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PO Box 3003, Lancaster Pa, 17603

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Kevin Pogue (Whitman College) and Chris Oze (Bryn Mawr College)
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Origin of big garnets in amphibolites during high-grade metamorphism, Adirondacks, NY
Kurt Hollocher (Union College)
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Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

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The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
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Keck Geology Consortium: Projects 2007-2008
Short Contributions – Walla Walla

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PO Box 3003, Lancaster Pa, 17603
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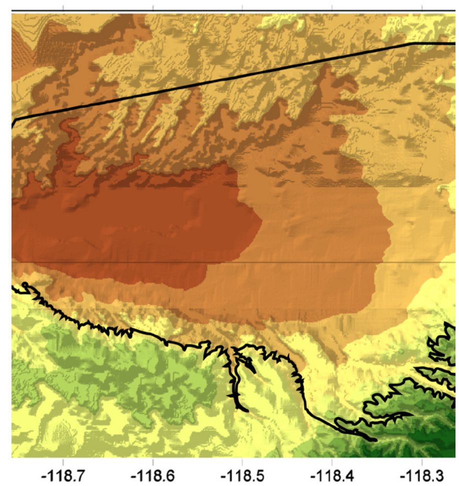
VARIATIONS IN TEXTURAL, HYDROLOGIC, AND CHEMICAL PROPERTIES OF SOILS WITHIN THE WALLA WALLA VALLEY AMERICAN VITICULTURAL AREA

JOHN NOWINSKI: Carleton College
Research Advisor: Mary Savina

INTRODUCTION

The French term "*terroir*" is used to describe the unique and complex environment of a particular vineyard site. Though it may seem logical that the terroir of a vineyard should influence the wine produced form its grapes, these influences have not been rigorously studied or quantified. The interaction between geology and climate plays a fundamental role in soil formation and thus has a strong influence on a vineyard's terroir. Although the geology and climate of the Walla Walla Valley American Viticultural Area (AVA) influences the grapevines and thereby the character of the wines from this region, the specific role they play is only partially understood. This study aims to further the understanding of how the geology and climate in the Walla Walla Valley AVA affect viticulture by quantifying the soil-water interactions.



ital elevation model of the Walla Walla Valley with American Viticultur
untains in the east create a ~1370 m elevation gradient.

BACKGROUND

Spanning the Washington-Oregon border, the 3,266 km^2 Walla Walla Valley AVA is a distinct subsection of the much larger Columbia Valley AVA. It is bounded on the east by the Blue Mountains, which create a ~1370 m elevation gradient in the Valley (Fig. 1). The bedrock of the Walla Walla Valley is composed of the Columbia River basalt, which was erupted in a series ~300 flows between 17 and 14 Ma (Carson and Pogue, 1996; Swanson, 1978).

Most soils in the Walla Walla Valley are poorly developed and are derived from a combination of exotic aeolian and fluvial sediments. The predominant soil type in the AVA is loess that was deposited by the prevailing southwesterly winds for at least 2 million years (Carson and Pogue, 1996). A principal sediment source for the loess is the Touchet beds, which were deposited by catastrophic glacial outburst floods that occurred between ~15,300 and 12,700 years ago (Waitt, 1980; Waitt, 1985).

Climatically, the Walla Walla Valley is fairly dry due to the Cascade Mountains, which block incursions of moist marine air. However, some moisture does pass over the Casacdes, and although the summers are very dry, precipitation increases in the fall and peaks in midwinter before gradually declining through June (Harrison et al., 1964). Precipitation, which falls both as rain and snow, is not distributed equally over the Valley, rather it increases from west to east, with more precipitation falling at higher elevations due to orographic lifting (Harrison et al., 1964).

METHODS

Sample Collection: Soil samples were collected at 21 sites between July 25 and August 8, 2007, primarily at sites located in uncultivated portions of vineyards. Samples were collected at 0.5, 1.0, 1.5, and 2.0 m using a bucket-style soil auger and stored in airtight bags.

