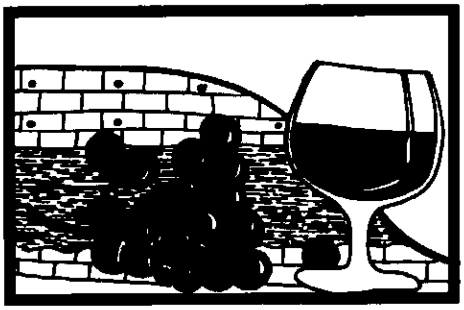
SERIES



Geology and Wine 3: *Terroirs* of the Walla Walla Valley *appellation*, southeastern Washington State, USA[1]

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SUMMARY

Terroir of the Walla Walla Valley *appellation* of Washington State is influenced by 1) the rain shadow effect and volcanic tephra of the Cascade Mountain Range, 2) soils derived from Quaternary glacial sediments and wind-blown loess overlying Miocene basalt, and 3) a warm, dry climate with abundant sunshine and cool nights due to high latitude (45-48°N) and elevation. Wine flavours of Walla Walla Valley varietals (including Cabernet Sauvignon, Chardonnay, Merlot, and Syrah) appear to be influenced by low humidity, long growing season (1500-1800°C degree days), soil type and drainage, drip irrigation, pruning to restrict vine vigour, trellising methods, and overall topographic climatic setting of the vineyards. Microclimates within the Walla Walla Valley *appellation*, combined with variations in soil and bedrock stratigraphy, yield a range of wine styles as great as many larger regions and some countries.

RÉSUMÉ

Le terroir de la vallée de Walla Walla d'appellation de l'État de Washington est caractérisé par 1) l'effet parapluie de la topographie locale et la nature téphritique des dépôts de la chaîne des monts Cascade, 2) les sols issus de dépôts glaciaires et de loess éoliens recouvrant un basalte Miocène, et 3) un climat chaud et sec très ensoleillé, avec les nuits fraîches des hautes latitudes (N45° à N48°) et de l'altitude élevée. Les goûts des vins des variétés de la vallée de Walla Walla (incluant le Cabernet Sauvignon, le Chardonnay, le Merlot, et le Syrah) semblent dépendre de la faible humidité de la région, sa saison végétative longue (1 500°C à 1 800°C degrés-jours), de la nature de son sol et de son drainage, d'une irrigation goutte à goutte, de la taille de la vigne pour en restreindre la vigueur végétative, des méthodes de treillages et, des conditions topographiques et climatiques générales où baignent ces vignobles. L'effet combiné des microclimats de la région d'appellation de la vallée de Walla Walla avec les variétés de ses sols et de la stratigraphie du substratum rocheux régional permet la production de styles de vin aussi prestigieux que bien des régions reconnues et même de certains pays.

INTRODUCTION

Terroir is a relatively simple term to describe the complex interplay of climate, soil, geology, and other physical factors that influence the character and quality of wine. Although the term has long been used in France, recent publications such as Halliday (1993, 1999), Wilson (1998), Haynes (1999, 2000), and Tesic (2000) have explored the concept of *terroir* in other parts of the world with considerable success. The purpose of the present paper is to describe the *terroir* of the Walla Walla Valley *appellation*, a relatively small and young winemaking region in southeastern Washington and overlapping into northeastern Oregon (Fig. 1) that is producing some outstanding wines, particularly stout red wines such as Cabernet Sauvignon, Merlot, and Syrah.

Washington State is a region of superlatives, both oenological and geological, with exposures of some of the world's largest and most spectacular flood basalts, dune and loess fields, and glacial outburst flood deposits. All of these play a part in the *terroirs* of Washington State wines. In addition, recent volcanic

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[1] Geology and wine is an international topic, much like *Geoscience Canada's* current series on Oceanic Lithosphere, and Economic Geology Models. Accordingly we are pleased to publish this third paper in the Geology and Wine series, on the Walla Walla Valley *appellation* of Washington State. Although the geology of the Walla Walla Valley *appellation* is unusual, with vast Miocene plateau basalts, slackwater flood deposits, widespread loess, and a variety of derived soil types, it is the *integration* of these geological attributes with climatic factors and viticultural practices that demonstrates the importance of *terroir* with all of its components. This third Geology and Wine series paper is a further example of the kinds of papers we are hoping to publish in *Geoscience Canada* as the series develops. R.W. Macqueen, editor.

activity such as the well-known 1980 eruption of Mt. St. Helens continues to shape the oenological and geological landscape. Most Washington vineyards lie in the rain shadow of the Cascade volcanic arc, and many vineyard soils have a component of ash from Mt. St. Helens and other Cascade volcanic eruptions such as the much larger Mt. Mazama eruption (6850 years B.P.) which formed present-day Crater Lake in Oregon (Busacca *et al.*, 2000).

Washington State is second only to California in terms of wine produced in the United States (Table 1). This is somewhat surprising in that Washington has a relatively short history of wine production by international standards. Although the first *Vitis vinifera* grapes were planted in 1825 by the Hudson's Bay Company along the banks of the Columbia River in southwest Washington (Peterson-Nedry, 2000), commercial production extends back only about 100 years and most of the state's 155+ wineries were started in the past 15 years (there were only 19 wineries when the first author moved to Washington in 1981).

Most Washington State wineries are located between latitudes 45°N and 48°N, well to the north of the more widely known California vineyards but parallel to some of the great French wine regions such as Burgundy and Bordeaux. This northerly latitude provides about two hours more summer sunlight than occurs in California wine regions. Wine quality is also influenced by the arid conditions created by the large rain shadow of the Cascade Mountains; almost all commercial vineyards lie east of the Cascade Mountain Range (Fig. 1).

Although there is considerable local variability, most Washington vineyards are located on Quaternary

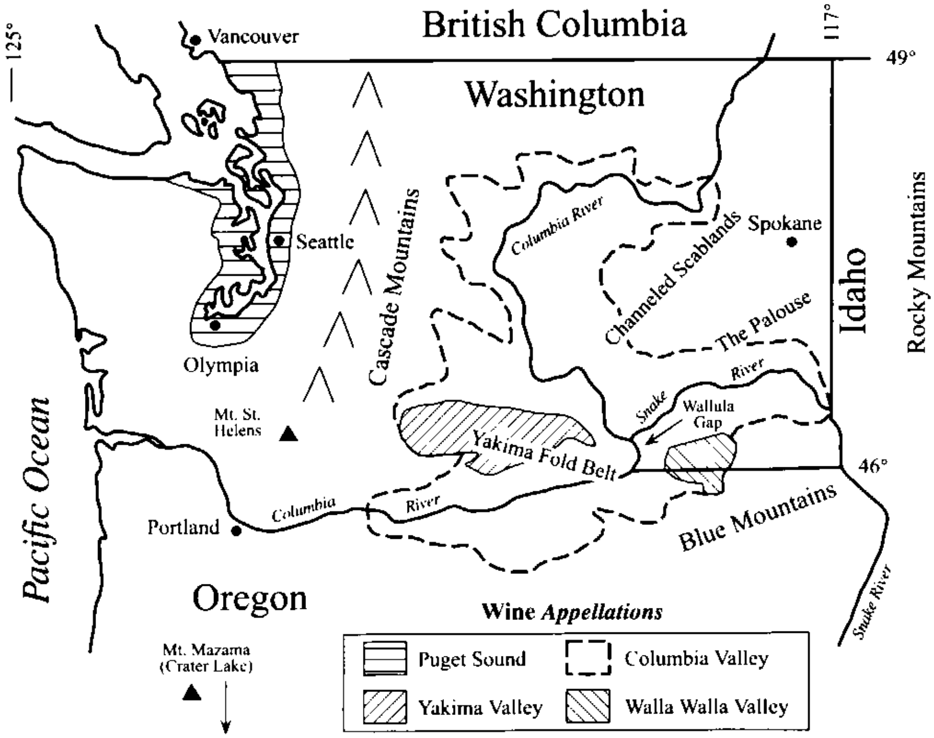

Figure 1 Location map of the Pacific Northwest showing wine *appellations* and major geologic features described in the text.

Table 1 US *vinifera* wine grape production 1997-1999. Data from http://www.nass.usda.gov/wa/graperpt.htm.

		Tons Utilized			Average Price (US$/ton)		
Rank	**Variety**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**
1	California	2,895,000	2,528,000	2,655,000	603	586	570
2	Washington	62,000	70,000	70,000	972	922	910
3	New York	44,000	36,000	50,000	328	392	348
4	Oregon *	18,500	14,700	17,900	1,120	1,180	1,310
5	Pennsylvania	6,000	11,500	13,000	350	303	325
6	Michigan	2,600	2,500	3,000	800	775	700
7	Missouri	1,800	2,050	2,600	480	535	583
8	Georgia	1,000	1,300	2,000	627	500	1,000
9	Ohio	1,000	800	2,000	492	679	725
	Other States	4,500	4,910	3,485	549	574	735
	United States	3,036,400	2,671,760	2,818,985	503	510	517

* Includes small quantities used for other processing (jam, jelly, *etc.*).

sediments and soils that overlie Miocene basaltic rocks of the Columbia River flood basalt province. Many of the Quaternary sediments are related to cataclysmic glacial outburst floods that formed the spectacular geomorphic features of the Channeled Scablands (cover photo). This in itself is one of the great geologic stories of all time, and the fact that it is intimately related to superlative wine makes a brief synopsis of the geologic history particularly worthwhile. The fact that some of the geological and soil features are unique to this part of the world suggests the possibility that Washington wines may develop flavour and quality characteristics that set them apart from other wine-producing areas.

OVERVIEW OF WASHINGTON STATE WINE

Washington State has four wine *appellations* called American Viticultural Areas (AVAs) by the Bureau of Alcohol, Tobacco, and Firearms (BATF), the chief regulatory agency of the wine industry in the United States (Fig. 1). Unlike *appellations* in many parts of the world, AVAs are not defined in terms of wine quality or even wine characteristics. An AVA is defined by the Bureau of Alcohol, Tobacco, and Firearms as "a delimited grape growing region distinguished by geographical features, the boundaries of which have been recognized and defined..." (http://www.atf.treas.gov/core/regulations/27cfr9.html). In Washington State the wine *appellations* (AVAs) are Columbia Valley, Yakima Valley, Walla Walla Valley, and Puget Sound (Fig. 1). Sub-*appellations*, that may someday become AVAs, include Alder Ridge, Canoe Ridge, Cold Creek, Columbia River Gorge, Horse Heaven Hills, Red Mountain, Wahluke Slope, and Zephyr Ridge (Peterson-Nedry, 2000). As with most other regions, AVAs can be nested such that the Columbia Valley *appellation*, which produces more than 90% of the state's wine grapes, includes the Yakima Valley and Walla Walla Valley *appellations*.

Total wine grape production in Washington State in 1999 was 70,000 tons from approximately 17,000 acres of bearing vineyards (Table 2). Wine grape production will continue to increase in that there are an additional 6000 acres of

Table 2 Washington State *vinifera* wine grape production 1995-1999. Data from http://www.nass.usda.gov/wa/graperpt.htm

	Tons Utilized					Acres Planted	Acres Bearing	Yield Tons/Acre	Average Price (US$/ton)				
Variety	1995	1996	1997	1998	1999	1999	1999	1999	1995	1996	1997	1998	1999
Chardonnay	15,000	8,000	17,700	20,500	22,900	6,100	5,030	4.6	732	1,240	1,055	971	882
White Riesling	11,000	8,800	10,100	11,500	9,800	1,900	1,780	5.5	385	478	489	533	547
Sauvignon Blanc	3,700	2,300	3,300	3,900	3,400	700	600	5.7	519	726	729	750	746
Semillon	3,600	1,800	2,800	3,100	2,600	600	590	4.4	502	642	661	625	598
Chenin Blanc	3,400	1,100	1,800	2,300	1,700	400	400	4.3	339	464	499	488	473
Gewürztraminer	1,700	700	1,700	1,600	1,300	400	310	4.2	413	541	552	629	706
Other (*)	600	300	600	600	800	400	290	2.8	546	755	789	952	777
Total White	39,000	23,000	38,000	43,500	42,500	10,500	9,000	4.7	542	786	794	772	753
Merlot	10,000	4,500	12,800	14,100	14,300	5,600	4,040	3.5	933	1,400	1,360	1,197	1,149
Cabernet Sauvignon	8,000	5,900	7,800	8,300	8,400	5,000	2,690	3.1	834	1,230	1,195	1,204	1,236
Cabernet Franc	500	600	1,100	1,700	2,000	700	510	3.9	834	1,170	1,120	1,102	1,066
Pinot Noir	1,200	400	1,000	1,100	1,000	200	200	5.0	520	698	653	661	647
Syrah	#	#	#	#	800	1500	290	2.8	#	#	#	#	1,398
Lemberger	400	300	500	500	500	150	110	4.5	565	844	757	760	785
Other (+)	900	300	800	800	500	350	160	3.1	917	1,110	1,400	1,386	1,152
Total Red	21,000	12,000	24,000	26,500	27,500	13,500	8,000	3.4	862	1,260	1,255	1,168	1,152
Washington total	60,000	35,000	62,000	70,000	70,000	24,000	17,000	4.1	654	948	972	922	910

* Includes muscat, pinot gris, and viognier
\+ Includes gamay beaujolais, grenache, nebbiolo, sangiovese, and zinfandel
\# Included in "Other" Red Varieties for 1995-1998

wine grapes planted that were not yet bearing fruit in 1999 (most grape varieties start producing in the third year). Projected production for 2000 is 88,500 tons (Roger Gamache, Washington Association of Wine Grape Growers, written communication, 2000). For comparison, to the north in British Columbia in 1999 there were 4200 acres of bearing vineyards, yielding 11,200 short tons of crops; just over 50% of the acreage under cultivation for wine grapes in British Columbia in 1999 was located in the Oliver-Osoyoos area of the Okanagan Valley region, about 320 km north of the Walla Walla Valley *appellation* (British Columbia Wine Institute, 2000).

In the early days of the Washington State wine industry most wine was made from Riesling and Gewürztraminer grapes because it was assumed that Washington was a cool-climate viticultural area due to its northern latitude, and therefore best suited to production of light fruity white wines. Although such grapes can produce excellent wine in Washington, it was quickly realized that varieties that benefit from warmer conditions also prosper in Washington (Clore and Nagel, 1969; Tukey and Clore, 1972; Nagel *et al.*, 1972). Of the wine produced in Washington State in 1999, 60% was white and 40% was red, a ratio which is almost identical in British Columbia (British Columbia Wine Institute, 2000). This ratio is likely to swing toward a predominance of red wine in Washington State in the future because of the increased plantings of red varietals. For example, in 1999 there were 9000 acres bearing white wine grapes and 8000 acres bearing red wine grapes, whereas in terms of planted but not-yet-bearing grapes, there are only 1500 acres of white wine grapes *versus* 5500 acres of red wine grapes. This trend appears to be accelerating with the newest plantings and those that are on the drawing boards (Norm McKibben, past president Washington Association of Wine Grape Growers, oral communication, 2000).

