment of the soil, and they influence many soil properties (Birkeland, 1999). The various clay minerals discussed here-in include illite, mica, chlorite, vermiculite, smectite, kaolinite,

halloysite, and interlayered clays. These clay minerals could be the result of inheritance from the parent material, simple K ion exchange, or complex neo-formation and transformation from Al and silicon in the soil water solution (Birkeland, 1999).

Figure 58. Cation Exchange Capacity (CEC) in meq/100 g soil for each vineyard sorted by parent material in a box and whisker plot.

The samples sent for analysis in this study were obtained during grain size analysis using the pipette method (Table 99). In this way, samples of the clay size fraction of the soil were collected, allowed to condense via evaporation, and then sent for analysis using x-ray diffraction of four different preparations that aid in differentiating between types of clay minerals. The selected sample for each soil profile was the horizon with the highest clay content based on the grain size analysis performed in this study. The

suite of clay minerals determined in each soil sample can be used to infer details on age, development, and pedogenic history of the site (Birkeland, 1999). This study did not attempt to quantify clay minerals present in these soils because of the impracticality of methods that attempt to do so at any precision. Therefore, as commonly practiced, qualitative terms such as trace, minor, moderate, and abundant are used to differentiate between the relative abundance of certain clays in these samples.

Table 99. Clay mineralogy by parent material.

Parent Material	Volcanic	Marine Sediment	Loess
Soil Series	Jory	Willakenzie & Bellpine	Laurelwood
	Kaolinite	Smectite	Illite (All Sites)
Clays	Chlorite Intergrade	Kaolinite	Chlorite/Vermiculite
	Illite (Some sites)	Chlorite Intergrade	Kaolinite
Quartz Phase	Cristobalite	Trace Cristobalite	Cristobalite
Fe Phase	Goethite	Goethite	Moderate Goethite
Approximate Age	Old	Old	Mixed Ages

As background, clay minerals are mostly hydrous Al silicates. Table 100 is provided for reference to types of clays and other minerals associated with them (Klein and Dutrow, 2007). Clay minerals are classified as 1:1 or 2:1, in reference to their crystal structure, with some having interlayer cations. Kaolinite and halloysite are the most common 1:1 layer clay minerals (Birkeland, 1999). Kaolinite clays show minimal shrinkage or swelling with change in water content. Water and solute molecules do not penetrate the interlayer spaces in kaolinite, therefore soils with kaolinite tend to have

Table 100. Common clay minerals, chemical formulas, and notes concerning their formation in soils (Klein and Dutrow, 2007).

Mineral	Chemical Formula	Notes
Talc	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$	Forms from alteration of Mg silicates (olivine, pyroxenes and amphiboles) Al-silicate that weathers to create kaolinite clay
Feldspars	KAlSi_3O_8 or $\text{NaAlSi}_3\text{O}_8$ or $\text{CaAl}_2\text{Si}_2\text{O}_8$	
Muscovite	$\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	
Biotite	$\text{K}(\text{Mg},\text{Fe})\text{Al}_2(\text{AlSi}_3\text{O}_{10})(\text{F},\text{OH})_2$	
Chlorite	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 \cdot \text{Mg}_3(\text{OH})_6$ or $(\text{Mg}, \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Al})_3(\text{Al},\text{Si})_4\text{O}_{10}(\text{OH})_2 \cdot (\text{Mg},\text{Fe}^{2+},\text{Fe}^{3+}, \text{Al})_3(\text{OH})_6$	
Illite	$(\text{K},\text{H}_3\text{O})(\text{Al},\text{Mg},\text{Fe})_2(\text{Si},\text{Al})_4\text{O}_{10}[(\text{OH})_2,(\text{H}_2\text{O})]$ Alkali-deficient mica near muscovite composition.	Less substitution of Al for Si, containing more water, K partly replaced by Ca and Mg. [Mg] represents exchangeable ions in the structure
Vermiculite	$\text{Mg}_3(\text{Si},\text{Al})_4\text{O}_{10}(\text{OH})_2 \cdot 4.5\text{H}_2\text{O}[\text{Mg}]_{0.35}$	
Smectite	$(\text{Na},\text{Ca})_{0.3}(\text{Al},\text{Mg})_2\text{Si}_4\text{O}_{10} \cdot n\text{H}_2\text{O}$ (Montmorillonite) Pyrophyllite ($\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$) with sheets of water and exchangeable cations.	
Kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ Si ₂ O ₅ sheet bonded to a gibbsite sheet ($\text{Al}(\text{OH})_3$)	Weathered or hydrothermal alteration of Al-silicates (feldspars) Kaolinite-group. Forms from volcanic rocks.
Halloysite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ or $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot 2\text{H}_2\text{O}$	
Goethite	$\alpha\text{-FeO}(\text{OH})$	Oxides
Hematite	$\alpha\text{-Fe}_2\text{O}_3$	
Brucite	$\text{Mg}(\text{OH})_2$	
Gibbsite	$\text{Al}(\text{OH})_3$	

lower cation exchange capacity. Halloysite has the same structure as kaolinite, but two sheets of water molecules exist between crystal layers, and the clay shows expansion. Halloysite is mostly only found in weathered volcanic ash soils (Bednarz, 2002). According to Birkeland (1999), within the 2:1 clay minerals, differentiation is based on relative charge. Low charge (smectite), medium charge (vermiculite), high charge (mica and illite), and variable charge (chlorite) of the clay minerals in the soils will affect cation exchange capacity and soil chemistry as discussed in the previous section.

Many researchers (Jackson, 1964; Birkeland, 1999; Wilson, 1999) have formed a theory on the development of clay minerals over time due to different environments within the soil. These pathways of formation allow us to estimate relative ages of the soil based on clay mineral assemblage (Figure 59). Soils in the early stages of development will contain primary mica minerals, illite, and chlorite. The intergrade process (interlayering of illite, chlorite, vermiculite, or smectite) indicates more time has passed. Smectite will develop when the soils are wetter. With enough time, kaolinite forms and Fe and Al accumulates (due to insolubility) and goethite and gibbsite will accumulate in the soil. This general theory of soil development based on clay mineralogy is used in this study to discuss the age of these vineyard soils.

The existence of mica in a soil that formed on volcanic material indicates an eolian component, since the mica is most likely not from the parent material especially if

Figure 59. Pathways for the formation of soil clay minerals (adapted from Wilson, 1999 and Birkeland, 1999 after Jackson, 1964).

it is basalt. Similar studies on Hawaiian soils have also shown the presence of mica from eolian sources (Wilson, 1999). Micaceous minerals found in the clay fraction must either be inherited from the parent material or be added by some process, since there is very little evidence that mica forms pedogenically (and only in special circumstances) (Wilson, 1999). Illite clay is thin micromica with less K and less charge than the micromica found in soils. Therefore, illite is thought to have evolved from the weathering of mica minerals, losing K and layer charge because of the physical process of particle microdivision (Wilson, 1999). Vermiculite also forms from the weathering of mica minerals and therefore should be present where there is illite.

Chlorite is a group of minerals within the phyllosilicate group that consists of 2:1 sheets of talc (or pyrophyllite) separated by brucite- or gibbsite-like sheet. Al substitutes commonly for Si in the tetrahedral sites, and members of the chlorite group differ based on the amount of substitution of Al for Si and for Mg, Fe, or Al in the octahedral sites of both talc and brucite-like sheets (Klein and Dutrow, 2007). Illite is commonly associated

with mica minerals. As illite weathers, the charge decreases as K is replaced by Ca and Mg in the interlayers (White, 2003). When the structure is hydrated, the chlorite becomes vermiculite by replacing Ca and Mg in the interlayers with Al. When Al and other cations fill sites, the resulting mineral is somewhere in between clay and mica. When K rich, these clays are commonly referred to as illite (Wilson, 1999). When the pyrophyllite sheets are hydrated with water containing exchangeable cations, smectite (or montmorillonite) is formed.

Montmorillonite is the Mg variety of smectite with both Al and Mg in the octahedral sheet (Birkeland, 1999). These clays are expanding-lattice clays and result in visible shrinking and cracking when dry and swelling when wet (White, 2003). Some illite is mica intermixed with layers of smectite, vermiculite, and chlorite (Birkeland, 1999). Common interlayered clays are illite/smectite, chlorite/smectite, chlorite/vermiculite, and mica/vermiculite (Birkeland, 1999).

Fe oxides in the soil accumulate when highly weathered, indicating time and moisture available to remove other cations, leaving insoluble Fe and Al to migrate down through the profile and accumulate. This occurs in soils that form on volcanic parent material, like the soils in this study, over tens of thousands of years. Basalt rocks provide Fe, Al, and Mn for oxidation in soils that then become redder in color. With enough moisture, Fe will transform into goethite ($\text{FeO}(\text{OH})$), which is the most common and stable Fe oxide in the soil. Over time and under dry conditions, the goethite will

transform to hematite (Fe_2O_3), indicating highly weathered soils (White, 2003). The principal Al oxide in soil is gibbsite ($\text{Al}(\text{OH})_3$) which can be found in the interlayers of chlorite, vermiculite, and smectite and as coatings on these clay minerals (White, 2003). Black Mn dioxide coatings in the soil are common in soils that experience both wetting and drying (anaerobic and aerobic) conditions. These coatings on the surface have a tendency to attract Co and Pb (White, 2003).

Cristobalite, SiO_2 , is present in many siliceous volcanic rocks as a lining in cavities and as part of the fine-grained groundmass. Many times, cristobalite forms from the weathering of obsidian and glass in andic parent material and is associated with smectite clays (Wada, 1987; Van Rast et al., 2008). According to research on clay minerals in volcanic soils in Mexico, cristobalite in the soil was enriched in the clay fraction in mottles and were interpreted to be from the transformation of halloysite. This 1:1 clay mineral undergoes transformation into opal, then in turn is transformed into cristobalite (Elsass et al., 2000). Other research indicates that cristobalite can form from high or low temperatures or in place. High-temperature cristobalite is volcanic in origin (Mizota et al., 1987). This study suggests that the cristobalite accumulated in these soils as the result of precipitation of silica during prolonged dry summer conditions and is not necessarily from the parent material unless Cascadian ash deposits can be identified (Mizota et al., 1987).

The occurrence of interlayered clays may be the result of Al weathered from feldspars in the parent material in acidic conditions. The soil in this study is mostly within the 4.0 to 5.8 pH range, which has been shown as a favored pH for the stability of Al-hydroxy interlayers. My sites with higher amounts of Al (data in soil chemistry) may be associated with certain pH and the presence of Al-hydroxy-interlayered clays. These clays are common and are typical in highly weathered soils. Therefore, the presence of interlayered clays in the volcanic soils in this study support the idea that these soils are the oldest. Also, the application of fertilizers at these sites before they became vineyards have contributed to the formation of interlayers with the addition of K (Wilson, 1999).

The soils in this study are separated by parent material to discuss trends in the clay mineralogy for these vineyard sites (Table 101). Soils formed on marine sediments have different trends in the clay mineralogy than the volcanic and loess soils. Trace to moderate amounts of illite are found in these samples. This suggests a mica component that is weathering to illite in the marine sediments. There are trace amounts or more of chlorite in all soils that formed on marine sediments. Vermiculite/chlorite interlayers are moderately pronounced in the Aliette Vineyard, but vermiculite exists in trace or minor amounts in the others. Smectite clays are found in six of seven soils excluding Aliette Vineyard. Kaolinite is the most common clay in moderate amounts in the soils formed on marine sediment parent material. A minor amount of halloysite is present in a few of these marine sediment soils as well. Minor goethite is present in all soils. No sites other

than Aliette Vineyard and Abbott Claim have gibbsite present. Ridgecrest Vineyard is the only site that has some hematite. The development of goethite in the marine sediment soils is less pronounced than in the volcanic soils.

The volcanic soils should not contain illite, but four of six sites contain trace to moderate amounts of illite clay. This suggests a mica component in these few volcanic soils that would have a regressive influence on the soil development. Soils with illite present must have a loess component if the parent material for the soil is volcanic basalt which does not contain mica. Trace amounts to abundant (Elk Cove Clay Court) chlorite intergrades are also present in the soils from volcanic parent material. Vermiculite was only present in the Elk Cove Clay Court soils. Trace amounts of smectite are found in two volcanic soils and two others have minor to moderate smectite present. It is most common to have moderate amounts of kaolinite clay with trace to moderate amounts of halloysite in the soils on volcanic parent material. Goethite is the main Fe phase in all volcanic soils; some also include gibbsite and hematite. Clay Court, Stoller, and Jory Hills vineyards all show minor to moderate amounts of cristobalite in the clay fraction as well. These soils also have moderate kaolinite and halloysite present, which suggests older soils, while illite suggests a younger soil. Therefore, the Stoller, Clay Court, Mia Block, and Jory Hills Vineyards all have some loess material that is causing to the presence of illite and a more mixed-age and development signature.

The sites that were meant to be my only loess/volcanic parent material locations, having many similarities to the volcanic soils, suggest that some of the volcanic soils have a loess component I was not expecting. The loess/volcanic sites contain abundant illite clay and moderate chlorite intergrade and mixed-layer vermiculite and smectite clays. Mica is present in the clay sized fraction of these soils, also suggesting a more recent eolian input that has not weathered yet. Minor to moderate amounts of kaolinite and trace amounts of halloysite are also common in these soils suggesting an older soil while the illite suggests a younger soil. Therefore, these soils show mixed stages of development, similar to the four soils on volcanic parent material.

My youngest sites, according to the BW color index and other physical properties, include the Terres Basses (Missoula Flood sediment parent material) and the Jacob-Hart Vineyards (ancient landslide deposits). I assume that these sites are approximately less than 15,000 years old, according to the timing of the Missoula Floods (Allen et al., 2009). Terres Basses contains abundant smectite clay, minor vermiculite clays, and only trace amounts of kaolinite and goethite. This soil developed since the Missoula Flood sediments were deposited and the high clay content and poor drainage, is attributed to the shale parent material. The Jacob-Hart Vineyard soils contain minor to moderate amounts of smectite clay with trace amounts of goethite, vermiculite, and kaolinite. These assemblages suggest a geologic history that includes kaolinite that developed on an older

Table 101. Clay mineral interpretation from x-ray diffraction. Key: - none present, o trace amounts, + minor amounts, ++ moderate amounts, +++ abundant amounts, bold grayscale = interlayers.

Vineyard	Parent Material	Mica	Illite	Chlorite	Vermiculite	Smectite	Kaolinite	Halloysite	Cristobalite	Goethite	Gibbsite
ECRV	Marine Sediments	o	+	++	-	++	+	+	o	+	-
WEAB	Marine Sediments	o	o	++	++	-	++	-	o	+	+
CWR	Marine Sediments	++	++	+	o	+	++	+	+	+	-
LEY	Marine Sediments	-	o	o	-	o	++	o	-	++	-
KWAC	Marine Sediments	-	o	o	-	o	++	-	-	+	+
LEFH	Marine Sediments	o	o	o	+	+	+	-	+	+	-
KWFH	Marine Sediments	o	o	o	+	+	+	-	+	+	-
ECCC	Volcanic	+	++	+++	++	++	+	+	+	++	-
WEJH	Volcanic	-	+	+	-	-	++	+	+	+++	+
CWS	Volcanic	++	++	+	-	+	++	++	++	++	-
LEM	Volcanic	-	o	o	-	o	++	o	o	++	+
RHS	Volcanic	-	-	o	-	o	++	o	o	++	+
KWN	Volcanic	-	-	++	-	-	++	+	+	++	-
ECFM	Loess	+	++	++	++	++	+	+	+	+	-
CWCC	Loess	++	+++	+	+	-	++	o	+	o	+
RH12	Loess	++	+++	++	++	+	+	o	o	-	-
WETB	Missoula Floods	o	-	-	+	+++	o	-	-	-	-
RHJH1	Landslide	-	-	-	o	++	o	-	o	o	-
RHJH5	Landslide	-	-	-	o	++	o	-	o	o	-
KWM	Ancient Volcanic	-	-	-	+	+	o	o	o	o	-

geomorphic surface of basalt bedrock before being disrupted with an event that supplied new material, like the floods or a landslide.

The final soil, on ancient volcanic bedrock parent material, is from the Meredith Mitchell Vineyard. This soil contains minor amounts of vermiculite, smectite and trace amounts of kaolinite, mixed interlayers, goethite, and halloysite. This is a soil with no loess component and moderate weathering and development. It is located in the Coast Range on older volcanic bedrock, possibly diabase or Tillamook basalts, and the clay minerals present suggest an older soil similar to the volcanic soils previously discussed.

The occurrence of smectite in the soils formed on marine sedimentary parent material is most likely the result of inheritance from weathering of these silts, sands, and shale. The Terres Basses Vineyard soil contains the most prominent amount of smectite clays, suggesting the presence of smectite in the parent material and from the formation from vermiculite in this poorly drained location from transformation or neo-formation. As illite and mica decrease in the sample, the vermiculite content increases (Figure 59). There is general acceptance that vermiculite forms from the weathering of mica by the release of K or during the oxidation of Fe (Wilson, 1999). The intergrades (interstratified) represent an intermediate stage in transformation and weathering of mica, chlorite, smectite, and vermiculite and are not expected to be found in highly weathered soils, but soils of intermediate or young age.

According to prior studies by Reed Glasmann of OSU, the main difference between soils on basalt and on tuffaceous sandstone is that the clay-sized fraction over the sandstone contains quartz and that over the basalt does not. On both rock types, the clay minerals consist of halloysite and gibbsite, and the red to yellow Fe oxide coloring agents consist of hematite and goethite (Moore, 2002). Considering the soil series mentioned earlier that are associated with the different types of parent material in this study, the Jory and Laurelwood soils both form on volcanic bedrock of basalt and the Willakenzie soils form on marine sediments of sandstone and siltstone. In this study, the clay mineralogy associated with the basalt derived soil types consists mostly of kaolinite and chlorite interlayers with the presence of halloysite and goethite in the more weathered zones (Eggleton et al., 1987).

According to Nelson (2011), feldspar will commonly weather to kaolinite and therefore the soils with volcanic basalt parent material have more feldspars than marine sediment parent material. The Jory will have the highest goethite percentage of the three soils because it is the oldest and will have the highest percentage of available Fe available (Nelson, 2011). The Willakenzie and Bellpine soils will have similar amounts of kaolinite, chlorite, and goethite because of age, but will have more illite due to presence of mica in the parent material. The Laurelwood soils, and other volcanic soils with an eolian contribution of loess, will have a mixture of clays including kaolinite and goethite but substantial amounts of illite and chlorite/vermiculite.

Soil Chemistry

Based on parent material the mean maximum values for most elements tested in this study, only a few had distinguishing differences. Concerning macronutrients, P values are higher in both volcanic and loess soils than marine sediment soils (Table 102). K is highest in loess soils and volcanic and marine sediment soils had similar values. All parent materials had similar values for Ca. Mg was highest in loess soils, the marine sediment soils were the most variable (with the outlier value from Lange Estate Yamhill Vineyard of 4670 ppm removed), and volcanic soils had the lowest concentration of Mg. S was highest in volcanic soils while loess and marine sediments were similar. Cl was detected in marine sediment soil at higher concentrations than the few volcanic soils.

The composition of the Grande Ronde basalt, the bedrock and parent material for both the volcanic and loess/volcanic soils, has been widely studied. A summary of the chemical make-up of the Grande Ronde basalt flow indicates that Mn, P, titanium, K, Na, Ca, Mg, Fe, and Al are most abundant in these rocks (Mangan et al., 1986; Swanson et al., 1989). Most of the CRB flows are tholeiitic basalt: High MgO, relatively rich in silica, and poor in Na. Average SiO₂ is 53.84%, Al₂O₃ is 14.37%, FeO is 11.37%, CaO is 8.97%, and MgO is 5.25%. Other elements include Na₂O at 2.92%, K₂O at 1.10%, TiO₂ at 1.75%, P₂O₅ at 0.23%, and MnO at 0.19% (Mangan et al., 1986; Swanson et al., 1989). The marine sediments in the Coast Range are mostly composed of quartz sand and muscovite mica, according to the grain size analysis in this study. These sandstones also

contain high amounts of silt in some cases. Because of the marine depositional environment, higher amounts of Na, Ca, and Mg could be expected in this parent material.

Table 102. Maximum macronutrient values for vineyard soils separated by parent material (* Indicates value after removing outlier value of 4670 ppm from the Lange Estate Yamhill Vineyard).

Element (ppm)	Volcanic	Marine	Loess/Volcanic	Trend
P	1870 ± 341	642 ± 195	1530 ± 211	Volcanic & Loess Highest
K	926 ± 472	1040 ± 373	1520 ± 75	Loess Highest
Ca	1660 ± 716	2070 ± 526	1780 ± 284	All Similar
Mg	1460 ± 435	1940 ± 677*	3140 ± 227	Loess Highest
S	245 ± 46.0	168 ± 35.9	172 ± 22.7	Volcanic Highest
Cl	17.7 ± 0.07	24.1 ± 11.3	ND	Marine Highest

The parent material has little influence on many of the micronutrients tested and many values are similar (Table 103). Volcanic soils have the highest concentrations of Fe, Co, and Mn. Al concentrations were very similar between the different parent materials. Cu values were highly variable, especially in the marine sediment soils. This is most likely due to the possible addition of Cu in practice as a fungicide, even in organic vineyards. Mo was not detected in loess soils and at very small concentrations for the others. Na concentrations were all similar when the outlier value of 3330 ppm for Ken Wright Freedom Hill Vineyard was removed. This high value of Na in the Freedom Hill Vineyard is most likely due to the Coast Range sediments being from a marine environment.

Table 103. Maximum micronutrient values for vineyard soils separated by parent material (* Indicates value after removing Na outlier value of 3330 ppm from Ken Wright Freedom Hill Vineyard).

Element (ppm)	Volcanic	Marine	Loess/Volcanic	Trend
Fe	58900 ± 6770	41500 ± 10300	38000 ± 2820	Volcanic Highest
Al	19500 ± 1880	20300 ± 10800	24300 ± 10800	All Similar
Co	35.6 ± 13.9	16.1 ± 8.04	20.7 ± 1.40	Volcanic Highest
Cu	22.4 ± 5.53	31.0 ± 36.9	20.3 ± 7.40	All Similar
Mn	2530 ± 465	821 ± 330	1357 ± 162	Volcanic Highest
Mo	0.652 ± 0.056	0.678	ND	All Similar
Na	203 ± 11.0	205 ± 43*	234 ± 41.8	All Similar
Ni	7.55 ± 1.05	11.0 ± 7.14	18.7 ± 14.4	All Similar
Zn	63.8 ± 24.0	49.8 ± 27.3	62.0 ± 4.65	All Similar

Few trace elements can be used to distinguish the different vineyard soil parent material (Table 104). As is lowest in the volcanic soils and both marine sediment and loess soils have similar values. This makes sense since As in Oregon is attributed to tuffs and marine sediments from the Coast Range and not to basalts (Ricker, 2013). The As in the loess soils seems to be coming from the loess itself and not the volcanic bedrock. The loess was introduced to the Willamette Valley via multiple floods that brought sediment from eastern Washington (Allen et al., 2009). This sediment is more similar to the marine sediments (sandstones and siltstones) from the Coast Range than the volcanic bedrock. Sr concentration is also higher in the marine and loess soils than volcanic soils. V is highest in the volcanic soils with loess/volcanic soils second highest, most likely because the bedrock of the loess soils is the same volcanic material. Ba is lowest in the marine soils after an outlier of 669 ppm from Chehalem Coral Creek Vineyard was removed. All the

rest of the trace elements are similar, despite parent material differences. A Pb value of 47.1 ppm was removed as an outlier from the Rex Hill Estate Vineyard Block 12, making all parent materials have similar values.

Table 104. Maximum trace element values for vineyard soils separated by parent material (* Indicates value after removing outlier value of 669 ppm Ba from Chehalem Coral Creek, 47.1 ppm Pb from Rex Hill Estate, and 452 ppm Sr from Ken Wright Freedom Hill).

Element (ppm)	Volcanic	Marine	Loess/Volcanic	Trend
As	2.15 ± 0.56	6.24 ± 3.25	6.24 ± 5.16	Marine & Loess Highest
Ba	308 ± 0.22	166 ± 85.6	245 ± 1.00*	Volcanic & Loess Highest
Be	1.02 ± 0.27	0.856 ± 0.181	0.941 ± 0.101	All Similar
Cd	0.456 ± 0.196	0.300 ± .279	0.421 ± .278	All Similar
Cr	25.3 ± 5.11	22.2 ± 3.41	21.7 ± 2.05	All Similar
Hg	0.0448	0.0462 ± 0.007	0.0426	All Similar
Pb	12.3 ± 1.57	10.6 ± 2.86	10.8 ± 2.37*	All Similar
Se	0.715 ± .136	0.595 ± 0.078	0.686	All Similar
Sr	17.4 ± 5.48	29.1 ± 14*	27.5 ± 7.03	Marine & Loess Highest
V	175 ± 29.3	82.2 ± 39.3	123 ± 10.2	Volcanic Highest

Grape Juice Chemistry

All 24 elements (similar to the soil samples) were analyzed for in the grape juice from grapes collected adjacent to the soil pits. K, Na, and Sr are the only elements found in all 20 grape juice samples and P is detected in 15 of the 20 sites (Table 105). The majority of the elements analyzed were found to be non-detectable using just the grape juice. This suggests that much of the chemistry that influences the end flavor of the wine comes from the contact the juice has with the skin, seeds, and stems and not from the

juice alone. Another possibility is that the methodology diluted the grape juice samples to the point that the elements were undetectable. It is also possible that wine flavor is not influenced by the elements taken up by the grapes since they occur in such low concentrations. Much more analysis will be done utilizing the grape samples that I have from these sites, but at this time I can present a few things including interesting discoveries previously unknown.

The average K concentrations were highest in loess soils, but volcanic and marine sediment soils had the highest maximum values (Table 106). K is the most mobile nutrient in the make-up of winegrapes, necessary for cell osmoregulation, turgor, and growth of the grape (White, 2003). K is concentrated in the berry skins until veraison (color change) when it then becomes concentrated in the pulp where fifty percent or more of the vine K is redistributed by harvest time (White, 2003). Soil K is the most important source for K found in the grapes (Boulton, 1980). Clay mineralogy has a great effect on the K availability in the soils. Kaolinite clays have the least sites for fixed K while vermiculitic clays have exchangeable K on the surfaces and edges like kaolinite but also has slowly released K available between clay sheets. Therefore, the loess soils have more vermiculite and smectite clays and also have slightly higher K available for uptake by the vine and incorporation into the grapes. K is also higher in soils formed on rocks containing mica, which is visible in the loess soils in this study (White, 2003).

Table 105. Elemental concentration (ppm) for grape juice obtained from vines adjacent to soil pits in this study.

Vineyard	K	Rank	Na	Rank	Sr	Rank	P	Rank	Mg	Mn	Ca	Cu	Zn
ECCC	530	20	161	3	0.973	6	ND		ND	ND	ND	ND	ND
ECRV	1240	12	144	12	0.852	7	361	1	ND	ND	ND	ND	ND
ECFM	1340	11	145	11	1.02	5	232	14	ND	2.04	ND	ND	ND
WEJH	1150	15	141	15	0.506	18	275	7	ND	2.14	ND	ND	ND
WEAB	1680	5	158	6	0.716	11	267	9	ND	ND	ND	ND	ND
WETB	1940	1	159	4	0.739	10	324	4	ND	ND	ND	ND	ND
CWS	1400	9	153	9	0.633	17	213	15	ND	4.56	ND	ND	ND
CWR	851	18	155	8	1.1	4	ND		ND	ND	ND	ND	ND
CWCC	1530	7	159	5	0.711	12	303	5	ND	ND	ND	ND	ND
LEM	1730	4	162	2	0.711	13	248	12	ND	ND	ND	ND	ND
LEY	1220	13	141	14	1.41	1	243	13	111	ND	115	ND	ND
LEFH	1380	10	150	10	0.697	14	266	10	ND	ND	ND	ND	ND
RHS	747	19	142	13	0.645	16	ND		ND	2.02	ND	ND	ND
RH12	1600	6	139	17	0.696	15	361	2	ND	ND	ND	ND	ND
RHJH1	1880	2	140	16	1.12	3	297	6	ND	ND	ND	2.41	ND
RHJH5	1500	8	131	19	0.447	19	272	8	ND	ND	ND	4.19	2.2
KWN	1070	16	138	18	1.14	2	257	11	ND	ND	102	ND	ND
KWAC	1730	3	166	1	0.844	8	ND		ND	ND	ND	ND	ND
KWFH	1160	14	126	20	0.816	9	ND		ND	ND	ND	ND	ND
KWM	883	17	156	7	0.332	20	328	3	ND	ND	ND	ND	ND
Mean	1328		148		0.805		283		111	2.69	109	3.30	2.2
SD	386		11.1		0.261		44.9		ND	1.25	9.19	1.26	ND

Table 106. Mean and standard deviation values (with maximum in parentheses) for elemental concentrations in grape juice separated by parent material.

Element (ppm)	Volcanic	Marine	Loess	Trend
K	1110 ± 434 (1730)	1320 ± 306 (1730)	1490 ± 135 (1600)	All Similar
Na	150 ± 10.6 (162)	149 ± 13.1 (166)	148 ± 10.3 (159)	All Similar
Sr	0.768 ± 0.239 (1.14)	0.919 ± 0.253 (1.41)	0.809 ± 0.183 (1.02)	Marine Highest
P	248 ± 26 (275)	284 ± 52.4 (361)	299 ± 64.6 (361)	All Similar
Mg	ND	111 ± 0 (111)	ND	Only Marine Detected
Mn	2.91 ± 1.43 (4.56)	ND	2.04 ± 0 (2.04)	Only Volcanic and Loess
Ca	102 ± 0 (102)	115 ± 0 (115)	ND	Very Few Detected

The Sr levels were highest in the marine soils and in the grapes from marine soils. Though the averages are all similar, the maximum Sr value is in the marine soils. This element may be the only useful element when distinguishing juice from the various parent material in this study. Sr is not utilized by the grapevine in any particular manner, but is taken up by the vine from the soil (White, 2009). This element has been used to determine provenance in wines in Portugal (Almeida and Vasconcelos, 2001). In future studies, Sr isotopes should be used to determine geographical origin since this element is taken up by the vine in the same proportion in which they occur in the soils and precipitation (Almeida and Vasconcelos, 2001).

The mean and maximum Na and P concentrations for each parent material are all similar and not useful for distinguishing between soil types. Mg was only detected in the Lange Yamhill vineyard grapes, though its concentration is highest in loess soils. This indicates that there is no direct relationship between soils Mg and Mg found in the grapes. Mg is mainly utilized in chlorophyll production and as an enzyme cofactor. Ca is only detected in two samples, Nysa (volcanic soils) and Yamhill (marine sediment soils) for unknown reasons. Ca is utilized in the making of cell walls in the vine and is not detected in many of the grape juice samples (White, 2003).

Interestingly, Mn is only picked up in grapes from volcanic and the loess/volcanic soils. This could be due to higher values of Mn in the soils because of the direct weathering of basaltic bedrock which contains minerals that may have Mn. There may be use in the future for determining volcanic versus marine sediment parent material in the Willamette Valley using Mn. Some elements were only detected in the grape juice from a few vineyards. Zn and Cu were only in the Jacob Hart grapes. This might be attributed to an application of these elements in the vineyard management program closer to the day of sampling than other vineyards. It is unlikely that the values are due to differences in vine uptake.

Wine Chemistry

Almost all elements detected in the wines were similar to the concentration ratios measured in the soil parent material. More elements were detected in the wines than in the grape juice. It is very difficult to determine what elemental concentrations in the wine are determined by the winemaking equipment and process and what are determined by the soil concentrations. Because I included analysis of the grape juice, I can see that certain elements found in the wine are added during the winemaking process by the winemaker. Also, my methodology in analyzing the grape juice does not account for elements found in the wine due to extended contact with the skins, seeds, and stems. All data from the wines has been organized into macronutrient (Table 107), micronutrient (Table 108), and trace element (Table 109) groups and ranked from highest to lowest concentration for comparison. Maximum P and K concentrations are found in the Ken Wright Nysa vineyard, a volcanic soil. Chehalem Ridgecrest vineyard, a marine sediments soil, has the highest concentration of Ca in the wine. The highest concentration of Mg in the wine is in the Ken Wright Freedom Hill vineyard, also a marine sediment soil.

Rex Hill Sims vineyard has the highest concentration of Fe in the wine. Co and Cu are highest in the Rex Hill Jacob Hart vineyards block 1 and block 5, respectively. Willakenzie Estate Terres Basses has the highest concentration of Mn in the wine. Trace elements in the wine include Ba, Pb, and Sr. The volcanic soil from Ken Wright Nysa

Table 107. Macronutrient concentration (ppm) for wines obtained from vines adjacent to soil pits in this study (mean calculated from multiple runs of the same bottle of wine). ND – Non-detected.

Vineyard & Vintage	P	Rank	K	Rank	Ca	Rank	Mg	Rank	S	Rank
ECCC '11 (mean)	73.0	20	436	20	33.2	16	46.2	19	51.6	20
ECRV '11 (mean)	502	2	791	8	50.0	8	72.3	8	75.7	13
ECFM '11 (mean)	247	11	816	6	42.3	12	61.5	11	62.1	19
WEJH '11	187	17	818	5	51.6	6	40.6	20	72.7	16
WEAB '11	222	13	835	4	55.8	3	47.9	18	71.3	18
WETB '11 (mean)	207	14	908	2	50.5	7	52.7	15	90.7	9
CWS '11 (mean)	233	12	785	9	52.3	5	50.1	17	75.1	14
CWR '11 (mean)	364	9	673	16	61.6	1	61.5	10	86.0	11
CWCC '11 (mean)	467	3	808	7	57.2	2	54.1	14	87.7	10
LEM '12 (mean)	168	19	739	13	28.5	19	73.3	7	108	4
LEY '12	206	15	743	12	31.7	17	94.4	2	74.2	15
LEFH '12	199	16	676	15	27.6	20	51.6	16	72.1	17
RHS '12 (mean)	186	18	453	19	35.1	15	79.9	6	115	3
RHB '12	447	4	713	14	42.9	11	80.4	5	97.0	8
RHJHB1 '12	412	6	563	17	35.2	14	59.2	13	119	2
RHJHB5 '12 (mean)	368	8	745	11	54.5	4	85.4	3	145	1
KWN '12	542	1	917	1	37.4	13	65.7	9	106	5
KWAC '12	403	7	767	10	30.6	18	60.4	12	77.2	12
KWFH '12	297	10	844	3	43.5	10	96.8	1	100	7
KWM '12	430	5	538	18	43.9	9	84.9	4	101	6

Table 108. Micronutrient concentration (ppm) for wines obtained from vines adjacent to soil pits in this study (mean calculated from multiple runs of the same bottle of wine). ND – Non-detected.