Soil Moisture: Gravimetric soil water content was determined for each sample by weighing 300 to 500 grams of moist soil, drying it, and then re-weighing it. Values were calculated by the equation: Gravimetric Soil Water Content = (Wet Mass- Dry Mass)/(Dry Mass). By measuring the volume of the soil in a graduated cylinder before samples were dried, volumetric soil water content was also calculated from the equation: Volumetric water content = (Wet Mass-Dry Mass)/(Wet Volume).

Soil Permeability: Field saturated hydraulic conductivity and matric flux potential were determined at 17 of the 21 field sites using a Guelph permeameter as a means of quantifying soil permeability. The permeameter was run at 5 cm and 10 cm heads until the rate of decrease in the instrument's water reservoir reached steady state. These readings were used to calculate the permeability parameters based on calculations specific to the device.

Soil Texture: Particle size analysis of the 0.5 m deep samples was completed at Carleton College using the hydrometer method. The specific procedure used was based on the protocol described by Ashworth et al. (2001).

Soil Chemistry: Seven 0.5 m deep samples were sent to International Ag Labs, Inc. for analysis. Plant available Ph, K, Ca, Mg, Na, Cu, Fe, Zn, and Mn were determined using the lab's particular weak acid extract, the Morgan extract. Soil pH was also determined.

RESULTS

Particle Size: The viticultural soils of the Walla Walla Valley are predominantly silty loams based on the USDA soil texture classification scheme. Of the samples tested, 19 out of 21 are silt loams, while one is a sandy loam and the other is a silt.

Sand content generally decreases with elevation, while clay content increases (Figs. 2 and 3). The linear best-fit line for sand and elevation has an R^2 value of 0.57, while the best-fit line for clay and elevation has an R^2 value of 0.84. When only the fines are considered, silt content generally decreases with elevation, and the best linear model has an R^2 value of 0.75. When sand is included, however, there is no clear relationship.

Soil Permeability: Data collected using the Guelph permeameter yield a mean field saturated hydraulic conductivity of 5.64×10^{-4} cm/hr with a standard deviation of 4.22×10^{-4} cm/hr for the 17 sites tested, while the soil matric flux potential for the sites has a mean value of 5.98×10^{-3} cm/hr with a standard deviation of 4.29×10^{-3} cm/hr. Although their values range widely, hydraulic conductivity and matric flux potential exhibit no clear relationships to elevation, soil texture, or soil moisture.

Soil Moisture: Soil moisture generally increases with depth, with the mean gravimetric moisture values being 7.83% for 0.5 m, 9.04% for 1.0 m, 10.34% for 1.5 m, and 11.50% for 2.0 m. Averaging all four values at each site yields a mean value of 9.63% with a standard deviation of 3.16%.
Insert figs 2 and 3

When all samples are considered, there is no definitive relationship between soil moisture and elevation. However, when only sites consisting of loess free from anthropogenic alteration are considered, there is a clear positive relationship between elevation and soil moisture, with R^2=0.84 (Fig. 4). A similar effect is also seen when soil moisture and soil texture are compared. When all sites are considered, there are no clear correlation between particle sizes and moisture. For the parsed data set, however, R^2 values for moisture versus sand increase to 0.49, and moisture verses clay to 0.75. The slopes of the best-fit line indicate that moisture generally decreases with higher sand content but increases with high

clay content. For silt and moisture, however, there is still no clear relationship.
Insert fig 4

Soil Chemistry: Soil pH in the samples ranges from 6 to 8 and generally decreases with elevation, with the best linear fit between the two parameters having an R2 value of 0.82. There is also a clear positive correlation between elevation and most of the cations, including Ph, Ca, Mg, Fe, and Mn (Table 1).
Insert table 1

DISCUSSION

Data Interpretation

The results of this study suggest topography and its control of precipitation are the primary factors responsible for the soil moisture distribution of the Valley. The high correlation between soil moisture and elevation and the similarity between the rainfall and soil moisture distributions in the loess are evidence that this is the case.

The relative unimportance of soil texture in controlling soil moisture is further demonstrated by the poor correlation between soil moisture and field saturated hydraulic conductivity/ matric potential. Soil texture may play a role in controlling soil moisture, especially when both Touchet Bed and loess soils are considered, however, for the loess the role appears relatively minor.