As shown in Table 2, white wine production is dominated by Chardonnay (54%) and Riesling (23%), whereas red wine production is led by Merlot (52%), Cabernet Sauvignon (31%), and Cabernet Franc (7%). Syrah currently is a fairly small part (3%) of Washington red wine production but is likely to grow in importance owing to spectacular early successes, as well as to the extensive new plantings of this grape. In 1999 only 290 acres of Syrah grapes were bearing commercial fruit but more than 1500 acres have been planted. This changing mix between red and white wine and among different grape varieties is to be expected in such a relatively young viticultural area. It is likely that further changes will occur as growers and winemakers learn more about which grapes are best suited to particular *appellations* and individual vineyards. Although at present about 85% of Washington State wines are blends of fruit from different vineyards, it is likely that single-vineyard wines will become more important in the future. This is one of the reasons why an understanding of *terroir* is so important as the Washington wine industry begins to mature. This is also the case in other Pacific Northwest viticultural areas such as the Okanagan Valley of British Columbia, where much experimentation with *vinifera* grape varieties is underway, following a major reorganization of the local wine industry, and the adoption of new high standards, in response to the Free Trade agreement of 1988 (*e.g.*, Aspler, 1999).

GEOLOGIC HISTORY

Columbia Plateau and Environs

The Columbia Plateau is bordered on the north and east by the Rocky Mountains, on the south by the Basin and Range Province, and on the west by the Cascade Mountains. The Walla Walla part of the Columbia Plateau is adjacent to the northwest flank of the Blue Mountains and is crossed by two of the largest rivers in North America: the Snake River that originates in Jackson Hole, Wyoming, and the Columbia River that starts in the Columbia Icefields of the Canadian Rockies.

The Blue Mountains (Fig. 1) are cored by an accreted terrain of late Paleozoic to early Mesozoic predominantly clastic and carbonate strata, intruded by late Mesozoic granitic plutons, and partly overlain by Tertiary volcanic rocks of the Columbia River Basalt Group (Hooper, 2000). The Columbia River Basalt Group covers an area of about 165,000 km^2. It was erupted mostly between 17-15 Ma (Early Miocene) from north-south fissures roughly paralleling the present-day Washington-Idaho border, and has individual flows with estimated eruptive volumes of at least 3000 km^3, making them the largest documented lava flows on earth (Baksi, 1989; Landon and Long, 1989; Tolan *et al.*, 1989). This dwarfs the erupted volumes of typical Cascade volcanoes: even the explosive eruption of Mt. St. Helens in 1980 yielded only about 1 km^3 of volcanic material (Pringle, 1993).

Stress Regime, South-central Washington State

Concurrent with Early Miocene volcanism were subsidence (*e.g.*, Pasco Basin), deformation (*e.g.*, Yakima fold belt), erosion (many of the valleys were later filled by intracanyon flows, Fig. 2a), and intraflow sedimentation (Fig. 2b). The north-south oriented compressional stress regime of south-central Washington State has existed from the Miocene to the present day. Some anticlines in the Yakima fold belt have developed as much as 100 m of structural relief in the past 10 m.y. (Reidel *et al.*, 1992), and the Walla Walla area experienced an intensity VII (approximate Richter magnitude 6) earthquake on 15 July 1936 (Brown, 1937), most likely caused by movement on the Wallula fault zone (Mann and Meyer, 1993), which is subparallel to the Yakima Fold Belt (Fig. 1).

Quaternary Processes and Products

The Quaternary Period brought a new group of processes. In the Pasco Basin were many sources for wind-blown detritus such as the Miocene Ellensburg Formation, the Pliocene Ringold Formation, sediment deposited by the Columbia and Snake rivers, and sediment from giant glacial outburst floods. The prevailing southwesterly winds transported silt from the Pasco Basin and deposited thick blankets of loess (Fig. 2c). Buried soils in the loess (Fig. 2d) indicate that deposition was intermittent during the Quaternary (Busacca, 1991).

Most of the basement geology has been masked and modified by a variety of features related to the Quaternary glaciation that affected much of the region. The vast continental ice sheet of the glacial maxima covered much of Canada, and the subsidiary Cordilleran Ice Sheet, which originated in the mountains of British Columbia, expanded southward into northern Washington, Idaho, and Montana. Of particular significance to the landscape of eastern Washington State was a lobe of the Cordilleran Ice Sheet which flowed along the Purcell Trench and blocked the northwest-flowing Clark Fork River near Cabinet Gorge on the Idaho-Montana border.

Lake Missoula and the Channeled Scabland

The Cordilleran Ice Sheet lobe dammed glacial Lake Missoula (Fig. 3), which covered 7800 km^2 of western Montana (Pardee, 1910). At the ice dam the water was approximately 600 m deep (Weis and Newman, 1989). The ice dam failed repeatedly, releasing the largest floods documented on earth (Baker and Nummedal, 1978). These floods overwhelmed the Columbia River drainage system and sent up to 2500 km^3 of water across the Columbia Plateau with each outburst (called jökulhlaups). The floods created a spectacular complex of anastomosing channels cut into southwest-dipping basalt surfaces. They also formed huge cataracts now seen as dry falls, "loess islands" that are erosional remnants of an early thick loess cover on the plateau, immense gravel bars, and ice-rafted erratic boulders at high elevations (Fig. 3, 12B).

In a series of early papers (Bretz, 1923, 1925, 1928a,b,c, 1932), J Harlen Bretz shocked the geological community and precipitated one of the most celebrated scientific debates in American geology with his studies of this enormous series of proglacial channels eroded into the loess and basalt of the Columbia Plateau. This region, which he named the "Channeled Scabland," contains erosional and depositional features that are unique among fluvial phenomena. With painstaking field work, before the advent of aerial photographs and modern topographic maps, Bretz documented the field relationships of the region. He argued that the landforms could only be explained as originating from a relatively brief, but enormous flood, which he called the "Spokane Flood." Considering

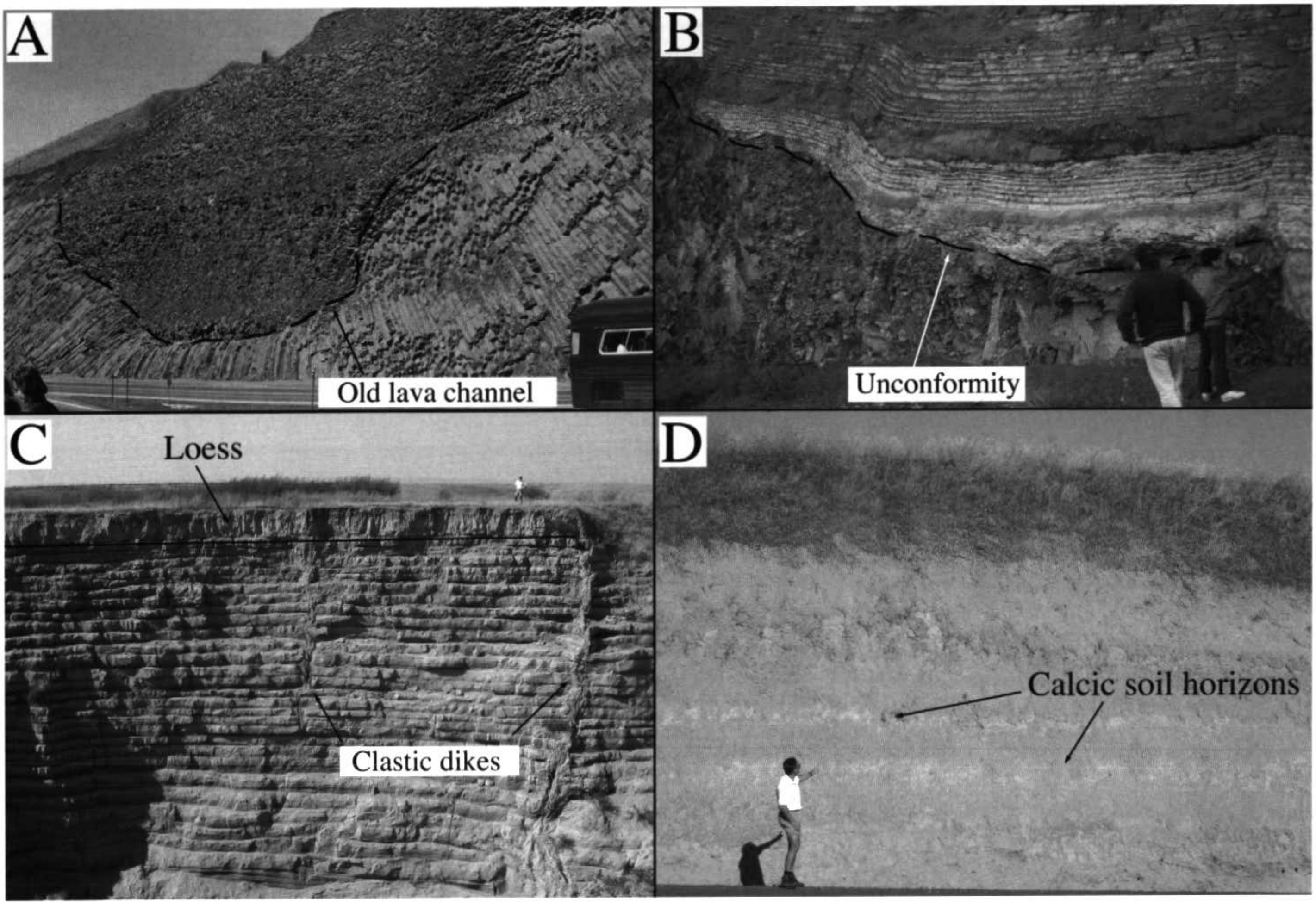

Figure 2 (**A**) Contact of intra-canyon lava flow with slightly older lava flow with well-developed columns. Both flows are part of the Miocene Columbia River Basalt Group. (**B**) Miocene sedimentary rocks deposited on unconformity developed within Columbia River Basalt Group. (**C**) Quaternary slackwater sediments (Touchet beds) deposited by backflooding of the Walla Walla Valley. Each horizontal layer represents a separate glacial outburst flood event. Touchet beds are overlain by 2 m thick loess bed with characteristic vertical prismatic structure. Entire sequence is cut by clastic dikes, thought to form by infill of surficial cracks (Alwin, 1970). Exposure is in Burlingame Canyon ~3km south of Touchet, Washington. (**D**) Multiple loess beds separated by calcic paleosol horizons. Exposure is on Hwy 12 ~3 km ENE of Walla Walla, Washington.

the nature and vehemence of the opposition to this outrageous hypothesis, the eventual triumph of his ideas constitutes one of the most fascinating episodes in the history of modern geomorphology (Bretz *et al.,* 1956; Bretz, 1969).

In south-central Washington State, the many paths of the onrushing floods converged on the Pasco Basin where floodwaters were slowed by the hydrologic constriction of Wallula Gap before draining out through the Columbia River Gorge to the Pacific Ocean (Figs. 1, 3). This caused *backflooding* up local river valleys and deposition of relatively fine-grained slackwater sediments characterized by rhythmically graded bedding (Bretz, 1928a,b,c); these graded rhythmites are locally called Touchet beds (Fig. 2c, cover), and multiple sets have been recognized (Flint, 1938). Waitt (1980, 1985) argued that each of about 40 Touchet beds resulted from separate catastrophic floods between 15,300 to 12,700 radiocarbon years B.P. Atwater (1986) determined that the interval between Missoula floods was 35-55 years based upon the number of flood deposits and varves in nearby glacial lakes. Mt. St. Helens "S" ash fell in eastern Washington about 13,000 years B.P., and is 10 rhythmites below the top of the Touchet beds, consistent with Waitt's (1985) age estimate. However, some researchers still prefer Bretz's original explanation of a single giant flood (Shaw *et al.*, 1999).

In recent decades, researchers have estimated the hydraulics of these giant flood flows (O'Connor and Baker, 1992; Smith, 1993) and explained the origin of many puzzling scabland features (Baker, 1973; Baker and Nummedal, 1978; Baker and Bunker, 1985). Other studies have shown that there were as many as 90 glacial floods (Waitt, 1980, 1984, 1985; Atwater, 1986) and that the floods were associated with not just one but at least six or seven major glacial advances in the Pleistocene (Patton and Baker, 1978). However, the detailed glacial stratigraphy is beyond the scope of the present paper.

Reworked Sediments/Loess

During the Holocene the prevailing southwesterly winds continued to rework Quaternary loess, slackwater, and other glacial sediments into the present thick blanket of loess (Fig. 2d) that covers much of the Columbia Plateau (45°30' to 48°N and 116°30' to 120°W). The core of this area, which is centered in eastern Washington, is called "The Palouse" (Fig. 1) and covers more than 10,000 km^2 with loess that is up to 75 m thick. Thinner and less continuous loess deposits cover an additional 30,000-40,000 km^2 in Washington, north central Oregon, and northern Idaho. As previously mentioned for the Quaternary, the presence of buried soils in the Holocene loess indicates that deposition was intermittent (Busacca, 1991).

