NATURAL RESOURCES

GEOLOGIC GUIDE TO THE YAKIMA VALLEY WINE-GROWING REGION, BENTON AND YAKIMA COUNTIES, WASHINGTON

by Alan J. Busacca,
David K. Norman,
and Wade Wolfe

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES
Field Trip Guide 2
June 2008

Produced for the
National Association of
Geoscience Teachers Field Trip,
Yakima, Washington,
June 20, 2008

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

GEOLOGIC GUIDE TO THE YAKIMA VALLEY WINE-GROWING REGION, BENTON AND YAKIMA COUNTIES, WASHINGTON

by Alan J. Busacca,
David K. Norman,
and Wade Wolfe

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES
Field Trip Guide 2
June 2008

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

WASHINGTON DEPARTMENT OF NATURAL RESOURCES
Doug Sutherland—*Commissioner of Public Lands*

DIVISION OF GEOLOGY AND EARTH RESOURCES
Ron Teissere—*State Geologist*
David K. Norman—*Assistant State Geologist*
John P. Bromley—*Assistant State Geologist*

Washington Department of Natural Resources
Division of Geology and Earth Resources

Mailing Address:
PO Box 47007
Olympia, WA 98504-7007

Street Address:
Natural Resources Bldg, Rm 148
1111 Washington St SE
Olympia, WA 98501

Phone: 360-902-1450
Fax: 360-902-1785
E-mail: geology@dnr.wa.gov
Website: http://www.dnr.wa.gov/AboutDNR/Divisions/GER/Pages/home.aspx

This and other DGER publications are available online at:
http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/pubs.aspx

Front Cover: View from the west edge of Red Mountain looking down the Yakima River and across Rattlesnake Ridge. Vineyard is the Fred Artz Vineyard next to Tapteil Winery and Vineyard.

Printed on recycled paper
Published in the United States of America

Geologic Guide to the Yakima Valley Wine-Growing Region, Benton and Yakima Counties, Washington

Alan J. Busacca[1], David K. Norman[2], and Wade Wolfe[3]

[1] Owner, Vinitas Vineyard Consultants, LLC, and Emeritus Professor, Department of Crops and Soils and Department of Geology, Washington State University
alan@vinitas.net

[2] Deputy State Geologist
Washington Division of Geology and Earth Resources
PO Box 47007; Olympia, WA 98504-7007
dave.norman@dnr.wa.gov

[3] Thurston-Wolfe Winery
588 Cabernet Court
Prosser, WA 99352
whwolfe@bentonrea.com

INTRODUCTION

This field trip will examine the geology of the Yakima Valley and the terroirs (pronounced *tehr-wahrs'*) of vineyards in the wine-growing areas of the valley. Terroir involves the complex interplay of climate, soils, geology, and other biophysical factors that influence the character and quality of wine grapes in a vineyard and of the resulting wines (Busacca and Meinert, 2003). Terroir can also be considered to include good viticultural practices in tune with the special characteristics of the vineyard and expert winemaking.

This trip will begin at Yakima Valley Community College, travel east-southeast along Interstate Highway 82 (I-82) through the Yakima Valley American Viticultural Area (AVA) and the Rattlesnake Hills AVA to the Red Mountain AVA near Benton City and back to Yakima via the same route. The stops along the way are shown on Figure 1.

Washington State is second only to California in wine production in the United States, and some of its vineyards and wines are top ranked with any in the world: Robert Parker recently awarded two Washington wines a perfect 100 score.

Terroir factors, including geology, are responsible for the success of the Washington wine industry, along with wonderful winemaking. Most Washington vineyards are east of the Cascade Range on soils formed from Quaternary sediments that overlie Miocene Columbia River Basalt Group flood basalts (Fig. 2). Eastern Washington has an optimal climate for wine-grape production—approximately 6 to 18 in. (15–45 cm) of rainfall annually with a pronounced winter maximum and warm, dry summers (Busacca and Meinert, 2003).

Currently there are more than 400 wineries in Washington and more than 300 wine-grape growers. Total wine-grape production in 2002 was 109,750 tons from 24,800 acres of bearing vineyards (WASS, 2002) and the 2007 harvest was estimated at 131,000 tons. Wine grape production will continue to increase, since there are an additional 6000 acres of wine grapes planted that were not yet bearing fruit in 2002. Most grapevines start producing commercial yields in their third year.

Of the wine produced in Washington in 2002, 43 percent was white and 57 percent was red, down from a majority (62 percent) of white wine in 1998. For example, the production of Semillon and Chenin Blanc in this four-year period decreased 35 percent, whereas the production of Cabernet Sauvignon, Merlot, and Syrah increased 200 percent. This trend toward a predominance of red wine production in Washington will likely continue because of the increased planting of red-grape varieties and the higher prices realized from red grapes in general (Busacca and Meinert, 2003).

Merriam-Webster's dictionary defines 'appellation' as "a geographical name (as of a region, village, or vineyard) under which a winegrower is authorized to identify and market wine". The current Washington appellations (American Viticultural Areas or AVAs) are Columbia Valley, Puget Sound, Red Mountain, Rattlesnake Hills, Walla Walla Valley, Horse Heaven Hills, Wahluke Slope, Columbia Gorge, and Yakima Valley (Fig. 2). As with most other wine-growing regions, some Washington AVAs are nested, such that the Columbia Valley appellation, which produces more than 90 percent of the state's wine grapes, includes the Yakima Valley, Rattlesnake Hills, Wahluke Slope, Horse Heaven Hills, Walla Walla Valley, and Red Mountain appellations.

The area available in Washington for future planting is very large. In the 10.7-million-acre Columbia Valley appellation,

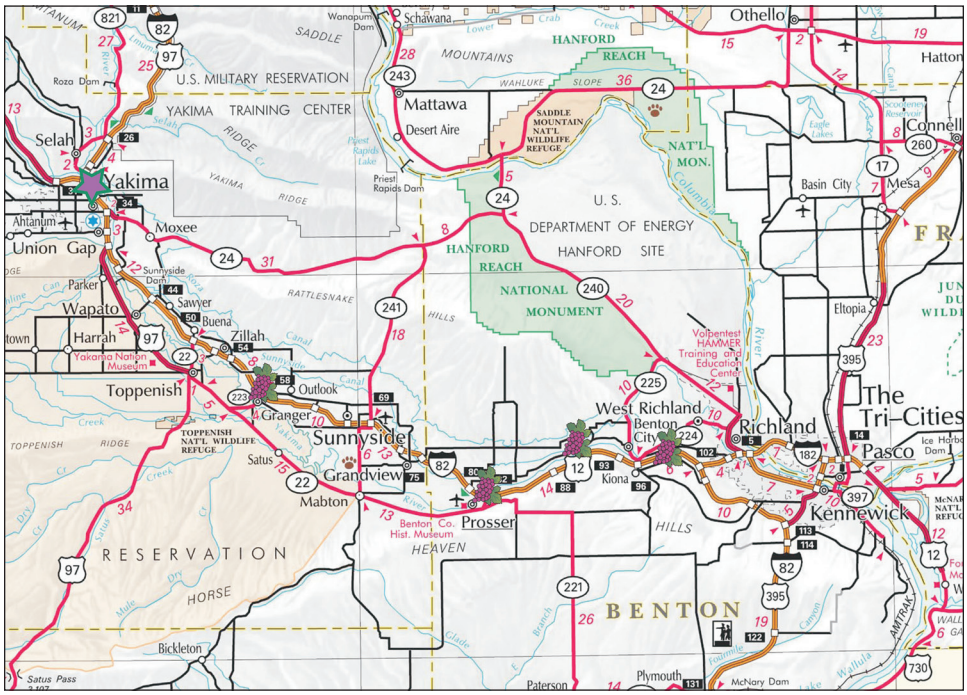

Figure 1. Route map. Star indicates field trip start; grapes indicate field trip stops. (Modified from WSDOT, 2008.)

only about 30,000 acres are planted with wine grapes. Even the smallest appellation, Red Mountain, has room for expansion, with only about 700 acres out of the 4040 acres of the AVA planted with vines. In most cases, the availability of water for irrigation is a greater limitation than the suitability of land for growing high-quality grapes (Busacca and Meinert, 2003).