Vineyard & Vintage	Fe	Rank	Co	Rank	Cu	Rank	Mn	Rank	Na	Rank	Ni	Rank	Zn	Rank
ECCC '11 (mean)	1.06	13	0.0262	11	0.120	5	1.29	11	3.82	19	ND		0.150	18
ECRV '11 (mean)	0.711	17	0.0255	13	0.0830	11	1.04	16	3.35	20	ND		0.102	20
ECFM '11 (mean)	0.772	15	ND		0.0918	9	0.986	18	4.12	17	ND		0.189	16
WEJH '11	0.645	18	0.0310	6	0.0272	18	1.30	10	4.50	14	ND		0.164	17
WEAB '11	0.768	16	0.0258	12	0.102	8	0.995	17	4.45	15	ND		0.333	13
WETB '11 (mean)	1.07	11	0.0315	4	0.127	4	2.56	1	4.04	18	0.0260	1	0.208	15
CWS '11 (mean)	1.64	6	0.0282	9	0.0704	15	1.70	7	17.5	1	ND		0.436	8
CWR '11 (mean)	2.14	3	0.0298	7	0.162	2	1.31	9	9.94	3	ND		1.09	1
CWCC '11 (mean)	2.13	4	0.0312	5	0.116	6	0.865	20	8.91	4	ND		0.567	6
LEM '12 (mean)	1.75	5	0.0330	2	0.141	3	2.30	4	10.2	2	ND		0.274	14
LEY '12	1.42	8	ND		ND		2.36	2	4.85	11	ND		0.334	12
LEFH '12	0.966	14	0.0290	8	0.0865	10	1.25	12	4.30	16	ND		0.118	19
RHS '12 (mean)	2.36	1	ND		0.0473	17	2.36	3	5.52	9	ND		0.343	10
RHB '12	1.11	10	ND		0.0810	12	1.06	15	7.74	7	ND		0.394	9
RHJHB1 '12	2.22	2	0.0338	1	0.111	7	1.07	14	8.42	5	ND		0.338	11
RHJHB5 '12 (mean)	1.23	9	ND		0.303	1	1.78	5	7.93	6	ND		0.453	7
KWN '12	1.58	7	0.0270	10	0.0742	14	1.67	8	4.50	13	ND		0.747	5
KWAC '12	0.517	20	0.0325	3	0.0750	13	1.13	13	5.77	8	ND		0.965	2
KWFH '12	0.544	19	ND		0.0540	16	1.73	6	5.40	10	ND		0.784	3
KWM '12	1.06	12	ND		ND		0.952	19	4.76	12	ND		0.768	4

Table 109. Trace element concentration (ppm) for wines obtained from vines adjacent to soil pits in this study (mean calculated from multiple runs of the same bottle of wine). ND – Non-detected.

Vineyard & Vintage	Ba	Rank	Pb	Rank	Sr	Rank
ECCC '11 (mean)	0.442	10	0.0598	14	0.982	12
ECRV '11 (mean)	0.511	4	0.0610	12	0.993	11
ECFM '11 (mean)	0.465	6	ND		0.784	17
WEJH '11	0.464	7	0.0615	11	0.954	14
WEAB '11	0.439	11	0.0610	13	1.21	2
WETB '11 (mean)	0.419	12	0.0890	3	1.15	5
CWS '11 (mean)	0.408	13	0.0815	5	0.698	19
CWR '11 (mean)	0.288	18	0.0622	10	1.19	3
CWCC '11 (mean)	0.298	17	0.0845	4	0.880	16
LEM '12 (mean)	0.462	8	0.0892	1	1.04	10
LEY '12	0.540	3	ND		1.62	1
LEFH '12	0.577	2	0.0782	6	1.05	9
RHS '12 (mean)	0.369	15	ND		0.965	13
RHB '12	0.406	14	ND		1.18	4
RHJHB1 '12	0.327	16	0.0892	2	1.12	6
RHJHB5 '12 (mean)	0.177	20	0.0678	9	0.769	18
KWN '12	0.584	1	0.0678	8	1.09	7
KWAC '12	0.457	9	0.0740	7	0.912	15
KWFH '12	0.470	5	ND		1.05	8
KWM '12	0.188	19	ND		0.681	20

vineyard has the highest concentration of Ba in the wine and the Lange Estate Mia vineyard has the highest Pb concentration in the wine. Lange Estate Yamhill vineyard has the highest Sr concentration. The mean and standard deviation of elemental concentrations grouped by parent material demonstrate that most elements in the wine

have similar concentrations (Table 110). These data exhibit a starting point for future research and do not answer many of the questions about soil and wine chemistry.

Ba, Co, Cu, Fe, Pb, S, and Zn were not detected (or only detected in a few) in the grape juice samples in this study, Therefore, these elements found in the wine samples

Table 110. Mean and standard deviation values (with maximum in parentheses) for elemental concentrations in wines separated by parent material disregarding vintage.

Element	Volcanic	Marine Sediments	Loess	Trend
Ba	0.453 ± 0.109 (0.592)	0.474 ± 0.157 (0.754)	0.422 ± 0.115 (0.576)	All Similar
Ca	38.7 ± 9.74 (52.3)	43.8 ± 12.8 (61.6)	44.8 ± 10.9 (57.2)	All Similar
Co	0.0291 ± 0.00285 (0.0330)	0.0286 ± 0.00295 (0.0325)	0.0312 ± 0 (0.0312)	All Similar
Cu	0.0800 ± 0.0431 (0.141)	0.0922 ± 0.0401 (0.162)	0.0938 ± 0.0168 (0.116)	All Similar
Fe	1.44 ± 0.567 (2.36)	0.972 ± 0.552 (2.14)	1.18 ± 0.664 (2.13)	All Similar
Pb	0.0720 ± 0.129 (0.0892)	0.0673 ± 0.00820 (0.0782)	0.0845 ± 0 (0.0845)	All Similar
Mg	57.4 ± 15.9 (79.9)	69.7 ± 19.5 (96.8)	64.0 ± 11.5 (80.4)	All Similar
Mn	1.70 ± 0.469 (2.36)	1.36 ± 0.469 (2.36)	0.980 ± 0.0864 (1.06)	Volcanic and Marine Highest
P	209 ± 159 (542)	337 ± 129 (560)	344 ± 137 (467)	All Similar
K	655 ± 207 (917)	765 ± 67.9 (844)	790 ± 52.1 (828)	All Similar
Na	7.12 ± 5.13 (17.5)	4.59 ± 2.83 (9.94)	6.92 ± 2.50 (8.91)	All Similar
Sr	0.959 ± 0.125 (1.09)	1.72 ± 1.10 (4.10)	0.907 ± 0.188 (1.18)	Marine Highest
S	82.8 ± 26.9 (115)	79.0 ± 9.62 (100)	76.4 ± 19.3 (97)	All Similar
Zn	0.323 ± 0.218 (0.747)	0.479 ± 0.407 (1.09)	0.339 ± 0.179 (0.567)	All Similar

must be a contribution from the winemaking process. S is added by the winemaker as a preservative while the metals found in the wine most likely came from the metallic equipment. Some elements may have come from the oak barrels. Sr is the only element that has a different concentration in the wine based on parent material. Sr is highest in marine soils and only slightly higher in the grape juice from marine soils. Sr is similar to Ca, and therefore could be taken up by the vine and incorporated into the cell walls in the grapes in place of Ca (White, 2003). Because of this, increased amounts of Sr in soils may result in increased concentrations in the wine. Wine from volcanic and marine soils have higher concentrations of Mn than loess soils. This is intriguing since Mn was not detected in the grape juice from marine soils.

Climate

Climate seems to have had a factor in the grape juice and wine chemistry in this study. These samples were collected in 2011 for some samples and 2012 for others. High and low daily monthly temperatures as well as monthly cumulative rainfall for the two vintages from this study are shown in Figure 60. Note the earlier rainfall in 2012, which started in September, compared to 2011 where rainfall commenced in September but at a slower rate shown by the slope of the line. Temperatures varied between vintages as well. 2012 had a warmer spring than 2011 and reached higher temperatures in July and August. The NOAA weather site that I used for these data is centrally located in Newberg, Oregon, though it is at a lower elevation than my sample sites. In general, the vineyard

owners and managers agree that 2011 was a cooler year (GDD 1966 °F/1092 °C) and that 2012 was warmer (GDD 2277°F/1265 °C) and more ideal.

Figure 60. High and low average monthly temperatures as well as cumulative rainfall for the two vintages (2011 and 2012) included in this study (NOAA, 2013).

Elevation of the vineyards in this study differ because of the geology of the region. Volcanic and marine soils are located on the uplifted Columbia River Basalts and Coast Range sediments, respectively. Loess soils are located on Columbia River Basalts but at an elevation that accumulated windblown silt from the last ice age. Therefore, a difference in vineyard elevation between parent materials is evident (Table 111). The mean elevation of volcanic vineyards is 612 ± 106 feet (186 ± 32 meters) and marine sediments vineyards 514 ± 110 feet (157 ± 34 meters). Loess vineyards have a mean

elevation of 347 ± 32 feet (106 ± 10 meters). This difference in elevation most definitely has an effect on the climate in each vineyard and on the uptake of water and nutrients from the soils into the wines.

Table 111. Elevations of soil pit locations for each vineyard, sorted by parent material (rounded to the nearest foot).

Volcanic		Marine		Loess	
ECCC	610	ECRV	620	ECFM 360	
WEJH	490	WEAB	600	CWCC 370	
CWS	480	CWR	640	RH12 310	
LEM	720	LEY	450	Mean 347	
RHS	660	KWAC	480	St. Dev. 32	
KWN	710	LEFH	340	Other	WETB 290
		KWFH	470		RHJHB1 320
Mean	612	Mean	514		RHJHB5 380
St. Dev.	106	St. Dev.	110		KWM 670

The elemental concentrations in the 2011 and 2012 wines show little variation from year to year (Table 112). Ca is slightly higher in the 2011 vintage of wines from the northern Willamette Valley disregarding parent material than in the 2012 vintage. Mn is slightly higher in the 2012 vintage of wines from the northern Willamette Valley (excluding the Freedom Hill vineyards since they are located farther south) disregarding parent material than in the 2011 vintage. Little variation is shown in the wine chemistry based on vintage, indicating that the previous discussion comparing parent material is valid even though this study was carried out over two seasons. In most cases, warmer

Table 112. Mean and standard deviation values (with maximum in parentheses) for elemental concentrations in wines from the northern Willamette Valley separated vintage disregarding parent material.

Element (ppm)	2011 Vintage	2012 Vintage	Trend
Ba	0.399 ± 0.133 (0.754)	0.456 ± 0.0785 (0.584)	Similar
Ca	50.8 ± 10.2 (67.1)	33.7 ± 4.99 (42.9)	2011 Higher
Co	0.0282 ± 0.00246 (0.0312)	0.0308 ± 0.00333 (0.033)	Similar
Cu	0.102 ± 0.0454 (0.191)	0.0867 ± 0.0416 (0.164)	Similar
Fe	1.39 ± 0.633 (2.21)	1.61 ± 0.615 (2.41)	Similar
Pb	0.0674 ± 0.010107 (0.0845)	0.0770 ± 0.0110 (0.0892)	Similar
Mg	56.0 ± 12.7 (85.7)	75.9 ± 11.9 (94.4)	Similar
Mn	1.20 ± 0.291 (1.80)	1.94 ± 0.570 (2.36)	2012 Higher
P	305 ± 144 (560)	288 ± 152 (542)	Similar
K	742 ± 129 (852)	690 ± 160 (917)	Similar
Na	8.26 ± 5.14 (18.7)	6.80 ± 2.33 (10.5)	Similar
Sr	0.932 ± 0.182 (1.26)	1.10 ± 0.228 (1.62)	Similar
S	74.0 ± 12.6 (94.6)	99.9 ± 16.3 (118)	Similar
Zn	0.437 ± 0.345 (1.15)	0.459 ± 0.255 (0.965)	Similar

weather during veraison at the end of the season should increase uptake of groundwater and potentially dilute the elemental concentrations in the vines or, conversely, the

increased uptake would provide more elements to be incorporated in the fruit and would increase the concentration of some elements. More study is needed to address this issue.

Chehalem also contributed multiple vintages of each vineyard to this study in order to look further into the possible influence of climate on the uptake of elements from the soil. Some of these variations in wine chemistry could be due to weather differences. The Stoller Vineyard 2007 vintage has higher concentrations of Ba, Cu, Mn, and Na than the 2008 and 2009 vintages. The Ridgecrest Vineyard 2007 vintage has higher concentrations of Ba, Ca, Co, Cu, Fe, Pb, P, Na, Sr, S, and Zn than the 2008 vintage (2009 vintage not tested). The Ridgecrest Vineyard Ca, Na, Sr, S, Zn in the 2007 vintage are very similar to the concentrations in the 2008 vintage. In 2007, fall-like weather started early, including cool temperatures and wet fields. Growers reported issues with powdery mildew and low sugar levels (USDA, 2008). From July 2 to July 15, the longest warm period, with higher than average temperatures, was 14 days long in 2007. March had the most warmer than average days (NOAA, 2013). The 2007 vintage has aged well, with humble beginnings and a lighter overall flavor.

The Stoller Vineyard 2008 vintage has the highest concentration of Fe, S, and Co but the lowest concentration of Mg and Ca compared to 2007 and 2009. The Ridgecrest Vineyard 2008 vintage has the higher concentrations of Mg, Mn, and K than the 2007 vintage. Corral Creek Vineyard 2008 vintage has higher concentrations of Ba, Cu, Fe,

Mg, Mn, and Sr than the 2009 vintage (2007 vintage not tested). In 2008, growers reported a late start to the growing season. There were various sources of fruit loss but an overall warm growing season (USDA, 2009). The hottest month in 2008 was July with an average daily high temperature of 80°F. The warmest month was September, with an average high temperature of 77°F, compared to a typical value of 75°F which had an effect on the vintage. For 15 consecutive days from September 4 to September 18 there were higher than average high temperatures. The month of November had the largest fraction of warmer than average days with 70% days with higher than average high temperatures (NOAA, 2013). The 2008 vintage was well-balanced in regards to tannin and fruit.

The Stoller Vineyard bottle of the 2009 vintage has the highest concentration of Ca and K, but the lowest concentration of Ba, Cu, Fe, Mn, Na, and Sr compared to 2007 and 2008 vintages. The Mn and Sr concentrations are very similar to the concentrations in the Corral Creek Vineyard 2009 vintage. The Corral Creek Vineyard 2009 vintage has the higher concentrations of Ca, P, K, Na, S, and Zn than the Corral Creek Vineyard 2008 vintage. The warmest month in 2009 was July, with an average high temperature of 86°F, compared to a typical value of 80°F. The longest warm spell was from May 21 to June 5, constituting 16 consecutive days with warmer than average high temperatures and an early start to the growing season. The month of July had the largest fraction of warmer than average days with 71% days with higher than average high temperatures (NOAA,

2013). The 2009 vintage produced many full bodied wines with intense tannin and deep fruit flavor.

New Soil Classifications

During this study, the NRCS reclassified the soils of the Willamette Valley. For the most part, the Willakenzie soil series has been split into many soils, all with marine sediment parent material, but with slightly differing characteristics. As stated before, the Jory soil series (Xeric Palehumult) is similar to the Nekia soil series (Xeric Haplohumult) with the main difference in depth to bedrock; The Nekia soils series is shallower. Now, the Gelderman soils series is also a Xeric Haplohumult and is found near Jory soils and is very similar except for having an umbric epipedon (thicker A horizon) than the Jory Soil (base saturation still similar). There are, by NRCS mapping, five sites in this study that are Jory, zero Nekia (although the Willakenzie Estate Jory Hill soil was classified as a Nekia in the field and mapped as a Jory), and one Jory-Gelderman soil.

There are now few Willakenzie soil series (Ultic Haploxeralf) mapped by the NRCS, since it has been split into many different series. One site is now Wellsdale soil series (Aquultic Haploxeralf) which differs from Willakenzie because it has a Bg horizon at 20 to 30 inches. One site is now Goodin-Melbourne soil series (Ultic Haploxeralf-Ultic Palexeralf) and one site is now classified as Melbourne-Goodin. The Goodin has siltstone parent material and the Melbourne has mottles in the Cr horizon according to the official

soil description (NRCS, 2015). Two sites are classified as being Wellsdale-Willakenzie-Dupee soil series (Dupee is an Aquultic Haploxeralf) that is similar to the Wellsdale with a Bg horizon at depth. Two sites are classified as Bellpine soil series (Xeric Haplohumult). The sites are located farthest south near Salem, which has a lower base saturation than most of the traditional Willakenzie Soils with an umbric epipedon.

The Laurelwood soil series (Ultic Haploxeralf) is still mapped at the three sites selected in this study. There are differences in the NRCS classification for the Terres Basses vineyard which is now a Witham soil series (Vertic Haploxeroll) which does not have a Bt horizon. It is the only site in the study that was sampled without the Bt horizon. The Meredith Mitchell vineyard is also now classified as Witzel-Dixonville. The Witzel is a Lithic Ultic Haploxeroll with a loamy skeletal structure and forms on colluvium from basalt with some loess input. The Jacob Hart vineyard is now classified as Dixonville soil series (Pachic Ultic Argixeroll) which is a superactive silty clay loam, well drained, clayey soil formed on basalt bedrock, sometimes forming on older basalts of the Siletz River Terrane. The Meredith Mitchell vineyard is most likely also on the Siletz River Terrane basalts. The reclassification and mapping done by the NRCS that occurred during this study does not influence the results of this study. The separation of vineyards based on parent material is still valid when looking at physical and chemical differences.

Chapter Twelve – Conclusions

This study has given us the first in depth description of the volcanic, marine sediments, and loess/volcanic soils in the Willamette Valley that are used for growing Pinot Noir. Similar studies have not been carried out in this region before now. It is evident that there are many similarities between the vineyards in this study, despite the differences in parent material. The physical characteristics indicate that these vineyards are planted on old soils (over 50,000 years) based on red color, the presence of Bt horizons with subangular blocky structure, high clay content and clay textures, low CEC, and moderate acidity. This is relevant because old soils have few nutrients (Ca, Mg, K, Na, P) and therefore reduce the vigor (vegetative growth) in grape plants. The idea is that the stress of growing on an old soil with less nutrients would cause the plant to focus more on creating flavor, color, or aroma compounds to attract pollinators and potential genetic dispersers. Young soils (under 20,000 years) have lots of nutrients and encourage vigor which leads to non-exciting wines because the fertile soils reduce the necessity for the vine to create enticing fruit (Andrés-de Prado et al., 2007; Bramley et al., 2011; Cortell et al., 2007; Goode, 2014; Jackson, 2008; Retallack and Burns, 2016).

Age of the Willamette Valley soils were qualitatively determined by clay content, pH, cation exchange capacity, clay mineral assemblage, and color values. Maximum clay percentages are 57% for volcanic soils, 60% for loess/volcanic soils, and 39% for marine

sediments. The pH is low with minimum average values for volcanic soils at 5.2 ± 0.2 , marine sediment soil at 5.1 ± 0.4 , and loess/volcanic soils at 5.6 ± 0.1 . The range of pH in the study is from 4.7 to 6.7 with the highest at 6.7 for Meredith Mitchell Vineyard. The mean pH for all horizons for the study is 5.5 ± 0.4 .

The average cation exchange capacity (CEC) for volcanic soils are 22.5 meq/100g, marine sediments are 20.8 meq/100g, and loess/volcanic soils are 28.0 meq/100g. Corral Creek Vineyard (42.2 meq/100g) and Meredith Mitchell (80.0 meq/100g) are outliers, and the rest are between 10 and 23 meq/100g. The clay mineral assemblage also indicates that these soils are well developed and old, but differ slightly based on parent material. The dominant clay minerals are kaolinite and chlorite intergrades, which require time for pedogenesis and indicate old soils (Jackson, 1964). The clay minerals also align with the low CEC values. Typical CEC values for fine-grained micas and kaolinite clays are between 5 and 25 meq/100g (Weil and Brady, 1990). Illite dominates in soils with loess and smectite was more prevalent in marine sediment soils, but kaolinite, chlorite intergrades, and Fe oxides are still present, reducing the CEC values for these parent materials (Weil and Brady, 1990). In general, the soils in this study would be considered old, while also suggesting a slightly younger age for soils with illite clay because of the addition of loess to an already old and developed soil. This loess is old weathered loess that would have been deposited more than 50,000 years ago

on soils that were already developing. The clay mineral assemblage has not been previously explored for the vineyard soils in the Willamette Valley.

The average organic matter (OM) of volcanic soils at 11.3%, marine sediment soils at 6.9% and loess/volcanic soils at 7.5%. Ultisols and Ultic Alfisols, like those in this study, would be expected to have a range of OM from 1.5% to 4% (Weil and Brady, 1990). These high OM values are most likely due to water released from clays not organic matter on ignition. These high values occurred even after using a 2 stage heating method to drive off water from the clays before putting the samples in the oven for OM combustion (Dean et al., 1974; Heiri et al., 2001; Horneck et al., 1989). Other methods for determining OM were not available to confirm, or deny, this issue.

Another indication of old soils is the Buntley-Westin color values are 20 ± 6.5 for volcanic, 19 ± 7.3 for marine sediments, and 13 ± 2.3 for loess/volcanic soils. This is an indication of very red soil colors and extensive weathering and age even for the loess/volcanic soils which have loess input and blurs the age with this more recent deposition of silt. The lowest values (9) for Buntley-Westin are for the Missoula Flood sediment soil and landslide soils. A Buntley-Westin value larger than 10 indicates the soil is at least 5000 years old and values larger than 15 indicate soils greater than 10,000 years old (Buntley and Westin, 1964; Miller and Birkeland, 1974). Volcanic soils have 7.5 YR and 5 YR hues in regards to soil color which are brown and reddish brown colors.

The marine sediment soils mostly are 10 YR hues which are yellowish brown hues. The loess/volcanic soils have hues that are 10 YR, 7.5 YR, and 5 YR, which includes brown, yellowish brown, and red hues. These red colors are due to high concentrations of Fe-oxides, which build up in soils over time. There is also very little gravel at the surface of these vineyard soils with the maximum at 2.9%, and none had O horizons. Similarly, almost all the soils in the study are well drained, with only two out of 20 having Bg horizons.

Significant differences in depth to bedrock, presence of pisolites or mica and quartz, clay mineral assemblage, and chemistry exist between the soils founded on the three parent materials. These differences are correlated with the differences in grape juice and wine chemistry. Physically, many of the soils are shallow to bedrock with 13 out of the 20 pits reaching refusal within two meters. These shallowest soils are mainly found in the marine sediment parent material (six of seven) whereas for the other parent materials only one third of the soils were less than 2 meters to bedrock. Because of the friability of the marine sediment parent material, one would easily continue digging into the sandstone parent material, as would the vine roots, without realizing that the actual soil that had developed on the marine sediments is not very thick. This is one main physical difference between the marine sediment soils and the volcanic and loess/volcanic soils.

Another major difference is that there are pisolites (concretions) in the volcanic and the loess soils and not in the marine sediments. This is the first study to point out that these pisolites exist in the soils formed on volcanic and loess/volcanic parent material, but not in the marine sediment soils. These pisolites formed in place based on chemistry, and mostly consist of silica, Al and Fe oxides. Excluding silica, volcanic soils contain pisolites with higher Al, Fe, Mn, Cr, V, and Zn while the loess/volcanic soils have pisolites with higher Mg, Ca, Na, P, Ba, and Sr. The pisolites are composed of concentric layers of phyllosilicates and clays that are pulling trace elements directly out of the soil. The volcanic soils have higher Al, Fe, and Mn than the loess/volcanic soils and the loess/volcanic soils have higher Mg, Ca, Na, and P concentrations. Therefore, the pisolites' elemental concentration reflects the chemistry of the soil they are from.

The marine sediments contain muscovite mica and quartz whereas the volcanic soils have little of those minerals implying that the development of pisolites is related to the volcanic bedrock and loess deposits and not related to the marine sediments. The volcanic soils that had pisolites, also were discovered to have illite clay, which suggests that they also had loess input. Other than removing some trace elements from soil, the pisolites change the texture of these clay rich soils. The clay content is still high, but pisolites increase the “sand” fraction and therefore increase soil permeability and root penetration. This deserves much more attention and research since the influence of the pisolites and how and under what conditions they form is still unknown.

Volcanic soils have kaolinite clays with some chlorite intergrades and only a few locations have illite. Marine sediment soils have smectite clays with some kaolinite and chlorite intergrades but no illite. Loess/volcanic soils have mostly illite with some chlorite and only a little kaolinite. Illite dominates in loess/volcanic soils indicating that they are the youngest because of the loess addition. Illite was also found in the volcanic soils, therefore there is a windblown input even in the soils previously thought to not have any loess. The dominant silica phase is cristobalite quartz. Marine sediment soil, as stated before, contain quartz in the clay fraction when the other soils do not. Goethite is the dominant Fe phase, with some containing hematite. Goethite is less developed in marine sediment soils.

The chemistry was examined for the soil, juice from grapes next to the soil pit, and finished wine from the block of the soil pit. Soil chemistry varied between the marine, volcanic, and loess/volcanic soils and the PCA showed significant differences between the soils with the greatest differences between the marine and volcanic, and loess/volcanic in between. Volcanic soils have the highest mean and maximum concentrations of P, S, Fe, Co, Mn, and V values and the lowest As and Sr values. Marine sediment soils are highest in Cl and Sr and lowest in P, Co, Mn, Ba, and V. The loess/volcanic soils are highest in K, Mg, similar to volcanic soils with higher values of P and V, and similar to marine sediment soils with higher values of Sr. According to the PCA, volcanic soils cluster with Fe, Zn, Mn, and Al while marine sediment soils cluster

with the Mo, Cu, and Na and the loess/volcanic soils lie in between. The main elements found to be significant in determining one parent material from the other are V (volcanic soils), Mn (volcanic soils), Mg and K (loess soils), and Sr (marine sediment soil or loess soils). Low values of As (volcanic soils) and low values of Ba (marine sediment soils) could also help determine the parent material.

The relative concentration of elements in the grape juice are markedly different than the soil concentrations with selectivity towards more mobile elements and those that are incorporated into the grapes themselves rather than in other tissues of the grape vine. The PCA does not suggest a correlation between soil parent material and the chemistry of the grape juice. This is most likely because K, Na, and Sr are the only elements found in all 20 grape juice samples due to methodological errors in this study. K is incorporated into grape juice because it is an essential nutrient for living plant cells and membranes of plants are highly permeable to K (Kodur, 2011). Na is similarly easy for the grapevine to obtain from the soil and incorporate into various parts of the plant, including the grapes. As an element, Sr has similar properties as Ca and Mg, allowing for it to also be mistaken as a nutrient and incorporated into the grapes. P was in 15 of 20 grape juice samples. K has the highest average concentration in loess/volcanic soils from the loess input but the highest peaks in the volcanic and marine sediment soils. Sr is highest in marine sediment soil and has been used to determine wine provenance in Portugal and other studies (Almeida and Vasconcelos, 2001). Na and P are similar in all soils. Sr is slightly higher

in grape juice from plants living on marine sediment soils compared to volcanic or loess soils. Mn in the grape juice may be used to indicate a volcanic or loess soils instead of a marine sediment soils.

The wine elemental concentrations were also different than the soil and the grape juice as shown by PCA. Other research suggests this is because of filtering, precipitation, or co-precipitation during the wine making process (Castiñeira-Gómez et al., 2004). In this study, similar concentrations of elements were found in wines from all soil types and two minor conclusions can be made: Mn is highest in wine from volcanic and marine sediments soils contrary to the high Mn values in loess soils. Sr is highest in wine from marine sediment soil but not associated with the similarly higher values of Sr in the loess soils.

In conclusion, these results can be used to indicate the source of origin for Pinot Noir wine from the soils in the Willamette Valley of Oregon. The persistence of some elements from soil to grape juice to wine indicate that the soil has influence on the grape and wine chemistry. There are significant differences in the physical and chemical characteristics of the soils of the three major soil parent materials.

Chapter Thirteen – Future Work

A comparison of the wines done by a tasting panel performed by Oregon State University will help determine how the elemental fingerprint from the soil changes the intensities of certain attributes of the wine. The tasting was completed in 2014, but the results were not available at the time of publication of this dissertation. The tasting results should reveal that the soil differences truly produce wines that taste different from one another. The soil fingerprint based on physical characteristics and some chemical characteristics and wine fingerprint may then be correlated to specific wine flavors. In the future, these data may help shed light on the mechanisms by which winegrapes obtain certain flavors from the soil.

Other interesting questions evolved during this study concerning soil development in the Willamette Valley. When considering clay mineralogy, especially where there could be a windblown addition of parent material, what is the ratio of illite to kaolinite that could be expected in these old soils? In the windblown soils, there may be work in determining the differences between sources of loess between the Dundee Hills and the Chehalem Mountains. A spatial comparison of soils with an input of loess would indicate prehistoric wind directions in the Willamette Valley.

More vineyard soils in this region should be analyzed for V, Sr, and Mn in order to determine if these elements do separate vineyards on different parent materials.

Testing of wines for these elements should also be done to determine the origin of the grapes and substantiate the results of this study in fingerprinting wines from different parent materials in the Willamette Valley. Further research into the creation and impact of pisolites in the soils, whether an increase in soil permeability or reduction in trace elements due to the formation of these concretions would also be an interesting direction to take this research.

As usual, more questions about the terroir of the Willamette Valley have developed due to this study on the soils of various parent materials than were answered. Further study into the impacts of various farming practices, soil microbiota, clay mineralogy, and climate all will satisfy some urge to understand this region and how it has become one of the most notable Pinot Noir wine producers in the world. Until then, I will have to continue to commiserate my unanswered questions over a glass or two of delicious wine.

References

- Allen, J.E., Burns, M., Burns, S.F., 2009, Cataclysms on the Columbia: The Great Missoula Floods (2nd ed.): Portland, Oregon, Ooligan Press, 204 p.
- Almeida, C.M.R., and Vasconcelos, M.T.S.D., 1999, UV-irradiation and MW-digestion pre-treatment of Port wine suitable for the determination of Pb isotope ratios by inductively couple plasma mass spectrometry: Journal of Analytical Atomic Spectrometry, v. 14, p. 1815-1821.
- Almeida, C.M.R., and Vasconcelos, M.T.S.D., 2001, ICP-MS determination of Sr isotope ratio in wine in order to be used as a fingerprint of its regional origin: Journal of Analytical Atomic Spectrometry, v. 16, p. 607-611.
- Almeida, C.M.R., Vasconcelos, M.T.S.D., Barbaste, M., and Medina, B., 2002, ICP-MS multi-element analysis of wine samples – a comparative study of the methodologies used in two laboratories: Analytical and Bioanalytical Chemistry, v. 374, p. 314-322.
- Almeida, C.M.R., and Vasconcelos, M.T.S.D., 2003, Multielement composition of wines and their precursors including provenance soil and their potentialities as fingerprints of wine origin: Journal of Agricultural and Food Chemistry, v., 51, p. 4788-4798.
- Álvarez, M., Moreno, I.M., Jos, Á.M., Cameán, A.M., González, A.G., 2007, Study of mineral profile of Montilla-Moriles “fino” wines using inductively couple plasma atomic emission spectrometry methods: Journal of Food Composition and Analysis, v. 20, p. 391-395.
- Andrés-de Prado, R. de, Yuste-Rojas, M., Sort, X., Andrés-Lacueva, C., Torres, M., and Lamuela-Raventós, R.M., 2007, Effect of soil type on wines produced from *Vitis vinifera* L. Cv. Grenache in commercial vineyards: Journal of Agricultural and Food Chemistry, v. 55, p. 779-786.
- Atwater, B.F., 1984, Periodic floods from glacial Lake Missoula into the Sanpoil arm of glacial Lake Columbia, northeastern Washington: Geology, v. 12, p. 464-467.
- Arrhenius, S.P., McCloskey, L.P., and Sylvan, M., 1996, Chemical markers for aroma of *Vitis vinifera* var. chardonnay region wines: Journal of Agricultural and Food Chemistry, v. 44, p. 1085-1090.

- Arvanitoyannis, I.S., Katsota, M.N., Psarra, E.P., Soufleros, E.H., and Kallithraka, S., 1999, Application of quality control methods for assessing wine authenticity: Use of multivariate analysis (chemometrics): *Trends in Food Science & Technology*, v. 10, p. 321-336.
- Augagneur, S., and Médina, B., 1996, Determination of rare earth elements in wine by inductively coupled plasma mass spectrometry using a microconcentric nebulizer: *Journal of Analytical Atomic Spectrometry*, v. 11, p. 713-721.
- Bargmann, C.J., 2006, Geology and Wine 7. Geology and wine production in the coastal region, Western Cape Province, South Africa *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective: Geological Association of Canada, St. John's, Newfoundland and Labrador, Canada*, p. 93-114.
- Barham, E., 2002, Translating terroir: the global challenge of French AOC labeling: *Journal of Rural Studies*, v. 19, p. 127-138.
- Barnard, K.B., 2009, Geology and Wine in Missouri: Spatial Analysis of Terroir Using a Geographic Information System and Remote Sensing: M.S. Thesis, Missouri State University, 204 p.
- Barthès B. and Roose E., 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels: *Catena*, v. 47, p. 133-149.
- Barto E.K., Alt F., Oelmann Y., Wilcke W. and Rillig M.C., 2010. Contributions of biotic and abiotic factors to soil aggregation across a land use gradient: *Soil Biology and Biochemistry*, v. 42, p. 2316-2324.
- Baxter, M.J., Crews, H.M., Dennis, M.J., Goodall, I., and Anderson, D., 1996, The determination of the authenticity of wine from its trace element composition: *Food Chemistry*, v. 60, p. 443-450.
- Bednarz, S., 2002, Influence of Halloysite on the Engineering Behavior of Basaltic Saprolites in Northwestern Oregon and Southwestern Washington, M.S. thesis: Portland, Portland State University, 30 p.
- Berry, E.M.W., 1990, The importance of soil in fine wine production: *Journal of Wine Research*, v. 1, i. 2, p. 179-195.

- Birkeland, P.W., 1999, *Soils and Geomorphology*, 3rd edition: New York, Oxford University Press, Inc., 430 p.
- Bowen, P.A., Bogdanoff, C.P., Estergaard, B.F., Marsh, S.G., Usher, K.B., Smith, C.A.S., and Frank, G., 2006, *Geology and Wine* 10. Use of geographic information system technology to assess viticulture performance in the Okanagan and Similkameen Valleys, British Columbia *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective: Geological Association of Canada*, St. John's, Newfoundland and Labrador, Canada, p. 137-152.
- Bramley, R.G.V., Ouzman, J., and Boss, P.K., 2011, Variation in vine vigour, grape yield and vineyard soils and topography as indicators of variation in the chemical composition of grapes, wine and wine sensory attributes: *Australian Journal of Grape and Wine Research*, v. 17, p. 217-229.
- Bretz, J.H., 1969, The Lake Missoula Floods and the Channeled Scabland; *The Journal of Geology*, v. 77, n. 5, p. 505-543.
- Buntley, G.J., and Westin, F.C., 1965, A comparative study of developmental color in a Chestnut-Chernozem-Brunizem soil climosequence: *Soil Science Society of America Procedures* 29, p. 579-582.
- Burns, S.F., 2012, The importance of soil and geology in tasting terroir with a case history from the Willamette Valley, Oregon, *in* Dougherty, P.H., ed., *The Geography of Wine – Regions, Terroir and Techniques*: Springer, Dordrecht, Heidelberg, London, New York, p. 95-108.
- Busacca, A.J., Begét, J.E., Markewich, H.W., Muhs, D.R., Lancaster, N., and Sweeney, M.R., 2004, Eolian Sediments *in* Gillespie, A.R., Porter, S.C., and Atwater, B.F., eds., *The Quaternary period in the United States*: Elsevier, Netherlands, p. 275-309.
- Busacca, A.J., and Meinert, L.D., 2003, Wine and geology – the terroir of Washington State *in* Swanson, T.W., ed., *Western Cordillera and Adjacent Areas*, *The Geological Society of America Field Guide* 4: The Geological Society of America, Boulder, Colorado, p. 69-85.
- Castiñeira, M.M., Brandt, R., von Bohlen, A., Jakubowski, N., 2001, Development of a procedure for the multi-element determination of trace elements in wine by ICP-MS: *Journal of Analytical Chemistry*, v. 370, p. 553-558.