Surface Soils, Columbia Plateau

Because of the Columbia Plateau's proximity to volcanoes of the Cascade Range, it is commonly assumed that the parent material of the loessial soils is predominantly volcanic tephra, or airborne volcanic material, and that the volcanic glass content of the soil is the cause of high susceptibility to wind erosion. However, the volcanic glass content is typically less than 8% in south central Washington (Fig. 4). In addition, the volcanic glass distribution in surface

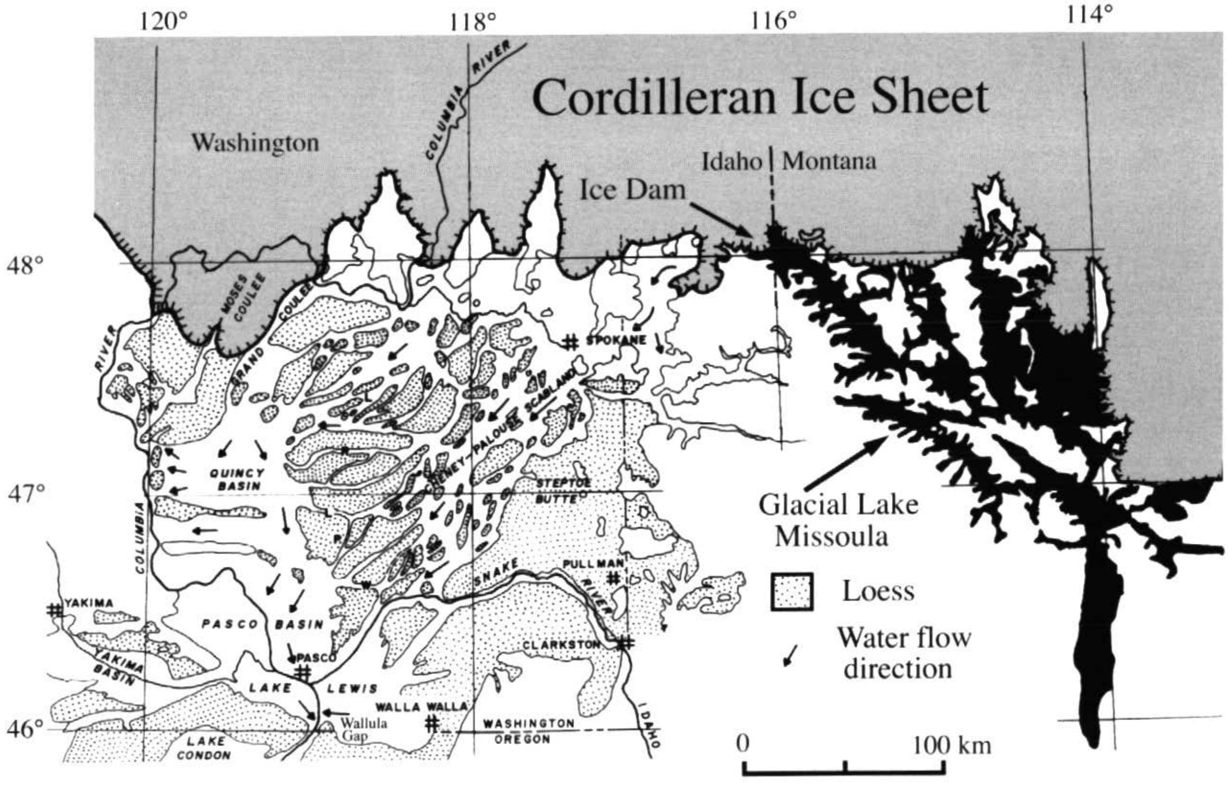

Figure 3 The Channeled Scabland of the Pacific Northwest showing Cordilleran ice sheet in its approximate position at 15,000 years before present, major outflow channels, and the distribution of loess. Modified from Baker and Nummedal (1978).

soils across the Plateau does not correspond to known patterns of tephra fallout from the 1980 Mt. St. Helens eruption. Electron microprobe analysis of glass composition confirms that the eruption of Mt. Mazama 6850 radiocarbon years B.P. contributed the majority of volcanic glass found in surface soils of the Columbia Plateau (Busacca *et al.*, 2000).

CLIMATE AND NATIVE VEGETATION

The climate of the Columbia Plateau is influenced to a great extent by prevailing westerly winds and by the Cascade and Rocky mountains. The Cascade Mountains create a rain shadow and as a result, the climate of the Columbia Plateau is arid to sub-humid (15-100 cm of mean annual precipitation; http://www.wrcc.dri.edu/climsum.html). The amount of precipitation closely correlates with elevation, generally increasing from west to east and southeast as elevation increases. The Rocky Mountains protect the Pacific Northwest from the coldest of the arctic storms that sweep down through Canada and this affects both vineyards and native vegetation.

During the summer, high pressure systems prevail in the Pacific Northwest, leading to dry, warm conditions and low relative humidity. Average afternoon temperatures in the summer range from 20°C to more than 35°C (http://www.wrcc.dri.edu/climsum.html). Most of the growing season is very dry and some vineyards experience no measurable precipitation during the summer months. The rainy season extends from October to late May or June, as frontal storms sweep across the area. In eastern Washington, most of the precipitation from mid-December to mid-February is in the form of snow.

Pre-agricultural Vegetation

As a result of the rainshadow and elevation effects, pre-agricultural vegetation in southeastern Washington ranged from sagebrush-steppe in the driest areas, to meadow steppe in areas of intermediate precipitation, to coniferous forest in areas of highest precipitation (Daubenmire, 1970). Xerophytic (drought tolerant) shrubs include several species of *Artemisia*, *Purshia*, and *Crysothamnus*. Perennial grasses include the major species bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), Sandberg bluegrass (*Poa sandbergii*) and a host of less common annual and perennial grasses and forbs. Mesophytic (moisture loving) shrubs include *rosa* spp., Serviceberry (*Amelanchier alnifolia*), and Snowberry (*Symphoricarpos albus*). Several zones of conifer vegetation have been recognized with increasing effective moisture and decreasing temperature (Daubenmire and Daubenmire, 1984); no zone of hardwoods is interposed between steppe and conifer habitats. The semiarid climate and steppe vegetation which have persisted throughout the Quaternary Period, have produced the Aridisol and Mollisol soils that form the backbone of Washington State wine grape production.

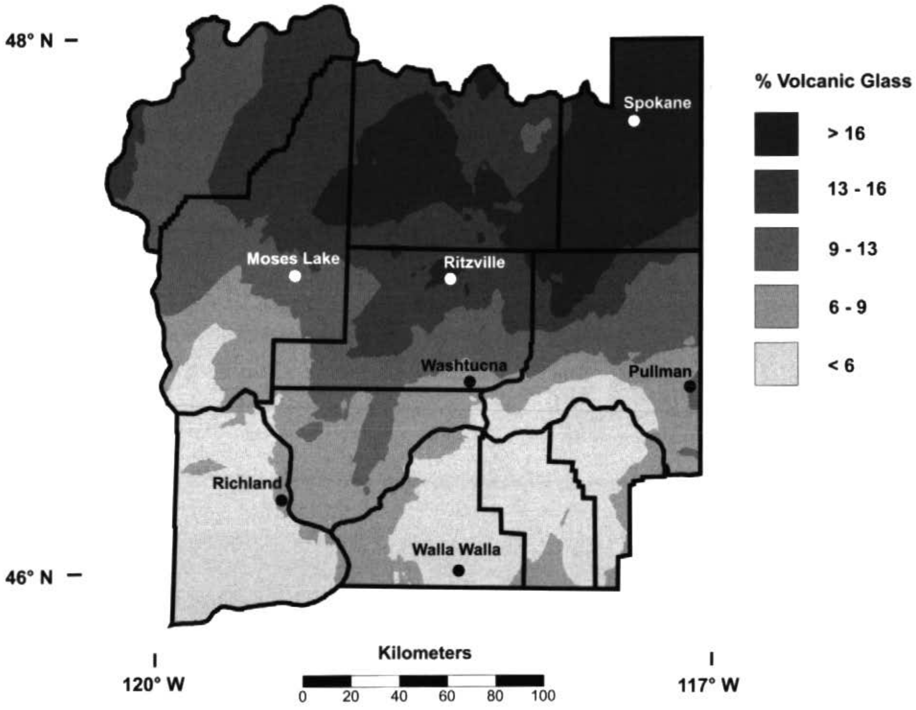

Figure 4 Map of volcanic glass content of Columbia Basin loess soils. From Busacca *et al.* (2000).

Climate and *Terroir*

Climate is one of the more important components of *terroir.* In some ways it is the most difficult to evaluate because it varies in both space and time. Adjacent vineyards may have quite different microclimates owing to factors such as wind direction, elevation, slope, and angle to the sun. Several of these factors can change within a single season and/or from year to year. For example, in years that are relatively warm and dry, vineyard "X" with a particular slope, elevation, sun angle, and soil type may produce better wine than vineyard "Y," whereas the reverse may be true in years that are cooler and wetter.

There are many weather variables that can be measured to describe the overall viticultural climate, such as average temperature during the growing season (warm temperatures promote plant growth and ripening), minimum temperature in winter (temperatures significantly below freezing can damage plant tissue and kill vines), and variation of temperature between day and night (cool nights preserve grape acidity).

Degree Days

Perhaps the most widely used temperature measurement is the concept of "degree days" (also called day-degrees, heat units, or heat summation) which is based on the observation, first made by de Candolle (1855), that relatively little plant growth and grape ripening occurs below 10°C (50°F).

Standard degree days are calculated based upon the amount of time above the 10°C (50°F) threshold. Conversion of degree days between °F and °C is difficult due to the variable number of days in a given summation. For example, if the mean temperature for a day, week, or month is 25°C, this would correspond to 15 (1x15), 105 (7x15), or 450 (30x15) degree days (°C), respectively (Winkler, 1936). The total degree days are summed for the entire growing season (sometimes approximated by April-October in the northern hemisphere) and the resulting number can be used to subdivide viticultural areas into five broad Regions: I (<2500°F day-degrees), II (2501-3000°F day-degrees), III (3001-3500°F day-degrees), IV (3501-4000°F day-degrees), and V (>4000°F day-degrees). Table 3 summarizes degree day information for representative viticultural regions of the world: Washington State vineyards are mostly in Winkler regions II and III. Annual variations for a particular Walla Walla Valley vineyard are shown in Figure 5. The concept of degree days can be further modified by excluding temperatures above 30°C when plant growth slows (Chas Nagel, written communication, 2000), or including only the time period from fruit ripening to harvest (Andrew Reynolds, written communication, 2000).

Table 3 Temperature summation during the growing season for representative viticultural regions of the world (data from Amerine *et al.*, 1980; Norm McKibben, written communication, 2000; Markus Keller, written communication, 2000; Dejan Tesic, written communication, 2000; and, for the Niagara Peninsula, the Niagara Agricultural Weather Network, St. Catharines, Ontario, Canada). Degree days °F and °C are not strictly convertible due to variable number of days of measurement, but approximately: degree days °C = degree days °F * 0.554.

Place	Degree Days (10°C)	Degree Days (50°F)	Winkler Region
Algiers, Algeria	2880	5200	V
Fresno, California	2590	4680	V
Hunter Valley, Australia	2340	4220	V
Naples, Italy	2220	4010	V
Davis, California	2000	3620	IV
Florence, Italy	1950	3530	IV
Walla Walla, Washington (high)	1830	3300	III
Napa Valley, California	1820	3280	III
Barossa Valley, Australia	1710	3090	III
Asti, Italy	1650	2980	II
Walla Walla, Washington (low)	1480	2670	II
Coonawarra, Australia	1450	2620	II
Niagara Peninsula, Canada	1440	2590	II
Bordeaux, France	1400	2520	II
Burgundy, France	1330	2400	I
Hawke's Bay, New Zealand	1300	2350	I
Otago, New Zealand	1000	1800	I
Geisenheim, Germany	950	1710	I

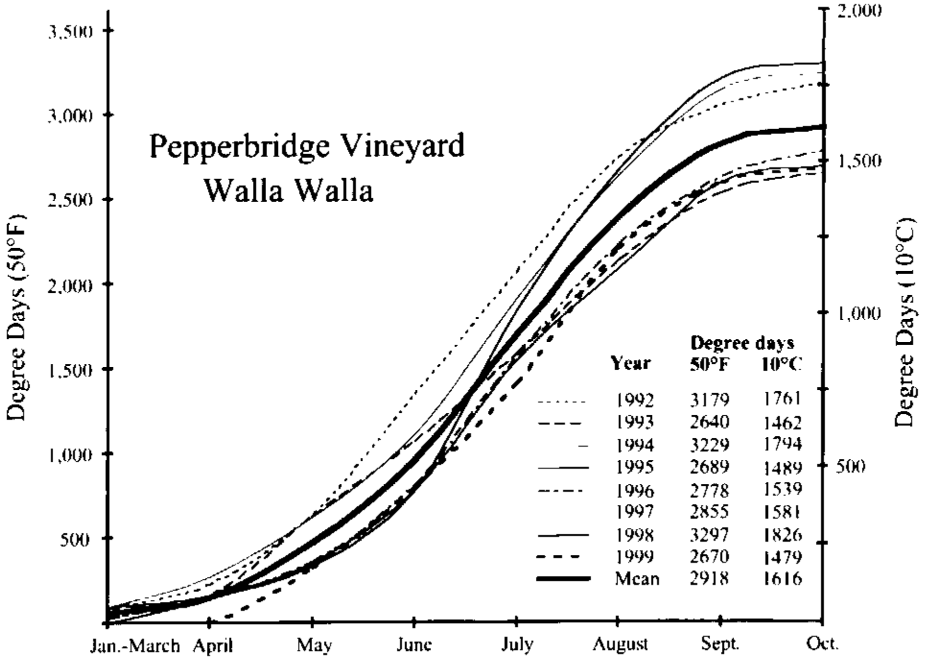

Figure 5 Annual variations in accumulated growing degree days for the Pepperbridge Vineyard in Walla Walla Valley. Data from Norm McKibben (co-owner, written communication, 2000).

Related Climatic Factors

Minimum temperatures are also of interest in Washington State, such as during the depths of winter, during bud break and fruit set in the spring, and during grape ripening (*véraison*) in the summer. Temperatures that are too cold can kill new vine growth or even the entire plant. This occurs in some vineyards in Washington about once a decade, and was responsible for the drastic drop in grape production in 1996 (Table 2).

Another measure of climate is continentality, which is defined as the difference between mean July and January temperatures (reversed for the southern hemisphere). For most Washington vineyards the continentality index is about 23°C, which is on the high end of regions with a typical Mediterranean climate of winter rain and summer drought, that is generally favourable for wine grapes. Some wineries have used the latitudinal similarity of Washington vineyards to suggest similarities of wine characteristics to famous European viticultural areas such as Burgundy and

Bordeaux or even Germany, but the degree day information in Table 3 makes it clear that even though the Walla Walla Valley of Washington State occurs at high northerly latitudes, it is in fact a warmer climate than comparable latitudes in Europe.

Most of the vineyard areas in Washington State are also blessed with abundant sunshine, due to the long summer days of northerly latitudes and to the generally cloud-free conditions during much of the growing season. During summer months most Washington vineyards experience more than 90% sunny days without measurable precipitation, in contrast to the generally cloudier conditions that prevail in much of northern Europe. Sunshine, precipitation and soil fertility are the natural controls on grapevine growth, but there are additional steps that can be taken in the vineyard to optimize the quality and/or quantity of the grapes produced. This is generally termed "canopy management" (control of the growing parts of the vine such as leaves and canes).

Importance of *Terroir*

There are a multiplicity of factors that contribute to the total quality of the grape that is then used as the raw ingredient in the process of making fine wine. To focus on a single factor of temperature, sunshine, rainfall, soil, bedrock, or viticultural practice, is to miss the essential synergy that marks the difference between an average wine and one that is exceptional. This is not to say that any one component is *insignificant*, but merely to assert that no one factor is *transcendent*. Thus, we return to the essential character of the term *terroir* in its influence on the quality of the grape and hence the quality of the wine. Lest this seem an impossible task, one has only to taste a single example of magnificent wine to be motivated to try to understand *terroir*. To better understand the concept of *terroir* in Washington State, the rest of this paper will focus on a single *appellation*, the Walla Walla Valley, and the features of geography, geology, pedology and climate that make it such a special place.