The Yakima Valley AVA, which, along with its nested siblings the Rattlesnake Hills and Red Mountain AVAs, was established in 1983 and is Washington's first appellation. The Yakima Valley has as much as a 190-day growing season, with annual precipitation of approximately 8 in. (20 cm). Presently there are more than 50 wineries in the Yakima Valley. More than one third of Washington's vineyards are in the Yakima Valley—about 11,000 acres.

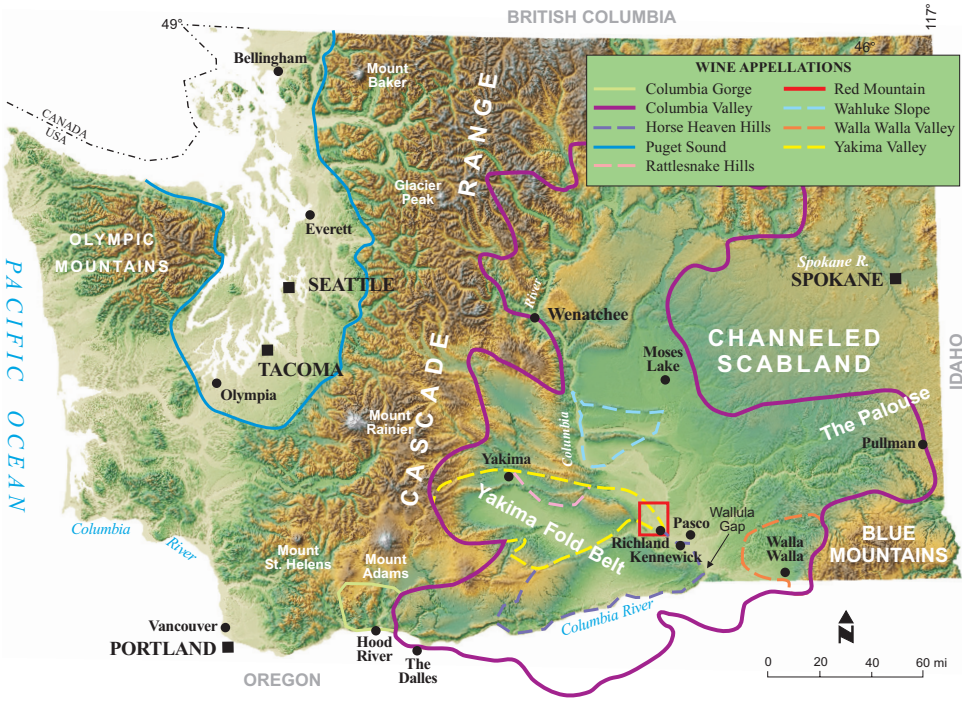

Figure 2. Location of selected Washington appellations (AVAs).

GEOLOGY

Most Washington vineyards are on the Columbia Plateau, which is bordered on the north and east by the Rocky Mountains, on the south by the Blue Mountains, and on the west by the Cascade Range (Fig. 3). The area is underlain by the Columbia River Basalt Group (CRBG), which covers more than 77,200 mi^2 (200,000 km^2) and has an estimated volume of more than 90,300 mi^3 (234,000 km^3) (Reidel and others, 2003). The CRBG is divided into five formations—the Saddle Mountains, Wanapum, Grande Ronde, Imnaha, and Picture Gorge Basalts. It was erupted mostly between 17 and 5.5 Ma (early Miocene) from north–south fissures roughly paralleling the present-day Washington–Idaho border and consists of a thick sequence of about 300 continental tholeiitic flood-basalt flows (Reidel and others, 2003). Most (more than 96 volume percent) of the lava flooded out in the first 2.5 million years (Reidel and others, 2003). The CRBG has individual flows each with estimated eruptive volumes of at least 700 mi^3 (3000 km^3), making them the largest documented individual lava flows on Earth (Baksi, 1989; Landon and Long, 1989; Tolan and others, 1989).

Based on geophysical evidence, the basalts are known to reach a maximum thickness of 16,000 ft (5000 m) in the Pasco Basin. Twenty-one of these flows poured through the Columbia River Gorge, forming layers of rock up to 2000 ft (600 m) thick. This dwarfs the erupted volumes of typical Cascade volcanoes; even the explosive eruption of Mount St. Helens in 1980 yielded only about 0.2 mi^3 (1 km^3) of volcanic material (Pringle, 2002). Concurrent with the CRBG eruptions was the folding and faulting of the basalt in the western part of the Columbia Basin. The east–west-trending anticlinal ridges and synclinal valley is known as the Yakima Fold Belt (Reidel and others, 2003). The Yakima River valley is bounded by the Horse Heaven Hills anticline to the south and Rattlesnake Hills anticline to the north.

The Quaternary history of eastern Washington is dominated by the cataclysmic Missoula (or Spokane) floods (Fig. 3). The Cordilleran ice sheet advanced from Canada several times during the Pleistocene and covered parts of Washington, Idaho, and Montana. The ice formed dams in river valleys that produced glacier-impounded lakes on several drainages in northern Washington, Idaho, and Montana. The largest of these blockages, on the Clark Fork River near the Idaho–Montana border, created glacial Lake Missoula (Pardee, 1910) (Fig. 3). The lake covered 3000 mi^2 (7800 km^2) of western Montana and held 600 cubic mi^3 (2500 km^3) of water (Carson and Pogue, 1996).

The ice dams failed repeatedly, releasing gigantic glacial floods that swept across northern Idaho, through the Spokane Valley, southwestward across eastern Washington, and down the Columbia River Gorge en route to the Pacific Ocean (Fig. 3) (Carson and Pogue, 1996). The Missoula floods are the largest known flows of water on Earth in the last two million years; the flow of water was ten times the combined flow of all the rivers of the world.

The flood crest at Wallula Gap on the Columbia River at the Washington–Oregon border was about 1200 ft (365 m), as evidenced by glacial erratics that were left stranded on the slopes of the Horse Heaven Hills and other anticlinal ridges. This constriction caused back-flooding of local river valleys and basins upstream of Wallula Gap, including, most prominently for this field trip, the Yakima Valley, which resulted in deposition of relatively fine-grained slackwater sediments characterized by rhythmically graded bedding. These graded rhythmites, locally called Touchet (pronounced *Too'-shee*) beds, are indicative of multiple floods during the last glacial maximum and may record more than 40 major glacial floods (Flint, 1938; Waitt, 1980, 1985).

