

Geology and Wine 10: Use of Geographic Information System Technology to Assess Viticulture Performance in the Okanagan and Similkameen Valleys, British Columbia

P. A. Bowen, C. P. Bogdanoff, B. F. Estergaard, S. G. Marsh, K. B. Usher, C. A.S. Smith and G. Frank

Volume 32, Number 4, December 2005

URI: https://id.erudit.org/iderudit/geocan32_4ser02

[See table of contents](#)

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)

1911-4850 (digital)

[Explore this journal](#)

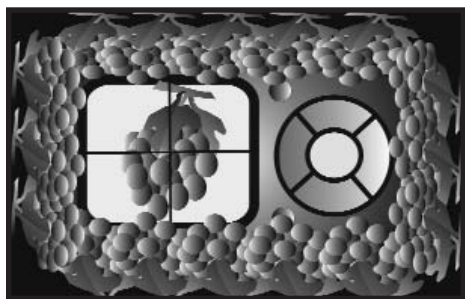
Cite this article

Bowen, P. A., Bogdanoff, C. P., Estergaard, B. F., Marsh, S. G., Usher, K. B., Smith, C. A. & Frank, G. (2005). Geology and Wine 10: Use of Geographic Information System Technology to Assess Viticulture Performance in the Okanagan and Similkameen Valleys, British Columbia. *Geoscience Canada*, 32(4), 161–176.

Article abstract

The complex geological history of the Okanagan and Similkameen valleys in British Columbia has created a wine growing region by way of diverse bedrock, soils, terrain and climate. Although wine grapes have been grown in the area for many decades, a recent conversion of vineyards to predominately *Vitis vinifera* varieties, and the subsequent world recognition of wine quality, suggests that there is further potential to improve wine quality through fine-tuning of grape varietal choices and vineyard management techniques. A geographic information system (GIS) application has been developed to study the relationships among site conditions, management practices and vineyard performance including fruit and wine quality. The production area was divided into six regions based on landform and climate: 1. Kelowna, 2. Penticton, 3. Vaseaux - Oliver, 4. Golden Mile, 5. Black Sage - Osoyoos, and 6. Similkameen. The complement of grape varieties planted varies among the regions. Comparisons of regional patterns of varieties planted, and medals received, have revealed significant regional differences in varietal suitability. Although most of the vineyards are sited on coarse-textured soils, comparisons of the distributions of all and medal-winning vineyard blocks among soil textural classes have revealed that quality wine grapes are grown on a broad range of soil types within, and among, the six regions studied. Loamy soils appear to be especially suitable for producing quality wine grapes in the Okanagan and Similkameen valleys.

SERIES



Geology and Wine 10: Use of Geographic Information System Technology to Assess Viticulture Performance in the Okanagan and Similkameen Valleys, British Columbia

P. A. Bowen, C.P. Bogdanoff, B.F. Estergaard, S.G. Marsh, K.B. Usher, C.A.S. Smith and G. Frank

Pacific Agri-Food Research Centre (PARC), Agriculture and Agri-Food Canada, Summerland, BC, V0H 1Z0 Corresponding author E-mail: bowenp@agr.gc.ca

SUMMARY

The complex geological history of the Okanagan and Similkameen valleys in British Columbia has created a wine growing region by way of diverse bedrock, soils, terrain and climate. Although wine grapes have been grown in the area for many decades, a recent conversion of vineyards to predominately *Vitis vinifera* varieties, and the subsequent world recognition of wine quality, suggests that there is further potential to improve wine quality through fine-tuning of grape varietal choices and vineyard management techniques. A geographic information system (GIS) appli-

cation has been developed to study the relationships among site conditions, management practices and vineyard performance including fruit and wine quality. The production area was divided into six regions based on landform and climate: 1. Kelowna, 2. Penticton, 3. Vaseaux - Oliver, 4. Golden Mile, 5. Black Sage - Osoyoos, and 6. Similkameen. The complement of grape varieties planted varies among the regions. Comparisons of regional patterns of varieties planted, and medals received, have revealed significant regional differences in varietal suitability. Although most of the vineyards are sited on coarse-textured soils, comparisons of the distributions of all and medal-winning vineyard blocks among soil textural classes have revealed that quality wine grapes are grown on a broad range of soil types within, and among, the six regions studied. Loamy soils appear to be especially suitable for producing quality wine grapes in the Okanagan and Similkameen valleys.

SUMMAIRE

L'histoire géologique complexe des vallées d'Okanagan et de Similkameen en Colombie-Britannique a créé une région vinicole en réunissant divers socles rocheux, sols, terrains et climats. Bien que le raisin de cuve ait été cultivé dans la région depuis plusieurs décennies, une conversion récente aux variétés de *Vitis vinifera*, et la reconnaissance mondiale de la qualité de ses vins qui s'en est suivie, permet de penser que la qualité des vins pourrait encore être améliorée par le choix de variétés de vignes et l'amélioration des techniques de production. Une application d'un système d'information géographique (SIG) a été mise au point pour étudier les relations entre les caractéristiques des sites, les pratiques de gestion, et les performances du vignoble,

dont la qualité des fruits et du vin. La zone de production a été subdivisée en six régions selon la forme du relief et le climat, soit : 1. Kelowna, 2. Penticton, 3. Vaseaux-Oliver, 4. Golden Mile, 5. Black Sage, et 6. Similkameen. Le complément des variétés de raisin plantées varie selon les régions. Les comparaisons d'arrangement des variétés plantées et des médailles reçues ont mis au jour d'importantes différences régionales quant aux variétés les mieux adaptées. Bien que la plupart des vignobles croissent dans des sols légers, les comparaisons des distributions des parcelles en fonction des types de texture des sols et des médailles reçues ont montré que des vignes de qualité sont cultivées sur une grande variété de types de sol à travers les six régions étudiées. Les sols loameux semblent particulièrement convenir pour la production de raisin de cuve dans les vallées d'Okanagan et de Similkameen.

INTRODUCTION

The Okanagan and neighbouring Similkameen valleys in south-central British Columbia (Fig. 1) are home to a young, expanding premium-wine industry. Premium-wine production in the two valleys has risen from 0.8 to 4.7 million litres in the last 12 years (British Columbia Wine Institute, 2004). Although *Vitis vinifera* varieties have been cultivated in the area for decades, prior to 1990, most of the vineyards were of French hybrid and *V. labrusca* varieties, which were found to be more productive, hardy and disease resistant than the enologically superior *V. vinifera* (Association of British Columbia Grape Growers, 1984). In the late 1980s, it became clear that development of an internationally competitive wine industry in the region must be based on premium *V. vinifera* wines. This spurred a govern-

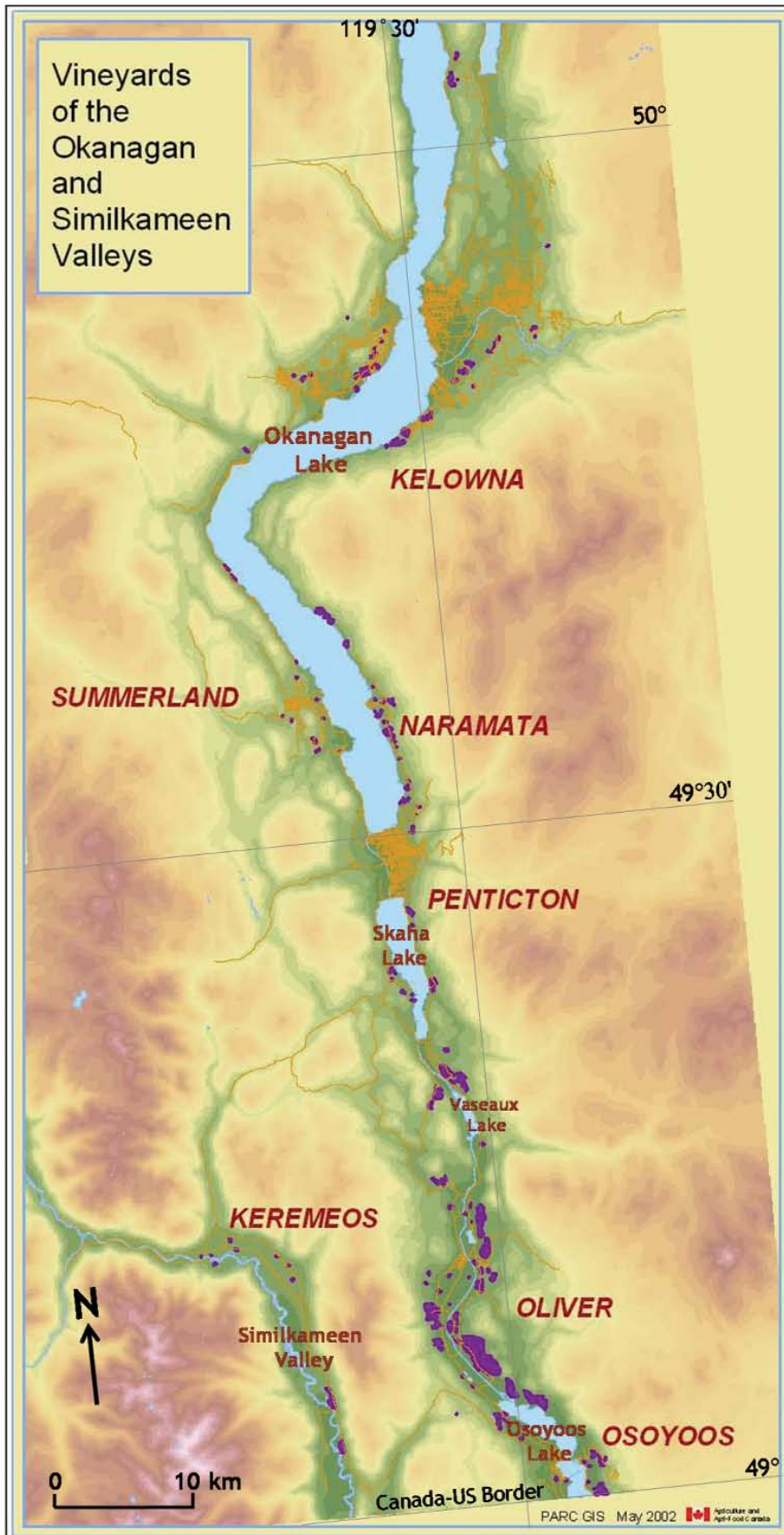


Figure 1. Distribution of vineyards (shown in purple) in the Canadian portions of the Similkameen and Okanagan valleys. The Okanagan Valley is occupied by Okanagan, Skaha, Vaseaux and Osoyoos lakes.

ment-supported vine pullout and replant program that resulted in the conversion of nearly all plantings to *V. vinifera*. In addition, the higher profit potential compared to some tree fruit production, and the opening of previously uncultivated vineyard-suitable lands, have resulted in further expansion of the vineyard area to its highest ever, totalling more than 2,000 ha. However, sites suitable for *V. vinifera* production are greatly limited by climate, terrain and the scarcity of arable soil. Thus individual vineyards are small, averaging *ca.* 10 ha.