THE WALLA WALLA VALLEY *APPELLATION*

Walla Walla is a Native American name meaning "many waters" or "small, rapid streams." Many diverse tribes, including the Walla Walla, Nez Perce, Cayuse and Umatilla, inhabited the region prior to European settlement. The Walla Walla Valley was one of the first areas between the Rockies and Cascades to be permanently settled. Lewis and Clark traveled through the area in 1805 and 1806 as part of the initial exploration of the American West. Fur traders carved out early settlements, trading posts, and forts in the early 1800s. With the lure of nearby gold in the Blue Mountains in 1860, Walla Walla quickly became a commercial, banking and manufacturing center, and soon became the largest city in Washington Territory. The City of Walla Walla was incorporated in 1862. After the gold rush ended, farming anchored the community and remains vital to the current economy. Early settlers planted wine grapes for personal vinification and consumption but no commercial production was attempted. Some of these now-wild vines can still be found, such as near the junction of Prunedale Road and County Road 517 south of Walla Walla (Gary Figgins, oral communication, 2000). In addition to wine grapes, the Walla Walla Valley is a major production area of alfalfa seed in the United States. Ground-dwelling native alkali bees are required to pollinate the alfalfa flowers and may also be important for wine grapes. The Green Giant cannery (now owned by Seneca) in Dayton on the edge of the Walla Walla Valley is the world's largest asparagus cannery, and formerly was a world leader in peas as well (Donald Turner, Manager of the Port of Columbia, oral communication, 2000). Thus, the Walla Walla Valley is in many ways a hub of agricultural activity in the state of Washington.

Location and Geology of the Walla Walla Valley *Appellation*

The Walla Walla Valley *appellation* is defined by elevation contours on the south and east and by lines approximating drainage divides on the west and north (Fig. 6). The valley is underlain by Miocene basalt flows of the Columbia River Group, consisting of parts of the Saddle Mountains, Wanapum and Grande Ronde formations, from youngest (~8.5 Ma) to oldest (~16.9 Ma) (Schuster, 1994). These units are exposed only in deep stream-cut valleys, but do crop out to the south and east on the slopes rising to the Blue Mountains (Figs. 2a, 7).

Overlying the basalt in the Walla Walla Valley are Quaternary sediments consisting of loess, dune, and flood deposits related to glacial processes, and alluvium from the streams that drain the Blue Mountains and the valley itself. As described previously, the draining of glacial Lake Missoula in Montana created cataclysmic floods across eastern Washington that scoured much of the scabland topography and backflooded the Walla Walla Valley. Sediments deposited from these slackwaters range from gravels near Wallula Gap on the western side of the valley, to massive silts and sands with local bedding in the central and eastern parts of the valley (Figs. 2c, 7). On the higher slopes above the slackwater deposits are thick mantles of loess (Fig. 2d). Rivers and streams have downcut into the loess and slackwater deposits during the Holocene (last 10,000 years) and, in some cases, the underlying basalts, to yield an overall dendritic pattern of Quaternary sedimentation (Fig. 7). Terrace remnants of the rhythmically bedded slackwater deposits form "islands" within the modern drainage network (Fig. 11b). Present-day drainages and flood plains consist of a mixture of reworked loess, slackwater deposits, and basalt (Carson and Pogue, 1996). Most of the basaltic cobbles are restricted to the larger streams that can carry relatively fresh pieces of basalt from the surrounding hillsides.

Soils of the Walla Walla Valley

Each of the rock units in the Walla Walla Valley is associated with distinctive soils, some of which are excellent for the production of wine grapes and some of which are not suited at all to grape production. Because of this, geographically adjacent vineyards can exhibit radically different *terroir* even though their major climatic features may be very similar.

Figure 8 is a generalized map of the associations or general groupings of major soils in the Walla Walla Valley. Detailed soil surveys for Walla Walla County, Washington (Harrison *et al.*, 1964), and Umatilla County, Oregon (Johnson and Makinson, 1988) name more than 75 different soils in the area. Many of the soils share a number of properties such as silty textures and a mixed mineralogy. Silty textures are characteristic of some of the slackwater sediments, of the loessial soils that were derived by wind reworking of these sediments (Busacca and McDonald, 1994), and of some of the alluvial soils that were formed by water erosion and transport of the same materials into valley bottoms. Similarly, a mineralogy dominated by quartz, feldspars, micas, and illitic clays is characteristic of the slackwater sediments and thus of the loessial and alluvial soils as well (Busacca, 1991). Composition and mineralogy of typical loess and slackwater soils are contrasted with underlying Columbia River Group basalt and granite boulder erratics in Table 4. The lack of correlation of the composition and mineralogy of the basalt with the overlying loess and slackwater soils (Table 4) reinforces the concept that almost all of the eastern Washington soils are ultimately derived not from basaltic bedrock but from glacial material related to the outburst floods, including ice-rafted boulders, water-born sediments, and wind-reworked sands. Not each one of the 75 soils found in the region is different enough to create a distinctive *terroir* for grape production; nevertheless, when grouped into the eight associations shown in Figure 8, several contrasts in soil properties become apparent that affect the choice of optimal grape varietal and the qualities of the wine produced. Note that the general soil map units in Figure 8 contain multiple soil series and that in some cases, a soil series occurs in more than one general soil map unit.

Walla Walla Valley Appellation *Soil Groups with Wine Production*

Soils in **map unit 1** (Fig. 8) are cobbly, loamy, and silty soils formed in recent alluvium on flood plains and terraces of the Walla Walla River and its tributary streams such as Dry Creek, Mill Creek, and Cottonwood Creek. Soils such as the Freewater and Yakima are deep, well drained to excessively drained, and formed in cobbly alluvium along ancestral channels of the Walla Walla River. These have been planted intensively for many years to apples and other orchard crops. These soils are very low in organic matter, are very well drained, and have no water table, so grape vigour can be controlled successfully with water and nutrient management. Catherine and related soils are formed in silty alluvium,

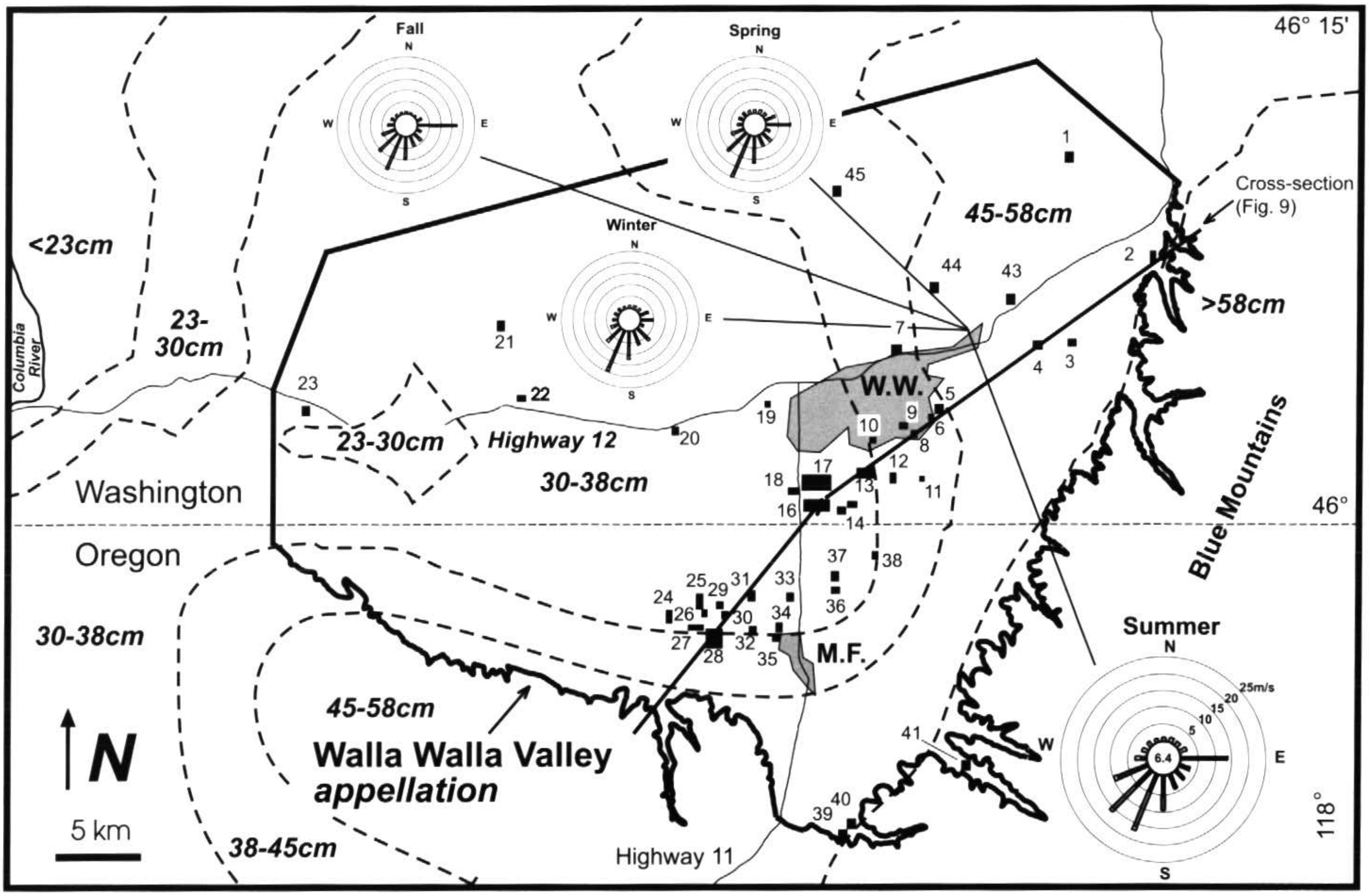

Figure 6 Precipitation, wind velocity in metres/second, and location of vineyards within the boundaries of the Walla Walla Valley *appellation*. Vineyard information in Table 4. Bars on wind roses represent percentage of the time that winds of a given velocity blew from the compass direction shown. Value in the centre of the wind rose is the percentage of time in the season that there was no sensible wind. Wind roses generated from PAWS (Public Agricultural Weather System) data at http://index.prosser.wsu.edu for the Walla Walla weather station at Latitude 46.06, Longitude 118.27, for the period July 1992 to December 1999. Precipitation contours modified from Oregon Climate Service (http://www.ocs.orst.edu/pub/maps/Precipitation/Total/Regional/West/westus_precip.GIF). WW = city of Walla Walla.

are somewhat poorly drained, have higher organic matter contents than do Freewater soils, and have a seasonal water table that has formed mottles in the lower part of the soil. Soils like the Ahtanum are similar to the Catherine soils but are not suited to grape production because of a saline-alkali condition and a hardpan at shallow depth.

Soils in **map unit 3** are silty and formed in loess that overlies stratified slackwater sediments from cataclysmic outburst floods. These soils are located mainly to the northwest of Walla Walla and generally receive between about 23 cm and 30 cm of mean annual precipitation (Fig. 6). Where the loess is greater than 150 cm thick, soils of the Ritzville series are recognized, which have deep, uniform silty profiles and low organic matter content. Where the loess is about 60 cm deep over stratified flood sediments, Ellisforde soils occur. The Woodward Canyon Vineyard (#21, Fig. 6, Table 5) is planted on Ellisforde and related soils. The characteristics of these soils are similar to those of the Sagemoor and Sagehill series in map unit 4. Cost of water development may limit the development of these soils for vineyards, as rainfall is insufficient for dryland production on these upland soils.

Soils in **map unit 4** have been and are being intensively developed for vineyards, particularly to the south and southeast of Walla Walla. The soils formed in thin to thick loess overlying slackwater sediments on flat-topped, dissected terraces. These soils are silty and uniform in texture down to the fluvial sediments, and consist of stratified sands and silts below that. They have low to moderate contents of organic matter. The soils receive from 30 cm to 45 cm of annual precipitation (Fig. 6). Soils of the Sagemoor, Ellisforde and Sagehill formed in only about 50-75 cm of loess over stratified sediments. Erosion on the sideslopes of terraces in these soils commonly exposes white subsoil carbonates in the slackwater materials. Soils of the Oliphant series formed on about 125 cm of loess overlying stratified sediments. Soils of the Walla Walla and Athena series formed on more than 150 cm of loess and may or may not be underlain by slackwater sediments.