Floodwaters were similarly constricted at places along the Columbia Gorge, such as near Arlington, Oregon, causing back-flooding of the Umatilla Basin. The water that poured down the Columbia River Gorge stripped away soil, surficial sediments, and talus up to 1000 ft (300 m) elevation as far as The Dalles, Oregon (Fig. 3).

The average time interval between Missoula floods was about 30 years (Waitt and others, 1994), with the last flood occurring about 13,000 years ago. On the Columbia Plateau, the

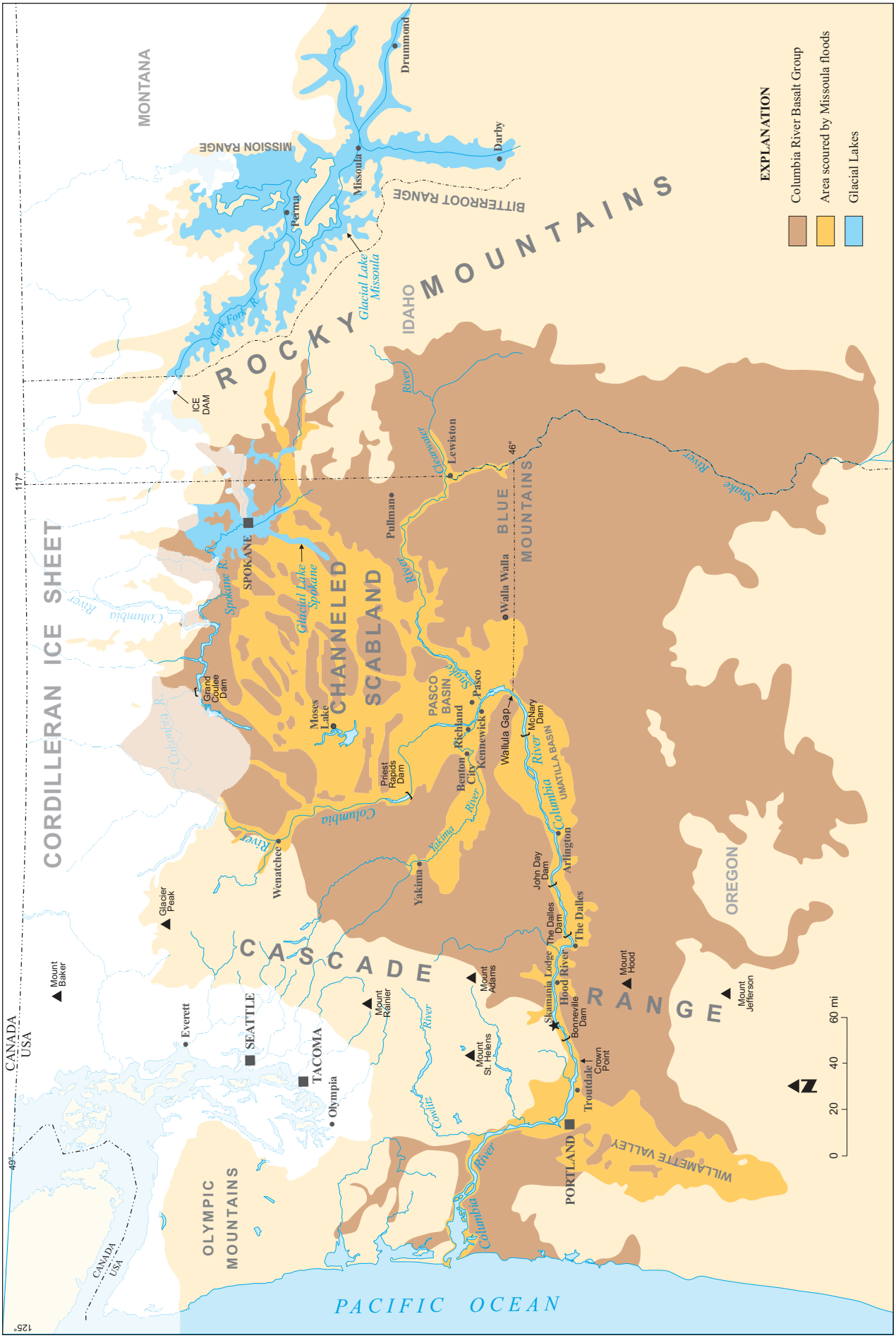

Figure 3. Columbia Plateau and surrounding area, showing the probable extent of the Cordilleran ice sheet, ice-dammed glacial lakes, Missoula floods, and Columbia River Basalt Group. The failure of the ice dam of the Clark Fork River in western Montana released a 2000-foot (600-m) wall of water that rushed across eastern Washington again and again, eroding a series of intertwining canyons called 'coulees'. This area is known as the Channeled Scabland. The various flood pathways converged in the Pasco Basin, where there was a narrow exit for the waters—Wallula Gap. The narrowness of the gap caused the floodwaters to back up and form a 1200-foot (365-m)-deep lake covering over 3500 square miles (9000 km^2). Several other temporary lakes were created by similar events near The Dalles and Portland, Oregon. (Modified from Waitt, 1985, and Weis and Newman, 1989. Extent of the Columbia River Basalt Group from Reidel and others, 1994.)

floods eroded a spectacular complex of anastomosing channels, locally called 'coulees', into southwest-dipping basalt surfaces. Huge cataracts also eroded into the basalt, forming what are now called 'dry falls' as well as 'loess islands', which are erosional remnants of an early thick loess cover on the plateau. The floods deposited immense gravel bars and ice-rafted erratic boulders at high elevations. Collectively all of these features make up the Channeled Scabland, as detailed in early work by J Harlen Bretz, who was the first person to describe the gigantic Missoula floods (Bretz, 1923, 1925, 1928a,b,c, 1932).

Figure 4. Exposure of Snipes Mountain Conglomerate along Emerald Road, east of Granger. From Last and others, 2008.

SOILS

Loess, sand dunes, and sand sheets have accumulated on the Columbia Plateau throughout much or all of the Quaternary Period (Busacca, 1989). The loess is thickest, up to 250 ft (75 m), in a 4000 mi^2 (10,000 km^2) area east of the Columbia Valley appellation called The Palouse. Most recently, during the last stages of the Pleistocene (from ca. 20 ka to 14 ka) and continuing through the Holocene, prevailing southwesterly winds have continued to erode rhythmites and other glacial sediments from older episodes of outburst flooding and redeposit them into the present sand dunes, sand sheets, and loess (McDonald and Busacca, 1988; Sweeney and others, 2002).

Soils formed from these windblown sediments are the backbone of agriculture in all of eastern Washington (Boling and others, 1998; Busacca and Meinert, 2003). In the Rattlesnake Hills area, many of the vineyards are located on thin loess deposits that have capped Miocene-age volcaniclastic sediments of the Ellensburg Formation and rhythmite deposits of the Missoula floods.