The bedrock, soils and terrain in the two valleys are highly diverse owing to the complex geological history of the region. East of Okanagan Valley, the Okanagan Highlands are composed of the Monashee Gneiss, representing the ancient western margin of North America, which was uplifted during the Cretaceous (Roed and Greenough, 2004). West of the Okanagan Valley, the bedrock geology is dominated by Jurassic granites and Eocene volcanic sedimentary rocks, which slid downward and westward off the rising crustal mass of the Highlands during the Eocene. The separation plane between these two bedrock terrains crops out as a complex network of faults in and around the margins of the lake, collectively referred to as the Okanagan Fault (Templeman-Kluit and Parkinson, 1986). Eocene volcanics of the Marron Group are of andesitic composition and were extruded in association with large calderas, the remnants of which are still present at Vernon, Kelowna, Summerland and Penticton (Roed and Greenough, 2004). Eocene sedimentary rocks of the White Lake Formation, including conglomerate, sandstone, siltstone and minor coal, were deposited as fluvial sediments in the landscape surrounding the volcanic edifices; these bedrock units underlie vineyards in the Okanagan Valley.

The valleys have endured many glacial advances, the last occurring in the late Pleistocene (Nasmith, 1962). River valleys were clogged with large volumes of sand and gravel during glacial advances. Although glacial processes eroded bedrock locally, they mainly redistributed pre-existing unconsolidated materials. Thus the materials lining the Okanagan and Similkameen valleys are heterogeneous mixtures derived from many different bedrock sources (see

detailed maps in Nasmith, 1962, and simplified map in Roed and Greenough, 2004)

The late glacial history of the Okanagan Valley has been described by Nasmith (1962). Most valley bottom landforms were created during deglaciation. The most influential activities were the melting of stagnant ice lobes in the valley, the periodic creation and breaching of ice dams south of Skaha Lake that created glacial Lake Penticton, and the deposition of thick glaciolacustrine silts which filled the valley. The draining of this lake and the erosional cutting led to benches and bluffs consisting of glacial lake sediments along the shores of Okanagan and Skaha lakes (Fig. 2), and fluvioglacial materials that gave rise to silty, sandy, gravelly and stony soils throughout the area but particularly south of Skaha Lake and to the east of Osoyoos Lake. The presence of ice lobes that filled the valley bottoms also allowed for the formation of alluvial fans that sit above the current valley floor.

Vineyards in the Okanagan and Similkameen valleys (Fig. 1) are established mostly on glaciofluvial and fluvial terraces (benches) and fans, glacial lake deposits, and slope deposit complexes that are reworked glacial deposits (Fulton, 2003). Soil parent materials are composed primarily of unconsolidated glacial deposits having a lithology reflecting regional geological inputs and producing a largely uniform, mixed mineralogy in most soils. What is variable is soil texture and thickness, characteristics that influence rooting depth and the water and nutrient holding capacities. Bedrock is rarely prominent in vineyards developed to date.

The geological events and processes, which led to the diverse bedrock, landforms and soils in the region, and the Okanagan Valley's wide latitude span (49° N to 50°30' N) create a wide range of vineyard edaphic and climatic conditions. Recognizing the challenge grape-growers face in selecting vineyard sites and varieties to cultivate in the valleys, government specialists in the early 1980s put significant effort into identifying and rating the viticultural suitability of agricultural lands. Lands were rated according to the suitability of their soil, climate and sun exposure, and maps showing these ratings were pub-

lished in the widely used "Atlas of Suitable Grape Growing Locations" (Association of B.C. Grape Growers, 1984). At the time the atlas was published, French hybrid varieties were recommended, and dominated in plantings. Winter survival and high yields, rather than premium winemaking quality, were the main goals of viticulture in the Okanagan and Similkameen valleys. Since that publication, the conversion to *V. vinifera* and emphasis on quality for winemaking have created needs for more detailed ratings of vineyard site characteristics, and a better understanding of how these characteristics interact with management practices to affect the performance of *V. vinifera* varieties. While much has been learned from other areas about the response of *V. vinifera* varieties to climate, soils and management practices, information derived from local experience can be more relevant in developing strategies to improve crop performance while minimizing risk and cost. Indeed, within the Okanagan and Similkameen valleys the combinations of soils, landforms and climates - those characteristics that define *terroir* (Haynes, 1999; Wilson, 2001) - are unique.

Our approach in constructing our viticultural GIS application for the Okanagan and Similkameen valleys has been to focus on site-specific vineyard attributes. The GIS contains informa-

tion on the conditions and activities that have resulted in the range of success growers have attained in producing high quality wine grapes from their sites and varieties planted. Its purpose is to provide a data model that growers and researchers can use to study relationships among the site characteristics, including physical, soil and climatic attributes, varieties grown, and viticultural practices that determine grape and wine quality. A similar model for France was described by Morlat (2001) in which a chain of factors contribute to the quality of the wine produced, beginning with site conditions, then influenced by planting material, annual climate, and human practices, including viticultural and wine-making methods.

Any grower or researcher who keeps and accesses records of field conditions, management practices and crop performance by block or site has, in effect, already created and is using a GIS. For large sets of location-based records, modern GIS software (i.e., ArcGIS, ESRI, Canada) facilitates data handling and analysis, and can be used to create maps displaying spatial relationships. In recent years the adoption of GIS analysis has become widespread in agriculture, both by single-farm operators and by regional commodity associations. For viticulture, GIS has been used successfully in the precision man-



Figure 2. A west-facing vineyard (foreground) on the benchlands north of Penticton, east of Okanagan Lake. The range of soil textures found on the benchlands results from the complex of medium to fine-textured glacial lacustrine materials that are overlain by a discontinuous sandy loam eolian veneer.

agement of nutrients and irrigation (e.g., Bramley and Williams, 2001; Lamb et al., 2004) and for modelling vineyard site suitability (e.g., Tesic et al., 2002a, b; Tesic, 2004; Wolf and Boyer, 2003). Application of GIS tools may be particularly useful in the Okanagan and Similkameen valleys where growers are challenged in managing vineyards sited on a limited land base characterized by variable bedrock, soils, climate and terrain.

Although *V. vinifera* culture in the Okanagan and Similkameen valleys is relatively recent, the potential for world-class wine production has already been verified by the increasing number of press commendations and gold medals received (British Columbia Wine Institute, 2004). Obviously some grow-

ers and wineries are already making good management choices and others may be able to learn from them. While France took centuries to develop its viticulture for each appellation, Okanagan and Similkameen growers have quickly adopted and modified techniques developed elsewhere (including France), and may be able to further fine-tune their varietal choices and management techniques for the specific conditions of their site. Since no two wine regions have the same growing conditions, the GIS should be able to provide growers with the most relevant information on what leads to the finest wines under the unique conditions in British Columbia's interior.

STRUCTURE OF THE GIS DATABASES

There are currently ca. 250 commercial vineyards in the Okanagan and Similkameen valleys. Vineyards operated by wineries average ca. 29 ha, whereas those operated by independent growers average ca. 4 ha. The average area of individual grape variety blocks is ca. 1 ha. As most vineyard managers keep records for cultural practices and performance on a variety block basis, information in our GIS is collected on the same basis and is organized in three modules: Site Conditions, Management Practices, and Vineyard Performance (Table 1). The Site Conditions module has information on soils, terrain and climate. The Management Practices module includes varieties planted, planting systems designs and management practices. The

Table 1: An example of data collected for an individual variety block for a single year. The list is incomplete, as the GIS database contains more detailed information on soil characteristics and cultural practices for this block.

SITE CONDITIONS		Production System Attributes (continued)	
Physical Attributes		Cordon wire height (cm)	80
Region	5: Black Sage/Osoyoos	Catch wire heights (cm)	104, 133, 163
Block area (acres)	0.73	Cover crop	Yes
Average aspect (degrees)	265	Irrigation type	overhead sprinkler
Aspect range (degrees)	255-275	Annual Cultural Practices	
Aspect variability score (0 = not variable, 4 = highly variable)	1	Year	2001
Average slope (degrees)	15	50% bloom date	156
Slope range (degrees)	0-20	Shoot thinning (Y/N)	yes
Slope variability score (0 = not variable, 4 = highly variable)	3	Shoot thinning date	134
Frost pocket(s) (% of block area)	0	Shoots: number per vine	18
Soil Attributes		Hedged (shoots trimmed) (Y/N)	yes
Soil series (verified by specialist)	Osoyoos	Hedging date	185
Soil (<2 mm) texture (1=coarse to 5=fine) (inspected)	1	Leaves removed in cluster zone (Y/N)	yes
Gravel (>2mm) content (0=none to 2=very gravelly) (inspected)	0	Leaf removal date	220
Surface stoniness (>25cm) (0=none to 5=excessive) (inspected)	0	Leaves removed (number/shoot)	3.5
Soil/land alteration		Cluster thinning (Y/N)	no
(0=not altered to 3= alterations to 100% of area) (inspected)	0	Cluster thinning date	N/A
Annual Frost Record		VINEYARD PERFORMANCE	
Year	2001	Annual Crop Performance	
Frost damage - spring, fall (%)	0, 0	Year	2001
Date of last spring frost	126	Harvest date	262
Date of first fall frost	278	Yield (tons/acre)	3.62
MANAGEMENT PRACTICES		Soluble solids (tank) (°Brix)	23.5
Production System Attributes		pH (tank)	3.49
Variety	Chardonnay	Titrateable acidity (tank) (g/L)	8.9
Clone	76	Winemaker-expected quality score	
Rootstock	SO4	(1=poor, 5=excellent) (historical)	4
Year planted	1997	Winemaker-actual quality score (1=poor, 5=excellent)	4
Trellis system type	Bilateral cordon with vertical shoot positioning	Number of previous years the winemaker used grapes from this block	3
Pruning style	mix (cane and spur)	Annual Wine Awards	
Row direction (degrees)	265	Year (vintage)	2000
In-row spacing (cm)	120	Competition	Okanagan Fall Wine Festival
Between-row spacing (cm)	240	Medal	silver
		Percentage of wine (%)	3.5

Vineyard Performance module contains phenological dates, crop yield, basic juice composition, winemaking quality ratings and the vineyard sources of medal-winning wines. An outline of the procedures used for collecting data for each module follows.

Site Conditions **Block Locations**

Perimeter coordinates for each grape-variety block were collected using a global positioning system (GPS); from these, the block area was calculated. Vineyard maps constructed by overlaying the block polygons onto base maps with elevation contours, roadways, and waterways using GIS software, were provided to growers. There are currently more than 240 mapped vineyards and more than 2,500 variety blocks in the GIS.