The soils in **map unit** 7 are also formed in deep silty loess on uplands. Soils in this map unit, such as the Athena, Palouse, and Calouse, are differentiated from those in unit 6 mainly in receiving more rainfall, about 38-58 cm annually (Fig. 6), which has promoted lush growth of the native bunchgrasses and allowed them to accumulate large amounts of organic matter. The Athena and Palouse soils are the classic Mollisols (prairie soils) of dryland grain production in eastern Washington State. Only one vineyard, the Mill Creek Upland Vineyard (#3, Fig. 6, Table 5), has been planted on these

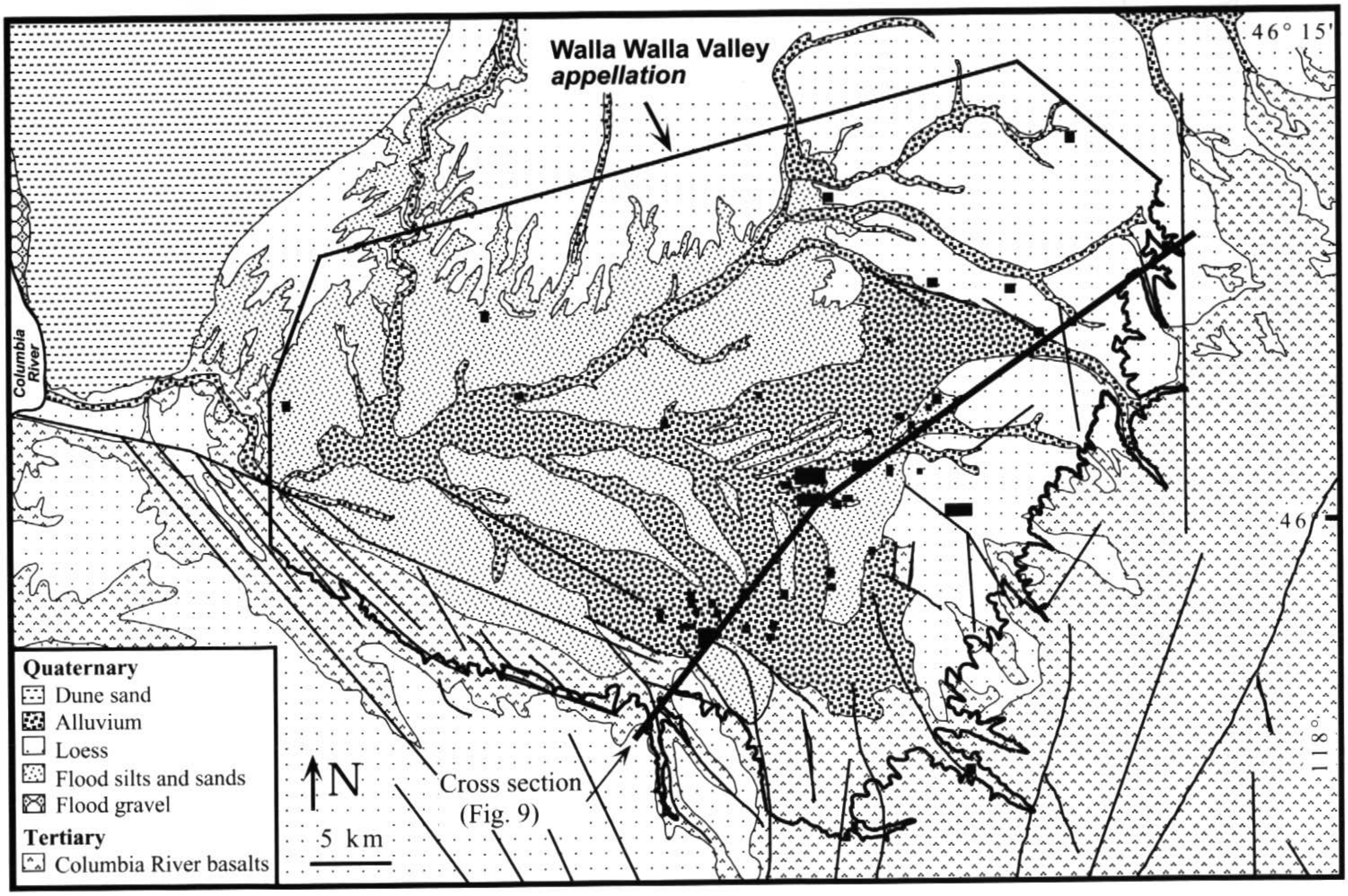

Figure 7 Surficial geology of the Walla Walla Valley region. Modified from Schuster (1994) and Schuster *et al.* (1997). Vineyards are identified in Figure 6 and Table 4.

soils at the present time; however, these soils may have potential for further vineyard development because of favourable soil moisture and other soil properties.

Walla Walla Valley Appellation Soil Groups Mostly Lacking Wine Production

Soils in **map unit** 2 lie along floodplains to the west of Walla Walla and are poorly drained, saline-alkali soils unsuited to grape production. The saline-alkali conditions result from excessive evaporation and wicking of salts from a standing water table at shallow depth. The Three Rivers Vineyard (#20, Fig. 6, 12f, Table 5) is on well-drained terrace soils close to these marginal alkaline soils.

Adkins and Quincy soils dominate the area of **map unit** 5 on the lower end of Eureka Flat to the northwest of Walla Walla (Fig. 8). These soils are well drained to excessively drained and formed in dune sands under less than 30 cm of rainfall (Fig. 6). No wine grapes are planted on these soils at the present time, although several thousand acres of table and juice grapes are planted on these soils along the Snake River outside the Walla Walla Valley *appellation* area.

Soil Groups Mainly or Completely Outside the Walla Walla Valley Appellation

Walla Walla and Ritzville series soils, formed in deep loess on uplands to the north and south of the Walla Walla Valley (Fig. 8), are the major soils in **map unit 6**. These soils receive from about 23 cm to 38 cm of annual rainfall, depending on location (Fig. 6). These soils have a uniform silty texture to more than 150

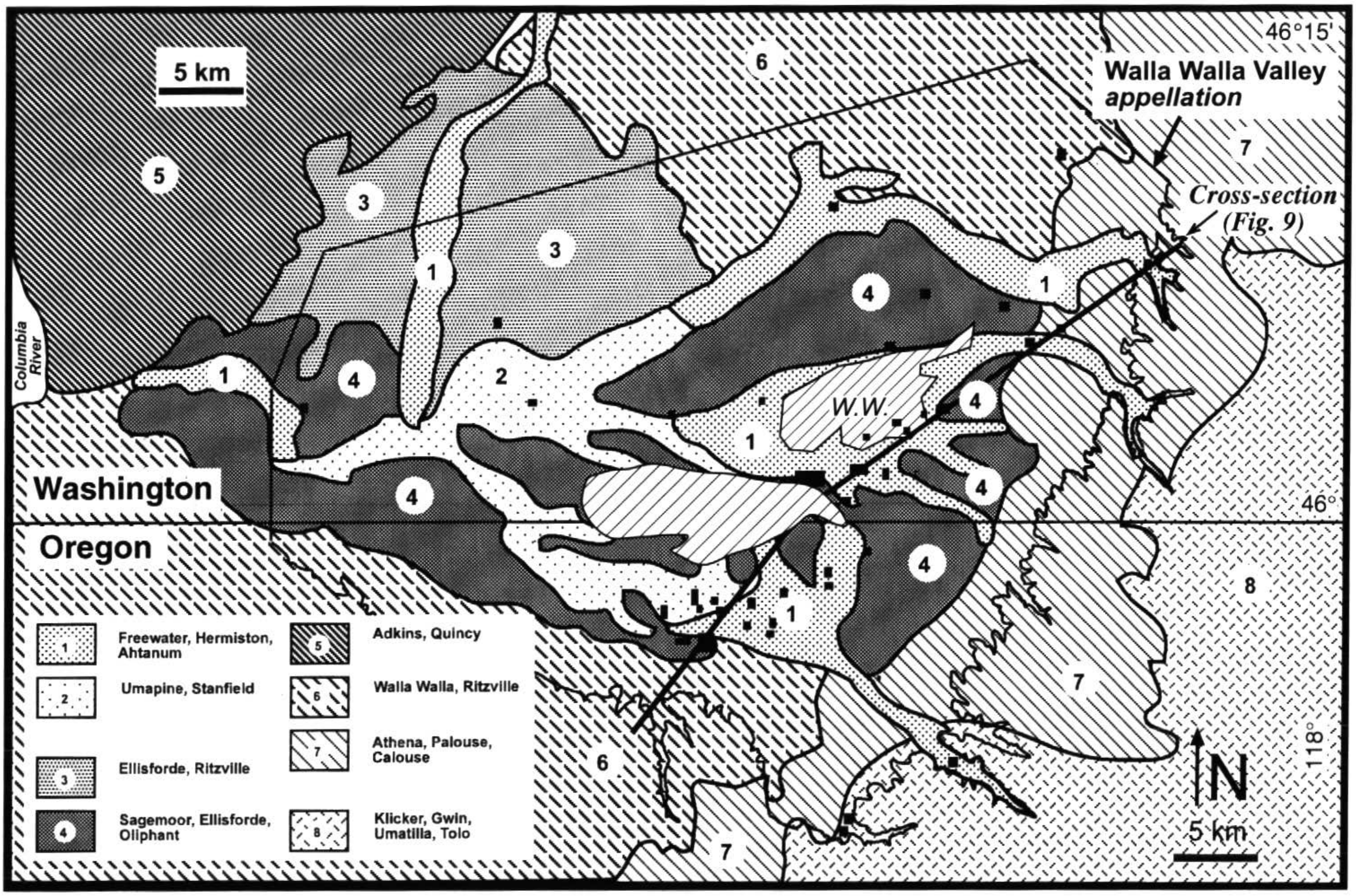

Figure 8 Generalized map of the soil associations of the Walla Walla Valley region. Modified from Harrison *et al.* (1964) and Johnson and Makinson (1988). Note that only one to three soil series are named for each association, although other soil series can and do occur in the associations. For example, a variant of the Athena soil series with slackwater sediments deeper than 150 cm occurs in unit 4, but it also is dominant in unit 7 where it is a named component. **Unit 1**: Freewater, Hermiston, Ahtanum: Cobbly to loamy, moderately well to well drained soils formed in alluvium, on floodplains and low terraces. **Unit 2**: Umapine, Stanfield: Loamy to silty, poorly drained saline and alkali soils formed in alluvium, on floodplains and low terraces. **Unit 3**: Ellisforde, Ritzville: Silty, well drained soils formed in thin to deep loess overlyng stratified silty to sandy outburst flood deposits, on dissected terraces and uplands. **Unit 4**: Sagemoor, Ellisforde, Oliphant: Silty, well drained soils formed in moderately deep to deep loess overlying stratified silty to sandy outburst flood deposits, on dissected terraces. **Unit 5**: Adkins, Quincy: Sandy, excessively drained deep soils formed mainly in dune deposits on high terraces. **Unit 6**: Walla Walla, Ritzville: Silty, well drained soils formed in deep loess on uplands in 20-38 cm rainfall zone. **Unit 7**: Athena, Palouse, Calouse: Silty, well drained soils formed in deep loess on uplands in 38-58 cm rainfall zone. **Unit 8**: Klicker, Gwin, Umatilla, Tolo: Loamy to cobbly, well drained soils formed mainly in loess, volcanic ash, and basaltic bedrock, on steep mountain slopes. WW = city of Walla Walla

Table 4 Comparison of chemical composition and mineralogy of representative samples of vineyard soil, loess, slackwater sediment, granitic glacial erratics, and Columbia River Group basalt. Data from Ross (1989), McCreery (1954), and the present study.

Unit	**Basalt**	**Granite erratic**	**Touchet 2m below loess**	**Touchet 5m below loess**	**Loess regular**	**Loess calcic**	**Loess soil**
Location	1	2	3	3	4	5	6
SiO_2	54.08	67.07	63.55	67.16	63.51	56.65	63.80
Al_2O_3	13.58	15.90	13.75	12.99	14.26	12.16	13.94
TiO_2	2.94	0.54	1.14	1.11	1.24	0.78	1.22
FeO(t)	13.20	3.90	5.64	2.44	6.73	4.32	6.16
MnO	0.21	0.11	0.11	0.04	0.12	0.07	0.12
CaO	6.45	4.20	4.50	2.49	2.88	10.00	3.14
MgO	3.13	1.54	2.43	1.15	1.96	1.87	2.02
K_2O	2.41	3.37	2.22	2.62	2.22	1.71	2.35
Na_2O	3.20	2.87	2.21	2.10	2.08	1.72	2.08
P_2O_5	0.80	0.26	0.25	0.47	0.24	0.15	0.26
L.O.I.	n.d.	n.d.	4.03	7.26	4.58	10.38	4.73
	100.00	99.77	99.81	99.83	99.82	99.83	99.82
Ni	n.d.	20	36	18	27	27	26
Cr	6	14	59	41	51	53	46
Sc	26	5	21	13	18	12	18
V	233	69	141	91	149	84	145
Ba	2848	848	704	636	668	626	673
Rb	43	119	82	82	84	63	81
Sr	268	754	280	246	263	355	265
Zr	415	186	277	282	268	262	264
Y	43	27	35	31	36	28	34
Nb	23	18	16	15	15	15	15
Ga	23	19	15	17	16	14	17
Cu	0	5	24	21	28	20	22
Zn	117	58	76	63	88	61	87
Pb	n.d.	12	17	10	16	9	17
La	n.d.	38	30	32	29	38	37
Ce	n.d.	58	60	74	70	72	69
Th	n.d.	10	13	11	12	8	10
quartz	0	25	30	30	40	40	40
orthoclase	0	20	0	0	12	10	12
plagioclase	48	43	1	1	2	1	2
olivine	2	0	0	0	0	0	0
pyroxene	21	3	<1	<1	<1	<1	<1
amphibole	0	3	<1	<1	2	2	2
muscovite	0	1	8	8	10	10	10
biotite	0	3	7	7	9	9	9
Fe-Ti oxides	11	1	0	0	1	1	1
apatite	1	1	0	0	n.d.	n.d.	n.d.
clay	2	0	10	10	10-15*	10-15*	10-15*
calcite	0	0	3	3	n.d.	10	n.d.
glass	14	0	n.d.	n.d.	1	0	1
rock fragments	0	0	35	35	n.d.	n.d.	n.d.
other	1	0	1	1	6	5	6

1) Bear Creek member of Saddle Mountains Basalt, Ross (1989), 2) Seven Hills Vineyard (Fig. 15b), granitic glacial erratic, mineralogy estimated from CIPW norm, 3) Seven Hills Vineyard, mineralogy from Alwin (1970), Touchet bed WW 3-13, 4) Seven Hills Vineyard (Fig. 15a), mineralogy from McCreery (1954), 5) Lower calcic paleosol (Fig. 2d) ~3 km ENE of Walla Walla, mineralogy estimated from CIPW norm, 6) Seven Hills Vineyard, Block 16, * Montmorillonite>illite>kaolinite, n.d. = not determined

cm depth and low to moderate organic matter contents. No vineyards are planted within map unit 6 at this time; however, with irrigation to supplement the scant rainfall, these soils should be capable of producing quality wine grapes because low soil moisture and a favourable rooting zone should allow the grower to control vine stress with judicious irrigation.

Map unit 8 consists of soils that are not in vineyard development at this time. This unit is formed on steep slopes of the foothills of the Blue Mountains, and a wide variety of soils developed in loess, volcanic ash, and basaltic bedrock have been recognized.

Soils Summary

In summary, the soils of the Walla Walla Valley *appellation* have formed from four different types of surficial sediments or bedrock. Various combinations of soil parent materials and a strong gradient of mean annual precipitation across the *appellation* are key to determining vineyard potential performance. Soils formed from young alluvium vary tremendously in their properties, such as texture (cobbly to clayey), salt effects, and presence or absence of a water table within the rooting zone of vines. Soils formed from loess more than 150 cm deep are found around the margins of the Walla Walla Valley *appellation* and have dominantly silty, uniform soil profiles. Mean annual rainfall varies widely depending on location in the *appellation*, and this, along with slope steepness and aspect, determine suitability or potential for development of dryland or irrigated vineyards. Soils formed from thin to moderately thick loess overlying slack-water sediments have been the main focus of vineyard development up to the present time in the *appellation*. Finally, soils located on steep slopes of the Blue Mountains that have bedrock at shallow depth have not been fully evaluated to determine their potential for vineyard development.