Soils in the Columbia Plateau and Columbia Gorge areas are dominantly Mollisols, Aridisols, and Entisols; soils in the forested areas are dominantly Andisols (Boling and others, 1998). Mollisols are the dark, humus-rich prairie soils; Aridisols are desert soils and often have cemented hardpans of lime (calcium carbonate) because of limited leaching; and Entisols are soils with no profile features, such as are found in shifting sand dunes. Andisols are the soils weathered from volcanic tephra and from some volcanic flow rocks. Soils used for wine grapes are commonly Aridisols in which the upper horizons are loess or sheet sands and the lower horizons are formed in stratified silty to gravelly outburst flood sediments. Some have a lime-silica cemented hardpan at the interface between materials. Some wine-grape soils are formed in loess or sand to a depth of 5 ft (1.5 m) or more. Thus there are major differences between different soils in rooting depth, texture, and resulting water-holding capacity, which are key properties for inducing controlled water stress to improve grape quality, and in nutrient status. Preagricultural vegetation in southeastern Washington ranges from sagebrush-steppe in the driest areas, to steppe (perennial grass prairie), to coniferous forest at higher and wetter elevations in the Cascade, Blue, and Rocky Mountains (Daubenmire, 1988).

CLIMATE

Climate is one of the more important components of terroir, and it is the most difficult to evaluate because it varies in both space and time. There are many climate variables, and these can be measured at three different scales. Macroclimate is on a continental to regional scale and controls the length of the growing season and other long-term trends and extremes. Mesoclimate is on a regional to vineyard scale and is affected by topography, elevation, slope, aspect, and proximity to bodies of water or other moderating influences. Microclimate ranges from the scale of a vineyard down to individual vines, grape clusters, and even smaller domains if measurement permits. Macroclimate changes on a geologic time scale (hundreds to millions of years), but both mesoclimate and microclimate can vary seasonally, daily, or even hourly. Both mesoclimate and microclimate can be affected by human activities such as urban development, wind machines, irrigation, and canopy management (Busacca and Meinert, 2003).

Although many climatic variables can be measured, four of the more important are temperature, humidity, wind, and sunlight (solar radiation). These and others are collected systematically by a variety of meteorological services, but in the state of Washington we are fortunate to have the Washington State University (WSU) AgWeatherNet that automatically and continuously collects climatic data, which are available at http://weather.wsu.edu/.

The climate of the Columbia Plateau is influenced to a great extent by prevailing westerly winds and by the Cascade Range and Rocky Mountains. The Cascade Range creates a rain shadow, and as a result, the climate of the Columbia Plateau is arid to subhumid (6–40 in. or 15–100 cm of mean annual precipitation). The amount of precipitation is closely correlated with elevation, generally increasing from west to east and southeast as elevation rises. The Rocky Mountains protect this section of Washington from the coldest of the arctic storms that sweep down through Canada (Busacca and Meinert, 2003).

During the summer, high-pressure systems prevail, leading to dry, warm conditions and low relative humidity. Average afternoon temperatures in the summer range from 68° to more than 95°F (20°– >35°C). Most of the growing season is very dry, and some vineyards experience no measurable precipitation during the summer months. Washington gets 17.4 hours per day of sunshine during the growing season, which is 2 hours more than the Napa Valley in California. The rainy season extends from October to late May or June, as frontal storms sweep across the area. In eastern Washington, much of the precipitation from mid-December to mid-February is in the form of snow (Busacca and Meinert, 2003).

As an example of climates of Washington appellations, the Red Mountain AVA (Fig. 2) is a warm vineyard site with 3409

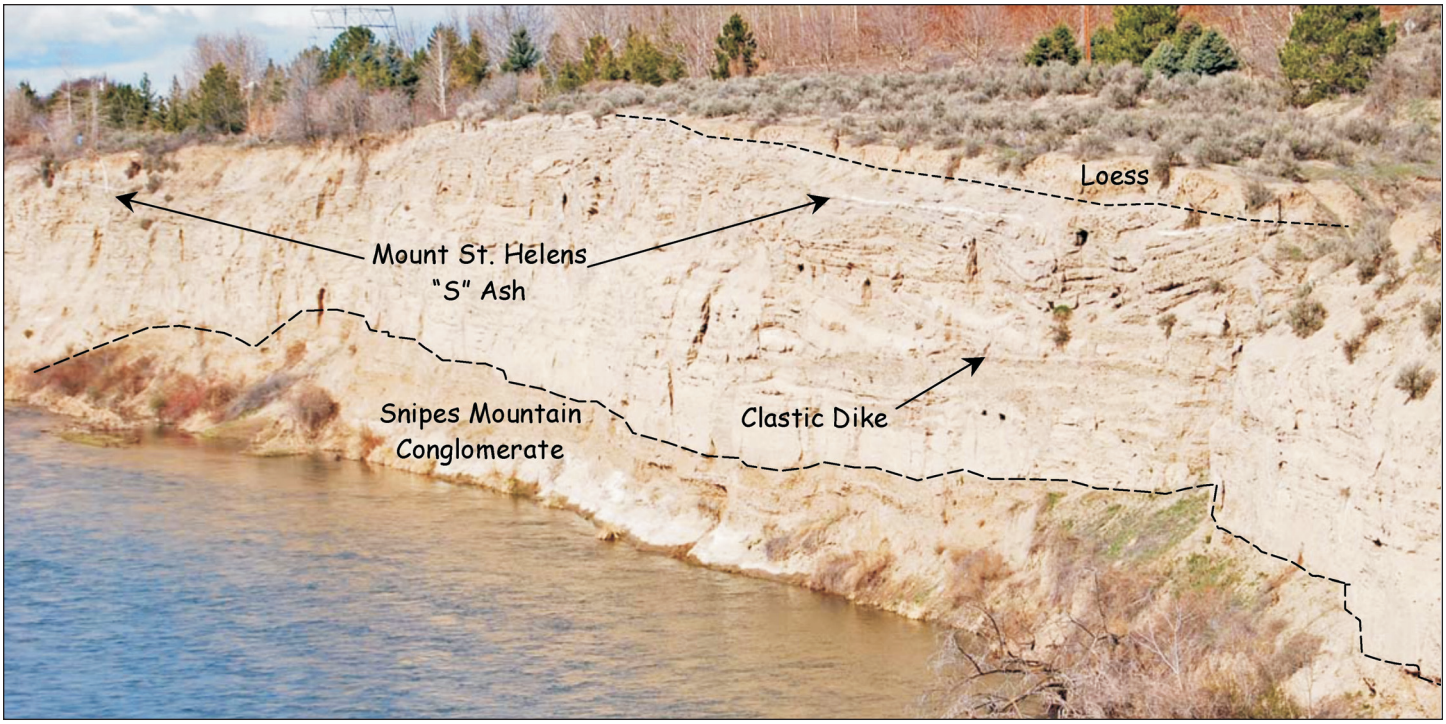

Figure 5. Exposure of rhythmically bedded slackwater flood deposits along the Yakima River east of Granger. Note Mount St. Helens set "S" ash (13,000 yr B.P. [ca. 15,400 cal yr B.P.]) near the top. Photo take March 15, 2008. From Last and others, 2008.

degree-days[1] recorded in 1998 and an average of 3016 degree-days for the years of record. For comparison, the Napa Valley in California and the Barossa Valley in Australia average 3280 and 3090 degree-days respectively; Bordeaux, France, averages 2520. Red Mountain also may be the driest viticulture area in Washington, with an average annual precipitation of 5 in. (17.8 cm) and a low in 1999 of 3.3 in. (8.4 cm). Typically, in most areas of the state, the time of year with lowest precipitation coincides with that of highest temperatures, and because of the low soil water-holding capacity and general absence of water tables, this creates a moisture deficit that requires irrigation in most vineyards. Because of the high evapotranspiration rates in such conditions, drip irrigation is the dominant method of supplying supplemental water (Busacca and Meinert, 2003). Early in the season, the growing degree-days accumulate slowly; however, as temperatures rise, they accumulate faster. Growing degree-days for grapes is commonly reported as the summation of the daily degree-days summed from April 1 to October 31.

