THE TERROIR OF PINOT NOIR WINE IN THE WILLAMETTE VALLEY, OREGON – A BROAD ANALYSIS OF VINEYARD SOILS, GRAPE JUICE AND WINE CHEMISTRY

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Abstract

Wine-grapes in the Willamette Valley, Oregon, are grown on three major soil parent materials: volcanic, marine sediments, and loess/volcanic. This study examines differences in the soil properties and elemental chemistry of the soil parent materials at various vineyards to document their effect on 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. 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. 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.

Keywords: Pinot Noir, ICP-MS/AES, particle size, cation exchange capacity, X-ray fluorescence, clay mineralogy, grape juice chemistry, wine chemistry, soil chemistry

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. 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 (Coetzee et al. 2005; Di Paola-Narajo et al. 2011; Fabani et al. 2010; Gozálvez 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 and chemical properties of the different soils used to grow grapes in this region.

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 and contribute to wine flavor. 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 the Willamette Valley there are specific regions that are known for producing wine of different flavors. Using "transparent" grapes, which are thin-skinned and more easily influenced by variations in terroir that could affect flavor than other grape varietals, the soil physical and chemical properties are presented here. The three transparent grapes varietals 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. Over 12,560 acres of Pinot Noir are planted in Oregon with a value over 53.8 million dollars in 2011 (USDA 2012).

There are now over 676 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 study. 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). The three major soil series groups that are used for growing Pinot Noir winegrapes in the Willamette Valley of Oregon are the Jory, 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.

The hypothesis is that the physical and chemical differences in the soil can be compared to the grape juice and wine chemistry to determine the contribution of soil to the terroir of this region. Using Pinot Noir, 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 on which the grapes are grown (Burns 2012). 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).

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 1). 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 1).

MATERIALS AND METHODS

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 with microwave digestion). 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.

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 (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 (Birkeland 1999; 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.

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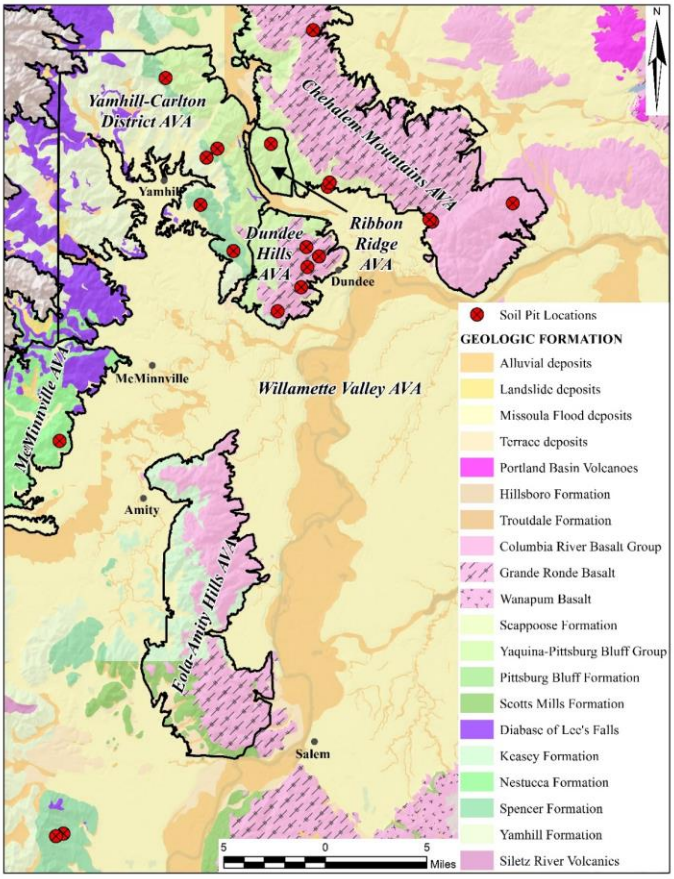

Figure 1. Geologic map of the Willamette Valley sub-AVAs (black outline) (Jones et al., 2010) in the Willamette Valley AVA based on geologic map compilation data (Madin, 2009).

Table 1. 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