Table 5 Vineyards in the Walla Walla Valley *appellation* (data from Myles Anderson, written communication, 2000; Norm McKibben, written communication, 2000)

Map #	Name	Grapes	First planted	Owner
1	Spring Valley	m, cf, sy, cs, pv	1994	Dean & Sherry Derby
2	Biscuit Ridge	7 g, 1 cf	1982	Duane & Mary Wollmuth
3	Mill Creek Upland	11cs, 3m, 1sg, 1pv	1997	Gary Figgins
4	Titus Creek	3cs, 3sy, 1v	1999	Ken Harrison
5	Leonetti estate	m, sy, sg, cf	1974	Gary Figgins
6	Patrick M. Paul	cs	*	Mike Paul
7	Waterbrook	chard	1998	Eric & Janet Rindal
8	Keiler	m	*	Fritz Keiler
9	Myson	cs, m	*	Steve Paul & Mark Colvin
10	Whitney	cf	*	Mike Paul
11	Morrison Lane	sy	1985	Dean & Verdi Morrison
12	Forgotten Hills	m, sy, cs	1999	Jeff and Kathyrn Hill
13	Cottonwood Creek	5 cf, 28 c	1989	Scott Byerly
14	Pheasant Run	cs, m	1998	Greg Basail
15	Via Piano	m, cs,	1999	Justin Wiley
16	Pepperbridge south	m, cs, sy	1991	Premier Partners IV
17	Pepperbridge north	m, cs, sy	1999	Premier Partners IV
18	Double River Ranch	*	2000	Kyle Mussman
19	Bunchgrass	m, cf, sy, cs, pv	*	Roger Cockerline
20	Three Rivers	c	2000	Steve Ahler, Bud Stocking, Duane Wollmuth
21	Woodward Canyon	cs, m, cf, c, b, d	1977	Rick & Darcie Small
22	Dunham	cs	1999	Eric Dunham & family
23	Ash Hollow	9 merlot, 1 cs	1999	Matt Tucker
24	Windrow	cs	*	Scott & Rebecca Hendricks
25	Veterinarian	*	*	California veterinarian
26	Hart	*	*	Ken Hart
27	Seven Hills west	cs, m, sy	1985	Walla Walla Valley *Appellation*
28	Seven Hills east	m, cs, sy, sg, gv, cf, s	1997	Blue Mountain Farm
29	Cayuse	syrah	1997	Christophe Barón
30	Seven Hills west	cs, m, sy	*	Blue Mountain Farm
31	Caillouxe	sy, v	1997	Christophe Barón
32	Cerise	sy, v	1997	Christophe Barón
33	Lefore	cs, sg	1987	Jack Lefore
34	Lefore	*	1999	John Lefore
35	Waliser	cs, cf, m	1998	Tom Waliser
36	Vanessa's	m, cs, s	1999	Terry & Diane Farley
37	Farley	m, cs, s	1999	Terry & Diane Farley
38	Mint Condition	cs, m	1999	Bob Buchannan
39	Couse Creek	pn	*	*
40	Alder Banks	pn, c	*	Mike & Maryann Banks
41	Wells	pn	*	Sam & Nancy Wells
42	Les Collines	cs, m, sy	2000	Norm McKibben
43	Homestead	g	*	Steve Ahler & Jeff Kolke
44	Minnick	cs, m, cf, sy	2000	Laura Minnick
45	Valley Grove	*	*	Henderson Orchard

Wine abbreviations: b = Barbera, ca = Carignane, cf = Cabernet Franc, cs = Cabernet Sauvignon, c = Chardonnay, d = Dolcetto, g = Gewürztraminer, gv = Grand Vidure, m = Merlot, pn = Pinot Noir, pv = Petite Verdot, s = Semillon, sb = Sauvignon Blanc, sg = Sangiovese, sy = Syrah, v = Viognier, * not known

Walla Walla Valley Vineyards

The first commercial vineyard planting in the Walla Walla Valley was in the early 1950s by Bert Pesciallo who produced wine from Black Prince, Muscatel and Concord grapes under the Blue Mountain Vineyards label. This was a short-lived effort as a deep freeze in 1955 killed all the vines, and the winery did not reopen (Bert Pesciallo, oral communication, 2000). Commercial production did not resume in the Walla Walla Valley until 1974 when half an acre of Cabernet Sauvignon grapes was planted at the Leonetti homestead. Early success was assured when the first vintage, a 1978 Leonetti Cellars Cabernet Sauvignon, was pronounced the "best Cabernet Sauvignon made in America" by the Wine and Spirits Buyers Guide in 1982. At present there are about 45 vineyards supplying grapes to 32 wineries in the Walla Walla Valley *appellation* (Table 5.) Another 15 vineyards have been planted, with more planned (Myles Anderson, Director of the Walla Walla Institute for Enology and Viticulture, oral communication, 2000).

The vineyards of the Walla Walla valley are located on four fundamentally different substrates including slackwater terrace (Fig. 2c), loess (Fig. 2d), river gravel, and flood plain silt (Fig. 8). Of the 45 vineyards listed in Table 5, the majority are planted in loess either overlying deep bedrock basalt or as a thin veneer on top of slackwater deposits (Fig. 2c), which in turn overlie basalt. Figure 9 is a cross section through six representative vineyards illustrating the considerable range of terroir and microclimate in the Walla Walla Valley. These six vineyards and their settings may be described as follows.

Pepperbridge Vineyard

Since no vineyards in the Walla Walla Valley are located directly on basalt, the Pepperbridge Vineyard (#16, #17, Fig. 6; Table 5), planted in a thin mantle of loess overlying slackwater terrace deposits, is the stratigraphically lowest vineyard (Figs. 7, 9). The slackwater terrace deposits in this area range from 10-50 m in thickness and are mantled by 0-2 m of loess (Fig. 10). Given the ability of grape roots to penetrate to depths of 10 m or more in such unconsolidated sediments (observation made in construction trenches, roots at 4 m depth shown in Fig. 11e), most Pepperbridge vines are rooted in the slackwater deposits. Soils of the Pepperbridge Vineyard are in the Oliphant, Walla Walla, and Sagemoor series (Fig. 8, map unit 4). The low organic content and good drainage of these soils make it relatively easy to control vine vigour and grape yield with modern viticultural techniques, particularly drip irrigation (Fig. 11a). This setting and these techniques contribute to the fruit intensity and concentration of grape flavours for which wines made from this vineyard are known. The main grape varieties planted at Pepperbridge are Merlot (83 acres), Cabernet Sauvignon (72 acres), and Syrah (12 acres) (Table 5). In contrast, the immediately adjacent but overly fertile flood plain soils (Fig. 11b) do not produce grapes of the same quality because of strong vegetal flavours (Norm McKibben, oral communication, 2000). This is one of several places in the Walla Walla Valley where a direct connection can be shown between soil characteristics and wine quality.

Like most Walla Walla Valley vineyards, Pepperbridge is relatively dry (<50 cm annual precipitation), sheltered from wind, with intense sun exposure (1,400 W/m^2 of annual solar radiation), and moderate wintertime temperatures (Table 6). The long growing season in most years exceeds 3000 (50°F) degree days and yields fully ripe fruit with good tannins (Fig. 5). In addition, the low humidity further concentrates fruit flavours through evaporation. A standard measure of humidity is the mean for July measured at 9 a.m. For the Pepperbridge vineyard in 1999 the mean humidity for July at 9 a.m. was 50.5% at an average temperature of 20.7°C (Table 6).

Another important feature of the Pepperbridge Vineyard is good air drainage. The slackwater terrace deposits have been dissected by strands of the Walla Walla River so that the vineyards are elevated above the valley floor on slackwater terrace "islands" (Fig. 11b). This allows cold air to drain away from the vines, thus avoiding excessive problems with frost during the growing season.

Cottonwood Creek Vineyard

Less than one kilometre east of the Pepperbridge Vineyard, the Cottonwood Creek Vineyard (#13, Fig. 6; Table 5) represents a completely different *terroir*. Cottonwood Creek is located on fine silty sediments of the floodplain of Cottonwood Creek (Figs. 8, 9, 11c). The floodplain soils contain more humified organic matter and have poorer drainage than the slackwater and loess soils (#1, Fig. 8; Fig. 10). In some places the water table and infiltration from Cottonwood Creek saturate the sediments at relatively shallow depths, such as in the Catherine series soils. This means that deep-rooted grapevines can tap ground water during the growing season, making supplemental irrigation unnecessary in most years, but also making it more difficult to control the natural plant vigour (Fig. 11c). Uncontrolled plant vigour makes it difficult to fully ripen the crop in some years and also increases vineyard management costs in terms of pruning, spraying, and general canopy management (Scott Byerly, vineyard owner, oral communication, 2000).

The wet soils also warm more slowly in the spring, due to the high heat capacity of water, delaying new plant growth and further exacerbating the problem of ripening the grapes in a normal growing season. The main variety planted at Cottonwood Creek vineyard is Chardonnay, which has produced award-wining wine in some years, proving that even in this difficult location exceptional wine can be produced. But in general, grapes from this vineyard produce wines with pronounced vegetal characteristics such that in some years the grapes are sold to the bulk juice market rather than being made into wine (Scott Byerly, vineyard owner, oral communication, 2000). This is another vineyard in which a direct connection can be shown between geological characteristics and wine quality.

Caillouxe Vineyard

The Caillouxe Vineyard (formerly called Cobblestone Vineyard) (#31, Fig. 6; Table 5) further to the West is perhaps the most unusual *terroir* in Walla Walla Valley (Figs. 7, 10, 11). At this site, very coarse but well rounded cobbles (1-10 cm) of basalt make up the gravel bed of the Walla Walla River. The surface of the vineyard is literally a pavement of stone (Fig. 11d). The stony nature of the soil forces the grapevine roots to go deep in search of water (Fig. 11e), and calcic soil horizons add further stress to the grape plant. These gravelly soils have extremely good drainage so that like Pepperbridge, supplemental drip irrigation can be used or withheld to control vine vigour and grape yield. Typical yield from this vineyard is kept to about 2 tons per acre to concentrate the fruit flavours. The basalt cobbles also perform another function in that they soak up the sun's heat and radiate it back to the vines. The Caillouxe Vineyard is planted predominately to a single grape variety, Syrah, because Syrah is a heat-loving grape. *Vigneron* Christophe Barón has accentuated these unique *terroir* features by trellising the plants very close to the ground and the hot basalt cobbles (Fig. 11f). The wine produced from this vineyard is an extremely concentrated, flavourful Syrah with excellent tannins. In only the vineyard's second year it has already won awards and promises great things for the future.

Seven Hills Vineyard

One of the oldest (first planted in 1981) and most prestigious vineyards in the Walla Walla Valley is Seven Hills (#27, #28, Fig. 6; Table 5). The vineyard is on a gentle north-facing slope of loess (Fig. 7, 12a) overlying slackwater terrace deposits (Figs. 9, 12b). This southernmost location within the Walla Walla Valley benefits from the strong southwesterly prevailing winds, which promotes excellent air drainage and avoids frost problems. The loess soil is well drained and, like Caillouxe and Pepperbridge, allows supplemental drip irrigation to be used or withheld to control vine vigour and grape yield. The main grape varieties planted at Seven Hills are Cabernet Sauvignon (91 acres), Merlot (61 acres), Syrah (19 acres), and Sangiovese (9 acres), with a further 2.5 acres of Viognier planted for blending with Syrah to make a classic Rhone-style wine. Grapes from this vineyard have produced many of the award-winning wines from L'Ecole No. 41, Leonetti Cellars, Seven Hills, and Woodward Canyon wineries. The Leonetti Cellars reserve Cabernet Sauvignon, which some feel is one of the best red wines made in the United States, draws most of its fruit from the oldest vines of the Seven Hills vineyard (Fig. 12c). This bodes well for future vintages from this vineyard as the younger vines mature.

Mill Creek Upland Vineyard

On the other side of the Walla Walla Valley and at significantly higher elevation lie two vineyards of completely dissimilar character, Mill Creek Upland Vineyard (500 m; #3, Fig. 6; Table 5) and Biscuit Ridge Vineyard (550 m; #2, Fig. 6; Table 5). Mill Creek Upland Vineyard is a new effort by Leonetti Cellars, one of the pioneer wineries of the Walla Walla Valley. It is located on a moderately steep south-facing slope of very deep (>50 m) loess (Figs. 7, 9). The soils are in the Athena series (Figs. 8, 10). The steep hillside provides excellent air drainage making it virtually a frost-free location (Fig. 12d). The occurrence on the eastern side of the Walla Walla valley means that there is more natural precipitation (56 cm per year, Fig. 6) but the well-drained loess soils still allow supplemental drip irrigation to be used to control vine vigour and grape yield. Natural grape yield at this site is about 3.5 tons per acre but this is usually reduced to 2 tons per acre with a combination of irrigation practice, canopy management, and bunch thinning (Chris Figgins, vineyard manager, oral communication, 2000). In most seasons, no additional water is needed. The water budget of the vineyard is monitored by neutron probe soil sensors that allow the vineyard manager to carefully control soil moisture for optimum grape maturity and flavour concentration (Fig. 13). The neutron probe measures soil water content with depth (usually in 0.3 m increments) and allows the infiltration of irrigation water to be tracked through the soil profile (Fig. 13).

Biscuit Ridge Vineyard

This vineyard is similar to the Cottonwood Creek Vineyard in that it is located on a silty flood plain (Figs. 7, 9, 10). The easterly location also means that it has the highest rainfall of any of the Walla Walla vineyards. Cold air collecting in the

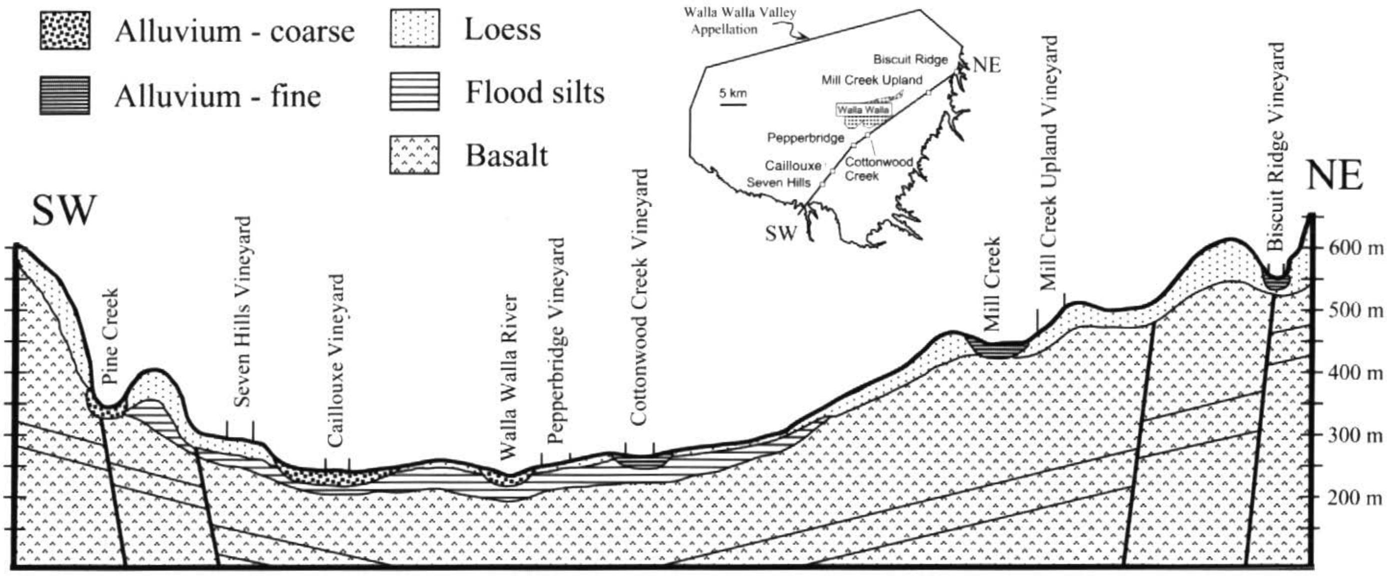

Figure 9 Cross section through Biscuit Ridge, Mill Creek Upland, Cottonwood Creek, Pepperbridge, Caillouxe and Seven Hills vineyards. Vertical exaggeration 25x. Thickness of surficial units is not to scale.

canyon bottom can be a problem for frost, and the high elevation (550 m) results in one of the coolest microclimates in the Walla Walla Valley (Fig. 12e). This vineyard is best known for Gewürztraminer, a grape that thrives in cool climates such as the Alsace region on the French-German border.