- Castiñeira-Gómez, M.M., Brandt, R., Jakubowski, N., and Anderson, J.T., 2004, Changes of the metal composition in German white wines through the winemaking process. A study of 63 elements by inductively coupled plasma-mass spectrometry: *Journal of Agricultural and Food Chemistry*, v. 52, p. 2953-2961.
- Coetzee, P.P., Steffens, F.E., Eiselen, R.J., Augustyn, O.P., Balcaen, L., and Vanhaecke, F., 2005, Multi-element analysis of South African wines by ICP-MS and their classification according to geographical origin: *Journal of Agricultural and Food Chemistry*, v. 53, p. 5060-5066.
- Colombo P.C. and Torrent C.J., 1991. Relationships between aggregation and Fe oxides in Terra Rossa soils from southern Italy: *Catena*, v. 18, p. 51-59.
- Constantini, E.A.C., Bucelli, P., and Priori, S., 2012, Quaternary landscape history determines the soil functional characters of terroir: *Quaternary International*, v. 265, p. 63-73.
- Cortell, J.M., Halbleim, M., Gallagher, A.V., Righetti, T.L., and Kennedy, J.A., 2007, Influence of Viney Vigor on Grape (*Vitis vinifera* L. Cv. Pinot Noir) Anthocyanins. 2. Anthocyanins and Pigmented Polymers in Wine: *Journal of Agricultural and Food Chemistry*, v. 55, p. 6585-6595.
- Dami, I., Bordelon, B., Ferree, D.C., Brown, M., Ellis, M.A., Williams, R.N., Doohan, D., 2005, Midwest Grape Production Guide, Bulletin 919: Ohio State University Extension, 155 p.
- Dean, W. E. Jr., 1974, Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. *Journal of Sedimentary Petrology*, v. 44, p. 242-248.
- Di Paola-Narajo, R.D., Baroni, M.V., Podio, N.S., Rubinstein, H.R., Fabani, M.P., Badini, R.G., Inga, M., Otera, H.A., Cagnoni, M., Gallegos, E., Gautier, E., Peral-García, P., Hoogewerff, J., and Wunderlin, D.A., 2011, Fingerprints for main varieties of Argentinean wines: terroir differentiation by inorganic, organic, and stable isotopic analysis coupled to chemometrics: *Journal of Agricultural and Food Chemistry*, v. 59, p. 7854-7865.
- Dougherty, P.H., 2012, Introduction to the geographical study of viticulture and wine production in Dougherty, P.H., ed., *The Geography of Wine – Regions, Terroir and Techniques*: Springer, Dordrecht, Heidelberg, London, New York, p. 3-36.

- Douglas, D., Cliff, M.A., and Reynolds, A.G., 2001, Canadian terroir: characterization of Riesling wines from the Niagara Peninsula: *Food Research International*, v. 34, p. 559-563.
- Ebeler, S.E., 2001, Analytical chemistry: unlocking the secrets of wine flavor: *Food Reviews International*, v. 17, i. 1, p. 45-64.
- Ebeler, S.E., and Thorngate, J.H., 2009, Wine chemistry and flavor: looking into the crystal glass: *Journal of Agricultural and Food Chemistry*, v. 57, p. 8098-8108.
- Eggers, N.J., Greenough, J.D., and Cernak, T., 2006, Classification of British Columbia's Okanagan chardonnay wines by origin using volatile components *in* Macqueen, R.W. and Meinert, L.D., eds., *Fine Wine and Terroir: The Geoscience Perspective*, Newfoundland and Labrador, Geological Association of Canada c/o Department of Earth Sciences, Memorial University of Newfoundland, p. 183-192.
- Eggleton, R.A., Foudoulis, C., and Varkevisser, D., 1987, Weathering of basalt: changes in rock chemistry and mineralogy: *Clays and Clay Minerals*, v. 35, n. 3, p. 161-169.
- Elliott-Fisk, D.L., 1993, Viticultural soils of California, with special reference to the Napa Valley: *Journal of Wine Research*, v. 4, i. 2, p. 67-78.
- Elsass, F., Dubroeuq, D., and Thiry, M., 2000, Diagenesis of silica minerals from clay minerals in volcanic soils of Mexico: *Clay Minerals*, v. 35, i. 3, p.477-489.
- EPA, 1998, Method 6020A (SW-846): Inductively Coupled Plasma-Mass Spectrometry, Revision 1, 23 p.
- EPA, 2007a, Method 3051A (SW-846): Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils, Revision 1, 30 p.
- EPA, 2007b, Method 6010C (SW-846): Inductively Coupled Plasma-Atomic Emission Spectrometry, Revision 3, 30 p.
- EPA, 2007c, Method 9056A (SW-846): Determination of Inorganic Anions by Ion Chromatography, 19 p.
- Eschnauer, H., Jakob, L., Meierer, H., Neeb, R., 1989, Use and limitations of IP-OES in wine analysis: *Mikrochimica Acta*, v. 3, p. 291-298.

- Fabani, M.P., Toro, M.E., Vázquez, F., Diaz, M.P., and Wunderlin, D.A., 2009, Differential absorption of metals from soil to diverse vine varieties from the Valley of Tulum (Argentina): consequences to evaluate wine provenance: *Journal of Agricultural and Food Chemistry*, v. 57, p. 7409-7416.
- Fabani, M.P., Arrúa, R.C., Vázquez, F., Diaz, M.P., Baroni, M.V., Wunderlin, D.A., 2010, Evaluation of elemental profile coupled to chemometrics to assess the geographical origin of Argentinean wines: *Food Chemistry*, v. 119, p. 372-379.
- Fischer, U., Roth, D., and Christmann, M., 1999, The impact of geographic origin, vintage and wine estate on sensory properties of *Vitis vinifera* cv. Riesling wines: *Food Quality and Preference*, v. 10, p. 281-288.
- Frías, S., Conde, J.E., Rodríguez-Bencomo, J.J., García-Montelongo, F., Pérez-Trujillo, J.P., 2003, Classification of commercial wines from the Canary Islands (Spain) by chemometric techniques using metallic content: *Talanta*, v. 59, p. 335-344.
- Galani-Nikolakaki, S., Kallithrakas-Kontos, N., and Katsanos, A.A., 2002, Trace element analysis of Cretan wines and wine products: *The Science of the Total Environment*, v. 285, p. 155-163.
- Galgano, F., Favati, F., Caruso, M., Scarpa, T., Palma, A., 2008, Analysis of trace elements in southern Italian wines and their classification according to provenance: *LWT – Food Science and Technology*, v. 41, p. 1808-1815.
- Gee, G.W., and Bauder, J.W., 1986, Particle-size analysis in Klute, A., ed., *Methods of soil analysis. Part 1: Physical and Mineralogical Methods*, American Society of Agronomy, Soil Science Society of America, Series in Agronomy 9, Madison, WI, p. 383–409.
- Gonzálvez, A., Llorens, A., Cervera, M.L., Armenta, S., and de la Guardia, M., 2009, Elemental fingerprint of wines from the protected designation of origin Valencia: *Food Chemistry*, v. 112, p. 26-34.
- Greenough, J.D., Longerich, H.P., and Jackson, S.E., 1997, Element fingerprinting of Okanagan Valley wines using ICP-MS: Relationships between wine composition, vineyard and wine colour: *Australian Journal of Grape and Wine Research*, v. 3, p. 75-83.

- Greenough, J.D., Mallory-Greenough, L.M., and Fryer, B.J., 2005, Geology and Wine 9. Regional trace element fingerprinting of Canadian wines: *Geoscience Canada*, v. 32, n. 3, p. 129-137.
- Haynes, S.J., 2006a, Geology and Wine 1. Concept of terroir and the role of geology *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective: Geological Association of Canada*, St. John's, Newfoundland and Labrador, Canada, p. 3-7.
- Haynes, S.J., 2006b, Geology and Wine 2. A geological foundation for terroirs and potential sub-*appellations* of Niagara Peninsula wines, Ontario, Canada *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective: Geological Association of Canada*, St. John's, Newfoundland and Labrador, Canada, p. 9-29.
- Heiri, O., Lotter, A.F., Lemcke, G., 2001, Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results: *Journal of Paleolimnology*, v. 25, p. 101-110.
- Helgason, B.L., Walley, F.L., and Germida, J.J., 2010, No-till soil management increases microbial biomass and alters community profiles in soil aggregates: *Applied Soil Ecology*, v. 46, p. 390-397.
- Heymann, H., and Noble, A.C., 1987, Descriptive analysis of commercial Cabernet Sauvignon wines from California: *American Journal of Enology and Viticulture*, v. 38, n. 1, p. 41-44.
- Horneck, D.A., Hart, J.M., Topper, K., and Koepsell, B., 1989, *Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University: Agricultural Experiment State, Oregon State University*, SM 89:4, 21 p.
- Jackson, M., 1964, Chemical composition of soils. *in* F.E. Bear, ed., *Chemistry of the Soil: Reinhold Publishing Corp.*, New York, p. 71-141.
- Jackson, R.S., 2008, *Wine Science Principles and Applications*, Third Edition: Academic Press, Burlington, MA, 776 p.
- Jackson, R.S., 2009, *Wine Tasting – A Professional Handbook*, Second Edition: Academic Press, Burlington, MA, 512 p.

- Jones, G.V., Snead, N., and Nelson, P., 2006, Geology and Wine 8. Modeling viticultural landscapes: a GIS analysis of the terroir potential in the Umpqua Valley of Oregon *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective*: Geological Association of Canada, St. John's, Newfoundland and Labrador, Canada, p. 115-126.
- Jones, G.V., Duff, A.A., Hall, A., and J. Myers, 2010, Spatial analysis of climate in winegrape growing regions in the western United States. *American Journal of Enology and Viticulture*, 61:313-326.
- Jones, G.V., Reid, R., and Vilks, A., 2012, Climate, grapes and Wine: Structure and suitability in a variable and changing climate *in* Dougherty, P.H., ed., *The Geography of Wine – Regions, Terroir and Techniques*: Springer, Dordrecht, Heidelberg, London, New York, 109-136 p.
- Joyce, E.B., 2004, Integrating soils, regolith and slope dynamics in the study of the terroir of wine regions in Central Victoria, Australia *in* Roach, I.C., ed., *Regolith 2004: Cooperative Research Centre for Landscape Environments and Mineral Exploration*, p. 157-160.
- Klein, C., and Dutrow, B., 2007, The 23rd edition of the manual of mineral science (after James D. Dana): Hoboken, John Wiley & Sons, Inc., 675 p.
- Kment, P., Mihaljevič, M., Ettler, V., Šebek, O., Strnad, L., and Rohlová, L., 2005, Differentiation of Czech wines using multielement composition – A comparison with vineyard soil: *Food Chemistry*, v. 91, p. 157-165.
- Kontkanen, D., Reynolds, A.G., Cliff, M.A., King, M., 2005, Canadian terroir: sensory characterization of Bordeaux-style red wine varieties in the Niagara Peninsula: *Food Research International*, v. 38, p. 417-425.
- Kodur, S., 2011, Effects of juice pH and K on juice and wine quality, and regulation of K in grapevines through rootstocks (*Vitis*): a short review: *Vitis VEA*, v. 50, n. 1, p. 1-6.
- Lara, R., Cerutti, S., Salonia, J.A., Olsina, R.A., Martinez, L.D., 2005, Trace element determination of Argentine wines using ETAAS and USN-ICP-OES: *Food and Chemical Toxicology*, v. 43, p. 293-297.
- Latorre, M.J., García-Jares, C., Médina, B., Herrero, C., 1994, Pattern recognition analysis applied to classification of wines from Galicia (Northwestern Spain) with

- certified brand of origin: *Journal of Agricultural and Food Chemistry*, v. 42, p. 1451-1455.
- Leeuwen, C.V., Friant, P., Choné, X., Tregoat, O., Koundouras, S., and Dubourdieu, D., 2004, Influence of climate, soil, and cultivar on terroir: *American Journal of Enology and Viticulture*, v. 55, i. 3, p. 207-217.
- Lim, C.H., and Jackson M.L., 1982, Method of loss on ignition *in* Page, A.L., ed., *Methods of Soil Analysis: Chemical and Microbiological Properties*, 2nd Edition: Soil Science Society of America, Madison Wisconsin, n. 9, part 2, p. 4.
- Louw, L., Roux, K., Tredoux, A., Tomic, O., Naes, T., Nieuwoudt, H.H., and van Rensburg, P., 2009, Characterization of selected South African young cultivar wines using FT-MIR spectroscopy, gas chromatography, and multivariate data analysis: *Journal of Agricultural and Food Chemistry*, v. 57, p. 2623-2632.
- MacNeil, K., 2001, *The Wine Bible*: New York, Workman Publishing, 910 p.
- Madin, I. P., 2009, Oregon: A Geologic History, Oregon Department of Geology and Mineral Industries Interpretive Series Map 28 [companion web page], <http://www.oregongeology.org/sub/publications/IMS/ims-028/index.htm> (accessed October 2015)
- Manceau, A., Tamura, N., Celestre, R.S., Macdowell, A.A., Geoffroy, N., Sposito, G., and Padmore, H.A., 2003, Molecular-Scale Speciation of Zn and Ni in Soil Ferromanganese Nodules from Loess Soils of the Mississippi Basin: *Environmental Science and Technology*, v. 37, p. 75-80.
- Mangan, M.T., Wright, T.L., Swanson, D.A., Byerly, G.R., 1986, Regional correlation of Grande Ronde Basalt flows, Columbia River Basalt Group, Washington, Oregon, and Idaho: *Geological Society of America Bulletin*, v. 97, p. 1300-1318.
- Medley, E., 2012, Ancient cataclysmic floods in the Pacific Northwest: ancestors to the Missoula Floods, M.S. thesis: Portland, Oregon, Portland State University, 185 p.
- Meinert, L.D., and Busacca, A.J., 2006a, Geology and Wine 3. Terroirs of the Walla Walla Valley appellation, southeastern Washington State, USA *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective*: Geological Association of Canada, St. John's, Newfoundland and Labrador, Canada, p. 31-57.

- Meinert, L.D., and Busacca, A.J., 2006b, Geology and Wine 6. Terroir of the Red Mountain Appellation, Central Washington State, U.S.A. *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective*: Geological Association of Canada, St. John's, Newfoundland and Labrador, Canada, p. 73-92.
- Miller, B.J., Lewis, G.C., Alford, J.J., and Day, W.J., 1985, Loesses in Louisiana and at Vicksburg, Mississippi: Guidebook for the Friends of the Pleistocene Field Trip, April 12-14: Louisiana State University and A & M College, Baton Rouge, LA, 126 p.
- Miller, C.D., and Birkeland, P.W., 1974, Probable pre-Neoglacial age of the type Temple Lake moraine, Wyoming: Discussion and additional relative-age data: *Arctic and Alpine Research*, v. 6, n. 3, p. 301-306.
- Mizota, C., Toh, N., Matsuhisa, Y., 1987, Origin of cristobalite in soils derived from volcanic ash in temperate and tropical regions: *Geoderma*, v. 39, p. 323-330.
- Moore, G.W., 2002, Geology of vineyards in the Willamette Valley, Oregon: Department of Geosciences, Oregon State University:
<http://www.cmug.com/chintimp/willamette.vineyards.htm> (accessed January 2013).
- Moore, G.W., 2005, Wine with a deep flavor: *Nature*, v. 434, p. 438.
- NRCS, 2013, National Cooperative Soils Survey, National Cooperative Soil Characterization Database: <http://ncsslabsdatamart.sc.egov.usda.gov> (accessed May 2013).
- NRCS, 2014, National Cooperative Soils Survey, Web Soil Survey:
<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> (accessed September 2014).
- NRCS, 2015, National Cooperative Soils Survey, Web Soil Survey:
<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> (accessed April 2015).
- Nelson, S. A., 2011, Weathering and clay minerals: Tulane University, Mineralogy,
<http://www.tulane.edu/~sanelson/eens211/weathering&clayminerals.htm>
(accessed May 2013).

- Noble, A.C., and Ebeler, S.E., 2002, Use of multivariate statistics in understanding wine flavor: *Food Reviews International*, v. 18, i. 1, p. 1-21.
- NOAA, 2013, National Centers for Environmental Information, Climate Data Online, <http://www.ncdc.noaa.gov> (accessed October 2013).
- Pérez-Magariño, S., Ortega-Heras, M., and González-San José, M.L., 2002, Multivariate classification of rosé wines from different Spanish protected designations of origin: *Analytica Chimica Acta*, v. 458, p. 187-190.
- Perk, M. van der, 2006, *Soil and Water Contamination from molecular to catchment scale*: London, Taylor & Francis, 389 p.
- Peterson, C.D., Minor, R., Peterson, G.L., and Gates, E.B., 2011, Pre-and post-Missoula flood geomorphology of the Pre-Holocene ancestral Columbia River Valley in the Portland forearc basin, Oregon and Washington, USA: *Geomorphology*, v. 129, p. 276-293.
- Pohl, P., 2007, What do metals tell us about wine?: *Trends in Analytical Chemistry*, v. 26, n. 9, p. 941-949.
- Polášková, P., Herszage, J., and Ebeler, S.E., 2008, Wine flavor: chemistry in a glass: *Chemical Society Reviews*, v. 37, p. 2478-2489.
- Pomeral, C., 1989, *The Wines and Winelands of France: Geological Journeys*: London, Robertson McCarta Limited, 370 p.
- Retallack, G.J., and Burns, S.F., 2016, The effects of soils on the taste of wine: *GSA Today*, v. 26, n. 5, p. 4-9.
- Ricker, T.R., 2013, *As in the soils of Northwest Oregon*: M.S. Thesis, Portland State University, 161 p.
- Rillig, M.C., Mardatin, N.F., Leifheit, E.F., and Antunes, P.M., 2010, Mycelium of arbuscular mycorrhizal fungi increases soil water repellency and is sufficient to maintain water-stable soil aggregates: *Soil Biology & Biochemistry*, v. 42, p. 1189-1191.
- Robert, P., Rey-Debove, J., and Rey, A., 2008, *Le nouveau petit Robert de la langue Francaise 2009*: Educa Books/ Le Robert, 2838 p.

- Sabon, I., De Revel, G., Kotseridis, Y., and Bertrand, A., 2002, Determination of volatile compounds in Grenache wines in relation with different terroirs in the Rhone Valley: *Journal of Agricultural and Food Chemistry*, v. 50, p. 6341-6345.
- Saurina, J., 2010, Characterization of wines using compositional profiles and chemometrics: *Trends in Analytical Chemistry*, v. 29, n. 3, p. 234-245.
- Schlosser, J., Reynolds, A.G., King, M., and Cliff, M., 2005, Canadian terroir: sensory characterization of Chardonnay in the Niagara Peninsula: *Food Research International*, v. 38, p. 11-18.
- Seguin, G., 1986, 'Terroirs' and pedology of wine growing: *Experientia*, v. 42, p. 861-873.
- Soil Survey Staff, 1999, *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys.*, 2nd edition.: Natural Resources Conservation Service, U.S. Department of Agriculture Handbook, 436 p.
- Soil Survey Staff, 2010, Natural Resources Conservation Service, United States Department of Agriculture, Soil Survey Geographic (SSURGO) Database for Willamette Valley, Oregon: <http://soildatamart.nrcs.usda.gov> (accessed September 2010).
- Spohn, M. and Giani, L., 2011, Impacts of land use change on soil aggregation and aggregate stabilizing compounds as dependent on time: *Soil Biology & Biochemistry*, v. 43, p. 1081-1088.
- Starr-Peace, D., 2005, *The geography of vineyard soils and terroir in the North Willamette Valley, Oregon*: M.A. Thesis, Portland State University, 93 p.
- Stroh, A., Brückner, P., and Völkopt, U., 1994, Multielement analysis of wine samples using ICP-MS: *Atomic Spectroscopy*, March/April, p. 100-106.
- Swanson, D.A., Cameron, K.A., Evarts, R.C., Pringle, P.T., and Vance, J.A., 1989, Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon: Field excursions to volcanic terranes in the western United States, Volume II: Cascades and Intermountain West, Chapin, C.E., and Zidek, J., eds., New Mexico Bureau of Mines & Mineral Resources Memoir 47, p. 1-43.

- Szentmihályi, K., Csiktusnádi-Kiss, G.A., Keszler, Á., Kótai, L., Candeaia, M., Bronze, M.R., Boas, L.V., Spauger, I., and Forgács, E., 2000, Method development for measurement of elements in Hungarian red wines by Inductively Couple Plasma Optical Emission Spectrometry (ICP-OES): *Acta Alimentaria*, vol. 29, n. 2, p. 105-121.
- Taylor, V.F., Longerich, H.P., and Greenough, J.D., 2003, Multielement Analysis of Canadian Wines by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Multivariate Statistics: *Journal of Agricultural and Food Chemistry*, v. 51, p. 856-860.
- Taylor, V.F., Longerich, H.P., and Greenough, J.D., 2006, Geology and Wine 5. Provenance of Okanagan Valley wines, British Columbia, using trace elements: promise and limitations *in* Macqueen, R.W., and Meinert, L.D., eds., *Fine Wine and Terroir – The Geoscience Perspective*: Geological Association of Canada, St. John's, Newfoundland and Labrador, Canada, p. 59-72.
- Theil, G., Geisler, G., Blechschmidt, I., and Danzer, K., 2004, Determination of trace elements in wines and classification according to their provenance: *Analytical and Bioanalytical Chemistry*, v. 378, p. 1630-1636.
- Tomasino, E., Harrison, R., Sedcole, R., Frost, A., and Sherlock, R., 2012a, characterizing regional New Zealand Pinot Noir: *Australian & New Zealand Grapegrower & Winemaker*, v. 581, p. 64-68.
- Tomasino, E., Harrison, R., Sedcole, R., and Frost, A., 2012b, Regional Differentiation of New Zealand Pinot Noir wine by professionals using canonical variate analysis, Ph.D. Dissertation: Lincoln, Canterbury, New Zealand, Lincoln University, 25 p.
- TTB - Alcohol and Tobacco Tax and Trade Bureau, 2007, Authorized wine appellations of origin – U.S. Viticultural Areas: U.S. Department of the Treasury, 9 p.
- Unwin, T., 2012 Terroir: At the heart of geography *in* Dougherty, P.H., ed., *The Geography of Wine – Regions, Terroir and Techniques*: Springer, Dordrecht, Heidelberg, London, New York, p. 37-48.
- USDA, 2012, 2011 Oregon Vineyard Report, National Agricultural Statistics Service, Oregon Field Office, Portland, Oregon, p. 1-2.
- USDA, 2010, 2009 Oregon Vineyard Report, National Agricultural Statistics Service, Oregon Field Office, Portland, Oregon, p. 1-2.

- USDA, 2009, 2008 Oregon Vineyard Report, National Agricultural Statistics Service, Oregon Field Office, Portland, Oregon, p. 1-2.
- USDA, 2008, 2007 Oregon Vineyard Report, National Agricultural Statistics Service, Oregon Field Office, Portland, Oregon, p. 1-2.
- Van Ranst, E., Utami, S.R., Verdoodt, A., Qafoku, N.P., 2008, Mineralogy of a perudic Andisol in central Java, Indonesia: *Geoderma*, v. 144, p. 379-386.
- Vilanova, M., Zamuz, S., Vilariño, F., and Sieiro, C., 2007, Effect of terroir on the volatiles of *Vitis vinifera* cv. Albariño: *Journal of the Science of Food and Agriculture*, v. 87, p. 1252-1256.
- Vilanova, M., Genisheva, Z., Bescansa, L., Masa, A., and Oliveira, J.M., 2009, Volatile composition of wines from cvs. Blanco lexítimo, Agudelo and Serradelo (*Vitis vinifera*) grown in Betanzos (NW Spain): *Journal of the Institute of Brewing*, v. 115, n. 1, p. 35-40.
- Wada, K., 1987, Minerals formed and mineral formation from volcanic ash by weathering: *Chemical Geology*, v. 60, p. 17-28.
- Weil, R.R., and Brady, N.C., 2016, *The Nature and Properties of Soils*, 15th edition: New York, Pearson, 1104 p.
- Wells, Ray, 2006, Oregon geology--Parent of the soil, foundation for the vine: U.S. Geological Survey Open-File Report 2006-1069: <http://pubs.usgs.gov/of/2006/1069/> (accessed November 2010).
- West, J.B., Ehleringer, J.R., and Cerling, T.E., 2007, Geography and vintage predicted by a novel GIS model of wine $\delta^{18}\text{O}$: *Journal of Agriculture and Food Chemistry*, v. 55, p. 7075-7083.
- Watkins, R.L. and Meyer, V.F., 1997, Vineyard site suitability in eastern California: *GeoJournal*, v. 43, i. 3, p. 229-239.
- White, R.E., 2003, *Soils for Fine Wines*: Oxford, University Press, 279 p.
- White, R.E., 2009, *Understanding Vineyard Soils*: Oxford, University Press, 230 p.
- Wilson, J.E., 1998, *Terroir: The Role of Geology, Climate, and Culture in the Making of French Wines*: London, Mitchell Beazley, 336 p.

- Wilson, M.J., 1999, The origin and formation of clay minerals in soils: past, present and future perspectives: *Clay Minerals*, v. 34, p. 7-25.
- Yang, Y., 2010, Trace element and rare earth element profiles in berry tissues of three grape cultivars: *American Journal of Enology and Viticulture*, v. 61, i. 3, p. 401-407.

Appendix A Vineyard Soil Descriptions

Elk Cove Vineyards, Clay Court Vineyard Block E

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults

Soil Series: Jory

Lat/long Coordinates: 45°19'31.7"N 122°50'05.7"W (45.325479, -122.834909)

UTM Coordinates: 512,947mE, 5,019,125mN

Physiographic Position: Hill crest

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 186 meters (611 feet)

Slope: 0-1 degree

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis, permanent cover between rows

Parent Material: Basalt (soil contains pisolites)

Bedrock: Basalt

- Ap 0-15 cm (0-6 in.); dark brown (7.5 YR 3/4), dark yellowish brown (10 YR 4/4) dry, silt loam; moderate medium granular to subangular blocky structure; very hard; very firm; slightly sticky and slightly plastic; common very fine roots; abundant fine concretions and dark staining; slightly acid (pH 6.4); gradual, wavy boundary.
- Bt1 15-90 cm (6-35 in.); dark reddish brown (5 YR 3/4), brown (7.5 YR 4/4) dry, silty clay; weak medium subangular blocky structure; very hard, very firm, very sticky and very plastic; common prominent clay films on faces of peds; abundant fine concretions; strongly acid (pH 5.4); augured at 44 cm.
- Bt2 90-115 cm (35-45 in.); dark red (2.5 YR 3/6), brown (7.5 YR 4/4) dry, silty clay; weak medium subangular blocky structure; 10% gravel (basalt); hard, very firm, sticky and plastic; common faint clay films on faces of peds and interstitial pores; abundant fine concretions; strongly acid (pH 5.4); augured.
- Bt3 115-150+ cm (45-59+ in.); reddish brown (2.5 YR 5/4), dark reddish brown (5 YR 3/4) dry, clay; moderate medium subangular blocky structure; hard, firm, sticky and plastic; common distinct clay films on faces of peds; abundant fine concretions; strongly acid (pH 5.1); augured.

Figure 61. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Elk Cove Vineyards, Clay Court Vineyard Block E soil.

Figure 62. Elk Cove Vineyards, Clay Court Vineyard Block E soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Bt3.

Elk Cove Vineyards, Roosevelt Estate Vineyard

Taxonomic Classification: Fine, mixed, superactive, mesic Ultic Haploxeralfs – Fine, mixed, superactive, mesic Ultic Palexeralfs (previously Fine-loamy, mixed, active, mesic Ultic Haploxeralfs)

Soil Series: Goodin – Melbourne (previously Willakenzie)

Lat/long Coordinates: 45°24'52.1"N 123°11'08.8"W (45.414466, -123.185770)

UTM Coordinates: 485,460mE, 5,029,012mN

Physiographic Position: Summit

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 190 meters (623 feet)

Slope: 0-1 degree

Aspect: West

Vegetation: Pinot Noir Vineyard on trellis, cultivated between rows

Parent Material: Coast Range marine sediments (soil contains muscovite mica and quartz sand)

Bedrock: Spencer Formation

- Ap 0-15 cm (0-6 in.); brown (10 YR 5/3), brown (10 YR 5/3) dry, silt loam; moderate medium subangular blocky structure; very hard, very firm, slightly sticky and slightly plastic; common very fine roots; strongly acid (pH 5.4); clear, wavy boundary; krotovina.
- AB 15-25 cm (6-10 in.); yellowish brown (10 YR 5/4), brown (7.5 YR 5/3) dry, silt loam; moderate medium subangular blocky structure; extremely hard, extremely firm, sticky and plastic; strongly acid (pH 5.5); abrupt, wavy boundary.
- Bt1 25-36 cm (10-14 in.); yellowish brown (10 YR 5/4), yellowish brown (10 YR 5/4) dry, silty clay loam; moderate medium subangular blocky structure; extremely hard, extremely firm, very sticky and very plastic; few faint clay films on faces of peds; strongly acid (pH 5.4); abrupt, wavy boundary.
- Bt2 36-64 cm (14-25 in.); yellowish red (5 YR 4/6), brown (7.5 YR 4/4) dry, clay; moderate medium subangular blocky structure; very hard, very firm, very sticky and very plastic; few large roots; common distinct clay films on faces of peds and interstitial pores; strongly acid (pH 5.4); augered at 45 cm.
- Bt3 64-84 cm (25-33 in.); dark reddish brown (5 YR 3/4), brown (7.5 YR 4/4) dry, silty clay; moderate medium subangular blocky structure; hard, firm, very sticky and very plastic; few large roots; few faint clay films on faces of peds; strongly acid (pH 5.1); augered.

- Bt4 84-110 cm (33-43 in.); reddish yellow (7.5 YR 6/6), yellow (10 YR 7/6) dry, silty clay loam; moderate medium subangular blocky structure; firm, very sticky and very plastic; few very faint clay films on faces of peds; secondary colors, gray (10 YR 6/1) and pale yellow (2.5 Y 8/4) dry; very strongly acid (pH 4.9); augered.
- C1 110-144 cm (43-57 in.); brownish yellow (10 YR 6/6), yellow (10 YR 7/8) dry, silty clay loam; moderate fine subangular blocky structure; firm, slightly sticky and slightly plastic; secondary colors, gray (7.5 YR 5/1) and very pale brown (10 YR 8/4) dry; very strongly acid (pH 4.9); augered.
- C2 144-161 cm (57-63 in.); strong brown (7.5 YR 5/8), yellowish brown (10 YR 5/6) dry, silty clay loam; single grain to massive structure; loose, friable, nonsticky and nonplastic (wet); very strongly acid (pH 4.9); augered.
- Cr 161+ cm (63+ in.); brownish yellow (10YR 6/8), pale yellow (2.5 Y 8/3) dry, silty clay loam; single grain to massive structure; loose, friable, slightly sticky and slightly plastic; secondary colors, pale brown (10 YR 6/3) and brownish yellow (10 YR 6/6) dry; very strongly acid (pH 4.7); augered (loose weathered sandstone).

Figure 63. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Elk Cove Vineyards, Roosevelt Estate Vineyard soil.

Figure 64. Elk Cove Vineyards, Roosevelt Estate Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - AB, Green - Bt1, Black - Bt2, Yellow - Bt3, Orange - Bt4.

Elk Cove Vineyards, Five Mountain Vineyard

Taxonomic Classification: Fine-silty, mixed, active, mesic Ultic Haploxeralfs

Soil Series: Laurelwood

Lat/long Coordinates: 45°26'55.3"N 123°02'11.6"W (45.448694, -123.036566)

UTM Coordinates: 497,134mE, 5,032,795mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 110 meters (362 feet)

Slope: Slight

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis, permanent cover between rows

Parent Material: Basalt (soil contains pisolites)

Bedrock: Basalt

Ap 0-30 cm (0-12 in.); yellowish brown (10 YR 5/4), yellowish brown (10 YR 5/4) dry, silt loam; weak fine subangular blocky structure; hard; firm; slightly sticky and slightly plastic; common very fine roots; abundant fine concretions; moderately acid (pH 5.7); clear, wavy boundary.

- Bt1 30-61 cm (12-24 in.); dark yellowish brown (10 YR 3/4), yellowish brown (10 YR 5/4) dry, silty clay loam; moderate medium subangular blocky structure; hard, firm, very sticky and plastic; common distinct clay films on faces of peds; few fine concretions and dark staining; moderately acid (pH 6.0); gradual, wavy boundary.
- Bt2 61-114 cm (24-45 in.); dark yellowish brown (10 YR 4/4), yellowish brown (10 YR 5/4) dry, silty clay loam; moderate medium subangular blocky structure; hard, firm, very sticky and very plastic; few faint clay films on faces of peds and interstitial pores; few fine concretions; moderately acid (pH 5.8); augered.
- Bt3 114-171+ cm (45-67+ in.); dark brown (10 YR 3/3), dark yellowish brown (10 YR 4/4) dry, silty clay loam; moderate medium subangular blocky structure; very sticky and very plastic; few faint clay films on faces of peds; few fine concretions and rock fragments; strongly acid (pH 5.5); augered.

Figure 65. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Elk Cove Vineyards, Five Mountain Vineyard soil.

Figure 66. Elk Cove Vineyards, Five Mountain Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Bt3.

Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults (previously Fine, mixed, active, mesic Xeric Haplohumults)

Soil Series: Jory (identified as Nekia)

Lat/long Coordinates: 45°17'16.4"N 123°01'49.7"W (45.287902, -123.030467)

UTM Coordinates: 497,608mE, 5,014,932mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 150 meters (493 feet)

Slope: 10 degrees

Aspect: North?

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt (soil contains pisolites)

Bedrock: Basalt

Ap 0-18 cm (0-7 in.); reddish brown (5 YR 4/4), reddish brown (7.5 YR 4/4) dry, silty clay; weak fine subangular blocky structure; very firm; sticky and plastic; many fine roots; many fine concretions; moderately acid (pH 5.6); abrupt, wavy boundary.

- Bt1 18-33 cm (7-13 in.); dark reddish brown (5 YR 3/3), dark brown (7.5 YR 4/4) dry, silty clay; weak medium subangular blocky structure; very firm, very sticky and very plastic; common distinct clay films on faces of peds; few coarse concretions; strongly acid (pH 5.5); abrupt, wavy boundary.
- Bt2 33-43 cm (13-17 in.); dark reddish brown (2.5 YR 3/4), yellowish red (5 YR 4/6) dry, silty clay; weak very fine subangular blocky structure; firm, sticky and plastic; common distinct clay films on faces of peds; few fine concretions; strongly acid (pH 5.2); abrupt, wavy boundary.
- Cr 43+ cm (17+ in.); yellowish red (5 YR 4/6) dry, clay loam; >75 percent basalt rock fragments.

Figure 67. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c soil.

Figure 68. Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Cr.

Willakenzie Estate Winery, Aliette Vineyard Block 2b

Taxonomic Classification: Fine, mixed, superactive, mesic Ultic Palexeralfs – Fine, mixed, superactive, mesic Ultic Haploxeralfs (previously Fine-loamy, mixed, active, mesic Ultic Haploxeralfs)

Soil Series: Melbourne – Goodin (previously Willakenzie)

Lat/long Coordinates: 45°21'28.6"N 123°08'39.7"W (45.357946, -123.144353)

UTM Coordinates: 489,560mE, 5,023,434mN

Physiographic Position: Upland

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 185 meters (604 feet)

Slope: 2-3 degrees

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis, permanent cover fescue between rows

Parent Material: Sandstone (soil contains muscovite mica and quartz sand)

Bedrock: Pittsburg Bluff Sandstone

A/E 0-26 cm (0-10 in.); brown (7.5 YR 4/4), yellowish brown (10 YR 5/4) dry, loam; moderate medium subangular blocky structure; very firm; slightly sticky and slightly plastic; many fine roots; strongly acid (pH 5.4); gradual, wavy boundary.