Terrain

Average slope and aspect of each grape-variety block were measured onsite, and terrain variation (roughness) was rated. More detailed terrain characterization, for determination of insolation (exposure to sunlight) and for mesoclimate modelling, is accomplished through analysis of elevation contours using GIS software (ArcGIS, Spatial Analyst extension, ESRI, Canada). Fruit ripening patterns can be affected by topography and terrain, which influence cold air drainage (Bowen et al., 2004) and insolation (Fialla et al., 2004).

Locations of vineyard areas frequently damaged by frost (frost pockets) were identified by the vineyard managers.

Soils

The classification of soils within each variety block was determined by first overlaying the block boundaries onto soil maps (Fig. 3) developed from a detailed (1:20,000) soil survey completed in 1981 (Wittneben, 1986). The soil series revealed for each block were verified by a specialist (Joe Fitzpatrick) who visited each vineyard and examined the soils and landforms. When necessary, he dug pits to observe the soil profile to confirm the series and the taxonomic classification. Subgroup names follow the Canadian system of soil classification (Soil Classification Working Group, 1998). For each soil series identified in

vineyards, the physical and chemical properties as described in the soil survey report and observed by the specialist were entered into the relational database supporting the GIS application. Properties included are: depth to bedrock; surface stoniness; texture (resulting from the size distribution of mineral particles); perviousness class; drainage class; depth to root restriction; shear strength; permeability; pH; salinity class and cation exchange capacity. Soil maps, such as the one shown in Figure 3, are provided to growers and show the soil series and textural class in each variety block.

Climate

Climatic variation is known to be a major contributor to variation in fruit quality (i.e., Giomo et al., 1996). Climatic information is included in the GIS in two scales. Regional climate, representing areas spanning 50-60 km, is characterized using data gathered from grower- and government-owned weather stations. From these, indices such as growing degree days (base 10°C) (GDD), dates of last-spring and first-fall frosts and frost-free days are calculated. Annual variation in climate may be wide ranging (Fig. 4) and contributes to vintage differences in wines.

Mesoclimate, representing areas of ≤ 2 ha (i.e., on the scale of individual variety blocks), is characterized using data collected with fine-grained networks of climate monitoring devices such as radio-transmitting motes (Crossbow, USA); small sensor-loggers (Watchdog, Spectrum, USA; Smartbutton, ACR, Canada); or with a mobile weather station with attached GPS unit, which is moved through vineyards in a grid pattern. Owing to the irregular topography found in many vineyards, the range in ambient air temperature within an area as small as 1 ha can be as high as 8°C (Bowen et al., 2004). This spatial variation in temperature can also be dynamic, especially during the daytime, and can result in substantial spatial variation in the diurnal temperature range. Maps of such mesoclimate characteristics (Fig. 5) are produced using data from the fine-grained measurements.

Management Practices **Planting Systems**

Vineyard planting systems and irrigation equipment types were determined onsite during the GPS survey. The planting system characteristics include training and trellis design, vine spacing within, and between, rows, and row direction. Irrigation equipment types include sprinkler, microjet and drip systems, and design features such as the spacing of emitters or risers.

Cultural Management

All management practices, including irrigation, pruning, thinning of shoots, leaves and clusters, crop protection (sprays and organic methods), nutrient applications and vineyard floor management (tillage methods and use of cover crops), are determined through an annual survey completed by vineyard managers.

Crop Performance **Crop Phenology**

Phenological records including dates of budbreak, bloom, veraison (onset of berry ripening) and harvest are provided by growers in the annual survey.

Fruit Yield and Quality

Yield, and measures of basic fruit quality characteristics such as juice pH, titratable acidity (TA) and soluble solids (°Brix) are provided by growers in the annual survey. For selected vineyards and grape varieties, more detailed compositional information, e.g., levels of colour pigments, yeast assimilable nitrogen and aromatic volatiles, has been obtained from associated research (i.e., Usher et al., 2004). For grape-variety blocks, from which wine was made separately, winemakers provide a fruit quality rating that represents their experienced perception of winemaking quality. The ratings, 1 to 5, respectively, indicate quality levels of unacceptable, poor, fair (average), good and excellent or outstanding. A rating is provided for the block overall (over all years of winemaking experience) and for the current year. When the quality ratings are analyzed for relationships with cultural practices and crop characteristics such as yield or °Brix at harvest, the appropriateness of using current cultural practices for each variety or growing region can be assessed. For example, the effect of yield level on fruit

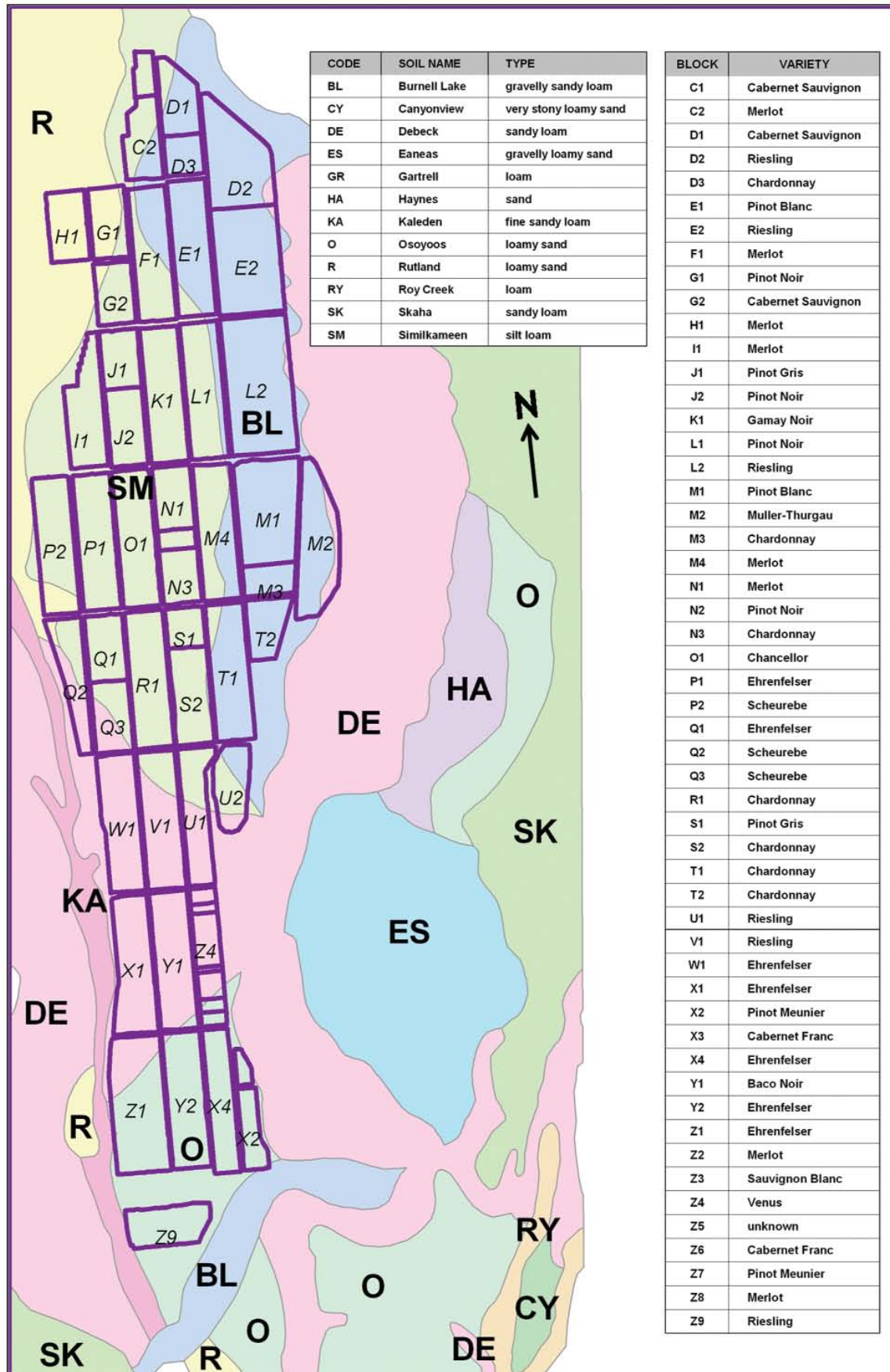


Figure 3. Grape variety block boundaries overlaid onto a soil map for Inkameep vineyard in Vaseaux – Oliver (Region 3). Type of soil (textural class) for each series is shown in the inset at top centre.

quality was analyzed to determine whether over-cropping (excess yield) has been a major quality-limiting factor. Results for Chardonnay, for example, indicate that although the overall relationship between yield and quality is not significant, excellent quality has been produced only in blocks yielding less than five tons of fruit per acre (Fig. 6); however, blocks producing low yields did not necessarily achieve high quality.

Wine quality from grape-variety blocks or vineyards is assessed by identifying the vineyard sources of fruit used in making wines that received medals in judged competitions. Both the fruit and wine quality assessment methods differentiate only levels of quality, and do not differentiate qualitative differences in fruit or wine sensory attributes or style which have already been shown to be influenced by site conditions in the Okanagan Valley (Reynolds et al., 1995, 1996). Such information is available, however, in data collected by the quality assurance program for wine in British Columbia, the Vintners Quality Alliance (VQA). Candidate wines for VQA status are evaluated by trained judges to ensure that these wines are free of defects and have varietal character. The judges also note wine quality characteristics including flavour and aroma notes, body, balance and other sensory attributes. With the winemakers' provision of the identity of the vineyard of origin, these data are being added to the GIS for studies of terroir effects on wine character and quality. Similar evaluations of the aging potential of medal-winning wines are being conducted in collaboration with researchers at the Wine Research Centre of the University of British Columbia.