CONCLUSIONS

The range of grapes grown in the six vineyards summarized in the previous section illustrates the variability of microclimate and *terroir* of the Walla Walla Valley. In this relatively small *appellation* within the much larger Columbia Valley *appellation* of Washington State there is as much variation as is seen in entire regions, and in some cases, entire countries, in other parts of the world. It cannot be said that a single variable of bedrock, soil type, precipitation, or temperature is essential for fine wine in Walla Walla. But it is very clear that there is a direct correlation between the *terroir* and the grape varieties and wine styles that do best in a particular location. For example, the Biscuit Ridge Vineyard produces outstanding Gewürztraminer but probably could not fully ripen Cabernet Sauvignon or Syrah in even the warmest vintage of the century. Conversely, the Seven Hills vineyard, which is acclaimed for Cabernet Sauvignon, Merlot, and Syrah, is not as favorable for Chardonnay, much less for a cool climate grape such as Gewürztraminer.

Based upon the quality of wines produced from different *terroirs* in Walla Walla Valley there are a few generalizations that can be drawn to guide future grape plantings. One of the key considerations is controlling the natural vigour of the grape vine so that the resulting wine has concentrated fruit and a complex flavour profile. The generally low precipitation of the Walla Walla Valley, combined with soils formed from well-drained loess, slackwater sediments, and cobbly alluvium, provide the dominant control on plant vigour and yield. Judicious application or withholding of supplemental irrigation water allows the vineyard manager to restrict yields and optimize the quality of the grapes produced. The highest quality vineyards in Walla Walla Valley are managed for yields of only 2-3 tons per acre, in contrast to the state-wide average of 4-5 tons per acre (Table 2). The extended daylight hours due to the northerly location combined with generally sunny, arid conditions (1500-1800°C degree days) promote grape ripeness and the generation of intensely flavoured wines (Keller *et al.*, 1998). The cool nights, due both to elevation and latitude, preserve natural grape acidity to produce crisp wines with long complex finishes.

Within these overall characteristics of the Walla Walla Valley, the increase in precipitation from west to east and the differences in organic content, level of the water table, and drainage characteristics of the loess, slackwater, flood plain, and river gravel soils provide individual *terroirs* of distinction that vary in their suitability for particular grape varieties. As an example of this, the Pepperbridge Vineyard, developed on loess overlying slackwater deposits, is planted with classic Bordeaux varietals such as Cabernet Franc, Cabernet Sauvignon and Merlot, whereas immediately adjacent flood plain soils (Fig. 11b) do not produce grapes of the same quality. Instead, these flood plain soils are planted with vidalia onions, a crop known locally as Walla Walla Sweets, for which the region is also

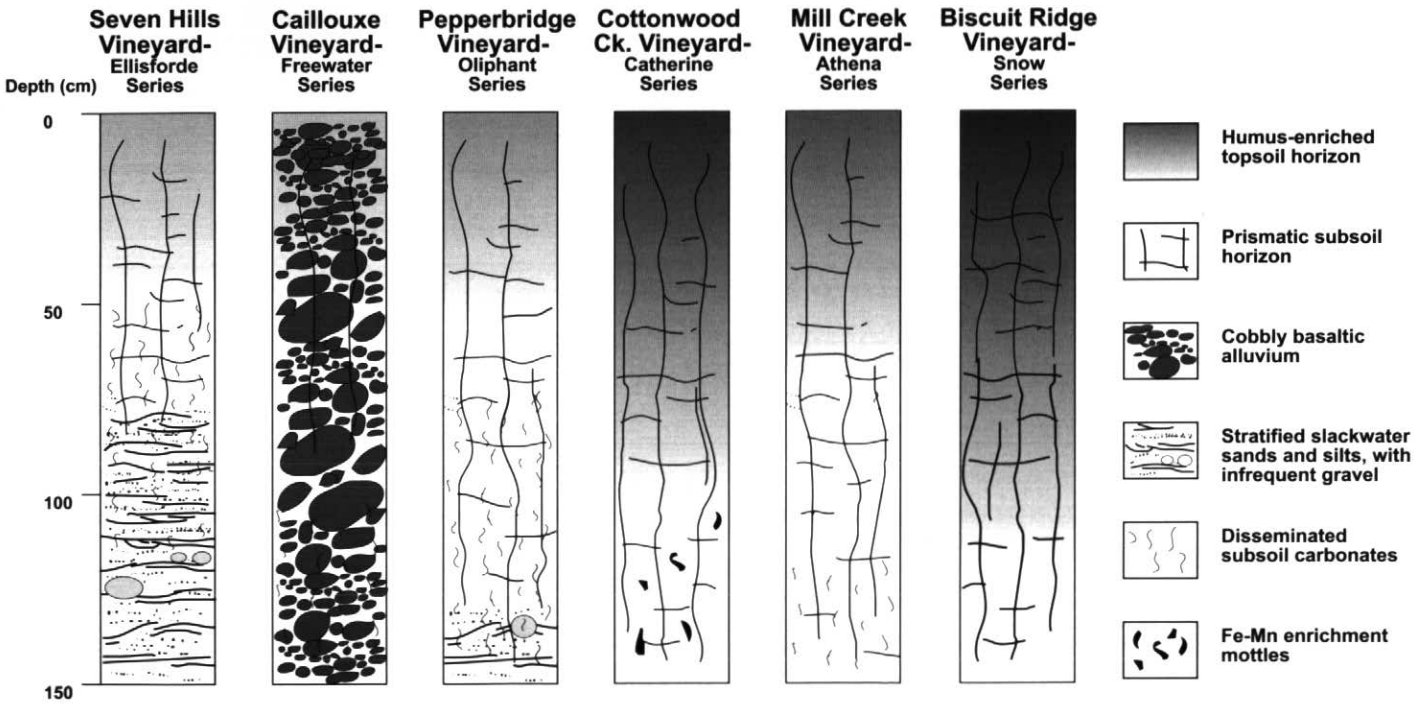

Figure 10 Selected representative soil profiles of the Biscuit Ridge, Mill Creek, Cottonwood Creek, Pepperbridge, Caillouxe, and Seven Hills vineyards. Degree of shading of the topsoil horizons is proportional to the content of humified organic matter. The irregular lines in the prismatic subsoil pattern represent the pattern of cracks that develops in this soil horizon.

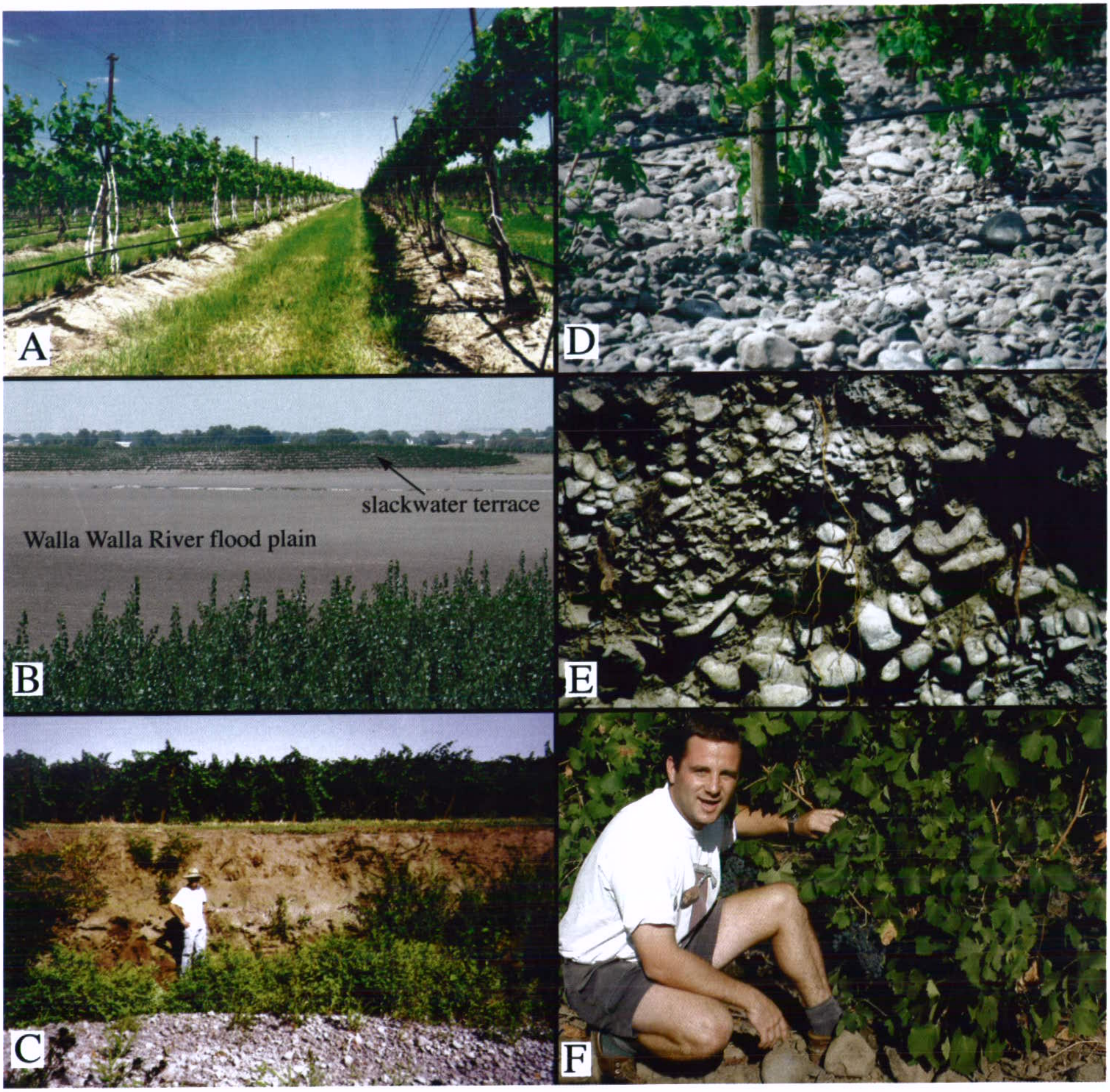

Figure 11 Photographs of vineyard features in the Walla Walla Valley area. (**A**) Smart-Dyson trellis system at the Pepperbridge Vineyard with Cabernet Sauvignon grape vines planted on a thin loess mantle over bedded slackwater terrace deposits. (**B**) Vineyard-covered "islands" of slackwater sediments separated by alluvial flood plains of the Walla Walla River. (**C**) Verdant growth of Chardonnay grapes on water-saturated flood plain silts at the Cottonwood Creek Vineyard. Grape grower Scott Byerly is standing at the edge of Cottonwood Creek with the dry gravel creekbed in the foreground. (**D**) Basalt cobbles from Walla Walla River alluvium pave the surface of the Caillouxe (formerly Cobblestone) Vineyard. Newly planted Syrah grapes are not yet trellised. (**E**) Trench near Caillouxe Vineyard exposes roots several meters below surface in the Walla Walla River alluvium. Longest root is approximately 1 m in length. (**F**) Vigneron Christophe Baron shows how Syrah grapes are trellised close to the ground to take advantage of the radiant heat of the basalt cobbles in the Caillouxe Vineyard.