- AB 26-35 cm (10-14 in.); dark brown (7.5 YR 3/4), yellowish brown (10 YR 5/4) dry, loam; moderate medium subangular blocky structure; very firm; slightly sticky and slightly plastic; few fine roots; few faint clay films on faces of peds; moderately acid (pH 5.9); gradual, wavy boundary.
- Bt1 35-100 cm (14-39 in.); dark brown (7.5 YR 3/4), dark yellowish brown (10 YR 4/6) dry, clay loam; moderate medium subangular blocky structure; extremely firm, very sticky and very plastic; few distinct clay films on faces of peds; moderately acid (pH 5.3); gradual, wavy boundary; charcoal pieces; auger.
- Bt2 100-150 cm (39-60 in.); dark reddish brown (5 YR 3/4), strong brown (7.5 YR 4/6) with yellowish red (5 YR 5/6) dry, clay; moderate medium subangular blocky structure; very firm, very sticky and very plastic; few faint clay films on faces of peds; few fine concretions; strongly acid (pH 5.4); gradual, wavy boundary; auger.
- Bt3 150+ cm (60+ in.); yellowish red (5 YR 4/6) clay loam, strong brown (5 YR 4/6) dry; moderate medium subangular blocky structure; very firm, sticky and plastic; few distinct clay films on faces of peds; sandstone parent material rock fragments; moderately acid (pH 5.7); auger.

Figure 69. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Willakenzie Estate Winery, Alette Vineyard Block 2b soil.

Figure 70. Willakenzie Estate Winery, Aliette Vineyard Block 2b soil pit horizon textures determined by pipette analysis. Red - A/E, Blue - AB, Green - Bt1, Black - Bt2, Yellow - Bt3.

Willakenzie Estate Winery, Terres Basses Vineyard

Taxonomic Classification: Fine, smectitic, mesic Vertic Haploxerolls (previously Very-fine, smectitic, mesic Vertic Haploxerolls)

Soil Series: Witham (previously Hazelair)

Lat/long Coordinates: 45°21'28.6"N 123°08'39.7"W (45.357946, -123.144353)

UTM Coordinates: 488,693mE, 5,022,723mN

Physiographic Position: Foot slope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 90 meters (293 feet)

Slope: 10 degrees

Aspect: West-Northwest

Vegetation: Pinot Noir Vineyard on trellis, permanent cover between rows

Parent Material: Missoula Flood sediments and Coast Range marine sediments (soil contains quartz sand)

Bedrock: Shale

Ap 0-25 cm (0-10 in.); very dark grayish brown (10 YR 3/2), brown (10 YR 5/3) dry, silty clay loam; weak medium granular to subangular blocky structure; hard; firm;

very sticky and very plastic; few fine roots; strongly acid (pH 5.4); abrupt, wavy boundary.

- AB 25-36 cm (10-14 in.); brown (10 YR 4/3), brown (10 YR 5/3) dry, silty clay loam; weak medium subangular blocky structure; hard; firm; very sticky and very plastic; common fine roots; moderately acid (pH 5.9); abrupt, wavy boundary.
- Bg1 36-65 cm (14-26 in.); dark gray (5 YR 4/1), brown (10 YR 5/3) dry, clay; moderate medium subangular blocky structure; very hard, very firm, very sticky and very plastic; common distinct clay films on faces of peds and interstitial pores; common fine prominent redoximorphic features, yellowish red (5 YR 4/6) and yellowish red (5 YR 4/6) dry; moderately acid (pH 5.3); abrupt, wavy boundary.
- Bg2 65-86 cm (26-34 in.); dark gray (5 YR 4/1), brown (10 YR 5/3) dry, clay loam; moderate medium subangular blocky structure; very hard, very firm very sticky and very plastic; common distinct clay films on faces of peds and interstitial pores; common fine prominent redoximorphic features, dark yellowish brown (10 YR 4/4) and yellowish red (5 YR 5/6) dry; few fine concretions; strongly acid (pH 5.4); abrupt, wavy boundary.
- Cg 86-102 cm (34-40 in.); yellowish brown (10 YR 5/4) clay loam, dark yellowish brown (10 YR 4/4) dry; weak fine subangular blocky structure; very hard, very firm, sticky and plastic; rock fragments and dark staining; moderately acid (pH 5.7); augered.
- R 102-118+ cm (40-47+ in.); shale rock fragments and dark staining; augered.

Figure 71. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Willakenzie Estate Winery, Terres Basses Vineyard soil.

Figure 72. Willakenzie Estate Winery, Terres Basses Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - AB, Green - Bg1, Black - Bg2.

Chehalem, Stoller Vineyards

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults

Soil Series: Jory

Lat/long Coordinates: 45°14'55.8"N 123°04'20.4"W (45.248827, -123.072347)

UTM Coordinates: 494,327mE, 5,010,596mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 145 meters (475 feet)

Slope: 1 degree

Aspect: Southeast

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt (soil contains pisolites)

Bedrock: Basalt

- Ap 0-10 cm (0-4 in.); brown (7.5 YR 4/4), dark yellowish brown (10 YR 4/4) dry, silt loam; strong fine subangular blocky structure; very firm; slightly sticky and slightly plastic; many fine roots; few fine concretions; moderately acid (pH 5.6); clear, smooth boundary.
- Bt1 10-60 cm (4-24 in.); brown (7.5 YR 3/3), dark yellowish brown (10 YR 4/4) dry, silt loam; moderate fine subangular blocky structure; firm, sticky and plastic; few faint clay films on faces of peds; few fine concretions; moderately acid (pH 5.4); krotovina.
- Bt2 60-100 cm (24-39 in.); dark reddish brown (5 YR 3/3), dark yellowish brown (10 YR 4/4) dry, silt loam; weak fine subangular blocky to loose structure; friable, sticky and plastic; few faint clay films on faces of peds; few fine concretions; strongly acid (pH 5.4); auger.
- Bt3 100-135 cm (39-53 in.); dark yellowish brown (10 YR 4/4), dark yellowish brown (10 YR 4/4) dry, silt loam; weak, fine subangular blocky to single grain, loose structure; friable, slightly sticky, slightly plastic <10 percent rock fragments; very few faint clay films on faces of peds; few fine concretions; moderately acid (pH 5.5); refusal.

Figure 73. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Chehalem, Stoller Vineyards soil.

Figure 74. Chehalem, Stoller Vineyards soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Bt3.

Chehalem, Ridgecrest Vineyard

Taxonomic Classification: Fine-loamy, mixed, active, mesic Aquultic Haploxeralfs (previously Fine-loamy, mixed, active, mesic Ultic Haploxeralfs)

Soil Series: Wellsdale (previously Willakenzie)

Lat/long Coordinates: 45°22'03.9"N 123°04'44.8"W (45.367757, -123.079108)

UTM Coordinates: 493,802mE, 5,023,809mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 195 meters (638 feet)

Slope: 10 degrees

Aspect: East

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Sandstone (soil contains quartz sand)

Bedrock: Sandstone

- Ap 0-25 cm (0-10 in.); yellowish brown (10 YR 5/4), yellowish brown (10 YR 5/4) dry, silt loam; weak fine granular structure; firm, nonsticky and nonplastic; many fine roots; strongly acid (pH 5.5); clear, smooth boundary.
- Bt1 25-65 cm (10-26 in.); strong brown (7.5 YR 4/6), dark yellowish brown (10 YR 4/4) dry, silt loam; moderate fine subangular blocky structure; firm, sticky and plastic; common faint clay films on faces of peds; moderately acid (pH 5.6); charcoal.
- Bt2 65-115 cm (26-45 in.); strong brown (7.5 YR 4/6), dark yellowish brown (10 YR 5/4) dry, clay loam; moderate fine subangular blocky structure; firm, sticky and plastic; <10 percent rock fragments; strongly acid (pH 5.3); auger.
- C1 115-200 cm (45-79 in.); strong brown (7.5 YR 5/6) and red (2.5 YR 4/8), strong brown (7.5 YR 5/6) and light yellowish brown (2.5 Y 7/4) dry, loam; single grain fine structure; friable, sticky and plastic; 10 percent rock fragments; very few faint clay films on faces of peds; dark staining; strongly acid (pH 5.1); auger.
- C2 200-220+ cm (79-87+ in.); reddish yellow (7.5 YR 6/8) and olive gray (5 Y 4/2), strong brown (7.5 YR 5/8) and light yellowish brown (2.5 Y 6/4) dry, loam; single grain to weak structure; <10 percent rock fragments; dark staining; very strongly acid (pH 5.0); auger.

Figure 75. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Chehalem, Ridgecrest Vineyard soil.

Figure 76. Chehalem, Ridgecrest Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - C1, Yellow - C2.

Chehalem, Corral Creek Vineyards Mid North Block

Taxonomic Classification: Fine-silty, mixed, active, mesic Ultic Haploxeralfs

Soil Series: Laurelwood

Lat/long Coordinates: 45°18'45.0"N 122°54'58.8"W (45.312503, -122.916342)

UTM Coordinates: 506,557mE, 5,017,665mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 114 meters (373 feet)

Slope: 1 degree

Aspect: Northwest

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Loess & Basalt (soil contains pisolites)

Bedrock: Basalt

- Ap 0-35 cm (0-14 in.); brown (7.5 YR 4/3), brown (10 YR 4/3) dry, silt loam; massive to weak fine subangular blocky structure; very firm; nonsticky and nonplastic; many fine roots; very few faint clay films on the faces of peds; few medium to coarse concretions; moderately acid (pH 5.7); clear, wavy boundary.
- Bt 35-55 cm (14-22 in.); brown (7.5 YR 4/4), brown (7.5 YR 4/4) dry, silty clay loam; moderate medium subangular blocky structure; very firm, very sticky and very plastic; common distinct clay films on faces of peds and interstitial pores; few medium to coarse concretions; moderately acid (pH 5.9); abrupt, wavy boundary.
- Cr 55-65 cm (22-26 in.); dark yellowish brown (10 YR 4/6), brown (7.5 YR 5/4) dry, silty clay loam; sticky and plastic; 50 percent rock fragments; few faint clay films on faces of peds and interstitial pores; moderately acid (pH 5.7); auger.
- R 65+ cm (26+ in.); >75 percent basalt rock fragments.

Figure 77. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Chehalem, Corral Creek Vineyards Mid North Block soil.

Figure 78. Chehalem, Corral Creek Vineyards Mid North Block soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt, Green - Cr.

Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults – Fine, mixed, active, mesic Xeric Haplohumults (previously Fine, mixed, active, mesic Xeric Palehumults)

Soil Series: Jory – Gelderman (previously Jory)

Lat/long Coordinates: 45°17'40.1"N 123°02'35.8"W (45.294480, -123.043289)

UTM Coordinates: 496,695mE, 5,015,462mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 220 meters (719 feet)

Slope: 0 degrees

Aspect: South - Southeast

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt (soil contains abundant pisolites)

Bedrock: Basalt

- Ap 0-20 cm (0-8 in.); dark brown (7.5 YR 3/2), brown (7.5 YR 4/3) dry, silt loam; moderate medium granular to subangular blocky structure; firm, slightly sticky and slightly plastic; many fine roots; abundant fine to coarse concretions; moderately acid (pH 5.6); clear, wavy boundary; krotovina.
- A/B 20-50 cm (8-20 in.); dark brown (7.5 YR 3/3), brown (7.5 YR 4/3) dry, silt loam; moderate medium subangular blocky structure; firm, sticky and plastic; very few faint clay films on faces of peds; abundant fine to coarse concretions; moderately acid (pH 5.8); clear wavy boundary; krotovina.
- Bt1 50-80 cm (20-31 in.); dark reddish brown (5 YR 3/3), brown (7.5 YR 4/3) dry, silt loam; strong medium subangular blocky; firm, very sticky and very plastic; common distinct clay films on faces of peds and interstitial pores; abundant fine to coarse concretions; moderately acid (pH 5.8); auger.
- Bt2 80-140 cm (31-55 in.); reddish brown (5 YR 4/4), brown (7.5 YR 4/4) dry, silty clay; strong medium platy to subangular blocky structure; firm, very sticky and very plastic; common distinct clay films on faces of peds and interstitial pores; abundant fine to coarse concretions; strongly acid (pH 5.5); auger.
- Bt3 140-195+ cm (55-77+ in.); yellowish red (5 YR 4/6), brown (7.5 YR 4/4) dry, silty clay; strong medium subangular blocky structure; firm, very sticky and very plastic; many distinct clay films on faces of peds and interstitial pores; abundant fine to coarse concretions; strongly acid (pH 5.3); charcoal; auger.

Figure 79. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North soil.

Figure 80. Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - A/B, Green - Bt1, Black - Bt2, Yellow - Bt3.

Lange Estate Winery and Vineyards, Yamhill Vineyard

Taxonomic Classification: Fine-loamy, mixed, active, mesic Aquultic Haploxeralfs – Fine-loamy, mixed, active, mesic Ultic Haploxeralfs – Fine, mixed, superactive, mesic Aquultic Haploxeralfs (previously Fine-loamy, mixed, active, mesic Ultic Haploxeralfs)

Soil Series: Wellsdale – Willakenzie – Dupee (previously Willakenzie)

Lat/long Coordinates: 45°19'28.0"N 123°09'00.8"W (45.324441, -123.150227)

UTM Coordinates: 488,316mE, 5,018,802mN

Physiographic Position: Summit

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 138 meters (453 feet)

Slope: 0 degrees

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Sandstone (soil contains muscovite mica and quartz sand)

Bedrock: Sandstone

- Ap 0-26 cm (0-10 in.); dark brown (7.5 YR 3/3), yellowish brown (10 YR 5/4) dry, loam; moderate fine granular to subangular blocky structure; many fine roots; few coarse sandstone concretions; moderately acid (pH 5.8); clear, wavy boundary.
- Bt1 26-42 cm (10-17 in.); brownish yellow (10 YR 6/6), light yellowish brown (10 YR 6/4) dry, clay loam; moderate medium subangular blocky structure; extremely hard, extremely firm, very sticky and very plastic; common distinct clay films on faces of peds; few coarse sandstone concretions; strongly acid (pH 5.5); abrupt, wavy boundary.
- Bt2 42-75 cm (17-30 in.); strong brown (7.5 YR 4/6), strong brown (7.5 YR 5/6) dry, clay loam; moderate medium subangular blocky structure; firm, sticky and plastic; common distinct clay films on faces of peds; few coarse sandstone concretions; <10 percent rock fragments; strongly acid (pH 5.3); abrupt, wavy boundary; krotovina.
- Bg 75-110 cm (30-43 in.); yellowish brown (10 YR 5/8), reddish brown (2.5 YR 5/8), red (2.5 YR 5/8), and pale yellow (5 Y 7/3), brown (7.5 YR 5/4), reddish yellow (5 YR 6/6) and pink (5 YR 7/3) dry, clay loam; weak coarse platy to fine subangular blocky structure; friable, nonsticky and nonplastic; 10 percent rock fragments; very few faint clay films on faces of peds; mottling in plates; very strongly acid (pH 4.9); clear, wavy boundary; auger.

- Cr1 110-160 cm (43-63 in.); pale yellow (5 Y 7/4), very pale brown (10 YR 7/4) dry, sandy loam; single grain to weak fine subangular blocky structure; loose, nonsticky and nonplastic; very strongly acid (pH 5.0); clear, wavy boundary; auger.
- Cr2 160-200+ cm (63-79+ in.); yellowish brown (10 YR 5/8), very pale brown (10 YR 7/4) dry, sandy loam; single grain to weak fine subangular blocky structure; loose, nonsticky and nonplastic; strongly acid (pH 5.1); auger.

Figure 81. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Lange Estate Winery and Vineyards, Yamhill Vineyard soil.

Figure 82. Lange Estate Winery and Vineyards, Yamhill Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Bg, Yellow - Cr1, Orange - Cr2.

Lange Estate Winery and Vineyards, Freedom Hill Vineyard

Taxonomic Classification: Fine, mixed, active, mesic Xeric Haplohumults

Soil Series: Bellpine

Lat/long Coordinates: 44°52'38.2"N 123°17'11.2"W (44.877285, -123.286436)

UTM coordinates: 477,378mE, 4,969,362mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 105 meters (344 feet)

Slope: 2 degrees

Aspect: East

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Sandstone (soil contains muscovite mica and quartz sand)

Bedrock: Sandstone

Ap 0-34 cm (0-13 in.); dark brown (7.5 YR 3/3), brown (10 YR 5/4) dry, silt loam; moderate very fine subangular blocky structure; firm, very sticky and very plastic; many fine roots; few distinct clay films on faces of peds; few coarse sandstone concretions; strongly acid (pH 5.4); abrupt, wavy boundary; krotovina.

- Bt 34-63 cm (13-25 in.); dark brown (7.5 YR 3/4), light yellowish brown (10 YR 6/4) dry, silty clay loam; moderate medium subangular blocky structure; firm, sticky and plastic; common distinct clay films on faces of peds; few coarse sandstone concretions; <10 percent sandstone paragravel; strongly acid (pH 5.3); abrupt, wavy boundary.
- Cr1 63-102 cm (25-40 in.); strong brown (7.5 YR 4/6) and light reddish brown (2.5 YR 6/3), light yellowish brown (10 YR 6/4) and yellowish red (5 YR 4/6) dry, silt loam; massive to strong medium platy structure; friable, nonsticky and nonplastic; strongly acid (pH 5.2); clear, wavy boundary; auger.
- Cr2 102-157+ cm (40-62 in.); strong brown (7.5 YR 5/8), yellowish red (5 YR 4/6) and pink (2.5 YR 8/4), brownish yellow (10 YR 6/6), pale yellow (2.5 Y 8/2) and dark yellowish brown (10 YR 4/6) dry, sandy loam; massive to strong medium platy structure; friable, nonsticky and nonplastic; dark staining on ped surfaces; strongly acid (pH 5.1); auger.

Figure 83. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Lange Estate Winery and Vineyards, Freedom Hill Vineyard soil.

Figure 84. Lange Estate Winery and Vineyards, Freedom Hill Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt, Green - Cr1, Black - Cr2.

Rex Hill, Sims Vineyard Block 2

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults

Soil Series: Jory

Lat/long Coordinates: 45°16'49.0"N 123°02'32.6"W (45.280286, -123.042398)

UTM Coordinates: 496,773mE, 5,013,885mN

Physiographic Position: Summit

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 200 meters (656 feet)

Slope: 5 degrees

Aspect: West

Vegetation: Pinot Noir Vineyard on trellis, permanent fescue cover crop

Parent Material: Basalt (soil contains pisolites)

Bedrock: Basalt

Ap 0-12 cm (0-5 in.); brown (7.5 YR 4/4), brown (7.5 YR 4/4) dry, clay loam; moderate fine granular to subangular blocky structure; extremely firm, slightly sticky and slightly plastic; many fine roots; abundant medium concretions; strongly acid (pH 5.2); abrupt, wavy boundary.

- Bt1 12-50 cm (5-20 in.); reddish brown (5 YR 4/4), strong brown (7.5 YR 4/6) dry, clay; moderate medium subangular blocky structure; extremely firm, sticky and plastic; many prominent clay films on interstitial pores; few coarse concretions and dark staining on peds; strongly acid (pH 5.4); clear, wavy boundary.
- Bt2 50-84 cm (20-33 in.); dark reddish brown (5 YR 3/4), brown (7.5 YR 4/4) dry, clay; moderate medium subangular blocky structure; extremely firm, sticky and plastic; common distinct clay films on faces of peds; few coarse concretions; dark staining on peds; <10 percent rock fragments; moderately acid (pH 5.6); clear, wavy boundary; auger.
- Bt3 84-130+ cm (33-51+ in.); dark reddish brown (2.5 YR 3/4), brown (7.5 YR 4/4) dry, clay; weak medium subangular blocky structure; firm, sticky and plastic; common faint clay films on faces of peds; few coarse concretions; dark staining on ped surfaces; <10 percent rock fragments; very strongly acid (pH 5.0); auger.

Figure 85. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Rex Hill, Sims Vineyard Block 2 soil.

Figure 86. Rex Hill, Sims Vineyard Block 2 soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Bt3.

Rex Hill, Estate Vineyard Block 12

Taxonomic Classification: Fine-silty, mixed, active, mesic Ultic Haploxeralfs

Soil Series: Laurelwood

Lat/long Coordinates: 45°18'50.3"N 122°55'08.3"W (45.313974, -122.918974)

UTM Coordinates: 506,366mE, 5,017,831mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 94 meters (308 feet)

Slope: 2 degrees

Aspect: Southeast

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt and loess (soil contains pisolites)

Bedrock: Basalt

:

Ap 0-25 cm (0-10in.); brown (10 YR 4/3), brown (10 YR 5/3) dry, silt loam; moderate fine subangular blocky structure; firm, non-sticky and non-plastic; many fine roots; few distinct clay films on faces of peds; few coarse concretions; moderately acid (pH 5.8); abrupt, wavy boundary; krotovina.

- Bt1 25-100 cm (10-39 in.); dark brown (10 YR 3/3), yellowish brown (10 YR 5/4) dry, silty clay loam; strong medium subangular blocky structure; firm, very sticky and very plastic; many prominent clay films on faces of peds and on interstitial pores; few coarse concretions; moderately acid (pH 5.6); abrupt, wavy boundary; auger started at 70 cm.
- Bt2 100-130 cm (39-51 in.); strong brown (7.5 YR 4/6) and dark yellowish brown (10 YR 4/6), yellowish brown (10 YR 5/4) and yellowish red (5 YR 5/8) dry, silt loam; strong medium subangular structure; firm, very sticky and very plastic; few medium roots; common distinct clay films on faces of peds; few coarse concretions; <10 percent basalt gravel; strongly acid (pH 5.4); abrupt, wavy boundary; auger.
- R 130+ cm (51+ in.); dark coatings on weathered basalt bedrock; refusal.

Figure 87. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Rex Hill, Estate Vineyard Block 12 soil.

Figure 88. Rex Hill, Estate Vineyard Block 12 soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2.

Rex Hill, Jacob-Hart Vineyard Block 1

Taxonomic Classification: Fine, mixed, superactive, mesic Pachic Ultic Argixerolls
(previously Fine-loamy, mixed, superactive, mesic Ultic Haploxerolls)

Soil Series: Dixonville (previously Steiwer)

Lat/long Coordinates: 45°20'14.3"N 123°01'18.1"W (45.337304, -123.021697)

UTM Coordinates: 498,298mE, 5,020,413mN

Physiographic Position: Toe of ancient landslide

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 96 meters (315 feet)

Slope: 2 degrees

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Colluvium (soil contains pisolites)

Bedrock: Basalt

Ap 0-30 cm (0-12 in.); dark brown (7.5 YR 3/2), brown (10 YR 5/3) dry, silt loam; moderate medium subangular blocky structure; <10 percent gravel; firm, sticky and plastic; many fine roots; common distinct clay films on faces of peds; moderately acid (pH 5.7); gradual, wavy boundary; lots of worms.

- At 30-78 cm (12-31 in.); dark reddish brown (5 YR 3/2), brown (10 YR 5/3) dry, silt loam; moderate medium subangular blocky structure; firm, very sticky and very plastic; many distinct clay films on faces of peds; moderately acid (pH 5.7); abrupt, wavy boundary.
- Bt 78-145 cm (31-57 in.); dark brown (7.5 YR 3/3), brown (10 YR 4/3) dry, silty clay loam; moderate medium subangular blocky structure; <10 percent basalt gravel; firm, very sticky and very plastic; many distinct clay films on faces of peds; few fine concretions; moderately acid (pH 5.7); clear, wavy boundary; auger.
- Cr 145-185+ cm (57-73+ in.); red (2.5 YR 4/6), very pale brown (10 YR 7/3) dry, clay loam; 75 percent basalt gravel; very firm; moderately acid (pH 6.0); auger; basalt saprolite.

Figure 89. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Rex Hill, Jacob-Hart Vineyard Block 1 soil.

Figure 90. Rex Hill, Jacob-Hart Vineyard Block 1 soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - At, Green - Bt, Black - Cr.

Rex Hill, Jacob-Hart Vineyard Block 5

Taxonomic Classification: Fine, mixed, superactive, mesic Pachic Ultic Argixerolls

(previously Fine, mixed, superactive, mesic Pachic Ultic Haploxerolls)

Soil Series: Dixonville (previously Yamhill)

Lat/long Coordinates: 45°20'25.5"N 123°01'11.6"W (45.340408, -123.019881)

UTM Coordinates: 498,465mE, 5,020,755mN

Physiographic Position: Shoulder/summit of ancient landslide

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 115 meters (377 feet)

Slope: 5 degrees

Aspect: South

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Colluvium (soil contains few pisolites)

Bedrock: Basalt

Apr 0-60 cm (0-24 in.); dark brown (7.5 YR 3/2) and brown (7.5 YR 4/4), brown (10 YR 4/3) dry, silt loam; massive to moderate medium subangular blocky structure; very firm, sticky and plastic; many fine roots; common faint clay films on faces of peds; 20 percent basalt gravel; slightly acid (pH 6.1); clear, wavy boundary; krotovina.

- Bt 60-80 cm (24-32 in.); brown (10 YR 4/3), brown (10 YR 4/3) dry, silty clay; moderate medium subangular blocky structure; very firm, sticky and plastic; few medium roots; many distinct clay films on faces of peds; <10 percent basalt gravel; moderately acid (pH 5.9); clear, wavy boundary; auger.
- Btg 80-138+ cm (32-54+ in.); strong brown (7.5 YR 4/6) and light reddish brown (2.5 YR 6/3), dark yellowish brown (10 YR 4/4) dry, clay; moderate medium subangular blocky structure; firm, very sticky and very plastic; very few faint clay films on faces of peds; redoximorphic features, pale red (2.5 YR 6/2) and light brownish gray (10 YR 6/2) dry; few coarse concretions; dark staining on gravel and on ped faces; <10 percent basalt gravel; moderately acid (pH 5.7); refusal.

Figure 91. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Rex Hill, Jacob-Hart Vineyard Block 5 soil.

Figure 92. Rex Hill, Jacob-Hart Vineyard Block 5 soil pit horizon textures determined by pipette analysis. Red - Apr, Blue - Bt, Green - Btg.

Ken Wright Cellars, Nysa Vineyard Midblock

Taxonomic Classification: Fine, mixed, active, mesic Xeric Palehumults

Soil Series: Jory

Lat/long Coordinates: 45°15'57.6"N 123°02'54.0"W (45.265995, -123.048344)

UTM Coordinates: 496,282mE, 5,012,292mN

Physiographic Position: Summit

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 217 meters (712 feet)

Slope: 0 degrees

Aspect: East

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt colluvium (soil contains pisolites)

Bedrock: Basalt

Ap 0-35 cm (0-14 in.); dark brown (7.5 YR 3/3), brown (7.5 YR 4/3) dry, silt loam; strong medium subangular blocky structure; firm, slightly sticky and slightly plastic; many fine roots; many prominent clay films on faces of peds; abundant coarse concretions; strongly acid (pH 5.4); clear, wavy boundary.

- Bt1 35-80 cm (14-32 in.); dark reddish brown (5 YR 3/4), brown (7.5 YR 4/4) dry, silty clay loam; strong medium subangular blocky structure; firm, sticky and plastic; common distinct clay films on faces of peds; abundant fine to coarse concretions; 20 percent rock fragments and dark staining; strongly acid (pH 5.5); clear, wavy boundary.
- Bt2 80-118 cm (31-47 in.); dark reddish brown (5 YR 3/3), brown (7.5 YR 4/4) dry, clay loam; weak medium subangular blocky structure; firm, sticky and plastic; few distinct clay films on faces of peds; few fine concretions; 70 percent rock fragments and dark staining; strongly acid (pH 5.5); clear, wavy boundary; auger.
- Cr 118-150+ cm (47-59+ in.); brown (7.5 YR 4/4) and dark grayish brown (2.5 YR 4/2), pale yellow (2.5 YR 7/4) and brownish yellow (10 YR 6/6) dry, loam; single grain to weak fine subangular blocky structure; firm, nonsticky and nonplastic; >75 percent basalt rock fragments and dark staining; strongly acid (pH 5.4); auger.

Figure 93. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Ken Wright Cellars, Nysa Vineyard Midblock soil.

Figure 94. Ken Wright Cellars, Nysa Vineyard Midblock soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt1, Green - Bt2, Black - Cr.

Ken Wright Cellars, Abbott Claim Vineyard

Taxonomic Classification: Fine-loamy, mixed, active, mesic Aquultic Haploxeralfs – Fine-loamy, mixed, active, mesic Ultic Haploxeralfs – Fine, mixed, superactive, mesic Aquultic Haploxeralfs (previously Fine-loamy, mixed, active, mesic Ultic Haploxeralfs)
 Soil Series: Wellsdale – Willakenzie – Dupee (previously Willakenzie)
 Lat/long Coordinates: 45°17'29.8"N 123°07'01.1"W (45.291616, -123.116963)
 UTM Coordinates: 490,797mE, 5,015,352mN
 Physiographic Position: Summit/Shoulder
 MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)
 Elevation: 145 meters (476 feet)
 Slope: 2 degrees
 Aspect: South
 Vegetation: Pinot Noir Vineyard on trellis (possibly ripped)
 Parent Material: Sandstone (soil contains abundant muscovite and quartz sand)
 Bedrock: Sandstone

Ap 0-24 cm (0-9 in.); dark brown (10 YR 3/3), yellowish brown (10 YR 5/4) dry, loam; weak fine subangular blocky structure; firm, slightly sticky and slightly plastic; many fine roots; slightly acid (pH 6.4); abrupt, wavy boundary; krotovina.

- Bt1 24-70 cm (9-28 in.); strong brown (7.5 YR 4/6) and brown (10 YR 4/3), strong brown (7.5 YR 5/6) and brown (7.5 YR 4/4) dry, clay; moderate medium subangular blocky structure to massive; firm, very sticky and very plastic; few medium roots; few distinct clay films on faces of peds; very few fine sandstone concretions; moderately acid (pH 5.6); abrupt, wavy boundary; auger.
- Bw 70-140 cm (28-55 in.); dark reddish brown (5 YR 3/4) and yellowish red (5 YR 5/8), reddish yellow (7.5 YR 6/6) and reddish yellow (7.5 YR 8/6) dry, sandy clay loam; single grain to weak fine subangular blocky structure; loose, slightly sticky and nonplastic; few medium roots; very few faint clay films on faces of peds and interstitial pores; very strongly acid (pH 4.9); abrupt, wavy boundary; auger.
- Cr1 140-150 cm (55-59 in.); strong brown (7.5 YR 5/8) and light greenish gray (GLEY 1 8/10Y), strong brown (7.5 YR 4/6) and pale yellow (2.5 Y 8/2) dry, sandy loam; single grain to fine granular structure; loose, nonsticky and nonplastic; few medium roots; very strongly acid (pH 4.7); abrupt, wavy boundary; auger.
- Cr2 150-215+ cm (59-85+ in.); reddish yellow (7.5 YR 6/8) and reddish yellow (7.5 YR 7/6), reddish yellow (7.5 YR 7/6) and very pale brown (10 YR 8/4) dry, loam; single grain to fine granular structure; loose, nonsticky and nonplastic; few medium roots; very strongly acid (pH 4.8); auger.

Figure 95. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Ken Wright Cellars, Abbott Claim Vineyard soil.

Figure 96. Ken Wright Cellars, Abbott Claim Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt, Green - Bw, Black - Cr1, Yellow - Cr2.

Ken Wright Cellars, Freedom Hill Vineyard

Taxonomic Classification: Fine, mixed, active, mesic Xeric Haplohumults (mapped as Fine, mixed, active, mesic Xeric Palehumults)

Soil Series: Bellpine (mapped as Jory)

Lat/long Coordinates: 44°52'31.2"N 123°17'38.3"W (44.875343, -123.293962)

UTM Coordinates: 476,874mE, 4,968,941mN

Physiographic Position: Midslope

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 142 meters (466 feet)

Slope: 2 degrees

Aspect: Southwest

Vegetation: Pinot Noir Vineyard on trellis, ripped

Parent Material: Sandstone (soil contains muscovite mica and quartz sand)

Bedrock: Sandstone

- Ap 0-15 cm (0-6 in.); brown (7.5 YR 4/3), yellowish brown (10 YR 5/4) dry, silt loam; moderate medium subangular blocky structure; firm, nonsticky and nonplastic; many fine roots; very few very fine sandstone concretions; moderately acid (pH 6.0); clear, wavy boundary.
- Bt 15-50 cm (13-20 in.); brown (7.5 YR 4/4), dark yellowish brown (10 YR 4/4) dry, clay loam; moderate medium subangular blocky structure; firm, sticky and plastic; many prominent clay films on faces of peds and interstitial pores; moderately acid (pH 5.6); clear, irregular boundary.
- Cr 50-75+ cm (20-30+ in.); light red (2.5 YR 7/6) and red (2.5 YR 4/6), dark yellowish brown (10 YR 4/6) and yellow (10 YR 7/6) dry, clay loam; moderate medium subangular blocky structure; firm, sticky and plastic; many prominent clay films on faces of peds and interstitial pores; 75 percent sandstone gravel; strongly acid (pH 5.3); auger.

Figure 97. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Ken Wright Cellars, Freedom Hill Vineyard soil.

Figure 98. Ken Wright Cellars, Freedom Hill Vineyard soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt, Green - Cr.

Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block

Taxonomic Classification: Loamy-skeletal, mixed, superactive, mesic Lithic Ultic Haploxerolls – Fine, mixed, superactive, mesic Pachic Ultic Argixerolls (previously Fine, mixed, superactive, mesic Pachic Ultic Haploxerolls)

Soil Series: Witzel – Dixonville (previously Yamhill)

Lat/long Coordinates: 45°09'22.9"N 123°17'30.2"W (45.156368, -123.291720)

UTM Coordinates: 477,053mE, 5,000,364mN

Physiographic Position: Summit

MAT/MAP: 11 degrees C (52 degrees F)/152 cm (60 in.)

Elevation: 204 meters (669 feet)

Slope: 2 degrees

Aspect: Southwest

Vegetation: Pinot Noir Vineyard on trellis

Parent Material: Basalt (Soil contains fine pisolites)

Bedrock: Basalt (Tillamook or Siletz?)

- Ap 0-10 cm (0-4 in.); very dark brown (7.5 YR 2.5/2), dark yellowish brown (10 YR 4/4), dry loam; strong fine subangular blocky structure; very firm, nonsticky and nonplastic; many fine roots; few faint clay films on faces of peds; abundant concretions; moderately acid (pH 6.0); clear, wavy boundary; krotovina.
- Bt 10-72 cm (4-23 in.); dark brown (7.5 YR 3/4), dark yellowish brown (10 YR 3/4) dry, silt loam; moderate medium subangular blocky structure; firm, sticky and plastic; common distinct clay films on faces of peds; 20 percent weathered basalt gravel; moderately acid (pH 6.0); krotovina; auger at 60 cm.
- Bw 72-121 cm (23-48 in.); brown (7.5 YR 4/3), brown (7.5 YR 4/3) dry, sandy loam; single grain to weak fine subangular blocky structure; loose, nonsticky and nonplastic; <10 percent weathered basalt gravel; slightly acid (pH 6.3); abrupt, wavy boundary; auger; saprolite.
- Cr 121-204+ cm (48-80+ in.); very dark grayish brown (10 YR 3/2), dark gray (7.5 YR 4/1) dry, loamy fine sand; single grain structure; loose, nonsticky and nonplastic; dark staining on ped surfaces; 25 percent weathered basalt gravel; neutral (pH 6.7); auger; saprolite; refusal.