VITICULTURAL REGIONS

To help evaluate the effects of differences in regional conditions on viticultural performance, we have divided the Okanagan and Similkameen grape-growing area into six viticultural regions based primarily on landform and climate (Fig. 7). Differences in the complement of grape varieties planted among regions (Fig. 8) likely reflect general knowledge of the suitability of *V. vinifera* to climatic conditions, and to published climatic suitability ratings for grape-growing (Association of B.C. Grape Growers, 1984) available to growers when a high

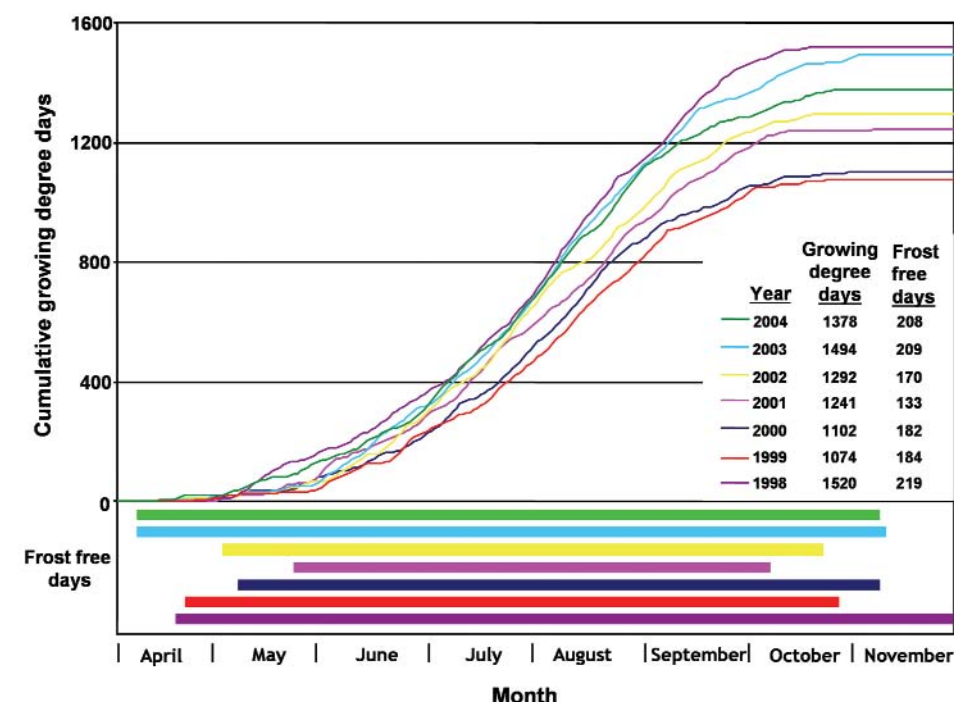


Figure 4. Cumulative growing degree days and frost free periods in Summerland, B.C. (Penticton, Region 2) from 1998 to 2004.

number of vineyards were planted in the early 1990s. White varieties dominated plantings in the northern regions and red varieties were planted more in the south. Experience from these *V. vinifera* plantings, and the value of varietal wines on the market, has likely affected varietal choices in more recent plantings as these contain relatively fewer varieties and are dominated by high-value noble varieties, including Chardonnay, Merlot and Cabernet Sauvignon. A general description of the site conditions and varieties grown in each region follow.

Kelowna: Region 1

The Kelowna region includes vineyards north of the bend in Okanagan Lake near Peachland (Fig. 7) which marks a major bedrock cross-fault. Many of the vineyards are located on terrain of Eocene sedimentary and volcanic bedrock. Kelowna is the coolest region, and is distinguished mainly by its relatively low total GDD accumulation of ca. 950 to 1,360 ($\bar{x} \pm \text{SD}$, for 1998 to 2003). This cool climate reflects both the region's northern latitude and its proximity to Okanagan Lake, which leads to relatively low daily maximum and mean temperatures during the growing season. Most vineyards in the region are sited near Okanagan Lake on sloped benches or hillsides. These vineyards

have excellent air drainage which, combined with the lake's moderating effect on nighttime temperatures, results in lower incidences of late-spring and early-fall frost episodes than in some regions to the south. Grape production occurs on a wide range of soils including very coarse glaciofluvial soils that have gravelly-sandy surface textures classified as Eluviated Eutric Brunisols (Gammil soils), and fine-textured soils formed on glaciolacustrine parent materials. These soils have silty clay loam surface textures and are classified as Orthic Grey Luvisols (Boucherie soils). Vineyard area is 12% (Fig. 9a) of the total in the two valleys, and the average age of plantings is 12 years.

The Kelowna region contains some of the oldest *V. vinifera* vineyards in the area, with blocks dating to the early 1960s. Varieties planted are predominantly whites, including a range of Germanic and French varieties suited to cool-climate viticulture, including Riesling, Chardonnay, Gewürztraminer, and Ehrenfelser (Fig. 8). Most of the red varieties grown are also suited to cool climates and include substantial plantings of the Burgundian variety Pinot noir and the Beaujolais variety Gamay, as well as small amounts of Merlot and Marechal Foch.

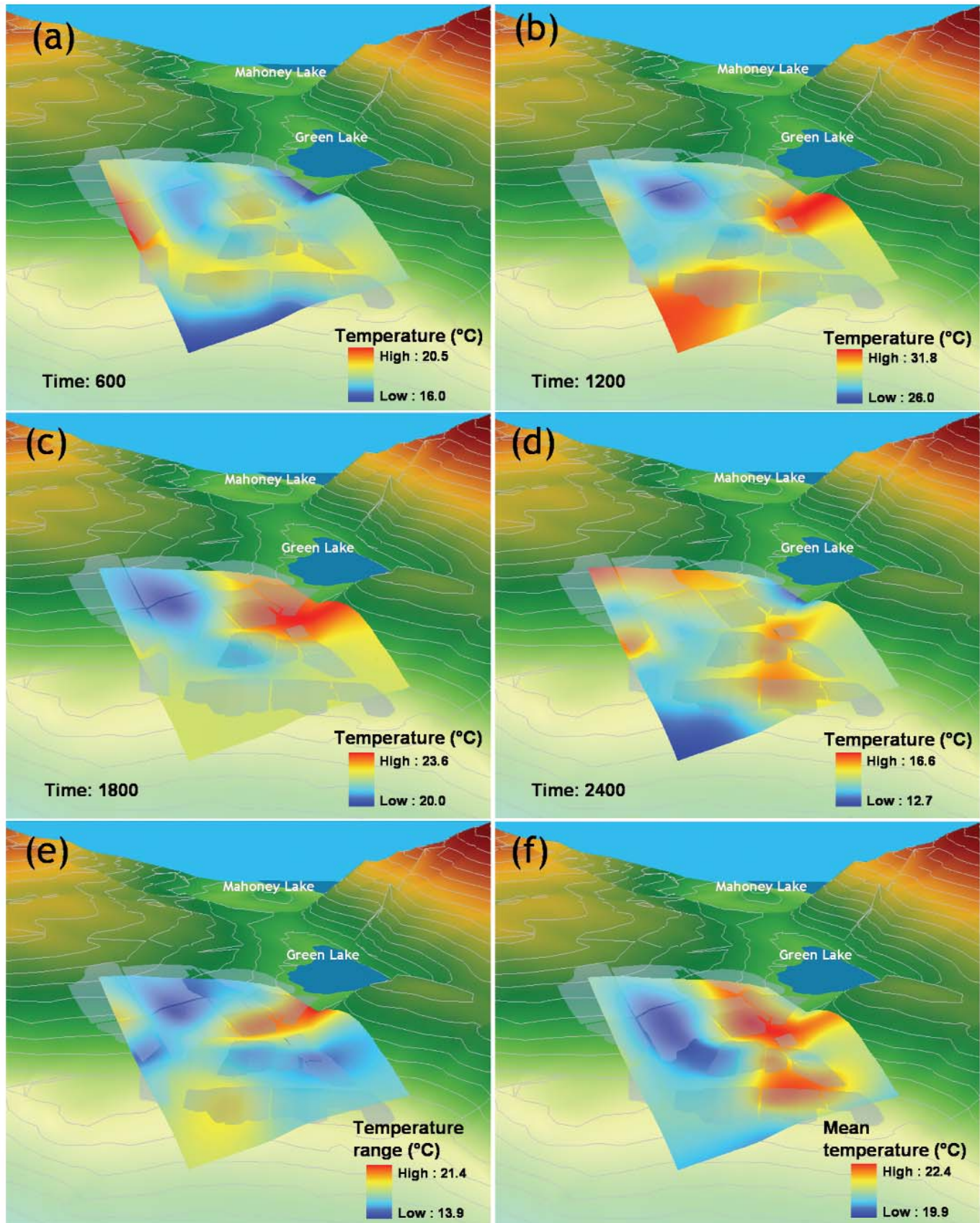


Figure 5. The dynamic spatial variation in ambient air temperature within Hawthorne Mountain Vineyard (Vaseaux – Oliver, Region 3) in the Okanagan Valley. Air temperature measurements were taken on August 9, 2004, using a 24-site sensor network installed in the *ca.* 40 ha vineyard. Maps show snapshots of air temperature at (a) 0600, (b) 1200, (c) 1800 and (d) 2400 hrs.; (e) the diurnal air temperature range and (f) mean air temperature. Vineyard blocks are shown in grey. Contour interval is 20 m.

Penticton: Region 2

Vineyards in the Penticton region are located along the southern-most part of Okanagan Lake and along Skaha Lake (Fig. 7). The region's total GDD range is *ca.* 1,140 to 1,500, which averages higher than that of the Kelowna region but significantly lower than in regions to the south. Vineyards in this region are concentrated along the glaciolacustrine benchlands on both the east and west sides of the southernmost reach of Okanagan Lake (Fig. 2) and along the benchlands above Skaha Lake. Those on the east sides of the lakes are underlain by Monashee Gneiss, whereas those on the west are underlain by Eocene volcanic and sedimentary substrates. The predominant vineyard soil of this region is composed of a sandy eolian veneer overlying clay loam to silty clay loam glaciolacustrine parent materials. The subsoils may be weakly saline. These soils are classified as Orthic Brown Chernozems (Olhausen soils). Where the sandy eolian veneer is missing and the fine-textured glaciolacustrine material is found at the surface, Orthic Brown Chernozems belonging to the Penticton series occur. In the Summerland area (Fig. 7), a sandy surface veneer overlies glacial till. These soils are also classified as Orthic Brown Chernozems, but are placed within the Giants Head soil series. In some cases, land levelling prior to vineyard planting has eradicated the native soil profile, and vines are growing in a mixture of unweathered parent materials. Most vineyards, particularly those on the east side of the lakes, slope gently to the west and have excellent air drainage which provides a relatively high number of frost free days. The region has 12% of the total vineyard area in the two valleys (Fig. 9a). The average age of plantings is 10 years.

Region 2 is planted predominantly with white varieties with less area in Germanic varieties than in Region 1, and more than a third of the total area planted with the whites Chardonnay, Pinot blanc and Pinot gris (Fig. 8). Bordeaux varieties dominate the red varieties, especially Merlot, but there is also significant area planted with Pinot noir.