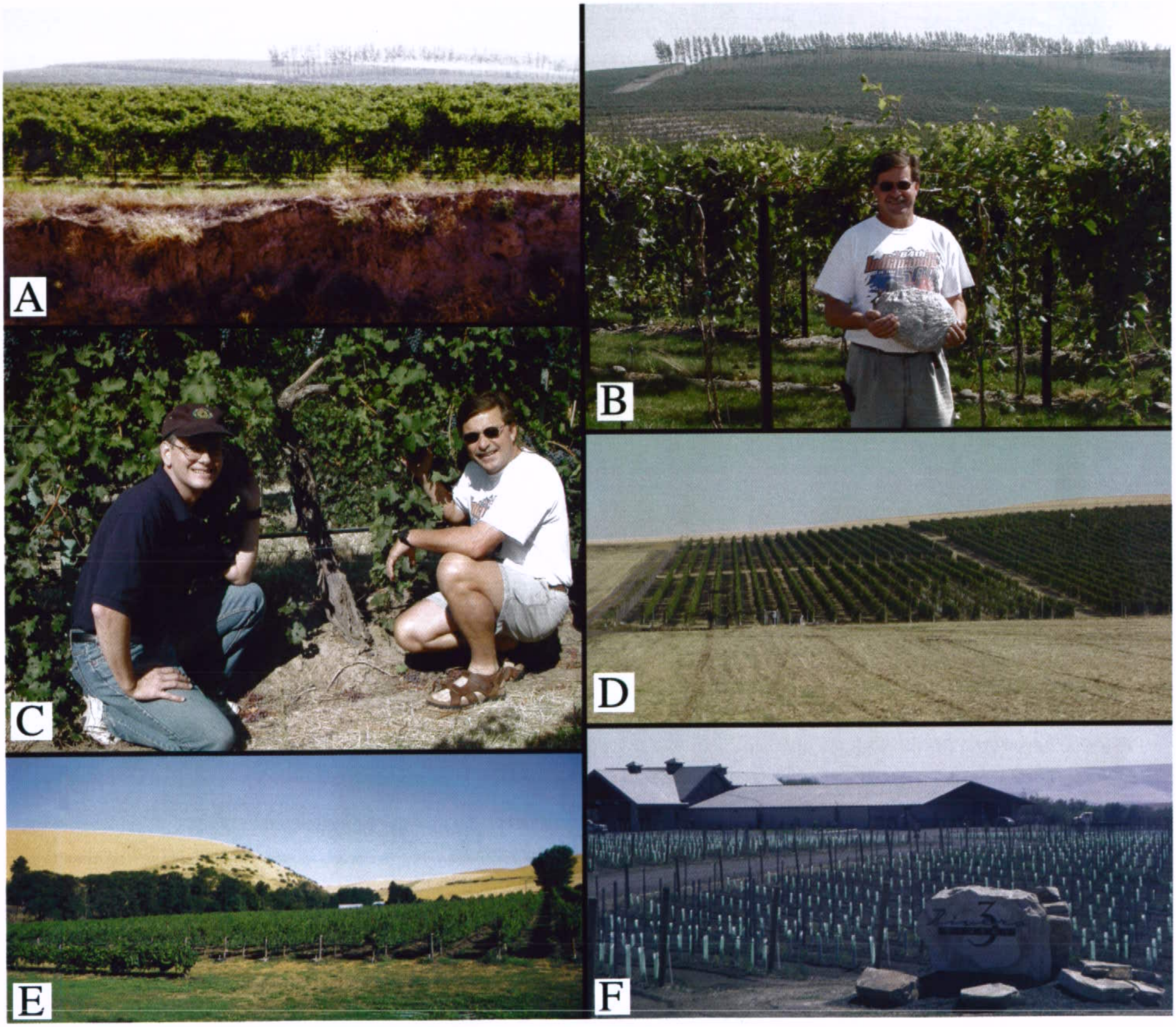

Figure 12 Photographs of vineyard features in the Walla Walla Valley area. (**A**) The Seven Hills vineyard is planted on ~2m of loess (in cliff exposure) overlying slackwater deposits (not visible here) similar to Figure 2c. (**B**) Further evidence of the glacial outburst flood activity that has shaped the *terroir* of the Walla Walla Valley are granitic erratics that were rafted in by floating glacial ice. Winemaker Gary Figgins is holding a 0.3 m granite boulder erratic that was found in the Seven Hills vineyard behind him. A chemical analysis of this rock is listed in Table 4. (**C**) The 20 year old vines, evidenced by the thick gnarled trunk, of this part of the Seven Hills vineyard have been the basis for some of the best wines produced by Casey McClellan (left), owner and winemaker at Seven Hills Winery, and Gary Figgins (right), owner and winemaker at Leonetti Cellars. (**D**) The Mill Creek Upland Vineyard is planted on thick loess soil on the eastern side of the Walla Walla Valley. Good air drainage off the moderate slopes prevents frost problems even though this vineyard at 500 m is higher than most in the valley. (**E**) Canyon-bottom flood plain soils are planted mainly with Gewürztraminer grapes at the Biscuit Ridge Vineyard. Cool air draining from the hillsides adds to the cool climate resulting from the 550 m elevation. (**F**) New grape vines (in grow tubes) were planted on flat flood plain soils surrounding the Three Rivers Winery in order to be close to the winery.

famous. Another negative example of *terroir* is the Cottonwood Creek Vineyard where poorly drained and overly fertile flood plain soils cause measurable sensory problems, including distinct vegetal characteristics.

Perhaps the purest illustration of *terroir* is the Syrah being produced from the Caillouxe Vineyard. Great Syrahs have been produced from several Walla Walla vineyards, but the Caillouxe Vineyard with its pavement of coarse basalt cobbles produces a wine distinct from neighbouring vineyards on loess or slackwater sediments. Although soils developed from loess, slackwater, flood plain, and river gravel sediments display considerable differences in mineralogy and chemistry (Table 4), the effect of each of these components on nutrient uptake and wine flavour is a subject of future research.

An appropriate place to end this discussion of Washington wine and *terroir* is with suggestions for future research. Much modern viticultural research has focussed on quantifiable aspects of plant physiology and the effects of *terroir* on wine composition and sensory attributes (*e.g.*, Reynolds *et al.*, 1995, 1996; Keller *et al.*, 1998). What remains to be done in a rigorous fashion is to examine the relationship between specific physical factors such as bedrock geology, hydrology, and pedology and the quality of wine produced from individual vineyards. One goal of this paper, and indeed of the *Geoscience Canada* series on Geology and Wine, is to explore the concept of *terroir* so that both producers and consumers of fine wine can continue the quest for quality. It is now time for the authors to get on with the latter part of this task. Truly indeed, it has been a pleasure conducting this research (Fig. 14).

ACKNOWLEDGMENTS

This study grew out of initial discussions with Rusty Figgins, owner and winemaker at Glen Fiona, about what factors were important in determining the quality of Walla Walla Valley wine. We are greatly indebted to all the vineyard owners and winemakers who so generously gave of their time and in many cases, their wine. In particular, Norm McKibben, Pepperbridge winery co-owner and past president of the Washington Association of Wine Grape Growers, was indispensable for his exhaustive knowledge of the Washington wine industry and viticultural practice. Chris Figgins, vineyard manager and assistant winemaker at Leonetti Cellars, deserves special mention for his energy and insight about connections between wine and the land. In particular, he inspired the authors to complete this study by coordinating several barrel tastings that showed not only how different vineyards contributed to a particular wine blend but also how a passion for quality at every stage of the winemaking process can result in wines of magnificence.

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Our motivation to prepare this paper was derived at least in part from a single vineyard, Seven Hills in the Walla Walla Valley *appellation* (Figs. 12a-c), and the wine made from that vineyard by a small group of vintners including L'Ecole No. 41, Leonetti Cellars, Seven Hills, and Woodward Canyon. A field examination of some of the old Seven Hills vines and

Table 6 Climate data for the Walla Walla Valley and Pepperbridge Vineyard. Data from Norm McKibben (written communication, 2000) and http://www.wrcc.dri.edu/climsum.html

Walla Walla Valley **Latitude 46° 02' Longitude 118° 20' Elevation 290 m Years of record: 40**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean max. temp.	4.1	8.4	12.6	17.1	21.8	26.4	31.4	30.3	25.0	17.7	9.5	5.4	17.5
Mean avg. temp.	0.9	4.6	7.9	11.5	15.7	19.9	24.0	23.3	18.4	12.3	5.9	2.3	12.2
Mean min. temp.	-2.3	0.9	3.2	5.8	9.7	13.3	16.7	16.3	11.8	6.8	2.3	-0.8	6.9
Precipitation (cm)	5.1	4.1	4.2	3.3	3.5	2.6	1.0	1.6	2.2	3.7	5.2	5.6	42.2
Snowfall (cm)	18.8	7.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.6	13.7	49.0
Degree days (50°F)	8	11	31	117	322	532	782	742	455	159	21	7	3187

Pepperbridge Vineyard **Latitude 46° 01' Longitude 118° 21' Elevation 250 m Year of record: 1999**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max. temp. °C	12.8	11.7	17.8	25.6	30.0	34.4	40.0	37.2	32.8	26.1	27.2	14.4	40.0
Min. temp. °C	1.7	-1.7	-0.6	-0.6	1.7	3.3	7.2	11.1	-0.6	-1.7	-2.2	-3.3	-3.3
Mean 9:00 a.m. temp. °C	3.9	4.4	5.6	9.4	12.2	17.2	20.6	22.2	15.0	7.8	6.7	3.9	10.7
Mean 9:00 a.m. humidity (%)	77	71	71	62	61	57	50	58	55	73	83	83	67
Precipitation (cm)	3.2	6.9	11.4	2.6	3.6	7.3	0.8	0.0	1.0	3.9	4.1	4.3	49.1
Daylight hrs wind >24 kph	2	2	0	2	0	0	0	0	0	0	2	2	10
Solar radiation (W/m²)	20	28	190	166	170	231	234	201	142	79	37	20	1518
Degree days (50°F)	0	0	0	196	147	440	1068	817	546	83	0	0	3297

some of the wines made from them by Gary Figgins, winemaker at Leonetti, and Casey McClellan, winemaker at Seven Hills, provided further insight into the history of this vineyard and Walla Walla winemaking (Fig. 12c).

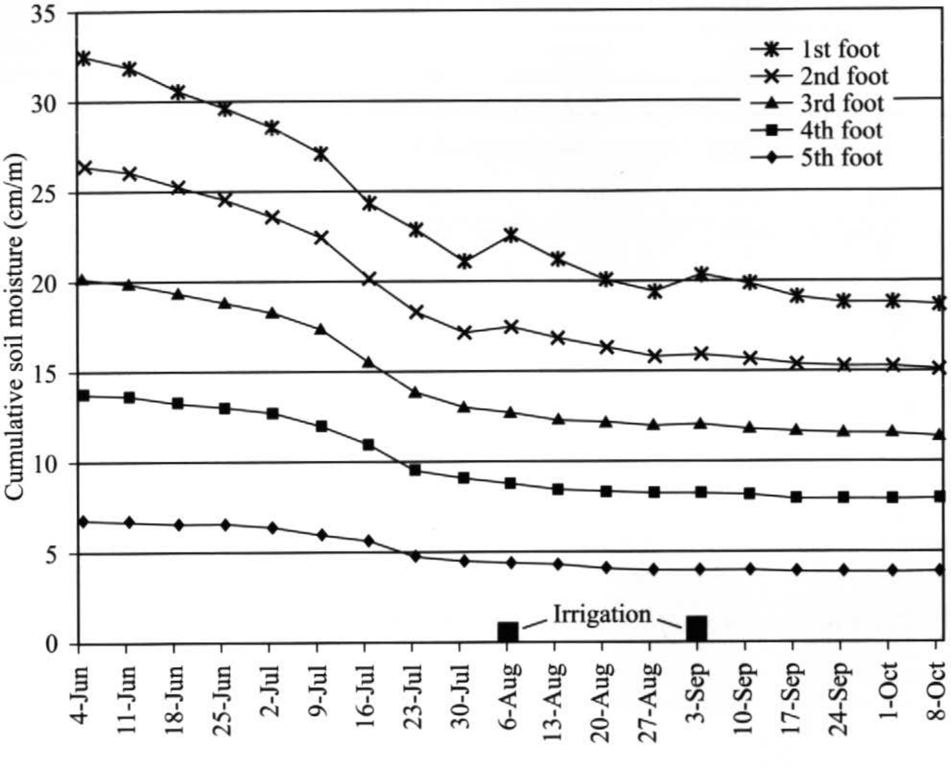

Figure 13 Neutron probe measurement of soil moisture for the Mill Creek Upland Vineyard (block 1, row 4) illustrating effects of irrigation and soil moisture retention properties. Drip irriation was applied on 6 August 1999 and 3 September 1999 (0.8 and 1.2 cm per acre, respectively) and affected the top metre of the soil profile. Data from Chris Figgins (written communication, 2000).

Figure 14 In order to fully understand the nuances of *terroir*, the authors, Larry Meinert (left) and Alan Busacca (right) tasted barrel samples of wine from many of the vineyards described in this paper. Some samples required repeated evaluation.

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Positions Available

OCEANOGRAPHY

DEPARTMENT OF OCEANOGRAPHY, DALHOUSIE UNIVERSITY AND CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Applications are invited for a probationary tenure track assistant professor position in GEOCHEMISTRY OF ANCIENT AND MODERN OCEANS. The successful candidate will be expected to develop a vigorous, externally funded research programme, supervise M.Sc. and Ph.D. students, and teach graduate and undergraduate classes. S/he will also be appointed a "Scholar" in the Earth System Evolution Programme (ESEP) of the Canadian Institute for Advanced Research (CIAR). Candidates should have an interest in quantitative interdisciplinary research into the role of ocean chemistry in regulating and recording the evolution of Earth's biogeochemical cycles.

The successful candidate will have a record of research achievement, contribution to the discipline, and assessed potential necessary to be appointed by CIAR. As a member of ESEP, the incumbent initially will be supported partly by CIAR and during this time will benefit from reduced teaching responsibilities and from association with an international network of researchers in earth system sciences. A Ph.D is required, and post-doctoral experience is normally expected.

Applicants should submit a c.v., a statement of research/teaching objectives, and the name, address, phone, and e-mail of four referees. Applications will be considered as soon as they are complete, and they will be accepted until the position is filled.

Applications should be sent to:
Chair, Geochemistry of Ancient and Modern Oceans Search Committee
Department of Oceanography
Dalhousie University
Halifax, NS, Canada B3J 4H1
Phone (902) 494-3557, Fax (902) 494-3877
E-mail: oceanography@dal.ca
For more specific information, access our websites:
www.phys.ocean.dal.ca/docs/jobsatdal.html; www.ciar.ca; adder.ocean.dal.ca/esep

DALHOUSIE UNIVERSITY is an Employment Equity/Affirmative Action Employer. The University encourages applications from qualified women, Aboriginal peoples, racially visible people, and persons with a disability. In accordance with Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents.

GEOLOGY OR EARTH SCIENCES

DEPARTMENT OF EARTH SCIENCES, DALHOUSIE UNIVERSITY PETROLEUM GEOLOGIST

Applications are invited for a probationary tenure track position at the assistant professor level. The successful candidate will establish a vigorous externally funded research programme, and will assist in undergraduate and graduate teaching. Workers in all areas of petroleum geoscience are encouraged to apply. The successful candidate will be strongly competitive in original research within the NSERC funding system, as well as able to interact with industry on practical problems in the local area. A Ph.D. is required and post-doctoral experience in academia or industry is expected. In an exceptional case, the appointment may be at a higher level, if experience warrants.

Dalhousie University's Strategic Research Plan gives special emphasis to oil and gas studies. The Department has strong connections to Canada's leading federal marine research institution, the Bedford Institute of Oceanography, and a rapidly expanding local petroleum industry.

Applicants should submit a c.v., a statement of research/teaching objectives, and the name, address, phone number and e-mail of four referees. The deadline for applications is March 27, 2001. Late applications will be considered if the position has not been filled.

Applications should be sent to:
Chair, Petroleum Geology Search Committee
Department of Earth Sciences
Dalhousie University
Halifax, NS, Canada B3H 3J5
Phone: 902-494-2358, Fax 902-494-6889
E-mail: earth.sciences@dal.ca

Dalhousie University is an Employment Equity/Affirmative Action employer. The University encourages applications from qualified women, Aboriginal peoples, racially visible people and persons with a disability. In accordance with Canadian Immigration requirements this advertisement is directed to Canadian citizens and permanent residents.