Figure 99. Particle size cumulative weight percent curve as determined by pipette analysis for each horizon of Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block soil.

Figure 100. Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block soil pit horizon textures determined by pipette analysis. Red - Ap, Blue - Bt, Green - Bw, Black - Cr.

Appendix B Clay Mineralogy

XRD analyses performed by Reed Glasmann of Willamette Geological Service (descriptions in this Appendix are his direct words as quoted from his report unless in brackets). Clays were Mg-saturated by rinsing several times with 0.5N MgCl₂, then rinsing with distilled water. Clays were then K-saturated by washing several times with 1.0M KCl, then rinsing with 50% methanol solution. The Mg-saturated slides were analyzed after air drying, then solvated with ethylene glycol and re-scanned. The K-saturated slides were analyzed after air drying then rescanned after 6 hours in an 110C oven. The scan conditions were shortened to try to limit re-hydration during analysis, but some minor re-expansion of smectitic clays is evident in the patterns.

Elk Cove Vineyards, Clay Court Vineyard Block E

The ECCC [Elk Cove Clay Court] Bt₂ soil sample has a clay mineral assemblage that includes disordered kaolinite, illite, and hydroxy interlayered smectite (Figure 101). The smectitic phase shows significant resistance to expansion and collapse, indicating strong development of chloritic character due to the formation of interlayer sheets of Fe/Al hydroxy material. The kaolin phase probably includes a minor component of dehydrated halloysite, as suggested by the moderate peak in the range of 20 degrees 2-theta. The clay fraction also includes minor amounts of cristobalite. The Fe phase is

dominated by goethite. The sample is probably too illitic to have formed from volcanic parent materials, unless windblown mica was a component of the parent material.

Figure 101. XRD patterns for the Bt2 soil horizon from Elk Cove Vineyards, Clay Court Vineyard Block E.

Elk Cove Vineyards, Roosevelt Estate Vineyard

This sample [ECRV Bt2] (Figure 102) may be genetically related to the WETB [Willakenzie Estate, Terres Basses] soil, given the occurrence of smectitic clay and

general low abundance of mica. The smectitic component shows full expansion with glycol and the progressive collapse anticipated with K-saturation and heating; however, there is a definite chloritic intergrade component that causes a non-expansive 14A chlorite peak in the glycol pattern. This character persists in the K-air dry pattern, where a remnant 14A phase causes the asymmetric character of the partially collapsed smectite. With heating, the 14A peak loses clarity and shows as a very weak peak remaining as the smectite has collapsed to ca 10A. The 7.3A peak doesn't show much variation during the 4 treatments shown, perhaps some weak broadening during glycol solvation (probably due to interference from the glycol 002 smectite peak). The kaolinite phase is dominated by disordered kaolinite, but may include a minor component of dehydrated halloysite. The absence of intensification of the 10A peak after K-saturation suggests that vermiculite is not present in the sample.

This sample does not show much cristobalite and has quartz as the main silica phase. If the cristobalite is an indicator of prolonged weathering and possible accumulation of plant opal (or primary cementation in paleosols affected by volcanic ash), then the general absence of cristobalite may suggest a less severe weathering history. This is also suggested by the occurrence of fully expansive smectite and the generally weak development of hydroxy interlayered clays. Perhaps the lower abundance of mica reduced the potential for vermiculitic/chloritic intergrade formation relative to the more micaceous clay mineral assemblages seen in this first set of soils.

Elk Cove Vineyards, Five Mountain Vineyard

This sample [ECFM Bt3] is mineralogically almost identical to the ECCC [Elk Cove Clay Court] Bt2 sample (Figure 103). The clay mineral assemblage includes disordered kaolinite with a component of dehydrated halloysite, illite, and hydroxy interlayered smectite. It is possible that the smectitic component includes a bit of high

Figure 102. XRD patterns for the Bt2 soil horizon from Elk Cove Vineyards, Roosevelt Estate Vineyard.

charge smectite/vermiculite, as there is slight intensification of the 10A component after K-saturation. The smectite component resists complete collapse with heating and K-saturation and shows only weak expansion with glycol solvation. This is very characteristic behavior of hydroxy interlayered material (chloritic intergrade minerals). These chloritic intergrade clays are very common in Pacific Northwest soils that have a history of moderate weathering. The sample also contains a minor component of cristobalite and moderate amounts of goethite (probably both goethite and hematite).

Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c

The clay mineral assemblage of this sample [WEJH Bt2] contains kaolinite (dehydrated halloysite) and chloritic intergrade clays (generally non-expansive, resists complete collapse, no intensification of the 10A peak with K-saturation suggests an absence of vermiculite). The halloysite peak at ca 20 degrees 2-theta occurs and the sample shows abundant goethite (oxidized to hematite after oven drying). There is a minor cristobalite component. The sample looks a lot like the CWS Bt3 soil, but shows less cristobalite and is somewhat less illitic (Figure 104). Patterns of this character are common in buried paleosols from the southern Willamette Valley. This pattern is very similar to the ECFM [Elk Cove Five Mountain] Bt3 clay mineral assemblage.

Willakenzie Estate Winery, Aliette Vineyard Block 2b

This sample [WEAB Bt3] is the least illitic of the first 6 soils analyzed [Elk Cove,

Figure 103. XRD patterns for the Bt3 soil horizon from Elk Cove Vineyard, Fine Mountain Vineyard.

Willakenzie, and Chehalem soils were the first to be analyzed]. The illitic component has probably been degraded to kaolinite and vermiculite. With K-saturation, there is a component that shows complete collapse to 10A (this indicates vermiculite). There is also a component that resists expansion with glycol and collapse with K-saturation and heating (this is well-developed chloritic intergrade). This sample looks very similar to

Figure 104. XRD patterns for the Bt2 soil horizon from Willakenzie Estate Winery, The Jory Hills Vineyard Block 50c.

buried/exhumed paleosols developed on basaltic and sedimentary materials in the southern Willamette Valley (Jory profile). There is not much indication of dehydrated halloysite, as the peak at ca 20 degrees 2-theta is very subdued (Figure 105). Most likely the sample consists of disordered kaolinite and vermiculitic chloritic intergrade possibly derived from strong weathering of mica.

Figure 105. XRD patterns for the Bt3 soil horizon from Willakenzie Estate Winery, Alette Vineyard Block 2b.

Willakenzie Estate Winery, Terres Basses Vineyard

The WETB Bg1 sample is highly smectitic and shows no evidence of the formation of hydroxy interlayer chloritic layers. The smectitic component expands fully with glycol and shows progressive collapse with K-saturation and heating. The slight shoulder in the K-air dry pattern at 10A suggests that some vermiculitic material is

present (possibly a high-charge smectite component?) (Figure 106). The clay fraction contains only traces of mica and low amounts of kaolinitic clay. Instead of cristobalite, this sample shows minor amounts of quartz and very low amounts of Fe oxide (consistent with the gleyed color of the clay). It is hard for me to picture how this material might develop from a micaceous parent material without more significant preservation of mica

Figure 106. XRD patterns for the Bg1 soil horizon from Willakenzie Estate Winery, Terres Basses Vineyard.

in the clay fraction. This probably represents a much wetter location than the highly oxidized soils with chloritic intergrade and kaolinite. It may be that this soil developed from alteration of tuffaceous material and reflects Cascadian provenance.

Chehalem, Stoller Vineyards

The CWS Bt3 sample could be genetically related to the CWR sample, showing similar illite-kaolinite-hydroxy interlayered smectite clay mineralogy. The sample contains quite a bit of cristobalite and has a much more halloysitic appearance than the CWR sample as indicated by intensification of the peak at around 20 degrees 2-theta (Figure 107). The smectite component is less expansive than the CWR [Chehalem Winery Ridgecrest] soil and shows greater resistance to collapse with K-saturation and heating, suggesting greater development of the hydroxy interlayer material and more chloritic character. The weathering of this soil has not yet caused complete degradation of the mica component. The presence of the strong mica component suggests that this soil was not derived from basaltic parent material, but represents weathered micaceous sedimentary material. The fairly strong cristobalite component may reflect accumulation of plant opal in the Bt3 horizon or could result from precipitation of silica during prolonged dry summer conditions. Goethite is the primary Fe phase.

Chehalem, Ridgecrest Vineyard

CWR Bt2 - This soil is potentially genetically related to the CWCC [Chehalem

Figure 107. XRD patterns for the Bt3 soil horizon from Chehalem, Stoller Vineyard.

Winery Corral Creek] sample, showing fairly large amounts of illite in the clay fraction (Figure 108). However, in contrast to the CWCC sample, the chloritic intergrade component of this sample shows moderate expansion and collapse behavior that suggests incomplete hydroxy sheet development. The expansive component showed moderate expansion with glycol solvation and weak collapse with K-saturation. It did not show a strong collapse typical of non-hydroxy interlayered vermiculite, but showed progressive

collapse with heating that is more typical of hydroxy interlayered smectite. The "kaolinite" component does not show asymmetry development when K-saturated, further evidence that there is probably not much mixed-layered chlorite/vermiculite in this sample. The kaolinite must consist of very fine particles as the 7A peak is displaced to

Figure 108. XRD patterns for the Bt3 soil horizon from Chehalem, Ridgecrest Vineyard.

the left, typical of highly disordered kaolinite and some dehydrated halloysite. There is also a very minor amount of cristobalite in this sample. Goethite is the primary Fe phase.

Chehalem, Corral Creek Vineyards Mid North Block

CWCC Bt - This sample is the most illite-rich of the first group of soils [Elk Cove, Willakenzie, and Chehalem samples]. The clay mineral assemblage also contains non-expansive chloritic intergrade, suggesting mixed-layer chlorite/vermiculite. This phase does not expand with glycol solvation and resists complete collapse to 10Å with K-saturation and heating. The odd character of the "kaolinite" component also indicates mixed-layer chlorite/vermiculite, as the collapse of vermiculitic layers causes the 7Å component to drift towards 10Å, causing the broad shoulder seen to the left of the kaolinite 7Å peak (Figure 109). The vermiculite may have formed from degradation of the mica component, then experienced hydroxy interlayer chloritization during repeated wetting and drying cycles associated with soil weathering. The clay fraction also contains minor cristobalite that could be due to plant opal accumulating in the soil. Goethite is the primary Fe oxide.

Lange Estate Winery and Vineyards, Estate Vineyard Mia Block North

The remaining soil samples [Including LEM Bt3] were placed together at the bottom [of the report] because they share characteristics indicative of strongly weathered

Figure 109. XRD patterns for the Bt3 soil horizon from Chehalem, Corral Creek Vineyard.

material. All of the soils are dominated by disordered kaolinite with low amounts of illite and hydroxy-interlayered smectite-vermiculite (chloritic-intergrade clays). The goethite component is fairly ordered and produces a relatively intense peak (Figure 110). Some of the samples include minor amounts of gibbsite. These patterns look much like the Jory series, or deeply weathered "red-hill" soils that have been exposed to prolonged weathering for 100,000's years+. There is some indication of dehydrated halloysite in a

couple of the samples. The hydroxy interlayered material shows very weak expansion and strong resistance to collapse. These are highly pillared clays with lots of hydroxy Al-Fe interlayer material due to prolonged weathering.

Figure 110. XRD patterns for the Bt3 soil horizon from Lange Estate Winery and Vineyards, Estate Vineyard Mia block.

Lange Estate Winery and Vineyards, Yamhill Vineyard

LEY Bt2 - The remaining soil samples were placed together at the bottom [of the report] because they share characteristics indicative of strongly weathered material. All of the soils are dominated by disordered kaolinite with low amounts of illite and hydroxy-interlayered smectite-vermiculite (chloritic-intergrade clays) (Figure 111). The goethite component is fairly ordered and produces a relatively intense peak. Some of the samples include minor amounts of gibbsite. These patterns look much like the Jory series, or deeply weathered "red-hill" soils that have been exposed to prolonged weathering for 100,000's years+. There is some indication of dehydrated halloysite in a couple of the samples. The hydroxy interlayered material shows very weak expansion and strong resistance to collapse. These are highly pillared clays with lots of hydroxy Al-Fe interlayer material due to prolonged weathering.

Lange Estate Winery and Vineyards, Freedom Hill Vineyard

This sample has much the same mineralogical character as the KWFH [Ken Wright Freedom Hill] Bt soil clay, right down to the well-ordered goethite (Figure 112). The parent materials and weathering history of these 2 samples must be related.

Rex Hill, Sims Vineyard Block 2

LEY Bt2 - The remaining soil samples [including RHS2 Bt1] were placed together at the bottom [of the report] because they share characteristics indicative of

strongly weathered material. All of the soils are dominated by disordered kaolinite with low amounts of illite and hydroxy-interlayered smectite-vermiculite (chloritic-intergrade clays). The goethite component is fairly ordered and produces a relatively intense peak (Figure 113). Some of the samples include minor amounts of gibbsite. These patterns

Figure 111. XRD patterns for the Bt3 soil horizon from Lange Estate Winery and Vineyards, Yamhill Vineyard.

Figure 112. XRD patterns for the Bt3 soil horizon from Lange Estate Winery and Vineyards, Freedom Hill Vineyard.

look much like the Jory series, or deeply weathered "red-hill" soils that have been exposed to prolonged weathering for 100,000's years+. There is some indication of dehydrated halloysite in a couple of the samples. The hydroxy interlayered material shows very weak expansion and strong resistance to collapse. These are highly pillared clays with lots of hydroxy Al-Fe interlayer material due to prolonged weathering.

Figure 113. XRD patterns for the Bt3 soil horizon from Rex Hill, Sims Vineyard.

Rex Hill, Estate Vineyard Block 12

RH12 Bt1 - This is the "odd-ball" sample of the set [Lange, Rex Hill, and Ken Wright]. The sample is strongly illitic and shows a mixture of chloritic intergrade, hydroxy-interlayered vermiculite, and mixed-layer kaolinite-vermiculite or smectite. The 0.7-nm peak does lots of funny things with the various sample treatments (Figure 114). There is a component of expandable clay that gives a broad shoulder in the glycol

treatment. With K-saturation, a peak between the illite 1.0-nm and kaolin 0.7-nm positions appears, suggesting mixed-layer vermiculite/kaolinite. This peak stays at about the same position with heating and drying, indicating a vermiculite-based mixed layer, as drying and collapse of smectite would have made this peak shift more towards illite. It is possible that this soil was derived from clays altered by intrusion of gabbro or basalt and

Figure 114. XRD patterns for the Bt3 soil horizon from Rex Hill, Estate Vineyard Block 12.

represents a weathered, baked sedimentary section. This is about the only way to get the strong illite, unless the illite is associated with loess material off the Columbia (Missoula) River. Not much goethite in this sample, plenty of weatherable mica. Looks like loess to me.

Rex Hill, Jacob-Hart Vineyard Block 1

RHJHB1 Bt - This soil sample includes a component of non-hydroxy-interlayered smectitic clay, as indicated by the expansion and collapse of the 1.5-nm component (Figure 115). There is no indication of strongly developed chloritic-intergrade clay (no remnant 1.4-nm component after heating) and no strong plateauing of the 1.0-nm peak in the direction of chlorite that would indicate irregular interstratified smectite/chlorite or chlorite/vermiculite. The disordered kaolinite peak shows no shifting with heat treatment, indicating an absence of mixed layer kaolinite/smectite. There may be some vermiculite in this sample, but I need the K-54%RH pattern to be sure. Goethite is present, but in lower amounts than the previous 2 patterns. This sample is probably less weathered than the prior 2 samples, based upon the moderate preservation of un-encumbered expansion of the smectite phase, and the absence of strong hydroxy-interlayering of the smectite and/or vermiculite component.

Rex Hill, Jacob-Hart Vineyard Block 5

RHJHB5 Bt - This soil is genetically related to the RHJH B1 sample, but looks

Figure 115. XRD patterns for the Bt3 soil horizon from Rex Hill, Jacob-Hart Vineyard Block 1.

like it represents a wetter site, perhaps deeper in the profile. The smectitic component is more strongly expressed, showing strong expansion and collapse (Figure 116). This suggests even less hydroxy-interlayering, much less pronounced effect of repeated wetting and drying cycles. This sample must maintain more uniform moisture content through the year that helps preserve the smectite expansion. This suggests that the sample could be from a younger geomorphic surface, a deeper part of a somewhat older surface,

or represent mixed alluvium where expansive clay has been added to older parent material. I see patterns like this on the Mary's River floodplain, where old eroded material from the foothills has been mixed with smectite from basalt that is derived from stream down cutting into freshly weathered bedrock. The absence of illitic clays would be consistent with derivation from basaltic parent materials.

Figure 116. XRD patterns for the Bt3 soil horizon from Rex Hill, Jacob-Hart Vineyard Block 5.

Ken Wright Cellars, Nysa Vineyard Midblock

The KWM and KWN patterns are fundamentally different, with the KWN pattern suggesting a much higher degree of weathering with essentially non-expansive chloritic intergrade clays, kaolin, and goethite as the dominant components of the clay fraction. The KWM sample has abundant expansive clay (smectite) and is much less kaolinitic (Figure 117).

Ken Wright Cellars, Abbott Claim Vineyard

The remaining soil samples [including KWAC Bt] were placed together at the bottom [of the report] because they share characteristics indicative of strongly weathered material. All of the soils are dominated by disordered kaolinite with low amounts of illite and hydroxy-interlayered smectite-vermiculite (chloritic-intergrade clays). The goethite component is fairly ordered and produces a relatively intense peak (Figure 118). Some of the samples include minor amounts of gibbsite. These patterns look much like the Jory series, or deeply weathered "red-hill" soils that have been exposed to prolonged weathering for 100,000's years+. There is some indication of dehydrated halloysite in a couple of the samples. The hydroxy interlayered material shows very weak expansion and strong resistance to collapse. These are highly pillared clays with lots of hydroxy Al-Fe interlayer material due to prolonged weathering.

Figure 117. XRD patterns for the Bt3 soil horizon from Ken Wright Cellars, Nysa Vineyard.

Figure 118. XRD patterns for the Bt3 soil horizon from Ken Wright Cellars, Abbott Claim Vineyard.

Ken Wright Cellars, Freedom Hill Vineyard

KWFH Bt - This sample peeled badly and is missing the K-54%RH sample. I'll try to re-run that treatment. The sample shows moderate expansion with glycol and intensification of the 1.0-nm with K-saturation and heating; however, there is a remnant of the 1.4-nm peak and a broad slope extending to the 1.0-nm peak (Figure 119). This indicates that the expansive clay is moderately interlayered by Al-Fe-oxides and indicates

Figure 119. XRD patterns for the Bt3 soil horizon from Ken Wright Cellars, Freedom Hill Vineyard.

a higher degree of weathering than the prior sample. The sample contains minor amounts of illitic clay, disordered kaolinite, hydroxy-interlayered smectite and vermiculite, and very weak development of chlorite. The goethite component is well expressed. This is a moderately weathered soil - not completely battered to the point that expandable clays are destroyed. Probably a bit wetter than some sites, keeping the smectitic clay component in a reduced state and preventing "pillaring" of the expansive clay.

Ken Wright Cellars, Meredith Mitchell Vineyard Martha Block

The clay mineral assemblage includes minor amounts of smectitic clay that shows expansion with glycol and classic behavior with K-saturation and different humidity treatments (Figure 120). This indicates that the smectite is not strongly interlayered with Al-Fe-hydroxy material (i.e., not strongly weathered or exceptionally old). There is also

Figure 120. XRD patterns for the Bt3 soil horizon from Ken Wright Cellars, Meredith Mitchell Vineyard Martha block.

minor vermiculite, reflected in the intensification of the 1.0-nm peak with K-saturation. It appears that this sample also has some mixed layer expansive material, possibly kaolinite/smectite, as indicated by the movement of the K-110 dry kaolin peak towards the 1.0-nm illite peak. As the smectite component decreases in d-spacing with heat treatment, the composite peak of the kaolinite/smectite mixed layer clay moves in the direction of the illite peak. The absence of a 1.4-nm peak with the KCl dry treatment indicates an absence of chlorite - so no strong chloritic intergrade clays - again, not a highly weathered, oxidized soil due to the absence of clays typical with long-term weathering. Looks like the kaolin component may include some dehydrated halloysite. Goethite is not strongly developed - another indicator of reduced weathering compared to some of the more Fe-rich soils.

Appendix C Soil Chemistry Data

The soil chemistry was analyzed at Apex Laboratories using Environmental Protection Agency (EPA) method 6020A for ICP-MS, 6010C for ICP-AES, and 9056A for ion chromatography were used (EPA, 1998; EPA, 2007; and EPA 2007c). These methods were preceded by acid digestion using EPA method 3051a (EPA, 2007a). Soil chemistry has been split into macronutrients, micronutrients, and trace elements according to the literature for vineyard soils (White, 2009). Because multiple horizons were analyzed for these elements, each vineyard site is presented here as a mean and maximum concentration of all horizons. From this data, the mean for each element separated by soil parent material is presented in the results section.

Using this appendix, one can see the mean and maximum soil element concentration and the mean, maximum, and standard deviation for the vineyards with the three main soil parent materials used for pinot noir vineyards in the Willamette Valley: volcanic, marine sediments, and loess/volcanic (Table 113 to Table 120). For individual soil pit values, see the results chapter for each winery.

Table 113. Mean and maximum macronutrient concentration for vineyard sites with volcanic and marine sediment parent material.

Vineyard		P	K	Ca	Mg	S
ECCC	Mean	1290	366	1130	1020	173
	Max	1740	591	2420	1910	191
WEJH	Mean	1450	342	695	535	212
	Max	1580	685	1110	951	274
CWS	Mean	1380	1170	1620	1540	176
	Max	2380	1800	2570	1850	309
LEM	Mean	1390	687	1250	1390	221
	Max	1750	936	1790	1590	270
RHS2	Mean	1210	226	752	591	165
	Max	1560	515	892	907	213
KWN	Mean	1580	736	1150	1210	160
	Max	2200	1030	1160	1550	212
<i>Volcanic</i>	<i>Mean</i>	<i>1380</i>	<i>588</i>	<i>1100</i>	<i>1050</i>	<i>184</i>
	<i>SD</i>	<i>128</i>	<i>350</i>	<i>341</i>	<i>414</i>	<i>25.6</i>
	<i>Max Mean</i>	<i>1870</i>	<i>926</i>	<i>1660</i>	<i>1460</i>	<i>245</i>
	<i>Max SD</i>	<i>341</i>	<i>472</i>	<i>716</i>	<i>435</i>	<i>46.0</i>
Vineyard		P	K	Ca	Mg	S
ECRV	Mean	388	487	1170	1520	130
	Max	637	841	1760	1950	158
WEA	Mean	485	769	1440	1170	158
	Max	594	1030	2240	1390	245
CWR	Mean	541	457	1780	1880	174
	Max	1040	902	3050	2840	174
LEY	Mean	367	1270	1140	2610	154
	Max	415	1790	1500	4670	154
KWAC	Mean	462	430	824	743	135
	Max	521	668	1610	955	135
LEFH	Mean	540	677	1470	1740	131
	Max	672	828	2260	2260	159
KWFH	Mean	518	831	2010*	1970*	151
	Max	614	1210	2100*	2270*	151
<i>Marine</i>	<i>Mean</i>	<i>472</i>	<i>703</i>	<i>1410</i>	<i>1660</i>	<i>147</i>
	<i>SD</i>	<i>70.5</i>	<i>296</i>	<i>403</i>	<i>599</i>	<i>16.4</i>
	<i>Max Mean</i>	<i>642</i>	<i>1040</i>	<i>2070</i>	<i>2330</i>	<i>168</i>
	<i>Max SD</i>	<i>195</i>	<i>373</i>	<i>526</i>	<i>1200</i>	<i>35.9</i>

Table 114. Mean and maximum macronutrient concentrations for vineyard sites with loess/volcanic and other soil parent material.

Vineyard		P	K	Ca	Mg	S
ECFM	Mean	825	1060	1360	2380	176
	Max	1550	1430	1560	3380	176
CWCC	Mean	1030	1030	1690	2350	148
	Max	1310	1560	2100	2930	148
RH12	Mean	1090	1220	1550	2500	155
	Max	1730	1560	1680	3100	193
<i>Loess/volcanic</i>	<i>Mean</i>	<i>982</i>	<i>1100</i>	<i>1530</i>	<i>2410</i>	<i>160</i>
	<i>SD</i>	<i>139</i>	<i>102</i>	<i>166</i>	<i>79.4</i>	<i>14.6</i>
	<i>Max Mean</i>	<i>1530</i>	<i>1520</i>	<i>1780</i>	<i>3140</i>	<i>172</i>
	<i>Max SD</i>	<i>211</i>	<i>75</i>	<i>284</i>	<i>227</i>	<i>22.7</i>
Vineyard		P	K	Ca	Mg	S
WETB (Missoula Floods)	Mean	537	758	4365	2398	183
	Max	758	970	6050	3330	270
RHJH1 (Landslide Deposit)	Mean	663	786	2005	2015	162
	Max	1040	1390	2650	2600	216
RHJH5 (Landslide Deposit)	Mean	392	403	3443	1870	152
	Max	515	718	3640	2030	152
KWM (Coast Range Basalt)	Mean	538	1060	11100	17800	226
	Max	873	2330	21900	22300	292

Table 115. S Mean and maximum micronutrient concentration for vineyard sites with volcanic parent material.

Vineyard		Fe	Al	Cl	Co	Cu	Mn	Mo	Na	Ni	Zn
ECCC	Mean	45000	17300	ND	22.0	16.3	1270	0.692	195	5.54	30.3
	Max	61800	18200	ND	27.9	18.2	1730	0.692	210	8.36	46.5
WEJH	Mean	54800	16500	13.8	21.8	17.6	1390	ND	178	5.23	35.6
	Max	60000	19100	17.6	28.4	19.8	2580	ND	206	6.76	47.9
CWS	Mean	32500	18900	17.7	42.0	19.7	2130	0.612	190	6.54	86.7
	Max	60500	19500	17.7	60.3	33.4	3190	0.612	201	7.25	111
LEM	Mean	43000	17300	ND	19.3	18.4	1900	ND	174	7.672	49.9
	Max	45700	19300	ND	21.1	22.3	2560	ND	199	9.25	63.1
RHS2	Mean	54100	15400	ND	34.6	15.9	1690	ND	172	4.36	36.7
	Max	65300	17800	ND	41.2	20.6	2510	ND	184	6.49	53.9
KWN	Mean	51200	21900	ND	26.6	15.7	1250	ND	182	6.32	47.3
	Max	60100	23100	ND	34.7	20.3	2590	ND	216	7.20	60.4
<i>Volcanic</i>	<i>Mean</i>	<i>46800</i>	<i>17900</i>	<i>15.8</i>	<i>27.7</i>	<i>17.3</i>	<i>1600</i>	<i>0.652</i>	<i>182</i>	<i>5.94</i>	<i>47.8</i>
	<i>SD</i>	<i>8470</i>	<i>2280</i>	<i>2.76</i>	<i>8.85</i>	<i>1.59</i>	<i>362</i>	<i>0.0566</i>	<i>8.99</i>	<i>1.16</i>	<i>20.5</i>
	<i>Max Mean</i>	<i>58900</i>	<i>19500</i>	<i>17.7</i>	<i>35.6</i>	<i>22.4</i>	<i>2530</i>	<i>0.652</i>	<i>203</i>	<i>7.55</i>	<i>63.8</i>
	<i>Max SD</i>	<i>6770</i>	<i>1880</i>	<i>0.0707</i>	<i>13.9</i>	<i>5.53</i>	<i>465</i>	<i>0.0566</i>	<i>11.0</i>	<i>1.05</i>	<i>24.0</i>

Table 116. Mean and maximum macronutrient concentration for vineyard sites with marine sediment parent material.

Vineyard		Fe	Al	Cl	Co	Cu	Mn	Mo	Na	Ni	Zn
ECRV	Mean	25900	16300	19.6	5.56	14.2	299	ND	195	3.70	20.7
	Max	43600	20500	29.8	13.2	22.2	971	ND	223	6.45	33.3
WEA	Mean	25400	11100	ND	7.50	13.7	398	ND	159	5.95	28.8
	Max	32000	14400	ND	12.0	17.0	751	ND	188	7.00	33.8
CWR	Mean	35600	22700	ND	19.1	14.2	732	ND	209	7.55	61.6
	Max	49000	36000	ND	24.6	19.2	1470	ND	267	15.9	85.8
LEY	Mean	26300	10900	11.1	6.98	13.0	272	ND	190	6.78	36.0
	Max	36900	13200	11.1	10.2	16.9	549	ND	222	11.9	53.5
KWAC	Mean	17400	7860	20.8	2.72	6.38	170	ND	134	1.75	12.2
	Max	30400	11800	31.5	7.37	8.44	552	ND	141	2.42	17.8
LEFH	Mean	30800	9660	ND	10.3	17.0	353	0.634	148	6.423	30.9
	Max	38700	11300	ND	16.0	19.2	584	0.678	189	9.67	36.7
KWFH	Mean	36500	19200	ND	18.6	42.0	690	ND	962	10.2	45.9
	Max	59700	35100	ND	29.5	114	869	ND	3330	24.0	87.6
<i>Marine</i>	<i>Mean</i>	<i>28300</i>	<i>14000</i>	<i>17.2</i>	<i>10.1</i>	<i>17.2</i>	<i>416</i>	<i>0.634</i>	<i>285</i>	<i>6.06</i>	<i>33.7</i>
	<i>SD</i>	<i>6630</i>	<i>5520</i>	<i>5.27</i>	<i>6.37</i>	<i>11.4</i>	<i>214</i>	<i>0</i>	<i>300</i>	<i>2.72</i>	<i>16.3</i>
	<i>Max Mean</i>	<i>41500</i>	<i>20300</i>	<i>24.1</i>	<i>16.1</i>	<i>31.0</i>	<i>821</i>	<i>0.678</i>	<i>651</i>	<i>11.0</i>	<i>49.8</i>
	<i>Max SD</i>	<i>10300</i>	<i>10800</i>	<i>11.3</i>	<i>8.04</i>	<i>36.9</i>	<i>330</i>	<i>0</i>	<i>1180</i>	<i>7.14</i>	<i>27.3</i>

Table 117. Mean and maximum macronutrient concentration for vineyard sites with loess/volcanic and other soil parent material.

Vineyard		Fe	Al	Cl	Co	Cu	Mn	Mo	Na	Ni	Zn
ECFM	Mean	28300	18700	ND	15.1	13.5	703	ND	187	8.80	42.8
	Max	35400	20900	ND	20.1	15.3	1330	ND	220	10.5	56.9
CWCC	Mean	34600	25700	ND	16.0	18.6	664	ND	234	16.9	54.3
	Max	37600	36400	ND	19.7	28.8	1210	ND	281	35.3	66.0
RH12	Mean	29500	13800	ND	17.3	14.3	1003	ND	195	9.43	50.4
	Max	41000	15700	ND	22.3	16.8	1530	ND	201	10.2	63.1
<i>Loess/volcanic</i>	<i>Mean</i>	<i>30800</i>	<i>19400</i>	<i>ND</i>	<i>16.1</i>	<i>15.5</i>	<i>790</i>	<i>ND</i>	<i>205</i>	<i>11.7</i>	<i>49.2</i>
	<i>SD</i>	<i>3350</i>	<i>5980</i>	<i>ND</i>	<i>1.13</i>	<i>2.73</i>	<i>186</i>	<i>ND</i>	<i>25.3</i>	<i>4.51</i>	<i>5.81</i>
	<i>Max Mean</i>	<i>38000</i>	<i>24300</i>	<i>ND</i>	<i>20.7</i>	<i>20.3</i>	<i>1360</i>	<i>ND</i>	<i>234</i>	<i>18.7</i>	<i>62.0</i>
	<i>Max SD</i>	<i>2820</i>	<i>10800</i>	<i>ND</i>	<i>1.40</i>	<i>7.40</i>	<i>162</i>	<i>ND</i>	<i>41.8</i>	<i>14.4</i>	<i>4.65</i>
Vineyard		Fe	Al	Cl	Co	Cu	Mn	Mo	Na	Ni	Zn
WETB	Mean	25500	13700	ND	12.9	42.8	416	ND	183	11.7	43.7
	Max	28600	18400	ND	24.4	64.4	849	ND	289	16.3	58.7
RHJH1	Mean	36100	13400	24	23.7	16.8	851	ND	222	8.06	48.7
	Max	51100	19500	24	28.0	19.3	1230	ND	299	8.89	63.2
RHJH5	Mean	43100	13600	ND	48.0	14.9	1710	ND	192	6.06	61.8
	Max	46000	14900	ND	67.4	15.8	2350	ND	212	8.03	64.1
KWM	Mean	81800	38700	ND	42.7	128	1560	ND	855	21.0	95.3
	Max	92100	41200	ND	48.4	146	1810	ND	1560	27.3	104

Table 118. Mean and maximum macronutrient concentration for vineyard sites with volcanic parent material.