Vaseaux - Oliver: Region 3

Vineyards in the Vaseaux-Oliver Region (Fig. 7) are sited on deep, sandy, glaciofluvial parent materials including

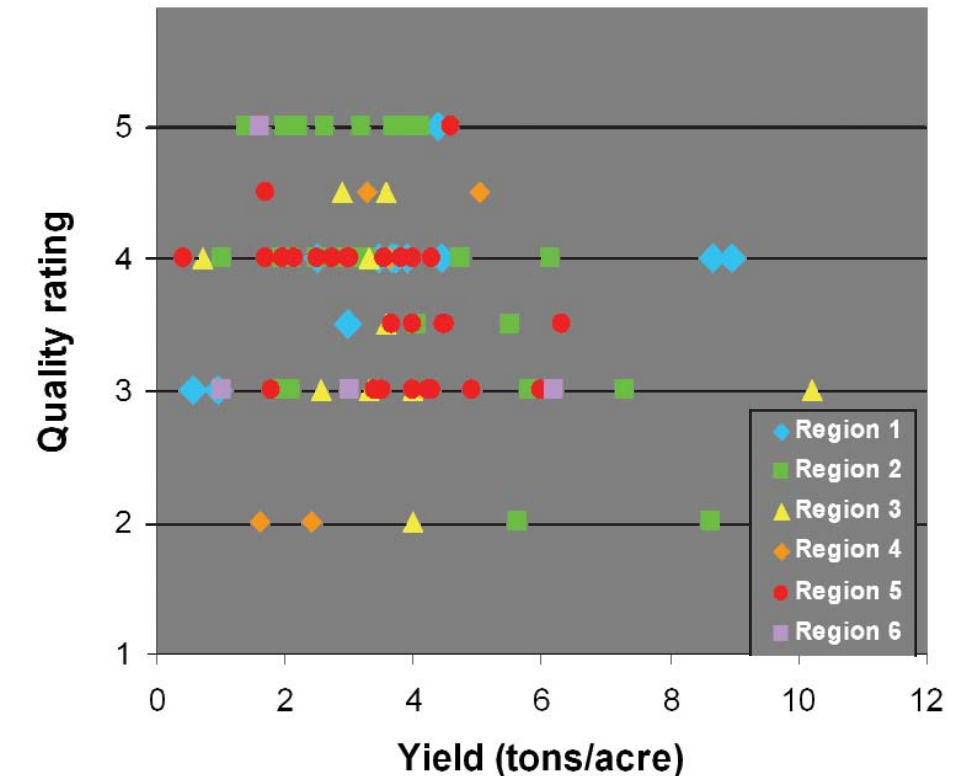


Figure 6. The relationship of Chardonnay fruit quality, as rated by winemakers, to yield (tons/acre). Quality ratings correspond to: 1=unacceptable, 2=poor, 3=fair (average), 4=good and 5=excellent or outstanding. Locations for Regions 1 to 6 are shown in Figure 7. A linear regression fit through the data was not significant ($P>0.05$, $R^2=0.02$, $n=166$).

kettled outwash deposits. Bedrock is dominated by gneisses and granite. The soils at higher elevations that were partially forested before clearing are classified as Eluviated Eutric Brunisols (Parkhill soils) while at lower elevations the soils formed under grassland conditions and are classified as Orthic Brown Chernozems (Osoyoos soils).

The rough topography of the region requires that vineyards are sited on a broad range of slopes at a variety of aspects. The total GDD range is *ca.* 1,320 to 1,490, with the lowest totals at the highest elevations and on north-facing slopes. Vineyard area in the region is 15% of the total in the two valleys (Fig. 9a), and the average age of plantings is 11 years.

Grape varieties planted are similar to those in the Kelowna region (Fig. 8) in that they include Germanic and French white varieties suited to cool climate viticulture, and the red varieties Pinot noir and Gamay. However, Vaseaux-Oliver has substantially more of the Bordeaux red varieties, Merlot and

Cabernet Sauvignon, which better suit its warmer climate.

Golden Mile: Region 4

The viticultural region, which has been known locally for some time as the Golden Mile, is located on the west side of the Okanagan Valley south of the town of Oliver (Fig. 7). Vineyards are mostly sited on fluvial fan soils that were deposited against an ice lobe that filled the bottom of the valley during the last glacial episode, and overlie metamorphosed Paleozoic rocks. The soils are mostly dark brown, stony, gravelly sandy loams or gravelly loamy sands. These are soils that developed under grasslands and are classified as Orthic Dark Brown Chernozems belonging to the Ratnip soil series. The total GDD range of Golden Mile is *ca.* 1,340 to 1,630. Vineyard area in the region totals 6% of the total vineyard area in the two valleys (Fig. 9a). The average age of plantings is 10 years.

Although Golden Mile is one of the warmest regions in the Okanagan

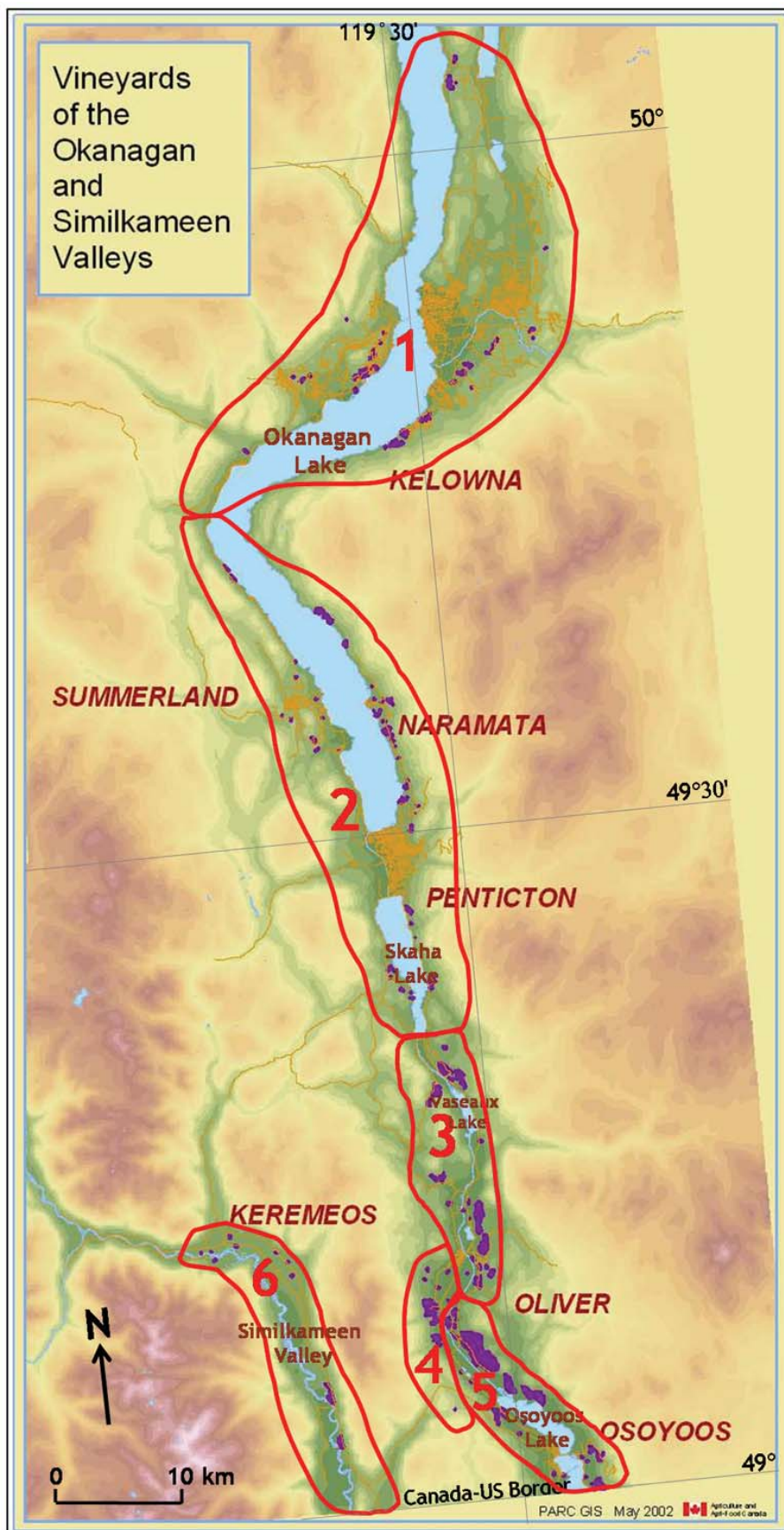


Figure 7. Viticultural Regions 1-6 in the Okanagan and Similkameen valleys. Regions are: Kelowna (Region 1), Penticton (2), Vaseaux – Oliver (3), Golden Mile (4), Black Sage – Osoyoos (5), and Similkameen (6). Vineyards are shown in purple.

and Similkameen valleys growing area, a significant portion of its vineyard area is planted with white varieties, mainly Gewurztraminer and Chardonnay (Fig. 8). Other whites grown are Pinot gris, Riesling, Pinot blanc, and Chenin blanc, a Loire variety that is uncommon in the other regions. Bordeaux varieties dominate the red varieties grown and include Cabernet Sauvignon, Cabernet Franc and Merlot, but Pinot noir plantings are also significant.

Black Sage - Osoyoos: Region 5

The Black Sage - Osoyoos region includes a large vineyard-dominated area south of Oliver on the east side of the Okanagan Valley and in areas around Osoyoos Lake to the US border (Fig. 7). Vineyards in this region are nearly all sited on deep, stone-free, sandy glaciofluvial parent materials that dominate the benchlands to the east and north of Osoyoos Lake, and overlie granite bedrock. These soils formed under grassland conditions and are classified as Orthic Brown Chernozems belonging to the Osoyoos soil series. The soils are rapidly drained and have very low moisture holding capacity, but are well suited to grape production. The total GDD range is *ca.* 1,360 to 1,630. The region contains some of the largest vineyards in the area and the average age of plantings is 7 years.

Although Black Sage - Osoyoos is a relatively young growing region, it has more than half of the planted area in the Okanagan and Similkameen valleys (Fig. 9a). About 60% of the area is planted with red varieties, mainly the Bordeaux varieties Cabernet Sauvignon, Cabernet Franc and Merlot, but there is also significant Pinot noir and a small amount of the Rhone variety Syrah (Fig. 8). The major whites grown are Chardonnay, Sauvignon blanc, Pinot blanc and Pinot gris.