Although the correlations between soil moisture and clay and sand contents suggests that soil texture does have a significant effect, it is likely that the correlation is controlled by one or several processes that are simultaneously influencing moisture and texture. For the positive correlation between clay content and soil moisture, it is probable that higher precipitation at greater elevations is increasing soil moisture while simultaneously causing increased weathering of silt to clay. This is consistent with the pH distribution results for the 0.5 m deep soils, which indicate greater soil weathering at higher elevations because soils are slightly acidic at this level, but slightly alkaline at lower elevations (Bohm et al., 2001).

Because sand resists weathering and sand content decreases rather than increases with elevation, the increased weathering does not account for the correlation between sand content and soil moisture. Instead, the loess deposition process is most likely responsible, with the eastward prevailing winds depositing more sand in the west (lower elevation and closer to source) and less sand in the east (high elevation and farther from source). This produces a correlation between sand content and moisture since moisture also increases with elevation. It is possible that the clay distribution in the loess soils is also a remnant of original deposition, however, the lack of a correlation between elevation and soil silt content does not support this contention. Given the strong (negative) correlation between silt and elevation when sand is not considered, it is more likely that the ratio of the finer grain sizes was originally relatively homogenous and that only after deposition did clay content increase with elevation due to weathering.

The chemical data suggest that there is also a relationship between elevation, clay content, and available cations. Intuitively one might expect to see lower amounts of available cations in areas with greater precipitation due to leaching; however, this is often not the case as there is a clear positive correlation between available Ph, Ca, Mg, Fe, and Mn and elevation. While it is still possible that more leaching is occurring at high elevations, this effect is apparently offset by the greater proportion of clay in these areas because clays facilitate cation exchange while silt is less effective.

Viticultural Implications

The distribution of soil moisture in the AVA is an important factor to consider when selecting future vineyard sites as soil moisture dictates how much irrigation, if any, a potential site will require. One study places optimal plant available water for wine grapes at 15 to 30 % (Sivilotti et al., 2005), which corresponds to volumetric soil water contents between ~2.5 and 5 % for silt loams (Sivilotti et al., 2005). In this study, all sites tested had volumetric water content values greater than 5%. While this does not imply that all sites in the AVA are suitable for dryland viticulture since water content would decrease at these sites once vines were planted, it does leave open the possibility of dryland viticulture in at least some areas. Future work looking at vine water consumption would help better delineate these areas; however, the presence of one existing dryland vineyard in the AVA gives a general idea of suitable sites (Fig. 4).

Wine grapes are unique from most other crops in that their quality decreases if they have too much available water because a greater proportion of a vine's energy is expended on plant growth rather than on fruit. In fact, numerous studies have shown that mild water stress can actually improve grape quality (des Gachons et al., 2005; Greven et al., 2005; Hardie and Considine, 1976; Kment, 2005; Koundouras et al., 2006; Santesteban and Royo, 2006). Given this body of research, it is likely that dryland vineyards in the Walla Walla Valley AVA would produce quality fruit since the lack of a constant water source would create mild water stress.

Coupled with their potential for quality fruit production, soils with higher moisture in the AVA have the added benefit of increased nutrient availability, presumably due to their higher clay content. Considerable debate exists concerning what role, if any, soil chemistry has on wine quality. It is clear at the very least that increased cation availability at higher elevations would promote vine health and reduce the need for fertilization.

CONCLUSIONS

The precipitation distribution in the Walla Walla Valley AVA strongly influences soil moisture and soil texture. Higher precipitation at greater elevation is the primary factor responsible for increased soil moisture in these areas. It is thought that higher precipitation also increases the weathering of silt to clay, which increases cation availability because of clay's high cation exchange capacity.

This study suggests that dryland viticulture is possible at high elevations in the Valley because natural soil moisture is great enough to support grapevines. Such vineyards could potentially produce high quality fruit because their vines would benefit from mild water stress and increased nutrient availability.

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