Vineyard		As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
ECCC	Mean	2.10	103	0.800	0.226	25.6	0.0421	10.2	0.733	10.4	137
	Max	2.78	190	0.828	0.267	30.0	0.0448	10.9	0.733	13.2	178
WEJH	Mean	1.26	249	0.808	0.281	27.1	ND	9.67	ND	12.3	156
	Max	1.62	430	0.910	0.346	31.8	ND	11.4	ND	15.4	195
CWS	Mean	1.75	235	1.44	0.419	16.9	ND	12.1	0.569	14.3	189
	Max	2.40	310	1.52	0.558	18.3	ND	15.3	0.569	16.8	219
LEM	Mean	1.96	194	0.718	0.263	24.0	ND	11.3	0.564	18.5	127
	Max	2.75	281	0.770	0.301	26.6	ND	12.4	0.604	24.8	139
RHS2	Mean	0.944	106	0.826	0.384	16.9	ND	9.26	0.630	8.86	135
	Max	1.72	168	1.05	0.475	23.1	ND	12.0	0.759	11.1	171
KWN	Mean	1.31	264	1.04	0.634	15.8	ND	7.90	0.668	16.3	133
	Max	1.61	467	1.05	0.787	22.0	ND	11.6	0.909	23.2	150
<i>Volcanic</i>	<i>Mean</i>	<i>1.55</i>	<i>192</i>	<i>0.938</i>	<i>0.368</i>	<i>21.0</i>	<i>0.0421</i>	<i>10.1</i>	<i>0.633</i>	<i>13.4</i>	<i>146</i>
	<i>SD</i>	<i>0.451</i>	<i>71.6</i>	<i>0.269</i>	<i>0.150</i>	<i>5.04</i>	<i>0</i>	<i>1.50</i>	<i>0.0707</i>	<i>3.63</i>	<i>23.0</i>
	<i>Max Mean</i>	<i>2.15</i>	<i>308</i>	<i>1.02</i>	<i>0.456</i>	<i>25.3</i>	<i>0.0448</i>	<i>12.3</i>	<i>0.715</i>	<i>17.4</i>	<i>175</i>
	<i>Max SD</i>	<i>0.562</i>	<i>122</i>	<i>0.270</i>	<i>0.196</i>	<i>5.11</i>	<i>0</i>	<i>1.57</i>	<i>0.136</i>	<i>5.48</i>	<i>29.3</i>

Table 119. Mean and maximum macronutrient concentration for vineyard sites with marine sediment parent material

	Vineyard	As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
ECRV	Mean	4.40	96.1	0.568	0.125	16.7	0.0461	7.38	0.579	18.3	42.3
	Max	6.17	205	0.661	0.174	21.6	0.0511	8.68	0.673	23.0	60.0
WEA	Mean	3.71	96.2	0.568	0.152	16.3	ND	7.02	ND	14.6	47.7
	Max	4.92	125	0.711	0.233	19.4	ND	8.89	ND	18.4	59.4
CWR	Mean	1.34	207	0.817	0.338	13.9	ND	9.17	0.578	23.8	95.5
	Max	2.34	328	1.220	0.916	23.8	ND	16.2	0.594	46.2	127
LEY	Mean	2.78	96.4	0.580	0.110	18.8	ND	6.82	0.517	21.6	43.2
	Max	3.41	116	0.855	0.119	21.4	ND	7.88	0.517	36.9	55.5
KWAC	Mean	3.11	62.8	0.444	0.156	10.7	ND	9.03	ND	8.06	36.0
	Max	8.99	92.2	0.790	0.192	17.2	ND	11.5	ND	11.3	54.9
LEFH	Mean	9.78	75.6	0.723	0.134	20.1	0.0412	8.98	ND	24.3	47.3
	Max	11.8	91.4	0.888	0.148	27.3	0.0412	11.9	ND	38.6	68.8
KWFH	Mean	4.00	142	0.700	0.240	20.3	ND	6.94	ND	127	74.8
	Max	6.03	201	0.868	0.319	24.9	ND	9.46	ND	452	150
<i>Marine</i>	<i>Mean</i>	<i>4.16</i>	<i>111</i>	<i>0.629</i>	<i>0.179</i>	<i>16.7</i>	<i>0.0436</i>	<i>7.91</i>	<i>0.558</i>	<i>33.9</i>	<i>55.2</i>
	<i>SD</i>	<i>2.67</i>	<i>48.9</i>	<i>0.125</i>	<i>0.0816</i>	<i>3.47</i>	<i>0.00343</i>	<i>1.09</i>	<i>0.0355</i>	<i>41.4</i>	<i>21.6</i>
	<i>Max Mean</i>	<i>6.24</i>	<i>166</i>	<i>0.856</i>	<i>0.300</i>	<i>22.2</i>	<i>0.0462</i>	<i>10.6</i>	<i>0.595</i>	<i>89.5</i>	<i>82.2</i>
	<i>Max SD</i>	<i>3.25</i>	<i>85.8</i>	<i>0.181</i>	<i>0.279</i>	<i>3.41</i>	<i>0.00700</i>	<i>2.86</i>	<i>0.0780</i>	<i>160</i>	<i>39.3</i>

Table 120. Mean and maximum macronutrient concentration for vineyard sites with loess/volcanic and other soil parent material.

Vineyard		As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
ECFM	Mean	2.54	133	0.701	0.214	20.9	0.0426	8.78	ND	16.3	90.3
	Max	3.51	244	0.827	0.244	24.1	0.0426	9.15	ND	20.1	127
CWCC	Mean	2.33	316	0.847	0.379	19.4	ND	10.6	0.686	23.8	101
	Max	3.02	669	1.02	0.741	20.6	ND	12.5	0.686	34.1	111
RH12	Mean	5.83	177	0.751	0.217	18.7	ND	22.1	ND	22.1	89.8
	Max	12.2	246	0.975	0.277	20.5	ND	47.1	ND	28.2	130
<i>Loess/volcanic</i>	<i>Mean</i>	<i>3.57</i>	<i>209</i>	<i>0.766</i>	<i>0.270</i>	<i>19.7</i>	<i>0.0426</i>	<i>13.8</i>	<i>0.686</i>	<i>20.7</i>	<i>93.6</i>
	<i>SD</i>	<i>1.96</i>	<i>95.7</i>	<i>0.0740</i>	<i>0.0945</i>	<i>1.14</i>	<i>ND</i>	<i>7.24</i>	<i>ND</i>	<i>3.89</i>	<i>6.23</i>
	<i>Max Mean</i>	<i>6.24</i>	<i>386</i>	<i>0.941</i>	<i>0.421</i>	<i>21.7</i>	<i>0.0426</i>	<i>22.9</i>	<i>0.686</i>	<i>27.5</i>	<i>123</i>
	<i>Max SD</i>	<i>5.16</i>	<i>245</i>	<i>0.101</i>	<i>0.278</i>	<i>2.05</i>	<i>ND</i>	<i>21.01</i>	<i>ND</i>	<i>7.03</i>	<i>10.2</i>
Vineyard		As	Ba	Be	Cd	Cr	Hg	Pb	Se	Sr	V
WETB	Mean	6.08	177	0.617	0.1	12.0	ND	6.94	0.560	54.1	45.5
	Max	8.97	250	0.748	0.132	12.8	ND	9.00	0.638	81.5	58.5
RHJH1	Mean	2.64	303	0.813	0.236	16.9	ND	14.3	ND	25.8	134
	Max	6.33	630	0.942	0.259	20.2	ND	25.9	ND	39.4	187
RHJH5	Mean	0.937	227	1.07	0.345	12.8	0.0418	9.68	0.749	33.8	186
	Max	1.04	290	1.15	0.413	13.4	0.0418	9.89	0.776	36.0	187
KWM	Mean	0.384	183	0.870	0.800	36.6	ND	2.39	0.621	337	223
	Max	0.426	214	0.954	1.11	40.7	ND	3.91	0.621	555	255

Appendix D Grape Chemistry Data

All data from Apex Laboratories for the grape samples analyzed from vineyards in this study. Grapes were collected from vines, frozen, and delivered to the lab. The grape juice was analyzed using EPA method 6020A for ICP-MS (EPA, 1998). These methods were preceded by acid digestion using EPA method 3051a (EPA, 2007a). Analyst notes include B-02: Analyte detected in an associated blank at a level between one-half the minimum reporting limit (MRL) and the MRL, J: Estimated Result. Result detected below the lowest point of the calibration curve, but above the specified minimum detection limit (MDL), Q-29: Recovery for Lab Control Spike (LCS) is above the upper control limit. Data may be biased high, and Q-41: Estimated Results. Recovery of Continuing Calibration Verification sample above upper control limit for this analyte. Results are likely biased high. Quality control data follows (Table 121 to Table 140).

Table 121. Chemical analysis using ICP-MS for the grape sample from Elk Cove Clay Court (ECCC) Vineyard. ND - Non-detect.

Lab ID A4A0576-02 ECCC						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	106	211	mg/kg	4	
Hg	ND	0.0423	0.0846	mg/kg	10	Q-41
Sr	0.973	0.211	0.423	mg/kg	4	
Al	ND	106	211	mg/kg	4	
As	ND	2.11	8.46	mg/kg	4	
Ba	ND	2.11	4.23	mg/kg	4	
Be	ND	2.11	4.23	mg/kg	4	
Cd	ND	2.11	4.23	mg/kg	4	
Ca	ND	106	211	mg/kg	4	
Cr	ND	2.11	4.23	mg/kg	4	
Co	ND	2.11	4.23	mg/kg	4	
Cu	ND	2.11	4.23	mg/kg	4	
Fe	ND	21.1	42.3	mg/kg	4	
Pb	ND	2.11	4.23	mg/kg	4	
P	ND	211	423	mg/kg	4	Q-29
Mg	ND	106	211	mg/kg	4	
Mn	ND	2.11	4.23	mg/kg	4	
Mo	ND	2.11	4.23	mg/kg	4	
Ni	ND	2.11	4.23	mg/kg	4	
K	530	106	211	mg/kg	4	
Se	ND	2.11	8.46	mg/kg	4	
Na	161	106	211	mg/kg	4	B-02, J
V	ND	2.11	4.23	mg/kg	4	
Zn	ND	2.11	4.23	mg/kg	4	

Table 122. Chemical analysis using ICP-MS for the grape sample from Elk Cove Roosevelt Vineyard (ECRV). ND - Non-detect.

Lab ID A4A0576-01 ECRV						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	101	203	mg/kg	4	
Hg	ND	0.0406	0.0811	mg/kg	10	Q-41
Sr	0.852	0.203	0.406	mg/kg	4	
Al	ND	101	203	mg/kg	4	
As	ND	2.03	8.11	mg/kg	4	
Ba	ND	2.03	4.06	mg/kg	4	
Be	ND	2.03	4.06	mg/kg	4	
Cd	ND	2.03	4.06	mg/kg	4	
Ca	ND	101	203	mg/kg	4	
Cr	ND	2.03	4.06	mg/kg	4	
Co	ND	2.03	4.06	mg/kg	4	
Cu	ND	2.03	4.06	mg/kg	4	
Fe	ND	20.3	40.6	mg/kg	4	
Pb	ND	2.03	4.06	mg/kg	4	
P	361	203	406	mg/kg	4	Q-29, J
Mg	ND	101	203	mg/kg	4	
Mn	ND	2.03	4.06	mg/kg	4	
Mo	ND	2.03	4.06	mg/kg	4	
Ni	ND	2.03	4.06	mg/kg	4	
K	1240	101	203	mg/kg	4	
Se	ND	2.03	8.11	mg/kg	4	
Na	144	101	203	mg/kg	4	B-02, J
V	ND	2.03	4.06	mg/kg	4	
Zn	ND	2.03	4.06	mg/kg	4	

Table 123. Chemical analysis using ICP-MS for the grape sample from Elk Cove Five Mountain (ECFM) Vineyard. ND - Non-detect.

Lab ID A4A0576-03 ECFM						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	98.2	196	mg/kg	4	
Hg	ND	0.0393	0.0786	mg/kg	10	Q-41
Sr	1.02	0.196	0.393	mg/kg	4	
Al	ND	98.2	196	mg/kg	4	
As	ND	1.96	7.86	mg/kg	4	
Ba	ND	1.96	3.93	mg/kg	4	
Be	ND	1.96	3.93	mg/kg	4	
Cd	ND	1.96	3.93	mg/kg	4	
Ca	ND	98.2	196	mg/kg	4	
Cr	ND	1.96	3.93	mg/kg	4	
Co	ND	1.96	3.93	mg/kg	4	
Cu	ND	1.96	3.93	mg/kg	4	
Fe	ND	19.6	39.3	mg/kg	4	
Pb	ND	1.96	3.93	mg/kg	4	
P	232	196	393	mg/kg	4	Q-29, J
Mg	ND	98.2	196	mg/kg	4	
Mn	2.04	1.96	3.93	mg/kg	4	J
Mo	ND	1.96	3.93	mg/kg	4	
Ni	ND	1.96	3.93	mg/kg	4	
K	1340	98.2	196	mg/kg	4	
Se	ND	1.96	7.86	mg/kg	4	
Na	145	98.2	196	mg/kg	4	B-02, J
V	ND	1.96	3.93	mg/kg	4	
Zn	ND	1.96	3.93	mg/kg	4	

Table 124. Chemical analysis using ICP-MS for the grape sample from Willakenzie Jory Hill (WEJH) Vineyard. ND - Non-detect.

Lab ID A4A0576-06 WEJH						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	97.3	195	mg/kg	4	
Hg	ND	0.0389	0.0778	mg/kg	10	Q-41
Sr	0.506	0.195	0.389	mg/kg	4	
Al	ND	97.3	195	mg/kg	4	
As	ND	1.95	7.78	mg/kg	4	
Ba	ND	1.95	3.89	mg/kg	4	
Be	ND	1.95	3.89	mg/kg	4	
Cd	ND	1.95	3.89	mg/kg	4	
Ca	ND	97.3	195	mg/kg	4	
Cr	ND	1.95	3.89	mg/kg	4	
Co	ND	1.95	3.89	mg/kg	4	
Cu	ND	1.95	3.89	mg/kg	4	
Fe	ND	19.5	38.9	mg/kg	4	
Pb	ND	1.95	3.89	mg/kg	4	
P	275	195	389	mg/kg	4	J
Mg	ND	97.3	195	mg/kg	4	
Mn	2.14	1.95	3.89	mg/kg	4	J
Mo	ND	1.95	3.89	mg/kg	4	
Ni	ND	1.95	3.89	mg/kg	4	
K	1150	97.3	195	mg/kg	4	
Se	ND	1.95	7.78	mg/kg	4	
Na	141	97.3	195	mg/kg	4	B-02, J
V	ND	1.95	3.89	mg/kg	4	
Zn	ND	1.95	3.89	mg/kg	4	

Table 125. Chemical analysis using ICP-MS for the grape sample from Willakenzie Estate Alette (WEAB) Vineyard. ND - Non-detect.

Lab ID A4A0576-05 WEAB						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	105	211	mg/kg	4	
Hg	ND	0.0421	0.0842	mg/kg	10	Q-41
Sr	0.716	0.211	0.421	mg/kg	4	
Al	ND	105	211	mg/kg	4	
As	ND	2.11	8.42	mg/kg	4	
Ba	ND	2.11	4.21	mg/kg	4	
Be	ND	2.11	4.21	mg/kg	4	
Cd	ND	2.11	4.21	mg/kg	4	
Ca	ND	105	211	mg/kg	4	
Cr	ND	2.11	4.21	mg/kg	4	
Co	ND	2.11	4.21	mg/kg	4	
Cu	ND	2.11	4.21	mg/kg	4	
Fe	ND	21.1	42.1	mg/kg	4	
Pb	ND	2.11	4.21	mg/kg	4	
P	267	211	421	mg/kg	4	J
Mg	ND	105	211	mg/kg	4	
Mn	ND	2.11	4.21	mg/kg	4	
Mo	ND	2.11	4.21	mg/kg	4	
Ni	ND	2.11	4.21	mg/kg	4	
K	1680	105	211	mg/kg	4	
Se	ND	2.11	8.42	mg/kg	4	
Na	158	105	211	mg/kg	4	B-02, J
V	ND	2.11	4.21	mg/kg	4	
Zn	ND	2.11	4.21	mg/kg	4	

Table 126. Chemical analysis using ICP-MS for the grape sample from Willakenzie Estate Terres Basses (WETB) Vineyard. ND - Non-detect.

Lab ID A4A0576-04 WETB						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	103	205	mg/kg	4	
Hg	ND	0.0411	0.0821	mg/kg	10	Q-41
Sr	0.739	0.205	0.411	mg/kg	4	
Al	ND	103	205	mg/kg	4	
As	ND	2.05	8.21	mg/kg	4	
Ba	ND	2.05	4.11	mg/kg	4	
Be	ND	2.05	4.11	mg/kg	4	
Cd	ND	2.05	4.11	mg/kg	4	
Ca	ND	103	205	mg/kg	4	
Cr	ND	2.05	4.11	mg/kg	4	
Co	ND	2.05	4.11	mg/kg	4	
Cu	ND	2.05	4.11	mg/kg	4	
Fe	ND	20.5	41.1	mg/kg	4	
Pb	ND	2.05	4.11	mg/kg	4	
P	324	205	411	mg/kg	4	Q-29, J
Mg	ND	103	205	mg/kg	4	
Mn	ND	2.05	4.11	mg/kg	4	
Mo	ND	2.05	4.11	mg/kg	4	
Ni	ND	2.05	4.11	mg/kg	4	
K	1940	103	205	mg/kg	4	
Se	ND	2.05	8.21	mg/kg	4	
Na	159	103	205	mg/kg	4	B-02, J
V	ND	2.05	4.11	mg/kg	4	
Zn	ND	2.05	4.11	mg/kg	4	

Table 127. Chemical analysis using ICP-MS for the grape sample from Chehalem, Stoller Vineyard (CWS). ND - Non-detect.

Lab ID A4A0576-07 CWS						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	105	211	mg/kg	4	
Hg	ND	0.0422	0.0844	mg/kg	10	Q-41
Sr	0.633	0.211	0.422	mg/kg	4	
Al	ND	105	211	mg/kg	4	
As	ND	2.11	8.44	mg/kg	4	
Ba	ND	2.11	4.22	mg/kg	4	
Be	ND	2.11	4.22	mg/kg	4	
Cd	ND	2.11	4.22	mg/kg	4	
Ca	ND	105	211	mg/kg	4	
Cr	ND	2.11	4.22	mg/kg	4	
Co	ND	2.11	4.22	mg/kg	4	
Cu	ND	2.11	4.22	mg/kg	4	
Fe	ND	21.1	42.2	mg/kg	4	
Pb	ND	2.11	4.22	mg/kg	4	
P	213	211	422	mg/kg	4	J
Mg	ND	105	211	mg/kg	4	
Mn	4.56	2.11	4.22	mg/kg	4	
Mo	ND	2.11	4.22	mg/kg	4	
Ni	ND	2.11	4.22	mg/kg	4	
K	1400	105	211	mg/kg	4	
Se	ND	2.11	8.44	mg/kg	4	
Na	153	105	211	mg/kg	4	B-02, J
V	ND	2.11	4.22	mg/kg	4	
Zn	ND	2.11	4.22	mg/kg	4	

Table 128. Chemical analysis using ICP-MS for the grape sample from Chehalem, Ridgecrest Vineyard (CWRC). ND - Non-detect.

Lab ID A4A0576-08 CWRC						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	106	212	mg/kg	4	
Hg	ND	0.0424	0.0847	mg/kg	10	Q-41
Sr	1.10	0.212	0.424	mg/kg	4	
Al	ND	106	212	mg/kg	4	
As	ND	2.12	8.47	mg/kg	4	
Ba	ND	2.12	4.24	mg/kg	4	
Be	ND	2.12	4.24	mg/kg	4	
Cd	ND	2.12	4.24	mg/kg	4	
Ca	ND	106	212	mg/kg	4	
Cr	ND	2.12	4.24	mg/kg	4	
Co	ND	2.12	4.24	mg/kg	4	
Cu	ND	2.12	4.24	mg/kg	4	
Fe	ND	21.2	42.4	mg/kg	4	
Pb	ND	2.12	4.24	mg/kg	4	
P	ND	212	424	mg/kg	4	
Mg	ND	106	212	mg/kg	4	
Mn	ND	2.12	4.24	mg/kg	4	
Mo	ND	2.12	4.24	mg/kg	4	
Ni	ND	2.12	4.24	mg/kg	4	
K	851	106	212	mg/kg	4	
Se	ND	2.12	8.47	mg/kg	4	
Na	155	106	212	mg/kg	4	B-02, J
V	ND	2.12	4.24	mg/kg	4	
Zn	ND	2.12	4.24	mg/kg	4	

Table 129. Chemical analysis using ICP-MS for the grape sample from Chehalem, Corral Creek Vineyard (CWCC). ND - Non-detect.

Lab ID A4A0576-09 CWCC						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	98.8	198	mg/kg	4	
Hg	ND	0.0395	0.0791	mg/kg	10	Q-41
Sr	0.711	0.198	0.395	mg/kg	4	
Al	ND	98.8	198	mg/kg	4	
As	ND	1.98	7.91	mg/kg	4	
Ba	ND	1.98	3.95	mg/kg	4	
Be	ND	1.98	3.95	mg/kg	4	
Cd	ND	1.98	3.95	mg/kg	4	
Ca	ND	98.8	198	mg/kg	4	
Cr	ND	1.98	3.95	mg/kg	4	
Co	ND	1.98	3.95	mg/kg	4	
Cu	ND	1.98	3.95	mg/kg	4	
Fe	ND	19.8	39.5	mg/kg	4	
Pb	ND	1.98	3.95	mg/kg	4	
P	303	198	395	mg/kg	4	J
Mg	ND	98.8	198	mg/kg	4	
Mn	ND	1.98	3.95	mg/kg	4	
Mo	ND	1.98	3.95	mg/kg	4	
Ni	ND	1.98	3.95	mg/kg	4	
K	1530	98.8	198	mg/kg	4	
Se	ND	1.98	7.91	mg/kg	4	
Na	159	98.8	198	mg/kg	4	B-02, J
V	ND	1.98	3.95	mg/kg	4	
Zn	ND	1.98	3.95	mg/kg	4	

Table 130. Chemical analysis using ICP-MS for the grape sample from Lange Estate, Estate Vineyard (LEMN). ND - Non-detect.

Lab ID A4A0576-11 LEMN						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	111	222	mg/kg	4	
Hg	ND	0.0444	0.0889	mg/kg	10	Q-41
Sr	0.711	0.222	0.444	mg/kg	4	
Al	ND	111	222	mg/kg	4	
As	ND	2.22	8.89	mg/kg	4	
Ba	ND	2.22	4.44	mg/kg	4	
Be	ND	2.22	4.44	mg/kg	4	
Cd	ND	2.22	4.44	mg/kg	4	
Ca	ND	111	222	mg/kg	4	
Cr	ND	2.22	4.44	mg/kg	4	
Co	ND	2.22	4.44	mg/kg	4	
Cu	ND	2.22	4.44	mg/kg	4	
Fe	ND	22.2	44.4	mg/kg	4	
Pb	ND	2.22	4.44	mg/kg	4	
P	248	222	444	mg/kg	4	J
Mg	ND	111	222	mg/kg	4	
Mn	ND	2.22	4.44	mg/kg	4	
Mo	ND	2.22	4.44	mg/kg	4	
Ni	ND	2.22	4.44	mg/kg	4	
K	1730	111	222	mg/kg	4	
Se	ND	2.22	8.89	mg/kg	4	
Na	162	111	222	mg/kg	4	B-02, J
V	ND	2.22	4.44	mg/kg	4	
Zn	ND	2.22	4.44	mg/kg	4	

Table 131. Chemical analysis using ICP-MS for the grape sample from Lange Estate, Yamhill Vineyard (LEYV). ND - Non-detect.

Lab ID A4A0576-12 LEYV						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	107	213	mg/kg	4	
Hg	ND	0.0426	0.0853	mg/kg	10	Q-41
Sr	1.41	0.213	0.426	mg/kg	4	
Al	ND	107	213	mg/kg	4	
As	ND	2.13	8.53	mg/kg	4	
Ba	ND	2.13	4.26	mg/kg	4	
Be	ND	2.13	4.26	mg/kg	4	
Cd	ND	2.13	4.26	mg/kg	4	
Ca	115	107	213	mg/kg	4	J
Cr	ND	2.13	4.26	mg/kg	4	
Co	ND	2.13	4.26	mg/kg	4	
Cu	ND	2.13	4.26	mg/kg	4	
Fe	ND	21.3	42.6	mg/kg	4	
Pb	ND	2.13	4.26	mg/kg	4	
P	243	213	426	mg/kg	4	J
Mg	111	107	213	mg/kg	4	J
Mn	ND	2.13	4.26	mg/kg	4	
Mo	ND	2.13	4.26	mg/kg	4	
Ni	ND	2.13	4.26	mg/kg	4	
K	1220	107	213	mg/kg	4	
Se	ND	2.13	8.53	mg/kg	4	
Na	141	107	213	mg/kg	4	B-02, J
V	ND	2.13	4.26	mg/kg	4	
Zn	ND	2.13	4.26	mg/kg	4	

Table 132. Chemical analysis using ICP-MS for the grape sample from Lange Estate, Freedom Hill Vineyard (LEFH). ND - Non-detect.

Lab ID A4A0576-10 LEFH						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	102	205	mg/kg	4	
Hg	ND	0.0410	0.0820	mg/kg	10	Q-41
Sr	0.697	0.205	0.410	mg/kg	4	
Al	ND	102	205	mg/kg	4	
As	ND	2.05	8.20	mg/kg	4	
Ba	ND	2.05	4.10	mg/kg	4	
Be	ND	2.05	4.10	mg/kg	4	
Cd	ND	2.05	4.10	mg/kg	4	
Ca	ND	102	205	mg/kg	4	
Cr	ND	2.05	4.10	mg/kg	4	
Co	ND	2.05	4.10	mg/kg	4	
Cu	ND	2.05	4.10	mg/kg	4	
Fe	ND	20.5	41.0	mg/kg	4	
Pb	ND	2.05	4.10	mg/kg	4	
P	266	205	410	mg/kg	4	J
Mg	ND	102	205	mg/kg	4	
Mn	ND	2.05	4.10	mg/kg	4	
Mo	ND	2.05	4.10	mg/kg	4	
Ni	ND	2.05	4.10	mg/kg	4	
K	1380	102	205	mg/kg	4	
Se	ND	2.05	8.20	mg/kg	4	
Na	150	102	205	mg/kg	4	B-02, J
V	ND	2.05	4.10	mg/kg	4	
Zn	ND	2.05	4.10	mg/kg	4	

Table 133. Chemical analysis using ICP-MS for the grape sample from Rex Hill, Sims Vineyard (RHSB). ND - Non-detect.

Lab ID A4A0576-17 RHSB						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	101	202	mg/kg	4	
Hg	ND	0.0403	0.0806	mg/kg	10	Q-41
Sr	0.645	0.202	0.403	mg/kg	4	
Al	ND	101	202	mg/kg	4	
As	ND	2.02	8.06	mg/kg	4	
Ba	ND	2.02	4.03	mg/kg	4	
Be	ND	2.02	4.03	mg/kg	4	
Cd	ND	2.02	4.03	mg/kg	4	
Ca	ND	101	202	mg/kg	4	
Cr	ND	2.02	4.03	mg/kg	4	
Co	ND	2.02	4.03	mg/kg	4	
Cu	ND	2.02	4.03	mg/kg	4	
Fe	ND	20.2	40.3	mg/kg	4	
Pb	ND	2.02	4.03	mg/kg	4	
P	ND	202	403	mg/kg	4	
Mg	ND	101	202	mg/kg	4	
Mn	2.02	2.02	4.03	mg/kg	4	J
Mo	ND	2.02	4.03	mg/kg	4	
Ni	ND	2.02	4.03	mg/kg	4	
K	747	101	202	mg/kg	4	
Se	ND	2.02	8.06	mg/kg	4	
Na	142	101	202	mg/kg	4	B-02, J
V	ND	2.02	4.03	mg/kg	4	
Zn	ND	2.02	4.03	mg/kg	4	

Table 134. Chemical analysis using ICP-MS for the grape sample from Rex Hill, Estate Vineyard (RHB12). ND - Non-detect.

Lab ID A4A0576-18 RHB12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	96.7	193	mg/kg	4	
Hg	ND	0.0387	0.0774	mg/kg	10	Q-41
Sr	0.696	0.193	0.387	mg/kg	4	
Al	ND	96.7	193	mg/kg	4	
As	ND	1.93	7.74	mg/kg	4	
Ba	ND	1.93	3.87	mg/kg	4	
Be	ND	1.93	3.87	mg/kg	4	
Cd	ND	1.93	3.87	mg/kg	4	
Ca	ND	96.7	193	mg/kg	4	
Cr	ND	1.93	3.87	mg/kg	4	
Co	ND	1.93	3.87	mg/kg	4	
Cu	ND	1.93	3.87	mg/kg	4	
Fe	ND	19.3	38.7	mg/kg	4	
Pb	ND	1.93	3.87	mg/kg	4	
P	361	193	387	mg/kg	4	J
Mg	ND	96.7	193	mg/kg	4	
Mn	ND	1.93	3.87	mg/kg	4	
Mo	ND	1.93	3.87	mg/kg	4	
Ni	ND	1.93	3.87	mg/kg	4	
K	1600	96.7	193	mg/kg	4	
Se	ND	1.93	7.74	mg/kg	4	
Na	139	96.7	193	mg/kg	4	B-02, J
V	ND	1.93	3.87	mg/kg	4	
Zn	ND	1.93	3.87	mg/kg	4	

Table 135. Chemical analysis using ICP-MS for the grape sample from Rex Hill, Jacob-Hart Vineyard Block 1 (RHJH1). ND - Non-detect.

Lab ID A4A0576-15 RHJH1						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	108	216	mg/kg	4	
Hg	ND	0.0431	0.0862	mg/kg	10	Q-41
Sr	1.12	0.216	0.431	mg/kg	4	
Al	ND	108	216	mg/kg	4	
As	ND	2.16	8.62	mg/kg	4	
Ba	ND	2.16	4.31	mg/kg	4	
Be	ND	2.16	4.31	mg/kg	4	
Cd	ND	2.16	4.31	mg/kg	4	
Ca	ND	108	216	mg/kg	4	
Cr	ND	2.16	4.31	mg/kg	4	
Co	ND	2.16	4.31	mg/kg	4	
Cu	2.41	2.16	4.31	mg/kg	4	J
Fe	ND	21.6	43.1	mg/kg	4	
Pb	ND	2.16	4.31	mg/kg	4	
P	297	216	431	mg/kg	4	J
Mg	ND	108	216	mg/kg	4	
Mn	ND	2.16	4.31	mg/kg	4	
Mo	ND	2.16	4.31	mg/kg	4	
Ni	ND	2.16	4.31	mg/kg	4	
K	1880	108	216	mg/kg	4	
Se	ND	2.16	8.62	mg/kg	4	
Na	140	108	216	mg/kg	4	B-02, J
V	ND	2.16	4.31	mg/kg	4	
Zn	ND	2.16	4.31	mg/kg	4	

Table 136. Chemical analysis using ICP-MS for the grape sample from Rex Hill, Jacob-Hart Vineyard Block 5 (RHJH5). ND - Non-detect.

Lab ID A4A0576-16 RHJH5						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	102	203	mg/kg	4	
Hg	ND	0.0407	0.0813	mg/kg	10	Q-41
Sr	0.447	0.203	0.407	mg/kg	4	
Al	ND	102	203	mg/kg	4	
As	ND	2.03	8.13	mg/kg	4	
Ba	ND	2.03	4.07	mg/kg	4	
Be	ND	2.03	4.07	mg/kg	4	
Cd	ND	2.03	4.07	mg/kg	4	
Ca	ND	102	203	mg/kg	4	
Cr	ND	2.03	4.07	mg/kg	4	
Co	ND	2.03	4.07	mg/kg	4	
Cu	4.19	2.03	4.07	mg/kg	4	
Fe	ND	20.3	40.7	mg/kg	4	
Pb	ND	2.03	4.07	mg/kg	4	
P	272	203	407	mg/kg	4	J
Mg	ND	102	203	mg/kg	4	
Mn	ND	2.03	4.07	mg/kg	4	
Mo	ND	2.03	4.07	mg/kg	4	
Ni	ND	2.03	4.07	mg/kg	4	
K	1500	102	203	mg/kg	4	
Se	ND	2.03	8.13	mg/kg	4	
Na	131	102	203	mg/kg	4	B-02, J
V	ND	2.03	4.07	mg/kg	4	
Zn	2.20	2.03	4.07	mg/kg	4	J

Table 137. Chemical analysis using ICP-MS for the grape sample from Ken Wright Cellars, Nysa Vineyard (KWNM). ND - Non-detect.

Lab ID A4A0576-19 KWNM						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	102	204	mg/kg	4	
Hg	ND	0.0407	0.0815	mg/kg	10	Q-41
Sr	1.14	0.204	0.407	mg/kg	4	
Al	ND	102	204	mg/kg	4	
As	ND	2.04	8.15	mg/kg	4	
Ba	ND	2.04	4.07	mg/kg	4	
Be	ND	2.04	4.07	mg/kg	4	
Cd	ND	2.04	4.07	mg/kg	4	
Ca	102	102	204	mg/kg	4	J
Cr	ND	2.04	4.07	mg/kg	4	
Co	ND	2.04	4.07	mg/kg	4	
Cu	ND	2.04	4.07	mg/kg	4	
Fe	ND	20.4	40.7	mg/kg	4	
Pb	ND	2.04	4.07	mg/kg	4	
P	257	204	407	mg/kg	4	J
Mg	ND	102	204	mg/kg	4	
Mn	ND	2.04	4.07	mg/kg	4	
Mo	ND	2.04	4.07	mg/kg	4	
Ni	ND	2.04	4.07	mg/kg	4	
K	1070	102	204	mg/kg	4	
Se	ND	2.04	8.15	mg/kg	4	
Na	138	102	204	mg/kg	4	B-02, J
V	ND	2.04	4.07	mg/kg	4	
Zn	ND	2.04	4.07	mg/kg	4	

Table 138. Chemical analysis using ICP-MS for the grape sample from Ken Wright Cellars, Abbott Claim Vineyard (KWAC). ND - Non-detect.

Lab ID A4A0576-20 KWAC						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	111	222	mg/kg	4	Q-41
Hg	ND	0.0444	0.0889	mg/kg	10	
Sr	0.844	0.222	0.444	mg/kg	4	
Al	ND	111	222	mg/kg	4	
As	ND	2.22	8.89	mg/kg	4	
Ba	ND	2.22	4.44	mg/kg	4	
Be	ND	2.22	4.44	mg/kg	4	
Cd	ND	2.22	4.44	mg/kg	4	
Ca	ND	111	222	mg/kg	4	
Cr	ND	2.22	4.44	mg/kg	4	
Co	ND	2.22	4.44	mg/kg	4	
Cu	ND	2.22	4.44	mg/kg	4	
Fe	ND	22.2	44.4	mg/kg	4	
Pb	ND	2.22	4.44	mg/kg	4	
P	ND	222	444	mg/kg	4	
Mg	ND	111	222	mg/kg	4	
Mn	ND	2.22	4.44	mg/kg	4	
Mo	ND	2.22	4.44	mg/kg	4	
Ni	ND	2.22	4.44	mg/kg	4	
K	1730	111	222	mg/kg	4	B-02, J
Se	ND	2.22	8.89	mg/kg	4	
Na	166	111	222	mg/kg	4	
V	ND	2.22	4.44	mg/kg	4	
Zn	ND	2.22	4.44	mg/kg	4	

Table 139. Chemical analysis using ICP-MS for the grape sample from Ken Wright Cellars, Freedom Hill Vineyard (KWFH). ND - Non-detect.

Lab ID A4A0576-14 KWFH						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	97.1	194	mg/kg	4	
Hg	ND	0.0388	0.0777	mg/kg	10	Q-41
Sr	0.816	0.194	0.388	mg/kg	4	
Al	ND	97.1	194	mg/kg	4	
As	ND	1.94	7.77	mg/kg	4	
Ba	ND	1.94	3.88	mg/kg	4	
Be	ND	1.94	3.88	mg/kg	4	
Cd	ND	1.94	3.88	mg/kg	4	
Ca	ND	97.1	194	mg/kg	4	
Cr	ND	1.94	3.88	mg/kg	4	
Co	ND	1.94	3.88	mg/kg	4	
Cu	ND	1.94	3.88	mg/kg	4	
Fe	ND	19.4	38.8	mg/kg	4	
Pb	ND	1.94	3.88	mg/kg	4	
P	ND	194	388	mg/kg	4	
Mg	ND	97.1	194	mg/kg	4	
Mn	ND	1.94	3.88	mg/kg	4	
Mo	ND	1.94	3.88	mg/kg	4	
Ni	ND	1.94	3.88	mg/kg	4	
K	1160	97.1	194	mg/kg	4	
Se	ND	1.94	7.77	mg/kg	4	
Na	126	97.1	194	mg/kg	4	B-02, J
V	ND	1.94	3.88	mg/kg	4	
Zn	ND	1.94	3.88	mg/kg	4	

Table 140. Chemical analysis using ICP-MS for the grape sample from Ken Wright Cellars, Meredith Mitchell Vineyard (KWMM). ND - Non-detect.