Similkameen: Region 6

The Similkameen region includes the viticultural area in the southern part of the Similkameen Valley to the US border (Fig. 7). Vineyards are underlain primarily by metamorphosed bedrock of Paleozoic age. Narrower than the Okanagan Valley, the Similkameen Valley is flanked by steep-sided mountains which significantly reduce sun exposure at some vineyard sites. However, most

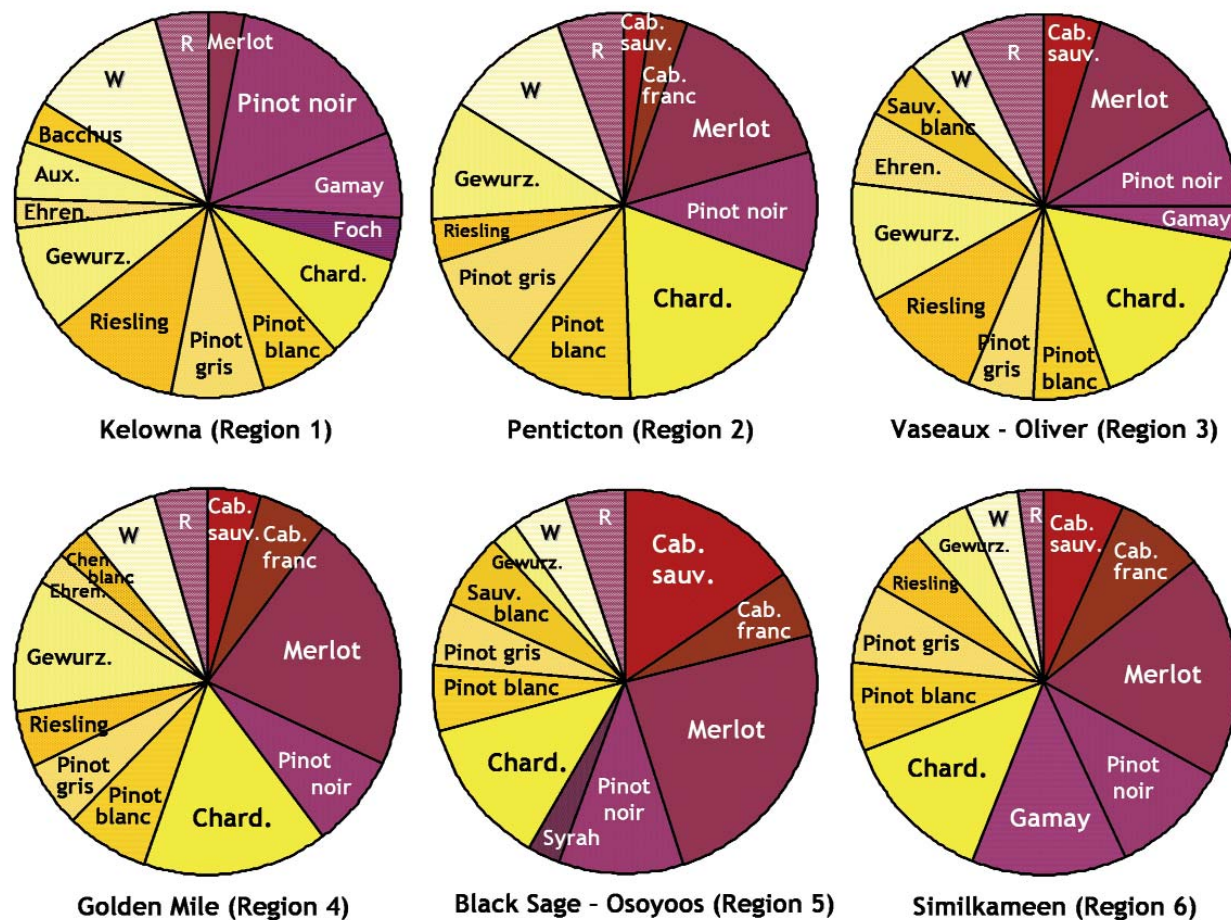


Figure 8. Division of planted area among grape varieties in each viticultural region in the Okanagan and Similkameen valleys. W and R, respectively, refer to total area planted to white and red varieties that individually total less than 2%, but collectively may total 15% (e.g. white varieties in Kelowna and Penticton regions).

vineyards have very favourable west-facing aspects and the total GDD range is ca. 1,180 to 1,540.

Vineyards are scattered throughout the region on gently to moderately sloping, gravelly, fluvial fan parent materials and in some locations, these soils have considerable surface stoniness. The soils formed under grassland conditions, and are classified as Orthic Dark Brown Chernozems belonging to the Stemwinder series.

Currently, Similkameen has 5% of the total vineyard area (Fig. 9a) and the age of plantings averages 5 years. More than half of the vineyard area is planted with red varieties including the Bordeaux varieties Merlot, Cabernet Sauvignon and Cabernet Franc, as well as Gamay and Pinot noir (Fig. 8). The major white varieties are Chardonnay, Pinot blanc, Pinot gris, Riesling and Gewurztraminer.

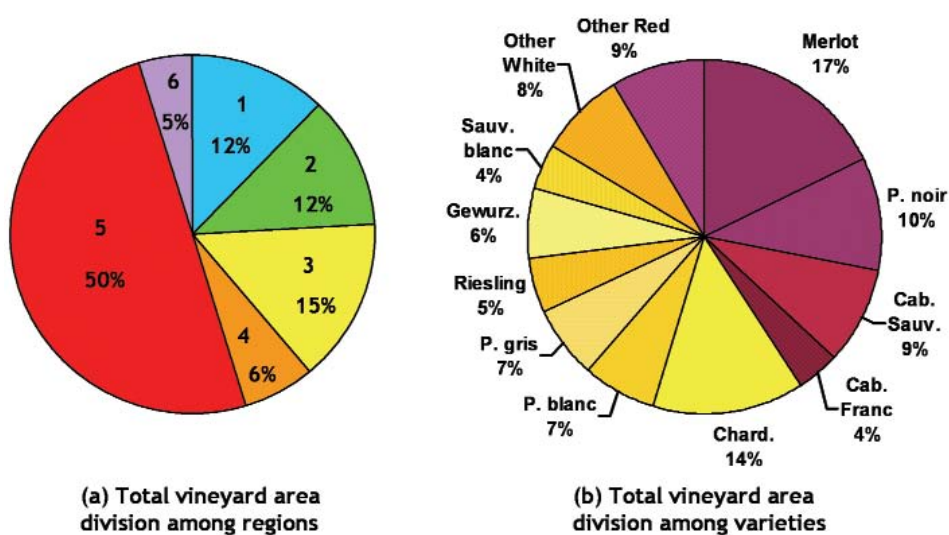


Figure 9. Total vineyard area in the Okanagan and Similkameen valleys. (9a) division among the six regions: note that Black Sage - Osoyoos (Region 5) has 50% of the total vineyard area; and (9b) division among grape varieties. "Other red" and "other white" varieties include the total areas of red and white grape varieties, respectively, that individually total less than 3%, but collectively total 9% (other red) and 8% (other white) as seen in 9b.

VARIETAL PERFORMANCE

Gauging the suitability of grape varieties to growing regions can be difficult, as differences in viticultural practices and winemaking styles may confound the effects of site conditions on fruit and wine quality. Unfortunately, chemical analyses used routinely to evaluate the composition of grapes do not give clear indications of quality, particularly those for aroma and flavour components, and it is rare to find sites that have had rigorous fruit analyses conducted routinely. A further complication in a young industry is the evolution of grape and wine quality resulting from adjustments made in grape-growing and winemaking methods while the industry gains experience. During that time sufficient evaluation of wines across vintages by experienced judges can be difficult to accomplish and may take several years. Although it may not be feasible to conduct a rigorous analysis of varietal suitability in a small and evolving industry, studies that provide early indications of success in grape varietal choices can be valuable to the industry. Thus we have developed a method for evaluating varietal suitability

to regions in the Okanagan and Similkameen valleys based on outcomes of an annual contest for medal awards, the Fall Okanagan Wine Festival, in which wines from all regions are entered and judged blindly by well-recognized and internationally experienced judges. The analysis reported here includes judging outcomes from four years (2000 through 2003), but future results from additional years and a more mature industry may be different and more reliable. Thus our present findings on varietal performance should be considered as a preliminary evaluation.

Best-Performing Grape Varieties in Each Region

An analysis to determine best-performing varieties in a region needs to take into account differences in production from the different varieties in the region. By comparing, for each region, the proportions among grape varieties of total area or numbers of blocks planted with the proportions of area or blocks that produce medal-winning wine, the relative success of the varieties grown can be evaluated. If the performance of all

varieties planted in a region is similar, the proportions planted and medal-winning are expected to be the same. If some varieties perform better than others, their portion of the medal-winning area or blocks will be larger than their portion of the total area or blocks planted. Such differences can be detected using a chi-square goodness-of-fit test in which the observed results (i.e., medal-winning planted area division among varieties) are compared with the results expected if there were no differences in performance (i.e., the total planted area division). The analysis determines the probability that the expected and observed proportions are the same and there are no differences in the performance of varieties in the region. We applied chi-squared goodness-of-fit tests, with a significance level of 5% ($P=0.05$), to detect performance differences among varieties in each of the six regions using results from the Fall Okanagan Wine Festival judging in 2000 to 2003. A summary of the results for each region on a vineyard area basis follows (Figs. 8 to 10).

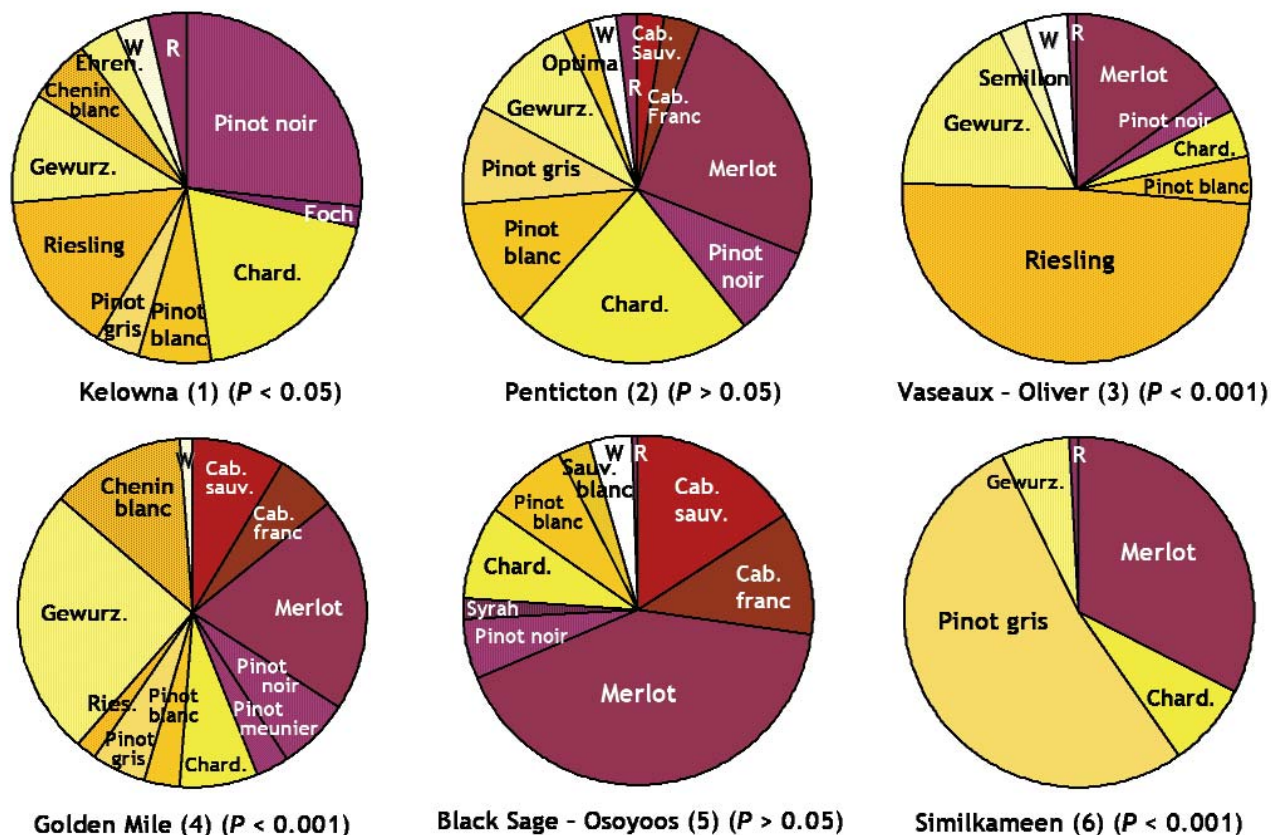


Figure 10. Division of medal-winning vineyard area among varieties in each viticultural region in the Okanagan and Similkameen valleys. P values are for the significance of chi-square goodness-of-fit tests comparing total and medal-winning area division among varieties.