FIELD TRIP STOPS

9:00–9:30 – Board bus, drive from Yakima to Granger.

[1] The concept of 'degree-days' (also called day-degrees, heat units, or heat summation) is based on the observation that relatively little plant growth and ripening occurs in grapes below 50°F (10°C). Standard degree-days are calculated based upon the amount of time above the 50°F (10°C) threshold. The calculation of the degree-day (DD) for a 24-hour period requires the following formula:

$$((\text{max.°F} + \text{min.°F})/2) - \text{base°F} = \text{DD}$$

where the base temperature is 50°F. For example: If on April 3 the maximum temperature is 60°F and the minimum temperature is 50°F, the DD for April 3 would be

$$((60°F+50°F)/2) - 50°F = (110°F/2) - 50°F = 55°F - 50°F = 5\ DD$$

Stop 1

9:30–10:15 – Emerald Road area, Granger (south side of Snipes Mountain), to view the rhythmite beds and Ellensburg Formation gravel beds.

Be extremely careful crossing the highway and stay at least 10 ft away from the edge of the bluff! The bluff is unstable and could collapse taking you with it. DO NOT TAKE ANY CHANCES HERE!

Snipes Mountain conglomerate of the Ellensburg Formation is exposed in road cuts along the left (north) side of the road (Fig. 4). The Snipes Mountain conglomerate is the oldest suprabasalt sedimentary unit laterally equivalent to the Levy interbed of the Ellensburg and the base of the Ringold Formation. Imbrication of the gravel clasts indicates deposition by a westward flowing ancestral Columbia River.

We will also see an excellent exposure of Ice Age flood slackwater deposits, the so-called Touchet Beds (Fig. 5). These interbedded sand and silt deposits, or rhythmites, underlie some of the better vineyard sites in the northwest. These deposits typically contain clastic dikes and volcanic ash (tephra), and are often covered by a veneer of windblown fine sand to silt (loess) from a few inches to several yards thick. The tephra seen near the top of this outcrop is the 'doublet' of the Mount St. Helens S ash, that has been radiocarbon dated at 13,000 yr B.P. (ca. 15,400 cal yr B.P.).

Each rhythmite bed generally grades upward from sand at the bottom to silt at the top, and as seen here, individual rhythmite beds are generally thicker at the bottom and thinner at the top of the rhythmite sequence. Elsewhere up to 100 rhythmites may have been deposited during the last glacial cycle (Bjornstad, 2006). Some geologists have suggested that each rhythmite bed represents a separate flood from Lake Missoula (Waitt, 1994). However, there is some evidence to suggest that there was no break in sedimentation between some rhythmites,

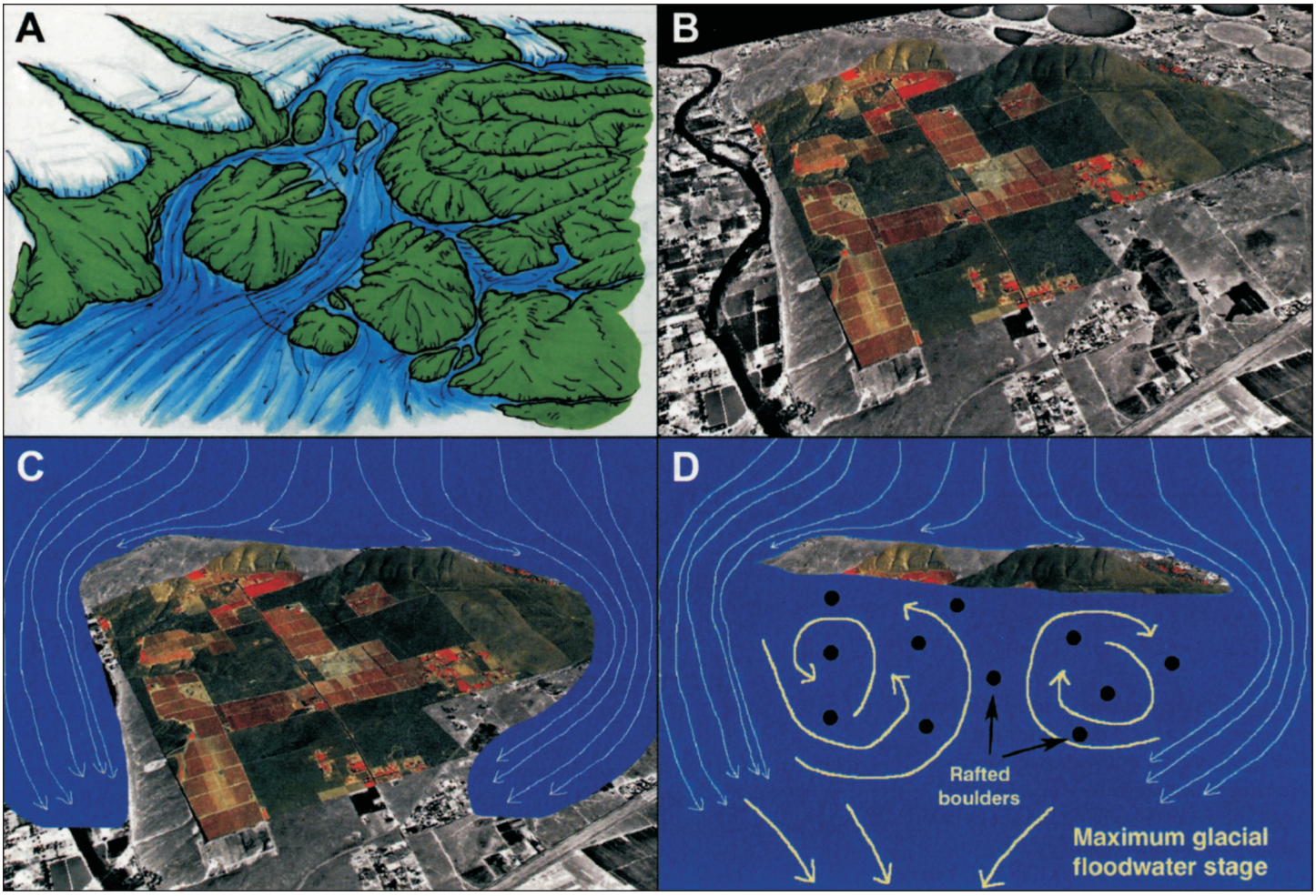

Figure 6. Cartoon illustrating the sequence of events during flooding caused by the catastrophic draining of glacial Lake Missoula. **A**, Artist's rendition of outburst flooding caused by failure of a glacial ice dam. Note torrent of water rushing around isolated hills analogous to Red Mountain. Modified from Molenaar (1988). **B**, 3-D perspective view of Red Mountain area with color infrared imagery draped over black and white ortho aerial photograph. Note that in infrared images, green vegetation, such as leafy vineyards are red, whereas arid range lands are dark green. Images courtesy of Francis Pierce, Center for Precision Agricultural Systems, WSU-IAREC. **C**, Approach of floodwaters, with flowlines around Red Mountain. Even though standing water, as evidenced by the strandline of ice-deposited erratics, did not cover Red Mountain, it is possible that the initial flood surge may have overtopped the peak, creating a temporary but rather large standing wave. **D**, Maximum flood stage as evidenced by the strandline of ice-deposited erratics, and schematic location of boulders deposited by melting of rafts of ice. See Figures 7A,B,C for example of such ice-rafted boulders.

so they may represent pulsations or surges during a single flood (Bjornstad, 1980). In any case, determining the true number of floods appears more complicated that a simple counting of the number of rhythmites (Bjornstad, 2006).