Lab ID A4A0576-13 KWMM						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	ND	104	207	mg/kg	4	
Hg	ND	0.0415	0.0830	mg/kg	10	Q-41
Sr	0.332	0.207	0.415	mg/kg	4	J
Al	ND	104	207	mg/kg	4	
As	ND	2.07	8.30	mg/kg	4	
Ba	ND	2.07	4.15	mg/kg	4	
Be	ND	2.07	4.15	mg/kg	4	
Cd	ND	2.07	4.15	mg/kg	4	
Ca	ND	104	207	mg/kg	4	
Cr	ND	2.07	4.15	mg/kg	4	
Co	ND	2.07	4.15	mg/kg	4	
Cu	ND	2.07	4.15	mg/kg	4	
Fe	ND	20.7	41.5	mg/kg	4	
Pb	ND	2.07	4.15	mg/kg	4	
P	328	207	415	mg/kg	4	J
Mg	ND	104	207	mg/kg	4	
Mn	ND	2.07	4.15	mg/kg	4	
Mo	ND	2.07	4.15	mg/kg	4	
Ni	ND	2.07	4.15	mg/kg	4	
K	883	104	207	mg/kg	4	
Se	ND	2.07	8.30	mg/kg	4	
Na	156	104	207	mg/kg	4	B-02, J
V	ND	2.07	4.15	mg/kg	4	
Zn	ND	2.07	4.15	mg/kg	4	

Appendix E Wine Chemistry Data

All data from Apex Laboratories for the wine samples analyzed from vineyards in this study (Table 141 to Table 183). Wines were collected from vineyard owners or winemakers, stored until sensory analysis, then sampled when opened and delivered to the lab. The wine was analyzed using EPA method 6020A for ICP-MS (EPA, 1998). These methods were preceded by acid digestion using EPA method 3051a (EPA, 2007a). Analyst notes include E: Estimated value. The result is above the calibration range of the instrument, E-03: Result is reported as an estimated value. QA protocols have not been met for this analyte, H-01: This sample was analyzed outside the recommended holding time, Q-41: Estimated results. Recover of continuing calibration verification sample above upper control limit. Results are likely biased high, Q-01: Spike recovery and/or RPD is outside acceptance limits, Q-02: Spike recovery is outside of established control limits due to matrix interference, Q-05: Analyses are not controlled on RPD values from sample or duplicate concentrations below 5 times the reporting limit, R-01: The reporting limit for this analyte has been raised to account for matrix interference, R-03: Elevated reporting limits due to limited sample volume, R-04: Reporting levels elevated due to dilution necessary for analysis. Multiple vintages were available from Chehalem and many wines were analyzed multiple times from the same bottle, unless otherwise noted.

Table 141. Chemical analysis using ICP-MS for the small sample of the 2011 wine from Elk Cove Clay Court (ECCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-13-27 ECCC 11S						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	50.4	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.990	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.292	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	37.5	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	ND	0.0450	0.0450	mg/L	1	
Fe	1.06	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	53.4	2.25	2.25	mg/L	1	
Mn	1.38	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	46.7	2.25	2.25	mg/L	1	
K	413	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	2.72	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.0960	0.0450	0.0450	mg/L	1	

Table 142. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Elk Cove Clay Court (ECCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-04-18 ECCC 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	52.7	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	E-03, R-04
Sr	0.973	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.592	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	28.8	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0262	0.0225	0.0225	mg/L	1	
Cu	0.120	0.0225	0.0225	mg/L	1	
Fe	1.05	0.225	0.225	mg/L	1	
Pb	0.0598	0.0225	0.0225	mg/L	1	
Mg	39.0	1.12	1.12	mg/L	1	
Mn	1.19	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	99.3	1.12	1.12	mg/L	1	Q-41
K	458	1.12	1.12	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.92	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.204	0.0225	0.0225	mg/L	1	

Table 143. Chemical analysis using ICP-MS for the small sample of the 2011 wine from Elk Cove Roosevelt (ECRV) Vineyard. ND - Non-detect.

Lab ID A4B0164-14 28 ECRV 11S						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	76.8	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.915	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.268	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	46.1	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0460	0.0450	0.0450	mg/L	1	
Fe	0.738	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	85.7	2.25	2.25	mg/L	1	
Mn	1.09	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	443	2.25	2.25	mg/L	1	
K	829	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	2.59	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.0785	0.0450	0.0450	mg/L	1	

Table 144. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Elk Cove Roosevelt (ECRV) Vineyard. ND - Non-detect.

Lab ID A4B0052-05 ECRV 2011						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	74.6	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.07	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.754	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	53.8	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0255	0.0225	0.0225	mg/L	1	
Cu	0.120	0.0225	0.0225	mg/L	1	
Fe	0.684	0.225	0.225	mg/L	1	
Pb	0.0610	0.0225	0.0225	mg/L	1	
Mg	58.9	1.12	1.12	mg/L	1	
Mn	0.996	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	560	1.12	1.12	mg/L	1	E
K	752	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.10	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.126	0.0225	0.0225	mg/L	1	

Table 145. Chemical analysis using ICP-MS for the small sample of the 2011 wine from Elk Cove Five Mountain (ECFM) Vineyard. ND - Non-detect.

Lab ID A4B0432-03 31 ECFM 11S						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	55.1	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.779	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.576	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	31.1	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0805	0.0450	0.0450	mg/L	1	
Fe	0.630	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	58.6	2.25	2.25	mg/L	1	
Mn	1.03	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	180	2.25	2.25	mg/L	1	
K	828	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	ND	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.222	0.0450	0.0450	mg/L	1	

Table 146. Chemical analysis using ICP-MS for the 1st bottle of the 2011 wine from Elk Cove Five Mountain (ECFM) Vineyard. ND - Non-detect.

Lab ID A4B0432-02 30 ECFM 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	63.0	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.774	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.404	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	46.5	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.102	0.0450	0.0450	mg/L	1	
Fe	0.829	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	59.4	2.25	2.25	mg/L	1	
Mn	0.942	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	282	2.25	2.25	mg/L	1	
K	775	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	4.34	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.172	0.0450	0.0450	mg/L	1	

Table 147. Chemical analysis using ICP-MS for the 2nd bottle of the 2011 wine from Elk Cove Five Mountain (ECFM) Vineyard. ND - Non-detect.

Lab ID A4B0432-16 45 ECFM11N						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	68.1	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.800	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.414	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	49.4	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.0930	0.0450	0.0450	mg/L	1	
Fe	0.858	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	66.6	2.25	2.25	mg/L	1	
Mn	0.986	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	280	2.25	2.25	mg/L	1	
K	846	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	3.89	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.172	0.0450	0.0450	mg/L	1	

Table 148. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Willakenzie Estate Jory Hill (WEJH) Vineyard. ND - Non-detect.

Lab ID A4B0164-05 19 WEJH 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	72.7	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	E-03, R-04
Sr	0.954	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.464	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	51.6	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0310	0.0225	0.0225	mg/L	1	
Cu	0.0272	0.0225	0.0225	mg/L	1	
Fe	0.645	0.225	0.225	mg/L	1	
Pb	0.0615	0.0225	0.0225	mg/L	1	
Mg	40.6	1.12	1.12	mg/L	1	
Mn	1.30	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	187	1.12	1.12	mg/L	1	Q-41
K	818	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.50	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.164	0.0225	0.0225	mg/L	1	

Table 149. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Willakenzie Estate Alette Block (WEAB) Vineyard. ND - Non-detect.

Lab ID A4B0052-01 1 WEAB 2011						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	71.3	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.21	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.439	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	55.8	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0258	0.0225	0.0225	mg/L	1	
Cu	0.102	0.0225	0.0225	mg/L	1	
Fe	0.768	0.225	0.225	mg/L	1	
Pb	0.0610	0.0225	0.0225	mg/L	1	
Mg	47.9	1.12	1.12	mg/L	1	
Mn	0.995	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	222	1.12	1.12	mg/L	1	
K	835	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.45	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.333	0.0225	0.0225	mg/L	1	

Table 150. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Willakenzie Estate Terres Basses (WETB) Vineyard. ND - Non-detect.

Lab ID A4B0164-11 25 WETB 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	92.5	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	1.13	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.406	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	55.4	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.108	0.0450	0.0450	mg/L	1	
Fe	1.15	0.450	0.450	mg/L	1	
Pb	0.0630	0.0450	0.0450	mg/L	1	
Mg	63.8	2.25	2.25	mg/L	1	
Mn	2.74	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	184	2.25	2.25	mg/L	1	
K	975	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	4.18	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.204	0.0450	0.0450	mg/L	1	

Table 151. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2011 wine from Willakenzie Estate Terres Basses (WETB) Vineyard. ND - Non-detect.

Lab ID A4B0164-03 17 WETB 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	88.8	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	E-03, R-04
Sr	1.16	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.431	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	45.6	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0315	0.0225	0.0225	mg/L	1	
Cu	0.146	0.0225	0.0225	mg/L	1	
Fe	0.991	0.225	0.225	mg/L	1	
Pb	0.115	0.0225	0.0225	mg/L	1	
Mg	41.5	1.12	1.12	mg/L	1	
Mn	2.38	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	0.0260	0.0225	0.0225	mg/L	1	
P	230	1.12	1.12	mg/L	1	Q-41
K	840	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	3.89	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.212	0.0225	0.0225	mg/L	1	

Table 152. Chemical analysis using ICP-MS for the bottle of the 2007 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B0432-08 36 CWS 07						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	68.4	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.858	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.557	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	49.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.298	0.0450	0.0450	mg/L	1	
Fe	2.68	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	71.5	2.25	2.25	mg/L	1	
Mn	2.12	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	327	2.25	2.25	mg/L	1	
K	774	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	3.93	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.702	0.0450	0.0450	mg/L	1	

Table 153. Chemical analysis using ICP-MS for the bottle of the 2008 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B0052-02 2 CWS 2008						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	88.1	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	0.812	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.393	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	32.5	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0358	0.0225	0.0225	mg/L	1	
Cu	0.213	0.0225	0.0225	mg/L	1	
Fe	2.82	0.225	0.225	mg/L	1	
Pb	0.0812	0.0225	0.0225	mg/L	1	
Mg	46.8	1.12	1.12	mg/L	1	
Mn	1.95	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	289	1.12	1.12	mg/L	1	E
K	710	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	3.87	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.550	0.0225	0.0225	mg/L	1	

Table 154. Chemical analysis using ICP-MS for the bottle of the 2009 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B0164-06 20 CWS 09						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	77.4	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.732	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.358	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	51.6	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.140	0.0450	0.0450	mg/L	1	
Fe	1.70	0.450	0.450	mg/L	1	
Pb	0.0475	0.0450	0.0450	mg/L	1	
Mg	60.8	2.25	2.25	mg/L	1	
Mn	1.91	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	319	2.25	2.25	mg/L	1	
K	860	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	3.32	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.356	0.0450	0.0450	mg/L	1	

Table 155. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B052-03 3 CWS 2011						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	74.6	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	0.758	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.446	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	47.2	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0282	0.0225	0.0225	mg/L	1	
Cu	0.0998	0.0225	0.0225	mg/L	1	
Fe	1.58	0.225	0.225	mg/L	1	
Pb	0.0815	0.0225	0.0225	mg/L	1	
Mg	37.8	1.12	1.12	mg/L	1	
Mn	1.62	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	286	1.12	1.12	mg/L	1	E
K	740	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	17.3	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.463	0.0225	0.0225	mg/L	1	

Table 156. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2011 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B0432-10 38 CWS 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	70.0	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.648	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.386	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	52.6	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0545	0.0450	0.0450	mg/L	1	
Fe	1.65	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	51.7	2.25	2.25	mg/L	1	
Mn	1.68	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	204	2.25	2.25	mg/L	1	
K	762	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	16.4	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.400	0.0450	0.0450	mg/L	1	

Table 157. Chemical analysis using ICP-MS for the 3rd sample from the same bottle of the 2011 wine from Chehalem Stoller (CWS) Vineyard. ND - Non-detect.

Lab ID A4B0432-13 41 CWS 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	80.7	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.688	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.392	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	57.1	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.0570	0.0450	0.0450	mg/L	1	
Fe	1.69	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	60.7	2.25	2.25	mg/L	1	
Mn	1.80	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	210	2.25	2.25	mg/L	1	
K	852	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	18.7	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.446	0.0450	0.0450	mg/L	1	

Table 158. Chemical analysis using ICP-MS for the bottle of the 2007 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0052-11 11 CWRC 2007						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	106	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	E-03, H-01, R-04
Sr	1.49	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.366	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	40.5	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0345	0.0225	0.0225	mg/L	1	
Cu	0.553	0.0225	0.0225	mg/L	1	
Fe	3.84	0.225	0.225	mg/L	1	
Pb	0.0822	0.0225	0.0225	mg/L	1	
Mg	49.5	1.12	1.12	mg/L	1	
Mn	1.34	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	326	1.12	1.12	mg/L	1	E, Q-41
K	700	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	8.54	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.644	0.0225	0.0225	mg/L	1	

Table 159. Chemical analysis using ICP-MS for the bottle of the 2008 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0432-18 47 CWRC 08						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	95.8	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.43	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.248	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	39.2	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.350	0.0450	0.0450	mg/L	1	
Fe	2.70	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	87.0	2.25	2.25	mg/L	1	
Mn	1.57	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	211	2.25	2.25	mg/L	1	
K	722	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	8.37	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.604	0.0450	0.0450	mg/L	1	

Table 160. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2008 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0432-12 40 CWRC 08						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	103	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.36	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.275	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	40.1	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.404	0.0450	0.0450	mg/L	1	
Fe	2.83	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	93.0	2.25	2.25	mg/L	1	
Mn	1.58	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	205	2.25	2.25	mg/L	1	
K	724	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	8.26	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.632	0.0450	0.0450	mg/L	1	

Table 161. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0052-06 6 CWRC 2011						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	83.4	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.26	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.312	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	55.6	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0298	0.0225	0.0225	mg/L	1	
Cu	0.191	0.0225	0.0225	mg/L	1	
Fe	2.10	0.225	0.225	mg/L	1	
Pb	0.0622	0.0225	0.0225	mg/L	1	
Mg	46.4	1.12	1.12	mg/L	1	
Mn	1.23	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	425	1.12	1.12	mg/L	1	E
K	620	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	9.55	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	1.11	0.0225	0.0225	mg/L	1	

Table 162. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2011 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0432-04 32 CWRC 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	80.1	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.15	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.273	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	62.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.150	0.0450	0.0450	mg/L	1	
Fe	2.10	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	62.4	2.25	2.25	mg/L	1	
Mn	1.31	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	341	2.25	2.25	mg/L	1	
K	659	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	9.46	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	1.02	0.0450	0.0450	mg/L	1	

Table 163. Chemical analysis using ICP-MS for the 3rd sample from the same bottle of the 2011 wine from Chehalem Ridgecrest (CWRC) Vineyard. ND - Non-detect.

Lab ID A4B0432-14 42 CWRC 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	94.6	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.17	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.278	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	67.1	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.146	0.0450	0.0450	mg/L	1	
Fe	2.21	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	75.8	2.25	2.25	mg/L	1	
Mn	1.40	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	325	2.25	2.25	mg/L	1	
K	739	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	10.8	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	1.15	0.0450	0.0450	mg/L	1	

Table 164. Chemical analysis using ICP-MS for the bottle of the 2008 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0432-06 34 CWCC 08						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	74.8	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.07	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.465	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	39.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.166	0.0450	0.0450	mg/L	1	
Fe	2.70	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	79.3	2.25	2.25	mg/L	1	
Mn	1.08	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	252	2.25	2.25	mg/L	1	
K	748	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	4.69	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.414	0.0450	0.0450	mg/L	1	

Table 165. Chemical analysis using ICP-MS for the 2nd sample from the bottle of the 2008 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0432-17 46 CWCC 08						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	76.9	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.09	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.472	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	39.7	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.176	0.0450	0.0450	mg/L	1	
Fe	2.66	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	85.8	2.25	2.25	mg/L	1	
Mn	1.11	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	240	2.25	2.25	mg/L	1	
K	793	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	5.04	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.418	0.0450	0.0450	mg/L	1	

Table 166. Chemical analysis using ICP-MS for the bottle of the 2009 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-08 22 CWCC 09						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	84.8	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.992	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.272	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	49.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.102	0.0450	0.0450	mg/L	1	
Fe	2.18	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	68.2	2.25	2.25	mg/L	1	
Mn	0.926	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	384	2.25	2.25	mg/L	1	
K	828	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	5.32	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.478	0.0450	0.0450	mg/L	1	

Table 167. Chemical analysis using ICP-MS for the bottle of the 2011 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-08 8 CWCC 2011						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	88.2	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	0.914	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.338	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	51.3	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0312	0.0225	0.0225	mg/L	1	
Cu	0.178	0.0225	0.0225	mg/L	1	
Fe	2.05	0.225	0.225	mg/L	1	
Pb	0.0845	0.0225	0.0225	mg/L	1	
Mg	42.4	1.12	1.12	mg/L	1	
Mn	0.816	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	523	1.12	1.12	mg/L	1	E, Q-41
K	761	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	8.79	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.596	0.0225	0.0225	mg/L	1	

Table 168. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2011 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-0 21 CWCC 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	86.2	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.858	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.274	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	59.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0750	0.0450	0.0450	mg/L	1	
Fe	2.20	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	57.9	2.25	2.25	mg/L	1	
Mn	0.869	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	444	2.25	2.25	mg/L	1	
K	814	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	8.94	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.550	0.0450	0.0450	mg/L	1	

Table 169. Chemical analysis using ICP-MS for the 3rd sample from the same bottle of the 2011 wine from Chehalem Corral Creek (CWCC) Vineyard. ND - Non-detect.

Lab ID A4B0164-12 26 CWCC 11						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	88.6	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.867	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.282	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	61.3	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0940	0.0450	0.0450	mg/L	1	
Fe	2.15	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	62.0	2.25	2.25	mg/L	1	
Mn	0.910	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	435	2.25	2.25	mg/L	1	
K	850	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	8.99	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.556	0.0450	0.0450	mg/L	1	

Table 170. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Lange Estate Mia North (LEMN) Vineyard. ND - Non-detect.

Lab ID A4B0164-01 15 LEMN 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	113	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	E-03, R-04
Sr	1.09	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.492	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	27.2	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0330	0.0225	0.0225	mg/L	1	
Cu	0.164	0.0225	0.0225	mg/L	1	
Fe	1.76	0.225	0.225	mg/L	1	
Pb	0.0892	0.0225	0.0225	mg/L	1	
Mg	63.2	1.12	1.12	mg/L	1	
Mn	2.27	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	192	1.12	1.12	mg/L	1	Q-41
K	735	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	10.5	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.294	0.0225	0.0225	mg/L	1	

Table 171. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2012 wine from Lange Estate Mia North (LEMN) Vineyard. ND - Non-detect.

Lab ID A4B0164-1024 LEMN 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	103	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	0.980	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.432	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	29.7	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.118	0.0450	0.0450	mg/L	1	
Fe	1.74	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	83.4	2.25	2.25	mg/L	1	
Mn	2.32	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	144	2.25	2.25	mg/L	1	
K	742	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	9.98	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.253	0.0450	0.0450	mg/L	1	

Table 172. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Lange Estate Yamhill (LEYV) Vineyard. ND - Non-detect.

Lab ID A4B0432-05 33 LEYV 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	74.2	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.62	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.540	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	31.7	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	ND	0.0450	0.0450	mg/L	1	
Fe	1.42	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	94.4	2.25	2.25	mg/L	1	
Mn	2.36	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	206	2.25	2.25	mg/L	1	
K	743	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	4.85	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.334	0.0450	0.0450	mg/L	1	

Table 173. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Lange Estate Freedom Hill (LEFH) Vineyard. ND - Non-detect.

Lab ID A4B0052-07 7 LEFH 2012						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	72.1	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.05	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.577	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	27.6	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0290	0.0225	0.0225	mg/L	1	
Cu	0.0865	0.0225	0.0225	mg/L	1	
Fe	0.966	0.225	0.225	mg/L	1	
Pb	0.0782	0.0225	0.0225	mg/L	1	
Mg	51.6	1.12	1.12	mg/L	1	
Mn	1.25	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	199	1.12	1.12	mg/L	1	
K	676	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.30	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.118	0.0225	0.0225	mg/L	1	

Table 174. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Rex Hill Sims (RHSB) Vineyard. ND - Non-detect.

Lab ID A4B0432-01 29 RHSB 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	111	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.978	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.378	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	34.7	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0470	0.0450	0.0450	mg/L	1	
Fe	2.41	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	75.9	2.25	2.25	mg/L	1	
Mn	2.36	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	192	2.25	2.25	mg/L	1	
K	445	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	5.40	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.336	0.0450	0.0450	mg/L	1	

Table 175. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2012 wine from Rex Hill Sims (RHSB) Vineyard. ND - Non-detect.

Lab ID A4B0432-19 44 RHSB 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	118	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.951	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.360	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	35.4	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.0475	0.0450	0.0450	mg/L	1	
Fe	2.31	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	R-03
Mg	83.9	2.25	2.25	mg/L	1	
Mn	2.35	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	179	2.25	2.25	mg/L	1	
K	460	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	5.64	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.350	0.0450	0.0450	mg/L	1	

Table 176. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Rex Hill Estate (RHB12) Vineyard. ND - Non-detect.

Lab ID A4B0164-09 23 RHB12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	97.0	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	H-01, R-04
Sr	1.18	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.406	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	42.9	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0810	0.0450	0.0450	mg/L	1	
Fe	1.11	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	80.4	2.25	2.25	mg/L	1	
Mn	1.06	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	447	2.25	2.25	mg/L	1	
K	713	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	7.74	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.394	0.0450	0.0450	mg/L	1	

Table 177. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Rex Hill Jacob-Hart Block 1 (RHJHB1) Vineyard. ND - Non-detect.

Lab ID A4B0052-10 10 RHJHB1 2012						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	119	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.12	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.327	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	35.2	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0338	0.0225	0.0225	mg/L	1	
Cu	0.111	0.0225	0.0225	mg/L	1	
Fe	2.22	0.225	0.225	mg/L	1	
Pb	0.0892	0.0225	0.0225	mg/L	1	
Mg	59.2	1.12	1.12	mg/L	1	
Mn	1.07	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	412	1.12	1.12	mg/L	1	E, Q-41
K	563	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	8.42	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.338	0.0225	0.0225	mg/L	1	

Table 178. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Rex Hill Jacob-Hart Block 5 (RHJHB5) Vineyard. ND - Non-detect.

Lab ID A4B0432-09 37 RHJHB5 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	139	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.766	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.170	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	53.0	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.286	0.0450	0.0450	mg/L	1	
Fe	1.23	0.450	0.450	mg/L	1	
Pb	0.0625	0.0450	0.0450	mg/L	1	
Mg	80.3	2.25	2.25	mg/L	1	
Mn	1.75	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	378	2.25	2.25	mg/L	1	
K	721	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	7.58	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.443	0.0450	0.0450	mg/L	1	

Table 179. Chemical analysis using ICP-MS for the 2nd sample from the same bottle of the 2012 wine from Rex Hill Jacob-Hart Block 5 (RHJHB5) Vineyard. ND - Non-detect.

Lab ID A4B0432-15 43 RHJHB5 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	151	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.772	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	R-03
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.183	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	R-03
Cd	ND	0.0450	0.0450	mg/L	1	R-03
Ca	56.0	2.25	2.25	mg/L	1	
Cr	ND	0.0450	0.0450	mg/L	1	R-03
Co	ND	0.0450	0.0450	mg/L	1	R-03
Cu	0.320	0.0450	0.0450	mg/L	1	
Fe	1.23	0.450	0.450	mg/L	1	
Pb	0.0730	0.0450	0.0450	mg/L	1	
Mg	90.4	2.25	2.25	mg/L	1	
Mn	1.81	0.0450	0.0450	mg/L	1	
Mo	ND	0.0450	0.0450	mg/L	1	R-03
Ni	ND	0.0450	0.0450	mg/L	1	R-03
P	357	2.25	2.25	mg/L	1	
K	769	2.25	2.25	mg/L	1	
Se	ND	4.50	4.50	mg/L	1	R-01
Na	8.28	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	R-03
Zn	0.462	0.0450	0.0450	mg/L	1	

Table 180. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Ken Wright Nysa (KWNM) Vineyard. ND - Non-detect.

Lab ID A4B0052-09 9 KWNM 2012						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	106	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	1.09	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.584	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	37.4	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0270	0.0225	0.0225	mg/L	1	
Cu	0.0742	0.0225	0.0225	mg/L	1	
Fe	1.58	0.225	0.225	mg/L	1	
Pb	0.0678	0.0225	0.0225	mg/L	1	
Mg	65.7	1.12	1.12	mg/L	1	
Mn	1.67	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	542	1.12	1.12	mg/L	1	E, Q-41
K	917	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	4.50	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.747	0.0225	0.0225	mg/L	1	

Table 181. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Ken Wright Abbott Claim (KWAC) Vineyard. ND - Non-detect.

Lab ID A4B0052-04 4 KWAC 2012						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	77.2	1.12	1.12	mg/L	1	
Hg	ND	0.000900	0.000900	mg/L	5	H-01, R-04
Sr	0.912	0.00202	0.00202	mg/L	1	
Al	ND	1.12	1.12	mg/L	1	
As	ND	2.25	2.25	mg/L	1	R-01
Ba	0.457	0.0225	0.0225	mg/L	1	
Be	ND	0.0225	0.0225	mg/L	1	
Cd	ND	0.0225	0.0225	mg/L	1	
Ca	30.6	1.12	1.12	mg/L	1	
Cr	ND	0.225	0.225	mg/L	1	R-01
Co	0.0325	0.0225	0.0225	mg/L	1	
Cu	0.0750	0.0225	0.0225	mg/L	1	
Fe	0.517	0.225	0.225	mg/L	1	
Pb	0.0740	0.0225	0.0225	mg/L	1	
Mg	60.4	1.12	1.12	mg/L	1	
Mn	1.13	0.0225	0.0225	mg/L	1	
Mo	ND	0.112	0.112	mg/L	1	
Ni	ND	0.0225	0.0225	mg/L	1	
P	403	1.12	1.12	mg/L	1	E
K	767	1.12	1.12	mg/L	1	E
Se	ND	4.50	4.50	mg/L	1	Q-41
Na	5.77	1.12	1.12	mg/L	1	
V	ND	0.0225	0.0225	mg/L	1	
Zn	0.965	0.0225	0.0225	mg/L	1	

Table 182. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Ken Wright Freedom Hill (KWFH) Vineyard. ND - Non-detect.

Lab ID A4B0432-11 39 KWFH 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	100	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	1.05	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.470	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	43.5	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	0.0540	0.0450	0.0450	mg/L	1	
Fe	0.544	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	96.8	2.25	2.25	mg/L	1	
Mn	1.73	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	297	2.25	2.25	mg/L	1	
K	844	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	5.40	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.784	0.0450	0.0450	mg/L	1	

Table 183. Chemical analysis using ICP-MS for the bottle of the 2012 wine from Ken Wright Meredith Mitchell (KWMM) Vineyard. ND - Non-detect.

Lab ID A4B0432-07 35 KWMM 12						
Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Analyst Notes
S	101	2.25	2.25	mg/L	1	
Hg	ND	0.00180	0.00180	mg/L	5	R-04
Sr	0.681	0.00405	0.00405	mg/L	1	
Al	ND	2.25	2.25	mg/L	1	
As	ND	4.50	4.50	mg/L	1	R-01
Ba	0.188	0.0450	0.0450	mg/L	1	
Be	ND	0.0450	0.0450	mg/L	1	
Cd	ND	0.0450	0.0450	mg/L	1	
Ca	43.9	2.25	2.25	mg/L	1	
Cr	ND	0.450	0.450	mg/L	1	R-01
Co	ND	0.0450	0.0450	mg/L	1	
Cu	ND	0.0450	0.0450	mg/L	1	
Fe	1.06	0.450	0.450	mg/L	1	
Pb	ND	0.0450	0.0450	mg/L	1	
Mg	84.9	2.25	2.25	mg/L	1	
Mn	0.952	0.0450	0.0450	mg/L	1	
Mo	ND	0.225	0.225	mg/L	1	
Ni	ND	0.0450	0.0450	mg/L	1	
P	430	2.25	2.25	mg/L	1	
K	538	2.25	2.25	mg/L	1	
Se	ND	9.00	9.00	mg/L	1	
Na	4.76	2.25	2.25	mg/L	1	
V	ND	0.0450	0.0450	mg/L	1	
Zn	0.768	0.0450	0.0450	mg/L	1	

Appendix F Quality Assurance/Quality Control

The following tables were duplicated from the elemental analysis report from Apex Laboratories for the soil samples (Table 184 to Table 189). Similar data were obtained for the grape juice and wine analysis. When analyte is not detected at or above reporting limit, ND is used. RPD means Relative Percent Difference and Minimum Detection Limit is MDL. Analyst notes include A-01: High Iron value in sample plus non-regulatory sample. No Post Spike performed, J: Estimated Results. Result detected below the lowest point of the calibration curve, but above the specified MDL, Q-03: Spike recover and/or RPD is outside acceptance limits, Q-16: Reanalysis of an original Batch QC sample.

Table 184. Batch 3090668 data from Apex Laboratories of Quality Assurance/Quality Control data for various elements using EPA 3051A sample prep and EPA 6020A analysis.

Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
As	ND	0.250	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Ba	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Cd	ND	0.100	0.200	mg/kg	10	Blank	-	-	-	-	-	-
Cr	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Co	ND	0.100	0.200	mg/kg	10	Blank	-	-	-	-	-	-
Cu	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Pb	ND	0.100	0.200	mg/kg	10	Blank	-	-	-	-	-	-
Mn	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Mo	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Ni	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Se	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
V	ND	0.500	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Zn	ND	2.00	1.00	mg/kg	10	Blank	-	-	-	-	-	-
Hg	ND	0.0400	4.00	mg/kg	10	Blank	-	-	-	-	-	Q-16
Matrix Spike - QC Source Sample: KWFH Ap												
As	46.4	0.247	0.986	mg/kg	10	49.3	1.41	91	75-125%	-	-	-

Table 185. continued from Table 153. Batch 3090668 data from Apex Laboratories of Quality Assurance/Quality Control data for various elements using EPA 3051A sample prep and EPA 6020A analysis.

Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
Ba	183	0.493	0.986	mg/kg	10	49.3	132	105	75-125%	-	-	-
Cd	51.5	0.0986	0.197	mg/kg	10	49.3	0.292	104	75-125%	-	-	-
Cr	64.0	0.493	0.986	mg/kg	10	49.3	13.1	103	75-125%	-	-	-
Co	62.6	0.0986	0.197	mg/kg	10	49.3	13.2	100	75-125%	-	-	-
Cu	65.7	0.493	0.986	mg/kg	10	49.3	14.0	105	75-125%	-	-	-
Pb	60.2	0.0986	0.197	mg/kg	10	49.3	9.29	103	75-125%	-	-	-
Mn	881	0.493	0.986	mg/kg	10	49.3	819	125	75-125%	-	-	-
Hg	1.04	0.0394	0.158	mg/kg	10	0.986	ND	105	75-125%	-	-	-
Mo	21.6	0.493	0.986	mg/kg	10	24.6	ND	88	75-125%	-	-	-
Ni	52.9	0.493	0.986	mg/kg	10	49.3	4.30	98	75-125%	-	-	-
Se	19.4	0.493	0.986	mg/kg	10	24.6	ND	79	75-125%	-	-	-
V	90.6	0.493	0.986	mg/kg	10	49.3	33.4	116	75-125%	-	-	-
Zn	80.7	1.970	3.94	mg/kg	10	49.3	24.0	115	75-125%	-	-	-
Post Spike												
Mn	5830	-	-	µg/L	10	2860	3110	95	80-120%	-	-	-

Table 186. Batch 3100753 data from Apex Laboratories of Quality Assurance/Quality Control data for various elements using EPA 3051A sample prep and EPA 6010C analysis.

Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
Sr	ND	0.200	0.400	mg/kg	4	Blank	-	-	-	-	-	-
Al	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
Ca	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
Fe	ND	20.0	40.0	mg/kg	4	Blank	-	-	-	-	-	-
P	ND	200	400	mg/kg	4	Blank	-	-	-	-	-	-
Sr	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
Mg	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
K	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
Na	ND	100	200	mg/kg	4	Blank	-	-	-	-	-	-
LCS												
Sr	103	0.200	0.400	mg/kg	4	100	-	103	80-120%	-	-	-
Al	5150	100	200	mg/kg	4	5000	-	103	80-120%	-	-	-
Ca	5080	100	200	mg/kg	4	5000	-	102	80-120%	-	-	-
Fe	5420	20.0	40.0	mg/kg	4	5000	-	109	80-120%	-	-	-
P	4670	200	400	mg/kg	4	4000	-	117	80-120%	-	-	-
Sr	4360	100	200	mg/kg	4	4000	-	109	80-120%	-	-	-
Mg	4990	100	200	mg/kg	4	5000	-	100	80-120%	-	-	-

Table 187. continued Batch 3100753 data from Apex Laboratories of Quality Assurance/Quality Control data for various elements using EPA 3051A sample prep and EPA 6010C analysis.

Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
K	5160	100	200	mg/kg	4	5000	-	103	80-120%	-	-	-
Na	5340	100	200	mg/kg	4	5000	-	107	80-120%	-	-	-
Duplicate - QC Source Sample: KWFH Bt												
Sr	17.7	0.217	0.435	mg/kg	4	-	17.1	-	-	3	40%	-
Al	16500	109	217	mg/kg	4	-	16300	-	-	1	40%	-
Fe	33200	21.7	43.5	mg/kg	4	-	33200	-	-	0.06	40%	-
P	561	217	43.5	mg/kg	4	-	541	-	-	4	40%	-
Sr	ND	109	435	mg/kg	4	-	ND	-	-	-	40%	-
Mg	2140	109	217	mg/kg	4	-	2100	-	-	2	40%	-
K	1240	109	217	mg/kg	4	-	1230	-	-	0.8	40%	-
Na	182	109	217	mg/kg	4	-	165	-	-	10	40%	J
Matrix Spike QC Source Sample: KWFH Bt												
Sr	123	0.213	0.426	mg/kg	4	107	17.1	99	75-125%	-	-	-
Al	21300	107	213	mg/kg	4	5330	16300	94	75-125%	-	-	-
Ca	7210	107	213	mg/kg	4	5330	1920	99	75-125%	-	-	-
Fe	36000	21.3	42.6	mg/kg	4	5330	33200	51	75-125%	-	-	A-01, Q-03
P	5410	21.3	426	mg/kg	4	4260	541	114	75-125%	-	-	-

Table 188. continued Batch 3100753 data from Apex Laboratories of Quality Assurance/Quality Control data for various elements using EPA 3051A sample prep and EPA 6010C analysis.

Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
Sr	4750	107	213	mg/kg	4	4260	ND	112	75-125%	-	-	-
Mg	7260	107	213	mg/kg	4	5330	2100	97	75-125%	-	-	-
K	6480	107	213	mg/kg	4	5330	1230	99	75-125%	-	-	-
Na	5590	107	213	mg/kg	4	5330	165	102	75-125%	-	-	-
Matrix Spike - QC Source Sample: RHJHB5 Btg												
Sr	137	0.202	0.404	mg/kg	4	101	36	100	75-125%	-	-	-
Al	20900	101	202	mg/kg	4	5050	16800	81	75-125%	-	-	-
Ca	8960	101	202	mg/kg	4	5050	3590	106	75-125%	-	-	-
Fe	51700	20.2	40.4	mg/kg	4	5050	53500	-37	75-125%	-	-	A-01, Q-03
P	4640	20.2	40.4	mg/kg	4	4040	314	107	75-125%	-	-	-
Sr	4300	101	202	mg/kg	4	4040	ND	106	75-125%	-	-	-
Mg	7270	101	202	mg/kg	4	5050	2160	101	75-125%	-	-	-
K	5280	101	202	mg/kg	4	5050	245	100	75-125%	-	-	-
Na	5360	101	202	mg/kg	4	5050	193	102	75-125%	-	-	-

Table 189. Sample data table from Apex Laboratories with Quality Assurance/Quality Control data for Chloride analysis using EPA 3051A sample prep and EPA 9056A analysis.