Kelowna - Region 1:

The analysis detected differences in varietal performance. White varieties predominate in the total and medal-winning vineyard area, and Chardonnay is the strongest performer. Pinot noir is the most planted red variety and the strongest performing red.

Penticton - Region 2:

No differences in varietal performance were detected. White varieties predominate in the total and medal-winning vineyard areas. Merlot predominates in red plantings and medals.

Vaseaux-Oliver - Region 3:

Substantial differences in varietal performance were detected in the analysis. Riesling accounts for only *ca.* 10% of the total vineyard area, but about half of the medal-winning vineyard area. Gewurztraminer is another strong-performing white. Merlot is the strongest performing red variety.

Golden Mile - Region 4:

Substantial differences in varietal per-

formance were detected. White varieties are planted in more than half of the total and medal-winning vineyard area, with Gewurztraminer and Chenin blanc showing the strongest performance. Bordeaux reds account for most of the total and medal-winning vineyard area in red varieties.

Black Sage - Osoyoos - Region 5:

No differences in varietal performance were detected. Chardonnay, Pinot blanc and Sauvignon blanc account for most of the medal-winning area in white varieties. Bordeaux reds account for most of the medal-winning area in red varieties.

Similkameen - Region 6

Substantial differences in varietal performance were detected. Pinot gris is planted in only 7% of the vineyard area, but accounts for more than half of the medal-winning area. Merlot is favoured in the medals for red varieties.

Best-performing Regions for Grape Varieties

The regions in which specific grape vari-

eties have performed well can be identified using an approach similar to that used to identify best varieties in each region. For each variety, this is accomplished on a vineyard area basis by comparing the proportions among regions of total planted area and medal-winning area. If a variety performs similarly in all regions, the proportions are expected to be the same as the planted proportions: i.e., no region is favoured. Conversely, if a grape variety performs better in some regions than in others, its portion of the medal-winning planted area will be greater than its portion of the total planted area. Application of a chi-squared goodness-of-fit test determines the probability that the medal-winning proportions are not different from the planted proportions, indicating that no regions are favoured for the variety. We applied such chi-square tests to results from Fall Okanagan Wine Festival judging, from 2000 to 2003, for the eight most widely planted varieties in the Okanagan and Similkameen valleys. These included five white varieties: Chardonnay, Pinot blanc, Pinot gris,

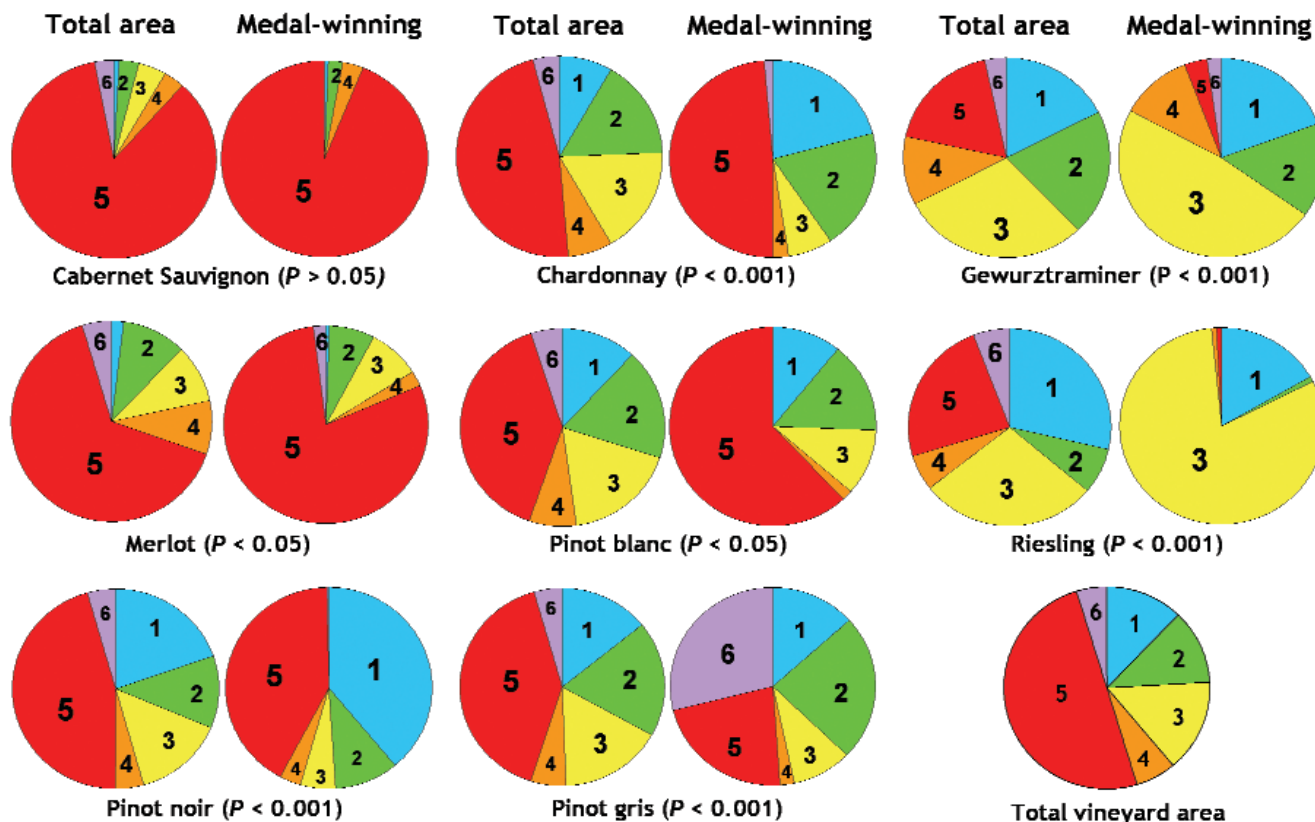


Figure 11. Total and medal-winning vineyard area divided among viticultural regions for each of the top eight varieties grown in the Okanagan and Similkameen valleys. P values are for the significance of chi-square goodness of fit tests comparing total and medal-winning area division among regions.

Gewurztraminer, and Riesling; and three red varieties: Cabernet Sauvignon, Merlot and Pinot noir (Fig. 9b). A summary of the results (Fig. 11) follows.

White Varieties

Although Chardonnay, Pinot blanc and Pinot gris are planted in similar proportions of the total vineyard area in all regions, analysis results indicate that the medals have favoured:

- Chardonnay from Kelowna and Penticton (Regions 1 and 2).
- Pinot blanc from Black Sage - Osoyoos (Region 5).
- Pinot gris from Penticton and Similkameen (Regions 2 and 6)

Gewurztraminer and Riesling are planted heavily in Vaseaux - Oliver (Region 3) which is favoured in the medals for both varieties, especially Riesling.

Red Varieties

Most of the total and medal-winning Cabernet Sauvignon and Merlot vineyard area is in Black Sage - Osoyoos (Region 5). The analysis results indicate that Merlot from Black Sage - Osoyoos is favoured. Pinot noir from Kelowna (Region 1) is strongly favoured.

Summary of Varietal Suitability

Based on the analysis of medals awarded to wines by variety and region, regional suitability for the eight most widely planted varieties was assessed (Table 2). While the influence of climate in deter-

mining high quality is apparent for red varieties (Bordeaux reds, including Merlot, Cabernet Sauvignon and Cabernet Franc, perform best in the southernmost regions where total growing degree days are highest, and Pinot noir, a Burgundian variety, performs best in Kelowna which has the coolest climate), climate does not appear to be a major quality-determining factor for white varieties. The influences on white wine quality of management practices and site conditions other than regional climate, such as soils or landforms, needs further study. It is notable that nearly all varieties, white and red, have performed well in Penticton (Region 2).

RESPONSE TO SOIL TEXTURE

One of the most variable characteristics of soils in the Okanagan and Similkameen vineyards is texture. Soil texture is determined by the size distribution of component mineral particles (Witneben, 1986). Coarse-textured soils have sand-sized particles as their main component, whereas fine-textured soils consist mostly of silt- and clay-sized particles. Soil texture affects permeability for drainage, water holding capacity, and the tension with which water is held to soil particles. It can thus have substantial impact on vine growth and development including vegetative vigour and berry composition, which determines wine-making quality. To examine whether soil texture has a major effect on the quality of wines produced in the Okanagan and

Similkameen valleys, the distribution among soil textural classes of all grape-variety blocks was compared with that of blocks from which medal-winning wines were produced (Fig. 12). If soil texture has no effect on wine quality the distributions are expected to be similar. Chi-square goodness-of-fit tests were used to detect differences in the distributions.

Although most of the vineyards in the Okanagan and Similkameen valleys are sited on coarse (i.e., loamy sand) or moderately coarse (i.e., sandy loam) soils, we found that medal-winning wines have been made from grapes originating from a range of soil textures, from loamy sands and sandy loams to finer textured clay loams and silty clay loams (Fig. 12). Nonetheless, based on the chi-square analyses, the distributions of all blocks and medal winning blocks among textural classes were different in Kelowna, Penticton, Golden Mile and Similkameen. Kelowna is the only region with significant grape production on moderately fine-textured soils (i.e., silty clay loams; Fig. 12), and these soils have produced a disproportionately high number of medal-winning wines. In Penticton (2) where a discontinuous eolian veneer overlies the glacial lacustrine deposits, medals have favoured grape production from the sandy loam soils associated with this veneer. In Golden Mile (4), where the soils originated from fluvial fan deposits, vineyards located on sandy loam soils have also performed exceptionally well. In

Table 2: The regional suitability of the eight most commonly grown wine grape varieties in the Okanagan and Similkameen valleys, determined by comparing the proportions of total and medal-winning areas among regions.

Variety	Growing region					
	1. Kelowna	2. Penticton	3. Vaseaux – Oliver	4. Golden Mile	5. Black Sage - Osoyoos	6. Similkameen
Chardonnay	**	**			*	
Pinot blanc	*	*			**	
Pinot gris	*	**				**
Gewurztraminer	*	*	**	*		*
Riesling			**			
Cabernet Sauvignon		*		*	*	
Merlot		*	*		**	
Pinot noir	**	*		*	*	

, *: Performs better than () or as well as (*) expected from the area planted of the variety in each region. Blank cells indicate either performance was lower than expected or there was insufficient data to evaluate for that variety and region.