10:15–11:15 – Drive from Granger to Red Mountain

Stop 2

11:15–12:00 – View Red Mountain from near Col Solare Winery on Red Mountain and discuss terroirs (geology, soils, and climate) and the recent development of vineyards and wineries at Red Mountain.

The Red Mountain AVA was established in 2001. Red Mountain covers 4040 acres (1635 hectares), with more than 700 acres of vines planted. It receives 6 to 8 in. average annual precipitation and enjoys an average annual growing season of 180 days. Soils in this area are dominated by sediments from Ice Age floods that were deposited from swirling back-eddies behind Red Mountain. The flood sediments were covered by a veneer of post-glacial eolian sediment of varying thickness (Figs. 6 and 7) (Meinert and Busacca, 2002). The generally sandy texture of the soils provides good water drainage. Very low rainfall allows vineyard managers nearly complete control over growing-season soil moisture, applying small amounts of water by drip irrigation. (Water stress is induced to heighten the intensity of grape flavors.)

Combined with the southerly aspect, the warm temperatures and a nearly cloud-free growing season provide very warm growing conditions (more than 3000 DD per year) to fully ripen varieties such as Cabernet Sauvignon, Merlot, Cabernet Franc, Syrah, and Sangiovese (Meinert and Busacca, 2002). Red Mountain is home to fifteen wineries. Land for development into new wineries and vineyards commands higher prices than perhaps in any other area of the Pacific Northwest.

The layered stratigraphy of bedrock basalt and overlying glacial floodwater and eolian sediments forms the basis for the soils in the Red Mountain AVA. Given the heterogeneity of these sediments, it is not surprising that there are a number of different soils in the Red Mountain AVA (Fig. 8), and that these soils perform very differently under grape production. A com-

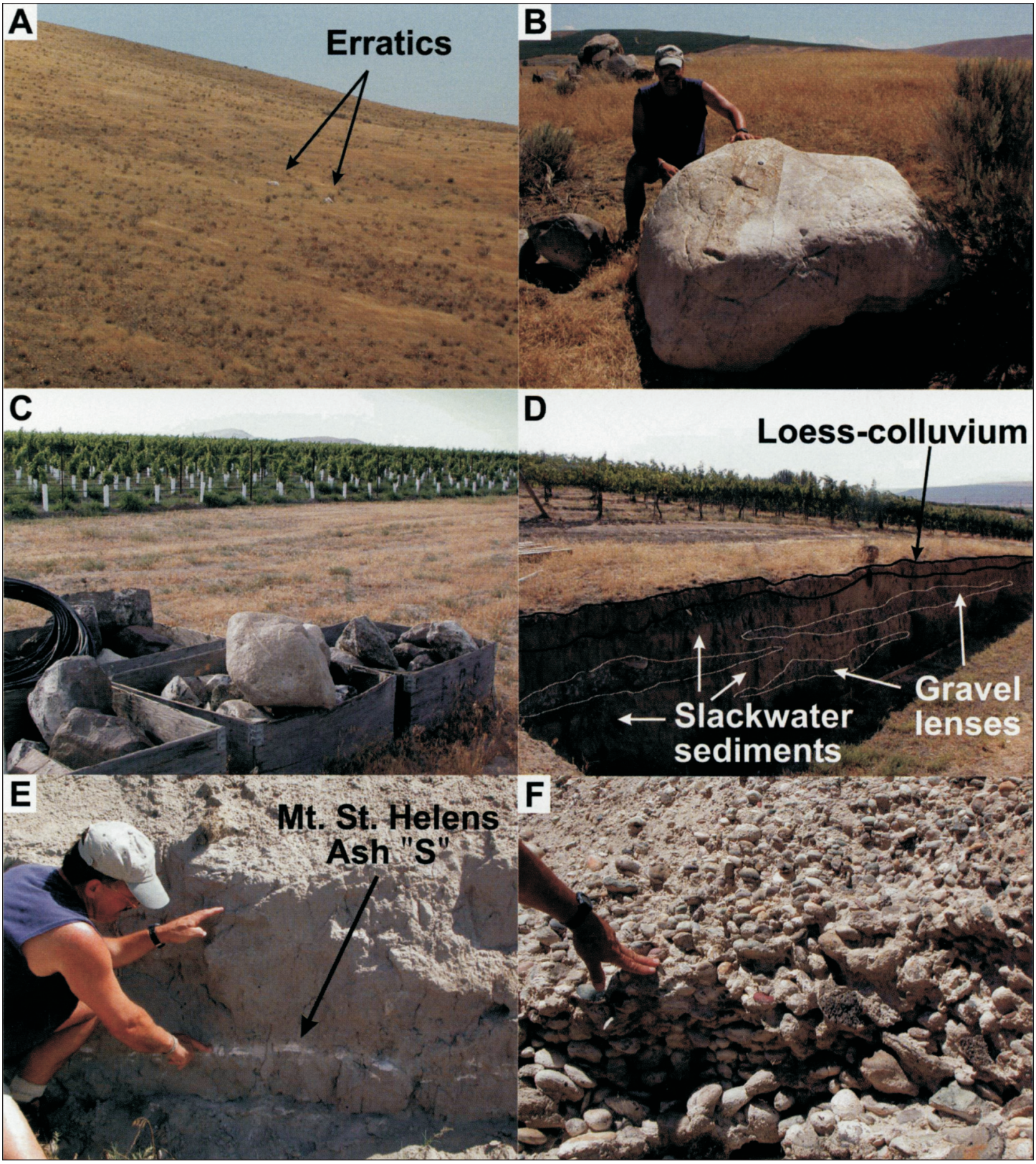

Figure 7. Photographs of vineyard features in the Red Mountain area. **A**, South side of Red Mountain about 330 ft (100 m) below the peak, showing the location of ice-rafted boulders. For scale, the sagebrush is about 3 ft (1 m) in height. **B**, Example of an ice-rafted boulder. The polished and rounded stone is gleaming white marble with layers of brown garnet skarn. **C**, Glacial erratic boulders gleaned from the Kiona vineyard are collecting in wooden boxes (grape-picking bins). **D**, cut bank in Tapteil vineyard exposing a 10 to 13 ft (3–4 m) cross section of Quaternary loess, slackwater deposits, gravel lenses, and loess-colluvium. Gravel in the lenses is similar in size to that in photo F. **E**, 1 to 2 in. (2–4 cm) white band of Mount St. Helens "S" ash in Quaternary slackwater and channel deposits exposed in a roadcut on the south side of the Red Mountain AVA. **F**, Lime-cemented gravels of the Scooteney soil association.

mon theme to the soils of the benched area of Red Mountain is that they formed in eolian materials (loess or dune) over slackwater sediments from giant glacial outburst floods (Meinert and Busacca, 2000). Yet within this landscape, no fewer than eight different soil series have been mapped, and these can have very different textures and profile morphology (Fig.9): Hezel series (XericTorriorthents), Quincy series (Xeric Torripsamments), and Finley, Scooteney, Prosser, Starbuck, Kiona, and Warden series (all Xeric Haplocambids) (Soil Survey Staff, 1999). Vineyards are planted on most of these, with development planned for the remainder. All but two of the principal soils are classified as Aridisols in soil taxonomy (formative word Arid) (Soil Survey Staff, 1999), based primarily on an aridic soil moisture regime.