Chloride Analyte	Result	MDL	Rep. Limit	Units	Dil.	Spike Amount	Source Result	% Rec.	% Rec. Limits	RPD	RPD Limit	Notes
Blank	ND	9.81	9.81	mg/kg	1	-	-	-	-	-	-	-
LCS	39	9.95	9.95	mg/kg	1	39.8	-	98	90-110%	-	-	-
LCS Dup.	38.6	9.81	9.81	mg/kg	1	39.3	-	98	90-110%	0.9	15%	-

Appendix G Cation Exchange Capacity Data

Oregon State University, Crop and Soil Science lab conducted the CEC analysis for this study using methods derived from the Methods of Soil Analysis Used in the Soil Testing Laboratory at Oregon State University (Hormeck et al., 1989). CEC was obtained using the Ammonium Acetate Method as described in the manual. This method determines of the $\text{NH}_4\text{·N}$ spectrophotometrically rather than by Kjeldahl distillation and titration (Hormeck et al., 1989).

Equation 2. Equation for the calculation of Cation Exchange Capacity.

$$CEC \frac{meq}{100 \text{ g of soil}} = (ppm \text{ NH}_4 \cdot \text{N in leachate}) \times \frac{0.25}{14} \times \frac{100}{\text{sample size g}}$$

Table 190. Cation Exchange Capacity (CEC) results from the Oregon State University Crop and Soil Science lab.

Sample Number	Vineyard	Horizon	Lab Number	CEC meq/100g	Sample Number	Vineyard	Horizon	Lab Number	CEC meq/100g
1	ECR	Ap	140128.01	18.5	35	LEM	Bt2	140128.35	18.9
2	ECR	AB	140128.02	15.4	36	LEM	Bt3	140128.36	15.6
3	ECR	Bt1	140128.03	16.9	37	LEF	Ap	140128.37	17.8
4	ECR	Bt2	140128.04	20.7	38	LEF	Bt	140128.38	18.9
5	ECC	Ap	140128.05	31.2	39	LEY	Ap	140128.39	20.2
6	ECC	Bt1	140128.06	16.1	40	LEY	Bt1	140128.40	14.0
7	ECC	Bt2	140128.07	16.8	41	LEY	Bt2	140128.41	15.3
8	ECC	Bt3	140128.08	14.4	42	LEY	Bg	140128.42	17.8
9	ECF	Ap	140128.09	18.6	43	RH1	Ap	140128.43	26.1
10	ECF	Bt1	140128.10	14.2	44	RH1	At	140128.44	20.3
11	ECF	Bt2	140128.11	14.9	45	RH1	Bt	140128.45	16.3
12	ECF	Bt3	140128.12	13.8	46	RH5	Ap	140128.46	22.3
13	WET	Ap	140128.13	25.3	47	RH5	Bt	140128.47	28.2
14	WET	AB	140128.14	23.1	48	RH5	Btg	140128.48	32.9
15	WET	Bg1	140128.15	38.1	49	RHB	Ap	140128.49	35.1
16	WET	Bg2	140128.16	34.6	50	RHB	Bt1	140128.50	17.8
17	WEA	A	140128.17	15.9	51	RHB	Bt2	140128.51	15.9
18	WEA	AB	140128.18	12.9	52	RHS	Ap	140128.52	23.2
19	WEA	Bt1	140128.19	17.5	53	RHS	Bt1	140128.53	20.2
20	WEA	Bt2	140128.20	14.9	54	RHS	Bt2	140128.54	15.0
21	WEJ	Ap	140128.21	14.4	55	RHS	Bt3	140128.55	20.0
22	WEJ	Bt1	140128.22	15.4	56	KWA	Ap	140128.56	16.9
23	WEJ	Bt2	140128.23	14.6	57	KWA	Bt	140128.57	11.7
24	CWS	Ap	140128.24	23.5	58	KWA	Bw	140128.58	20.5
25	CWS	Bt1	140128.25	18.7	59	KWF	Ap	140128.59	9.7
26	CWS	Bt2	140128.26	17.0	60	KWF	Bt	140128.60	20.3
27	CWS	Bt3	140128.27	16.5	61	KWM	Ap	140128.61	21.5
28	CWR	Ap	140128.28	14.8	62	KWM	Bt	140128.62	48.5
29	CWR	Bt1	140128.29	11.2	63	KWM	Bw	140128.63	80.0
30	CWR	Bt2	140128.30	19.1	64	KWN	Ap	140128.64	61.0
31	CWC	Ap	140128.31	42.2	65	KWN	Bt1	140128.65	20.2
32	CWC	Bt	140128.32	19.5	66	KWN	Bt2	140128.66	17.8
33	LEM	Ap	140128.33	22.6	67	LEM	Bt2	140128.67	21.7
34	LEM	A/B	140128.34	22.4					

Appendix H NSF Cascades to Coast GK-12 Fellowship Requirement

Created Curriculum – Radon Gas from the Missoula Floods

Fellow: Kat Barnard (Geology)

Teacher: Brie Bui (Dexter McCarty School)

Advisor: Dr. Scott Burns (Geology)

Learning goals: After learning about Missoula floods, and their impact on the creation of the Willamette Valley, this lesson ties the science of radon produced from the flood deposits to human health concerns, i.e. lung cancer. This lesson tries to impress the usefulness of the geological sciences to everyday life and how data collection for a government agency, like the Oregon Health Authority, is a community responsibility.

Prior lessons: Willamette Valley crops grown on Missoula Flood sediments like hazelnuts, grass seed, clover, and wheat. Missoula Flood gravels were included in a rock identification lesson about Oregon rocks. Upland Willamette Valley soils were used in a soil horizon and soil color lesson.

Target Grade: 8th grade Integrated Science. Earth and Physical emphasis.

State Standards: 6.1P.1 Describe physical and chemical properties of matter and how they can be measured. 7.2E.4 Explain how landforms change over time at various rates in terms of constructive and destructive forces. 8.2E.2 Describe the processes of Earth's geosphere and the resulting major geological events.

Activity Summary: Show presentation reviewing the Missoula Floods, watch video from Oregon Public Broadcasting – Oregon Field Guide, and pass out radon kits with Radon brochures from the Oregon Health Authority.

Activity Plan:

30 minutes' total -

- 5 minutes for first 4 slides
 - Slide 1

- Question posed to class: What ecoregion was affected by the Missoula Floods? (Willamette Valley)
- Question posed to class: How long ago did this occur? (The last ice age, about 15000-18000 years ago)
- “An ice dam from the iced sheet blocked and backed up a river that made a huge lake in Montana called Glacial Lake Missoula. When the dam breached, a giant flood came across Washington and caused scouring and erosion. The flood came down the Columbia Gorge, carrying the soil and rock into the Willamette Valley.”
- Slide 2
 - Question posed to class: On this elevation map can you see the flat areas in NE Portland and down into the valley? (Yes)
 - Question posed to class: What are the rough and bumpy areas called? (Uplands)
 - Question posed to class: Did these areas get covered by the floods? (No)
 - “Where do you live on this map? Dexter McCarty is here in the flat areas so it is possible that this land was covered by the Missoula Floods and rocks were deposited here that were carried down from Washington.”
- Slide 3
 - Go down the bullet points
 - Question posed to class: What radioactive elements have you heard of? (Uranium, K, Thorium...)
 - “In the natural decay of Uranium all the elements that are made are solids except for one, which is a gas... RADON.”
- Slide 4
 - Question posed to class: Have you ever heard of Oregon Public Broadcasting, OPB?

- Question posed to class: Have you ever watched Oregon Field Guide?
 - “They make cool videos about interesting things but put in the science behind it. For example, they want to teach you about hang-gliding and they will explain the physics behind how to obtain flight.”
- 13 minutes – Video: <http://www.opb.org/programs/ofg/segments/view/1808>
- 3 minutes to wrap up
 - Slide 5
 - Question posed to class: On the other map in the video where all the zip codes were one color, how many houses did they test in order color it red? (at least 30)
 - Question posed to class: How many houses do you think live in each of those zip codes? (100’s or 1000)
 - Question posed to class: Is 30 out of 1000, or 3%, a good amount of data? (No)
 - Question posed to class: What did Brett Sherry say about the data? (Need more data to make better maps because you can’t just look at the map and say whether your house is radon free or not)
 - Question posed to class: So what zip code are we in? (97080)
 - “It says that we have low potential of having high radon levels but... (Every house should be tested)”
 - Slide 6
 - Go through each bullet point and go over Radon detector instructions if needed.

Related Concepts: Geologic history of Oregon, permeability, rock types, radioactive decay, periodic table of the elements, human health, lung cancer, mapping data, community outreach.

Materials: 3-day radon test kits and brochures (English and Spanish) for each student.

Handouts and worksheets: 3-day radon test kits and brochures (English and Spanish) for each student.

Created Curriculum – Introduction to Soil Texture

Fellow: Kat Barnard (Geology)

Teacher: Brie Bui (Dexter McCarty School)

Advisor: Dr. Scott Burns (Geology)

Learning goals: Practice field techniques that are commonly used by soil scientists and by determining soil textures they will make a physical connection between texture, porosity and permeability. Once textures are learned, it is easy to relate soil texture to vegetation needs.

Target Grade: 8th grade Integrated Science. Earth and Physical emphasis.

State Standards: 6.1P.1 Describe physical and chemical properties of matter and how they can be measured. 7.2E.4 Explain how landforms change over time at various rates in terms of constructive and destructive forces. 8.2E.2 Describe the processes of Earth's geosphere and the resulting major geological events.

Activity Summary: One-day inquiry activity on soil textures. About 40-50-minute activity on using the scientific method of “magic fingers,” which is used by soil scientists in order to determine the texture of various soil types in the field. The method is clearly explained using the attached flow chart.

Activity Plan: Groups of 4 works well, but this could be done in pairs.

Set up:

1) Paint buckets of water should be placed around the room with towels for washing hands rather than letting the dirt go down the drains (if you have sinks).

2) Obtain approximately one quart-sized bag of soil for each of at least 4-6 soils with different textures from the region.

- 3) Place each soil texture type in a bowl for each group.
- 4) Each group will practice on at least two different soil textures.
- 5) Place one of the soil textures as an “unknown” in the center of the room as the mystery soil.

Introduction (5-10 minutes):

- 1) A flow chart for performing “magic fingers” is attached. Use approximately one fist full of soil and, wetting slowly with a spray bottle or dropper until a ball can be formed and then follow the flow chart. It is important to not let them add too much water to the samples.
- 2) Using your own sample and the overhead projector, wet a handful of soil and follow the flow chart provided in order to demonstrate how to make a ball with the soil, how to add more soil if the sample gets too wet, and how to SLOWLY add the water to wet it.

Work time (30 minutes):

- 1) The students should then practice “magic fingers” on the soils of known textures at their desks, following the flow chart, and when they think they know it, they can guess and you can tell them if they are correct or not.
- 2) When they are correct they can switch samples with another group and practice again.
- 3) When they have successfully identified two textures they then can attempt to determine the texture of a mystery soil.
- 4) Have the students wash their hands in the provided buckets between samples.

Related Concepts: Permeability and porosity should be addressed earlier in the soil curriculum. They will add to their concept of permeability and porosity when wetting sandy samples and the water flows through the sample vs. when they wet a clay sample and it holds onto the water.

Materials: Buckets for hand rinsing, paper towels, newspaper for the desks, water bottles/squirt bottles, bowls for soil, soil of various textures, soil texture flow chart.

Extensions: Grain size analysis, soil chemistry, agriculture. Students will start to see the relationship between soils and the types of vegetation that grow will in them. Agricultural needs differ with each crop, some doing well in sandy soils and others preferring more clay rich soils that hold water for longer periods of time. The concept of drought stress could also be introduced here.

Handouts and worksheets and Assessment Questions: On worksheet below.

DIRTY MUDDY STICKY GROSS!

Inquiry: What are soil textures and how do scientists determine them in the field?

Materials: 6 soil samples with different textures at stations
6 bowls (one for each sample)
Buckets for hand washing
Squirt bottle of water

Procedure:

- 1) You and your table partner practice on known soils.
- 2) Use the flow chart on the next page to determine the soil texture of each soil.
- 3) Record your texture in the table below for each of the 2 soils.
- 4) Ask your teacher if your known soil textures are correct before moving on.

Soil	Soil #	Soil #	Mystery Soil
Your texture			
Actual texture			

- 5) Redo soils until your texture is correct.
- 6) When you feel confident about the soil textures, go to the mystery soil and figure out its texture using the same flow chart you used before.

Questions:

- 1) What was easier to determine: loam, clay, or sand? Why?
- 2) For you, what soil texture was the hardest to figure out? Why?
- 3) Did you need the same amount of water to make a ball for all the different soil textures that you practiced on?
- 4) If not, explain why you think that is.

Appendix I Farming Practices and Certification

Sustainable

Low Input Viticulture and Enology (LIVE), Inc. is a non-profit organization that uses international standards for certifying sustainable agricultural practices in the US (Live, Inc., 2009). These standards are based on the International Organization for Biological and Integrated Control of Noxious Animals and Plants (IOBC-WPRS). The objectives of sustainability are not to remove synthetic fertilizers and pesticides from the vineyard but to use minimum amounts of both and only use them when absolutely necessary. Many vineyards in Oregon are certified under the LIVE program. There 118 wineries who have LIVE certified vineyards totaling 4031.7 acres of vine with 33 of these wineries located in the Willamette Valley AVA (Oregon Wine Board, 2009). Some wineries, like Rex Hill, have some acreage under Biodynamic® certification and some are LIVE Certified Sustainable (Rex Hill, 2009). Other wineries visited for this research that are LIVE certified include Lange Estate, Stoller, Amity, and Willakenzie (Lange Estate Winery and Vineyards, 2009; Stoller Family Estate, 2009; Amity Vineyards, 2009; Willakenzie Estate, 2009).

The main themes of sustainability are to promote grape production and the business while respecting the environment. It is important that the farmers' health is protected so education about the chemicals and timing of application are emphasized. At

some wineries, profit is the most desired aspect and the risk associated with going organic or Biodynamic® is not justified in their eyes (Lange, 2009). Other main aspects of sustainability involve promoting biological diversity in the vineyard by planting cover crops of clover and flowers (Brown, 2009; Malavolta, 2009). Natural mechanisms and cycles within the vineyard are also a priority and compost is made from the material taken out of the vineyards and put back each year. This promotes soil fertility without the use of synthetic fertilizers. The last objective is to minimize pollution so many vineyards will hand pick and sort and use biodiesel in the trucks and tractors (Lange, 2009). As with the other certification processes, there are fees, paperwork, and check-ups at certified vineyards in order to ensure that sustainable practices continue to occur (Malavolta, 2009).

At Sokol Blosser their motto includes the 3 P's, which are Planet, People, and Profit (Brown, 2009). This motto goes directly along with sustainability although they are not LIVE certified but are Oregon Tilth Organic certified (Sokol Blosser, 2009). Amity Vineyards is LIVE Certified Sustainable and they work very hard on experiments in the vineyard. One such experiment is to establish cover crops that reduce the competition for water and nutrients with the vines and prevent erosion while eliminating the need for herbicides to remove the bad weeds. Doing these experiments is a life-long passion of Myron Redford from Amity Vineyards and his desire is to reduce his dependence on synthetic herbicides as much as possible (Redford, 2009). Tilling is not a viable choice in

Redford's opinion because the machinery will compact the soil so he continues to test different cover crops that will not compete with his vines or need to be mowed (Redford, 2009).

Organic

There are around 20 wineries and vineyards in Oregon, four in the northern Willamette Valley, that are certified organic through the Oregon Tilth program with a total of 1010.9 acres. The certified organic vineyards in the Willamette Valley as of 2009 include Cooper Mountain Vineyards (110 acres), Sokol Blosser Vineyards (82.8 acres), Willamette Valley Vineyards (24.4 acres) and Evasham Wood Vineyard and Winery, Inc. (12.6 acres) (Oregon Wine Board, 2009). Oregon Tilth Certification is granted through a nonprofit organization utilizing the USDA National Organic Program guidelines (Oregon Tilth, 2009). Certification requires payment of fees, tremendous amounts of paperwork, and annual check-ups. Different certification requirements are needed for the words used and type of label on the wine. If all grapes are organic than "100% Organic" may be put on the label (Oregon Tilth, 2009). You may also put the phrase "Organically Grown Grapes" if all the grapes are grown organically. If "Organic Wine" is wanted on the label then the grapes must be grown organically and no sulfites are allowed to be added to the wine during the winemaking process (De Domingo, 2009). Other labeling includes "Organic," which means 95% of the ingredients are organic, and "Made with Organic Grapes," meaning only 70% of the ingredients are organic.

The requirements for being organic include that the vineyard have three years with no application of synthetic herbicides, pesticides, or fertilizers. No Genetically Modified Organics (GMOs) or synthetic products of any kind can be used in the growing process. Some non-synthetic or nonagricultural substances are also prohibited, as well as nonorganic agricultural substances, ionizing radiation, or sewage sludge (USDA, 2009). The land also must have defined boundaries and a buffer zone between areas where prohibited substances may be in use and the site of the organic cropland. For example, at Cooper Mountains Vineyards a housing development next to the vineyards must utilize organic landscaping and yard management so as not to hurt the vineyards (Cooper Mountain Vineyards, 2009) (Figure 121).

In order to promote healthy soil and prevent erosion and nutrient deficiencies, organic practices are implemented instead of using fertilizers and pesticides. These include tilling and cover cropping to promote vegetation in the vineyard rows that will not compete with the vines for nutrients and will reduce soil erosion during large rain events. Tilling the cover crop into the soil puts C and N back into the soil as well. Rotating the cover crop will also create a diverse environment for micro and macro organisms. To keep weeds from growing up around the vines, organic mulch or plastic (as long as it is removed later) can be laid. Hand or mechanized weeding is also allowed as well as using livestock grazing, mowing, and flaming (USDA, 2009).

Figure 121. Cooper Mountain Vineyards and the sold property to the north of the vineyards. This sold property has requirements for owners to also be organic and not use chemicals in their yards that could harm the vineyards (Ludlow, 2009).

One of the most important aspects of mono cropping is pest and disease management. In order to prevent the spread of diseases, sanitation of mechanical devices and work clothes is necessary. Since Amity Vineyards are not grafted onto resistant rootstock, extreme sanitation is required in their vineyards to prevent the spread of the phylloxera louse (Amity Vineyards, 2009). Enhancing crop health in general is another effective method for disease management. This includes selecting vine species that are more suitable for the site and resistant to prevalent pests and diseases (USDA, 2009). Pest problems can also be controlled through the augmentation or introduction of predators of

these pests, or using lures, traps, or repellents. Disease spread can be mitigated by using non-synthetic biological, botanical, or mineral inputs (USDA, 2009).

In the winery, all products used must be on the Organic Product List and all cleaning agents for the winery equipment must be organic. Ionization or CI products are strictly forbidden. When making wine, the yeast used for fermentation must also contain only organic N. No additions of synthetic products are allowed in the wine and total sulfites must be kept less than 100 ppm, which is 50% less than other commercial wines (De Domingo, 2009). Sulfites are needed to reduce oxidation in the wine and act as an antimicrobial agent. Sulfites act as a preservative which protects against off colors and flavors and prevents spoilage (Goode, 2014). Minimum amounts of sulfites needed to resist off flavors depends on the type of wine. These amounts range from 10 ppm for a Semillon to 400 ppm for a botrytis wines. Sulfites are the culprit when dealing with wine headaches in most cases (Goode, 2014). Being organic involves changing many standard farming practices like using compost instead of fertilizers to provide nutrients and using pheromone lures for bugs instead of pesticides. It takes courage to make the switch but many wineries and vineyards in Oregon have become organic in the last twenty years and many more are following (Hellman, 2003).

Biodynamic

Demeter Biodynamic® agricultural techniques are equated to organic certification with the addition of homeopathy and astrology. Biodynamic food will be ‘true to its essence and provides deeply penetrating nutrition that is medicinal as well as delicious’ (demeter-usa.com). These practices were based on Rudolf Steiner’s “Agricultural Course” and the spiritual context of Anthroposophy (Steiner et al., 2004). Steiner influenced a feeling of a ‘broader and richer’ world, wanted to start another religion like Christianity or Islam that fed the world’s hunger for ‘spiritual values’. Some bitter hostility came from the thought that only a trickster could preach a fundamentally irrational doctrine and acquire a large following. He toured Europe presenting his lectures in the early 1900’s, establishing a following, and his ambition was to build a temple by 1914 called the Goetheanum in Dornach, Switzerland that was made of wood and other natural products (Wilson, 1985). Rudolf Steiner lectured on ways to practice agriculture by focusing on the soil. The belief is that healthy soil is healthy for people and that people could be healed through the soil (De Domingo, 2009). The tangible and intangible forces that exist in the world can affect the soil quality through climate, wildlife, the sun, and the distant cosmos. (Demeter Association, Inc., 2009).

According to the Rex Hill website, Biodynamic® farming is more stringent than organic farming and takes into account the energy and spiritual aspect of farming as well as the physical aspect (Rex Hill, 2009). This was also conveyed at Cooper Mountain

where a balance in the vineyards is established by the energy transferred from the cosmos to the vines through certain practices. At Cooper Mountain Vineyards the homeopathic aspect includes making preparations and using water from an Energy Vortex Fountain (Ludlow, 2009). The preparations include things like yarrow, chamomile, nettle, oak bark, dandelion, valerian, horsetail, silica, and manure. They use the herbs and flowers to make compost and teas that are mixed with the energized water. This small amount of tea is then added to large vats of water, in which the energy from the tea can be propagated throughout the liquid by the force of the atomic particles. The teas are sprayed onto the vines at certain times, not as a preventative action, but as an enhancement and a giving of energies. This enhancement involves creating harmony between the energy in the cosmos and the energy needed to support good bacteria and microorganisms in the vineyard soil (De Domingo, 2009). At Montinore Estate, the same types of preparations are used in order to enhance the fruit on the vine (Montinore Estate, 2009).

The compost used at Biodynamic® farms includes the skins, seeds, stems, and clippings from each vineyard. In the spring the specific compost for each vineyard, made from the refuse and blended with buffalo or cow manure, is spread to enhance nutrients and release the energy that was taken out of vineyard back into it (De Domingo, 2009). Biodynamic® practices are based on using the natural energy cycles within the farm and keeping outside inputs to a minimum. Another major concept in Biodynamic® agriculture is that the vines needed to be stressed and taught how to survive with slightly

deficient amounts of nutrients. This will make the vines stronger so when a disease or drought attacks them they are more resistant to harm (De Domingo, 2009). All the nutrients needed are provided by using cover crops of grass and wildflowers, rotating them every year for the first couple years and mowing them down so they feel like their livelihood is threatened. This will cause them to over seed and establish strong roots. After a few years the result is a diverse environment for a variety of organisms (De Domingo, 2009).

The basis of using an astrological calendar is to harness the energies of the cosmos at certain times of the year and give them to the vineyard. This is accomplished by using cow horns, filling them with compost from the year before and strategically placing them throughout the vineyards. When burying them at sunrise the day of the spring solstice, you will harness energy in the universe and given it to the vines. At Cooper Mountain Vineyards, it is said that shortly after the horns are buried bud-break occurs. In the same manner, the horns are removed in the fall at sunset on the winter solstice to take the energy from the vines and release it back into the universe. This release signals the vines to go dormant for the winter (Ludlow, 2009).

In the winery, no additives are allowed to be added to the wine. All the yeast and bacteria in the wine are native for fermentation and a maximum of 100 ppm S (SO₂) can be residual in the bottle. No acidification, chaptalization (addition of sugar to increase

alcohol content), or corrective additions are allowed either (De Domingo, 2009). The astrological calendar is also used to determine fruit and flower days, which are days that you should spend in the vineyard or the winery, respectively. When you should open your bottle of wine is also determined by these fruit and flower days (Ludlow, 2009). The wine is allowed to express the climate, soil, and geology of the location in which the grapes were grown because even the preparations are so dilute they are like not adding anything at all. The grapes are harvested, brought to the winery, fermented and put in barrels by block in order to preserve the flavor of each unique area in the vineyard (De Domingo, 2009).

The certification process is the same as getting certified by other organizations. You fill out tons of paperwork, pay fees, and get annual check-ups. There are eight Demeter Biodynamic® wineries in Oregon totaling 650 acres and five of them are located in the northern Willamette Valley. The wineries with the most Biodynamic® acreage are Cooper Mountain (110 acres), Momtazi Vineyard (230 acres), and Montinore Estate (220 acres). Brick House Vineyard, Bergstrom, Resonance Vineyard, and Rex Hill also practice Biodynamic® agriculture and have 27.5, 23.5, 20, and 12 acres, respectively, of Demeter Biodynamic® certified vines (Oregon Wine Board, 2009).

Skeptics and supporters of Biodynamic® practices have looked into its effects on flavor and soil biology but published studies are scarce. In one study on soil biology in

organic and Biodynamic vineyards, the end result was that the Biodynamic preparations did not significantly affect the soil biotic parameters tested compared to just using compost. The parameters included microbial biomass, respiration, dehydrogenase activity, soil carbon, earthworm population and biomass (Carpenter-Boggs, 2000). Testing Merlot made from Biodynamic and organically grown winegrapes was performed using perceptible sensory differences. The results of these tests concluded that Biodynamic and organic 2003 and 2004 wines tasted differently. The 2003 Biodynamic wines were said to have higher musty/earth aroma and bitterness than the organic wine and that the 2004 organic wines was higher in musty/earthy aroma and astringency and bitterness than the Biodynamic wine of the same vintage (Ross, 2009).

Salmon-Safe

The Salmon – Safe program is partnered with the LIVE Certified Sustainable and Oregon Tilth Certified Organic programs. This is an optional additional certification that has its own fees and paperwork associated with it. Certification is valid for three years with annual check-ups. To be considered Salmon – Safe a scoring system is used and a field assessor visits the vineyards in question. The intent of Salmon – Safe certification is to commend farm operations that address the impacts they have on salmonid stream ecosystem health (Salmon – Safe, 2005).

The four ways that a farmer may impact salmon are 1) the introduction of surface or sub-surface runoff including sediment, energy (temperature), or chemicals into the stream, 2) elimination or reduction of riparian corridor vegetation, 3) direct alteration of the stream banks, streamside, or in-stream habitat, 4) alteration of flow regimes through groundwater pumping or water diversions (Salmon – Safe, 2005). To assess these impacts, the scoring system will subtract points when the farmer is ignorant to these best management practices and add points when the farmer is in full compliance with these practices for each element, or grouping of farm management ideas. These elements include riparian and wetland management, irrigation and water use, erosion and sediment control, fertility and pest management systems, animal management, and biological diversity. To meet the certification, all elements of best management practices must be positive; therefore, there can be negative scores within each group but the overall score must be positive. Annual visits will determine whether or not there is improvement or not and if certification is still valid in case major changes have occurred in the vineyard (Salmon – Safe, 2005).

Examples of things the assessors are looking for include buffer zones between the vineyard and the streams, allowing for riparian zones (Cooper Mountain Vineyards, 2009). If there are excessive stream crossings or poorly designed crossings, you will get a negative score. If the farmer uses cover crops and little irrigation in order to reduce erosion, a positive score is given. When the farmer uses natural methods to control weeds

and pests, without using “high risk” pesticides and herbicides, a positive score is given. The farmer’s knowledge of soil chemistry and nutrient needs, as well as having the soil tested regularly to determine what nutrients are needed, deserves a positive score as well. If the farmer uses heavy machinery in excess that compacts the soil and increases runoff a negative score is given (Salmon – Safe, 2005).

One of the elements of Salmon – Safe certification is optional and relates to biological diversity. To increase biodiversity there are many options for farmed areas and non-farmed areas. Some of the ways to increase biodiversity within the vineyard are to rotate the cover crops and alternate the rows that are mowed to ensure that not all the habitat for insects is removed at once. Minimizing tillage under the vines will allow for plant residues to accumulate and increase the diversity of the soil organisms. Compost, cover crops, and tilled-in plant residues are great ways to increase soil fertility and biodiversity. Outside of the vineyard, planting hedgerows of multiple species and improving riparian vegetation, as well as building water reservoirs, will attract and support beneficial organisms and wildlife. Allowing for neighboring fields to be fallow and woodlands to be left as natural as possible also will insure the biodiversity that is so important (Salmon – Safe, 2005).

Oregon Certified Sustainable

Practicing sustainable grape growing and winemaking ensures the land, animals, rivers, and aquatic life will still be here for generations to come. Oregon Certified Sustainable Wine (OCSW) focuses on shared principles of Low Input Viticulture and Enology (LIVE), Food Alliance, USDA National Organic Program and its certifying agencies (Oregon Tilth, Stellar Certification Services and others) and Demeter Biodynamic®. To be OCSW certified there are certain agricultural and winemaking requirements. Of the fruit used by the winemaker, 97% must be certified by LIVE, USDA Organic, Demeter Biodynamic®, Food Alliance, and Salmon – Safe. The winemaking requirements also include that the processor or facility must be certified by either LIVE, USDA Organic, Demeter Biodynamic®, or the Food Alliance. Once these certifications are in place, you can also be certified as an Oregon Certified Sustainable Wine (Live, Inc., 2009).

There are many wines already certified by the OCSW, which started in 2007. The first wineries to achieve this label were Sokol Blosser Winery and Willamette Valley Vineyards, both in the northern Willamette Valley. Many more wines were allowed to use this label in 2008 including wines from Adelsheim Vineyard, Amity Vineyards, Anne Amie, Argyle, Bethel Heights Vineyard, Chehalem, Cristom, Montinore, Panther Creek Cellars, Ponzi, Rex Hill, Sokol Blosser, Stoller, Willakenzie, Willamette Valley Vineyards, and Wooldridge Creek (Live, Inc., 2009; Montinore Estate, 2009; Sokol

Blosser, 2009). The OCSW is a great marketing strategy to allow for one label to represent all the others and many more wineries will probably be utilizing it in the future (Oregon Wine Board, 2009).

Conclusions

An abundance of information is available online about the organic, Biodynamic®, or sustainability practices carried out by various wineries in the northern Willamette Valley. Winery owners and employees are more than willing to discuss their own methodology or experimentation that they carry out in their vineyards to become more sustainable. Many are working towards sustainability or are organic in many ways but do not have the certification. Reasons for not being certified include, but are not limited to, the cost of the certification process, the paperwork that is necessary to track all input to the winery and vineyards, or the thoughts that it is unnecessary marketing and not needed if you make great wine.

Main themes of organic, Biodynamic®, or sustainable agriculture include using compost created by the vineyard and placed back into it, using cover crops to reduce erosion and provide a diverse habitat for good insects and organisms, and reducing need of synthetic additives in the wine because the fruit is taken care of. If the vineyard is healthy, the fruit will be delicious, and very little will need to be done in the winery to make good wine. The most important difference between these certifications and logos is

that some still allow for the input of synthetic pesticides and herbicides but the application is regulated and kept to an absolute minimum, while others do not allow any such application at all. Oregon Tilth Certified Organic and Demeter Biodynamic® wines are made from vineyards that have had no synthetic input for over 3 years. LIVE Certified Sustainable, Salmon – Safe, and Oregon Certified Sustainable Wine may still have used some amount of chemicals in the vineyard and winemaking.

Although much interest in being sustainable and/or organic scientific research is limited in determining if such practices actually improve the quality of the wine. Many highly rated wines in France, California, and Oregon are certified organic or biodynamic but the actual mechanism that makes the wines better is still not understood. Some research concludes that there are sensory differences between the organic and biodynamic wines (Ross, 2009). Whether or not this is based on differences in the vineyard is not supported, however, from the theory that biodynamic vineyards have more soil organisms that promote better vine health. A study found that there was no significant difference between vineyards given compost and compost with biodynamic preparations (Carpenter-Boggs, 2000). Further research is needed to understand the effects of organic, Biodynamic®, and sustainable practices on the wine produced in Oregon.

References for Appendix I

- Amity Vineyards, 2009, www.amityvineyards.com (accessed December 2009).
- Brown, M.K., 2009, GSA Vineyard tour: Direct Sales Manager, Sokol Blosser Winery, October 17, 2009.
- Carpenter-Boggs, L., Kennedy, A.C., and Reganold, J.P., 2000, Organic and Biodynamic Management: Effects of Soil Biology: Soils Science Society of America Journal, Vol. 64, p. 1651-1659.
- Cooper Mountain Vineyards, 2009, www.copermountainwine.com (accessed December 2009).
- De Domingo, Gilles, 2009, Personal communication: Winemaker, Cooper Mountain Vineyards, November 24, 2009.
- Demeter Association, Inc., 2009, www.demeter-usa.org (accessed December 2009).
- Goode, J., 2014, the Science of Wine from Vine to Glass: Berkeley, California, University of California Press, 216 p.
- Hellman, E., ed., 2003, Oregon Viticulture: Corvallis, Oregon State University Press, 264 p.
- Malavolta, C., and Boller, E.F., eds., 2009, Guidelines for Integrated Production of Grapes – IOBC Technical Guideline III, 3rd Edition: IOBC/WPRS Bulletin, Vol. 46.
- Montinore Estate, 2009, www.montinore.com (accessed December 2009).
- Lange Estate Winery and Vineyards, 2009, www.langewinery.com (accessed December 2009).
- Lange, J., 2009, Personal communication: Owner, Lange Estate Winery and Vineyard, November 28, 2009.
- LEED, 2009, New Construction and Major Renovations Rating System: U.S. Green Building Council, Inc., 108 p.
- Live, Inc., 2009, www.livecertified.org (accessed December 2009).

- Ludlow, Jason, 2009. Personal communication: Sales and Education, Cooper Mountain Vineyards, November 27, 2009.
- Oregon Tilth, 2009, www.tilth.org (accessed December 2009).
- Oregon Wine Board, 2009, www.oregonwine.org (accessed December 2009).
- Redford, M., 2009, Personal communication: Senior Winemaker/Owner/President, Amity Vineyards, November 28, 2009.
- Rex Hill, 2009, www.rexhill.com (accessed December 2009).
- Roberts, S., 2009, *Wine Trails of Oregon – A guide for uncorking your memorable wine tour*: Mercer Island, WA, South Slope Publishing, 537 p.
- Ross, C.F., Weller, K.M., Blue, R.B., and Reganold, J.P., 2009, Difference Testing of Merlot Produced from Biodynamically and Organically Grown Winegrapes: *Journal of Wine Research*, Vol. 20, No. 2, p. 85-94.
- Salmon - Safe, 2005, *Salmon – Safe® Farm Management Certification Program – Field Assessor’s Guidelines 4.2*: Salmon – Safe®, Inc., 21 p.
- Sokol Blosser, 2009, www.sokolblosser.com (accessed December 2009).
- Steiner, R., Adams, G., and Pfeiffer, E., 2004, *Agriculture Course: The Birth of the Biodynamic Method*: Forest Row, Rudolf Steiner Press, 176 p.
- Stoller Family Estate, 2009, www.stollervineyards.com (accessed December 2009).
- USDA, 2009, *National Organic Program Regulatory Text*: U.S. Department of Agriculture, Agricultural Marketing Service, 58 p.
- Willakenzie Estate, 2009, www.willakenzie.com (accessed December 2009).
- Wilson, C., 1985, *Rudolf Steiner, the Man and His Vision – An Introduction to the Life and Ideas of the Founder of Anthroposophy*: Wellingborough, Northamptonshire, Aquarian Press, 176 p.