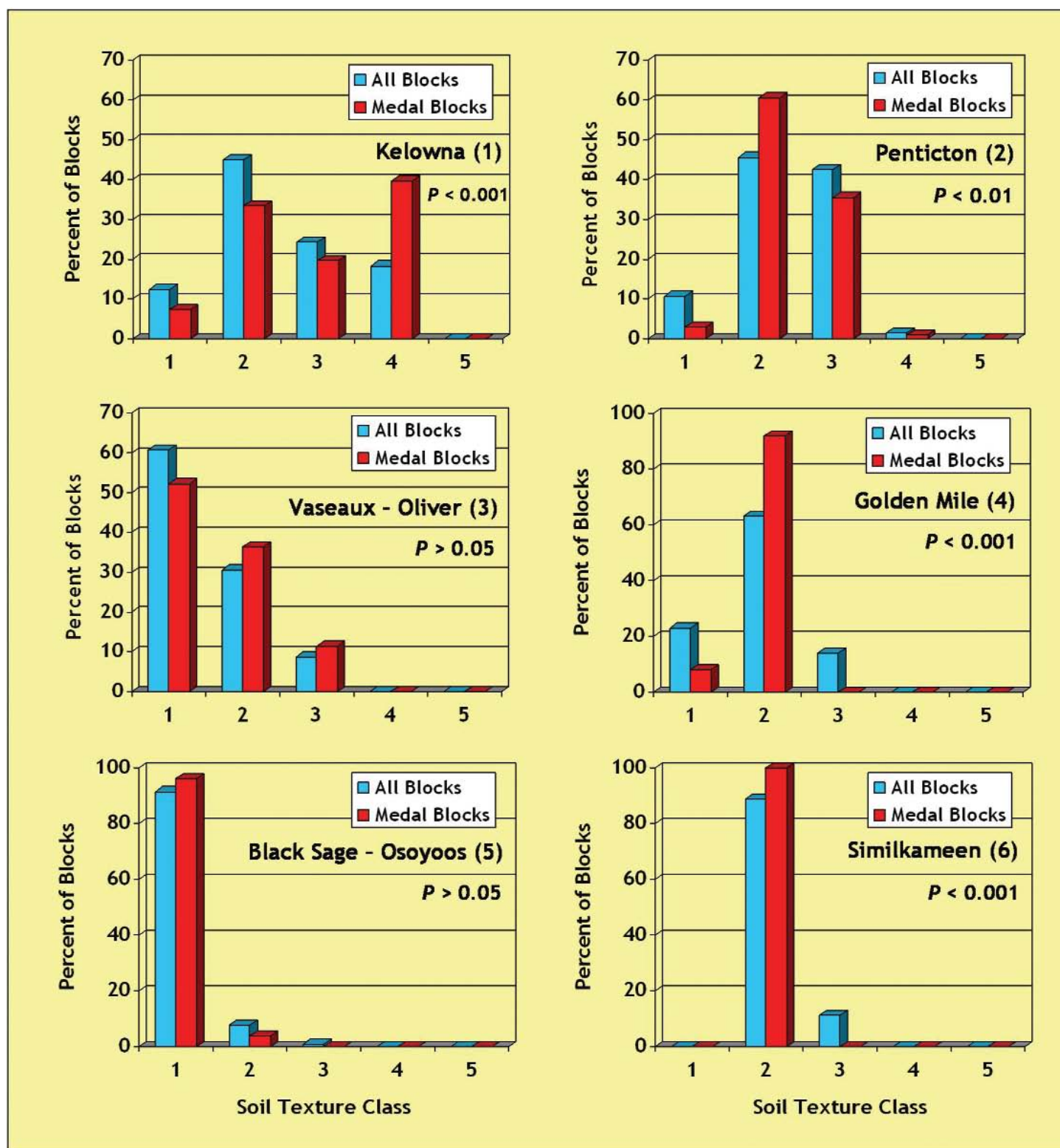


Figure 12. The division of all grape variety blocks and medal-winning grape variety blocks among soil textural classes in each viticultural region. Textural classes, ranging from coarse (1) to fine (5) texture, are: 1 = sand and loamy sand; 2 = sandy loam; 3 = loam, silt loam and silt; 4 = sandy clay loam, clay loam and silty clay loam; 5 = clay, heavy clay, silty clay and sandy clay. P values are for the significance of chi-square goodness-of-fit tests comparing the division of all and medal-winning blocks among soil textural classes.

Similkameen (6), medals also favour grapes produced on sandy loams. This suggests that loamy soils, which are neither extremely coarse nor fine, are especially suitable for producing quality wine grapes, perhaps because they are adequately drained yet hold sufficient water and nutrients to meet the requirements of vines for optimum performance.

Further study is needed to elucidate the mechanisms by which soil textural properties, as well as the mineralogical and chemical composition of soils, affect wine quality. As noted by Wilson (2001) and others, such affects may constitute an important aspect of terroir. The question of whether wine quality characteristics, such as aroma and flavour, are correlated with specific chemical or physical properties of the soils in the Okanagan and Similkameen valleys is being explored in our current work.

ACKNOWLEDGEMENTS

Viticulture GIS research at the Pacific Agri-Food Research Centre is funded by the Matching Investment Initiative of Agriculture and Agri-Food Canada, the British Columbia Wine Institute, and BC/Canada Crop Insurance. Substantial collaborative support has also been provided by the cooperating wineries and vineyards in the Okanagan and Similkameen valleys. We are particularly grateful to Vincor International for their excellent collaboration on the mesoclimate research, and to Inkameep Vineyard and Vincor International for permission to include maps of their vineyards in the publication.

We gratefully acknowledge the thoughtful comments and valuable suggestions of the critical reviewers of the manuscript, A.P Hamblin and R.W. Macqueen, as well as helpful comments from J.D. Greenough.

REFERENCES

- Association of B.C. Grape Growers, 1984, Atlas of Suitable Grape Growing Locations in the Okanagan and Similkameen Valleys of British Columbia: Agriculture Canada, Research Station, Summerland, BC, 141 p.
- Bowen, P., Estergaard, B., Bogdanoff, C., Marsh, S., Beckwith, R. and Tiebel, D., 2004 (abs.) Use of a geographic information system to study mesoclimate variation in Okanagan Valley vineyards: American Journal of Enology and Viticulture, v. 55, p. 301A.
- Bramley, R.G.V. and Williams, S.K., 2001, A protocol for winegrape yield maps, in Blackmore, S. and Greisner, G., eds., ECPA 2001 - 3rd European Conference on Precision Agriculture, agro Montpellier, Ecole Nationale Supérieure Agronomique de Montpellier, France, v. 2, p.773-778.
- British Columbia Wine Institute, 2004, British Columbia Wine Institute Annual Report 2003-2004: BCWI, Kelowna, Canada, 26 pp.
- Failla, O., Mariani, L., Brancadoro, L., Minelli, R., Scienza, A., Murada, G. and Mancini, S., 2004, Spatial distribution of solar radiation and its effects on vine phenology and grape ripening in an alpine environment: American Journal of Enology and Viticulture, v. 55, p. 128-138.
- Fulton, R.J., 2003, Geology of Okanagan Valley Wine Region of British Columbia (abs.): Geological Society of America Annual Meeting, Seattle, Washington, Program and Abstracts.
- Giomo, A., Borsetta, P. and Zironi, R., 1996, Grape quality: Research on the relationships between grape composition and climatic variables: Acta Hort. v. 427, p. 277-285.
- Haynes, S. J., 1999, Geology and Wine 1. Concept of terroir and the role of geology: Geoscience Canada, v. 26, p. 190-194.
- Lamb, D.W., Bramley, R.G.V. and Hall, A., 2004, Precision viticulture - an Australian perspective: Acta Hort. v. 640, p. 15-25.
- Morlat, R., 2001, Terroirs viticoles: Étude et valorization: Oenoplurimédia Sarl, Chaintré, France, 118 p.
- Nasmith, H., 1962, Late glacial history and surficial deposits of the Okanagan Valley, British Columbia: British Columbia Dept. of Mines and Petroleum Resources, Bulletin No. 46.
- Reynolds, A.G., Wardle, D.A., Hall, J.W., and Dever, M., 1995, Fruit maturation of four *Vitis vinifera* cultivars in response to vineyard location and basal leaf removal: American Journal of Enology and Viticulture, v. 46, p. 542-558.
- Reynolds, A.G., Wardle, D.A. and Dever, M., 1996, Vine performance, fruit composition, and wine sensory attributes of Gewurztraminer in response to vineyard location and canopy manipulation: American Journal of Enology and Viticulture, v. 47, p. 77-92.
- Roed, M.A., Greenough, J.D. (eds.), 2004, Okanagan Geology British Columbia: Kelowna Geology Committee, Kelowna, 220 pp.
- Soil Classification Working Group, 1998, The Canadian System of Soil Classification: Agric. and Agri-Food Can. Publ. 1646 (revised), Ottawa, 187 pp.
- Templeman-Kluit, D. and Parkinson, D., 1986, Extension across the Eocene Okanogan crustal shear in southern British Columbia: Geology, v. 14, p. 318-321.
- Tesic, D., Woolley, D.J., Hewett, E.W., and Martin, D.J., 2002a, Environmental effects on cv Cabernet Sauvignon (*Vitis vinifera* L.) Grown in Hawke's Bay, New Zealand. 1. Phenology and characterization of viticultural environments. Australian Journal of Grape and Wine Research, v. 8, p. 15-26.
- Tesic, D., Woolley, D.J., Hewett, E.W., and Martin, D.J., 2002b, Environmental effects on cv Cabernet Sauvignon (*Vitis vinifera* L.) Grown in Hawke's Bay, New Zealand. 2. Development of a site index: Australian Journal of Grape and Wine Research, v. 8, p. 27-35.
- Tesic, D., 2004, Vineyard location analysis for site selection and evaluation: Acta Hort. v. 640, p. 27-35.
- Usher, K., Girard, B., Bowen, P. and Eggers, N., 2004, Effects of site conditions on Pinot noir composition in the Okanagan and Similkameen valleys: British Columbia Wine Institute Research and Development Newsletter, v. 1, p. 10.
- Wilson, J.E., 2001, Geology and Wine 4. The Origin and Odyssey of *Terroir*: Geoscience Canada, v. 28, p. 139-141.
- Wittneben, U., 1986, Soils of the Okanagan and Similkameen valleys. MOE Technical Report 18. Report No.52, British Columbia Soil Survey. B.C. Ministry of the Environment, Victoria, B.C.
- Wolf, T.K. and Boyer, J.D., 2003, Vineyard Site Selection: Virginia Cooperative Extension Publication 463-020.