The two soils that formed in dune materials (Hezel and Quincy) are Entisols (formative word Recent) because the shifting sands lack most soil profile features. In sharp contrast to the Aridisols and Entisols of the appellation, soils on the flood plain of the Yakima River about half a mile (1 km) outside the appellation and planted to vinifera are Mollisols of the Pasco series (Fig. 9; Cumulic Endoaquolls), which are wet soils with very dark, thick, humus-enriched topsoils. These soils have a permanent water table whose height in the soil profile fluctuates seasonally with stages of the Yakima River. The generally high water table results in carbonates at the surface and uncontrolled access to water during the growing season.

Large areas of the benchlands of the Red Mountain appellation are underlain by the Warden series soils, formed in about 20 in. (50 cm) of loess or mixed loess and eolian sand over stratified flood sediments (Fig. 9), whereas adjacent areas, even within the same vineyard, are underlain by the Hezel series soils which formed in a cover of about 20 in. (50 cm) of dune sand over sandy stratified flood sediments. In contrast, areas of Scooteney soils grade downward from an eolian sandy loam or loam at the surface to a fluvial unit of very cobbly sandy loam at 60 in. (150 cm). All three of these soils can be tens of yards (meters) thick above hard basalt bedrock. Thus vineyards in the Red Mountain AVA have soils that range from loess to dune sand to gravel to slackwater sediments in the lower part of the rooting zone.

Still other areas in this same landscape are underlain by Prosser and Starbuck series soils (Fig. 9), with bedrock at less than 16 to 32 in. (40–80 cm) depth. Small areas have Quincy soils that formed in dune sand more than 60 in. (150 cm) deep. Soils of the Kiona series (Fig. 9) that occupy the steep south face of Red Mountain (with slopes up to 60 percent) have formed in slope colluvium of fractured basalt mixed with loess and are cobbly loams to more than 60 in. (150 cm). It appears that no vineyards have yet been planted on areas of Kiona soils.

The majority of the soils in the Red Mountain appellation are thicker than several yards (meters). The most important vineyard soils formed as the result of two end-member eolian pro-

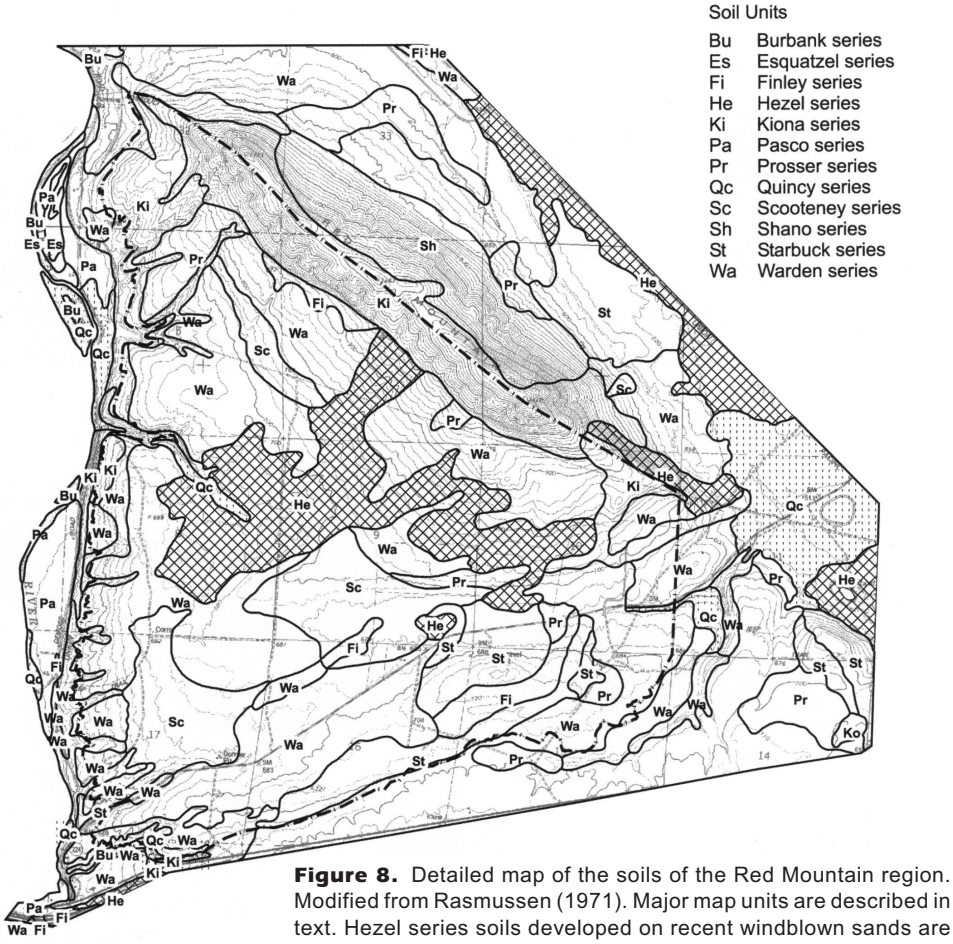

Figure 8. Detailed map of the soils of the Red Mountain region. Modified from Rasmussen (1971). Major map units are described in text. Hezel series soils developed on recent windblown sands are marked with a crosshatch pattern.

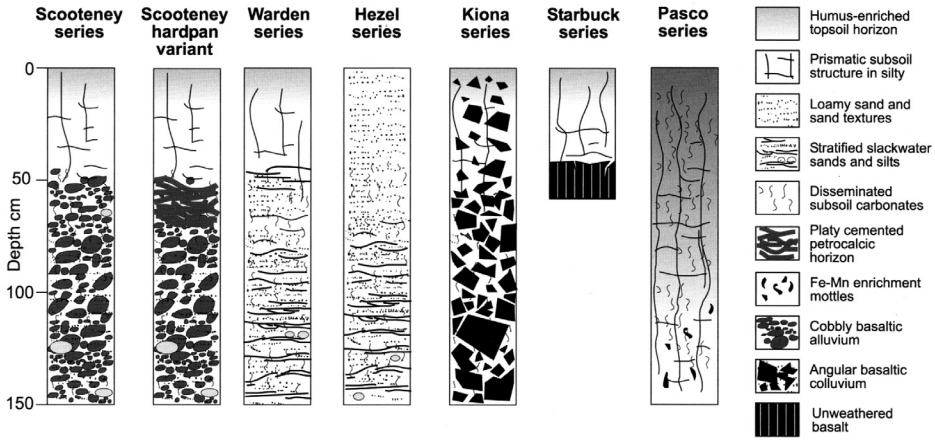

Figure 9. Representative soil profiles of the main soil series in the Red Mountain area. Shading of the topsoil horizons is proportional to the content of humified organic matter. The irregular lines in the prismatic subsoil pattern represent the pattern of soil structure that develops in these silty soil horizons.

cesses, dune saltation and loess suspension. Dominantly sandy dune materials accumulated over either flood gravels or stratified flood slackwater sediments (that is, Hezel series; Fig. 9) in some places on Red Mountain, whereas dominantly silty loess materials have accumulated over flood materials in other places (that is, Warden series; Fig. 9). In general, the soils are more sandy in the surface layer and more silty at 1 yd (1 m) depth, suggesting that loess deposition dominated early in the post-flood history of Red Mountain and that dune sands have more recently covered or influenced most of the soils.

Lunch and Wine Tasting at Tapteil Winery

Tapteil Vineyard is one of the older vineyards on Red Mountain; the first Cabernet Sauvignon vines were planted there in 1985. Tapteil Vineyard now encompasses 25 acres, and a few years ago, owners Larry and Jane Pearson opened a winery to make small quantities of wine from their estate grapes.

After lunch, travel back to the west in the direction of Prosser, with stops for geology to view the local areas of scablands, a flood-breached anticline in basalt, boulder fields, and a flood-induced landslide complex between Benton City and Prosser.

Stop 3

1:30–3:00 – Chandler Narrows area.

Ice Age floodwaters moving up the Yakima Valley through the constriction here, now known as the Chandler Narrows, created features like those in the better-known Channeled Scabland of eastern Washington. This area, known as 'The Badlands', consists of mesas, buttes, and channels eroded into the basalt bedrock. Erosion was concentrated here due to narrowing of the valley floor. West of here the valley widens, erosional features start to disappear, and depositional features again appear. A huge boulder field here was created as the floodwater eroded into a sedimentary interbed, undercutting a hard basalt flow, which then broke off along joints and fell to the bench below (Last and others, 2008).

Across the valley (to the south and a little east) lies the Chandler Butte landslide complex. This large landslide complex occurs along the steep northern flanks of east–west-trending folds of the Yakima Fold Belt. This landslide may have followed one or more Ice Age flood events by the rapid hydraulic loading and removal of loading and erosion that could have undercut the toe of the steep slope.

Stop 4

3:00–4:00 – Visit Dr. Wade Wolfe and taste wines at Thurston Wolfe Winery.

Dr. Wade Wolfe is one of the more experienced viticulturists and winemakers in Washington State. Among other accomplishments, he was the first viticulturist for Chateau Ste. Michelle Winery and was for many years general manager of Hogue Cellars. He and Rebecca Yeaman started Thurston Wolfe Winery in 1987 to make unique, finely crafted wines in small case lots (Fig. 10). Together, they have coaxed outstanding wines from a number of grape varietals not commonly used at other Washington State wineries. They have combined Wade's extensive knowledge of Washington State's vineyards with their passion for blending to create truly memorable wines.

4:00–5:00 – Back to Yakima.

Figure 10. Winter scene at the Thurston Wolfe vineyard.

REFERENCES CITED

Baksi, A. K., 1989, Reevaluation of the timing and duration of extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts, Columbia River Basalt Group. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonismthe Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 105-111.

Bjornstad, B. N., 1980, Sedimentology and depositional environment of the Touchet beds, Walla Walla River basin, Washington: Eastern Washington University Master of Science thesis, 137 p.

Bjornstad, Bruce, 2006, On the trail of the Ice Age floods—A geological field guide to the mid-Columbia Basin: Keokee Books, 307 p.

Boling, Maureen; Frazier, B. E.; Busacca, A. J., 1998, General soil map of Washington: Washington State University, 1 sheet, scale 1:760,000.

Bretz, J H., 1923, The Channeled Scablands of the Columbia Plateau: Journal of Geology, v. 31, p. 617-649, 1 plate.

Bretz, J H., 1925, The Spokane flood beyond the Channeled Scablands: Journal of Geology, v. 33, nos. 2-3, p. 97-115, 236-259.

Bretz, J H., 1928a, Alternative hypotheses for Channeled Scabland: Journal of Geology, v. 36, no. 3, p. 193-223; v. 36, no. 4, p. 312-341.

Bretz, J H., 1928b, Bars of Channeled Scabland: Geological Society of America Bulletin, v. 39, p. 643-701.

Bretz, J H., 1928c, The Channeled Scabland of eastern Washington: Geographical Review, v. 18, no. 3, p. 446-477, 1 plate.

Bretz, J H., 1932, The Grand Coulee: American Geographical Society Special Publication 15, 89 p.

Busacca, A. J., 1989, Long Quaternary record in easternWashington, U.S.A., interpreted from multiple buried paleosols in loess: Geoderma, v. 45, no. 2, p. 105-122.

Busacca, A. J.; Meinert, L. D., 2003, Wine and geology—The terroir of Washington State. *In* Swanson, T. W., editor, Western Cordillera and adjacent areas: Geological Society of America Field Guide 4, p. 69-85.

Carson, R. J.; Pogue, K. R., 1996, Flood basalts and glacier floods—Roadside geology of parts of Walla Walla, Franklin, and Columbia Counties, Washington: Washington Division of Geology and Earth Resources Information Circular 90, 47 p.

Daubenmire, R., 1988, Steppe vegetation of Washington: Washington State University Extension Bulletin 1446, 131 p.

Flint, R. F., 1938, Origin of the Cheney–Palouse scabland tract, Washington: Geological Society of America Bulletin, v. 49, no. 3, p. 461-523.

Landon, R. D.; Long, P. E., 1989, Detailed stratigraphy of the N_2 Grande Ronde Basalt, Columbia River Basalt Group, in the central Columbia Plateau. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 55-66.

Last, G. V.; Bjornstad, B. N.; Busacca, A. J., 2008, Influence of Ice Age floods on the terroirs of the Yakima Valley wine country—A geologic field trip guide from Richland to Zillah, Washington: Ice Age Floods Institute, Lake Lewis Chapter unpublished report, 17 p.

McDonald, E. V.; Busacca, A. J., 1988, Record of pre-late Wisconsin giant floods in the Channeled Scabland interpreted from loess deposits: Geology, v. 16, no. 8, p. 728-731.

McDonald, E. V.; Busacca, A. J., 1992, Late Quaternary stratigraphy of loess in the Channeled Scabland and Palouse regions of Washington state: Quaternary Research, v. 38, p. 141-156.

Meinert, L. D.; Busacca, A. J., 2002, Geology and wine 6—Terroir of the Red Mountain appellation, central Washington State, U.S.A.: Geoscience Canada, v. 29, no. 4, p. 149-168.

Molenaar, Dee, 1988, The Spokane aquifer, Washington—Its geologic origin and water-bearing and water-quality characteristics: U.S. Geological Survey Water-Supply Paper 2265, 74 p.

Pardee, J. T., 1910, The glacial Lake Missoula: Journal of Geology, v. 18, p. 376-386.

Pringle, P. T., 2002, Roadside geology of Mount St. Helens National Volcanic Monument and vicinity; rev. ed.: Washington Division of Geology and Earth Resources Information Circular 88, rev. ed., 122 p.

Rasmussen, J. J.; and others, 1971, Soil survey of Benton County area, Washington: U.S. Soil Conservation Service, 72 p., 104 p.

Reidel, S. P.; Martin, B. S.; Petcovic, H. L., 2003, The Columbia River flood basalts and the Yakima fold belt. *In* Swanson, T. W., editor, Western Cordillera and adjacent areas: Geological Society of America Field Guide 4, p. 87-105.

Reidel, S. P.; Tolan, T. L.; Beeson, M. H., 1994, Factors that influenced the eruptive and emplacement histories of flood basalt flows—A field guide to selected vents and flows of the Columbia River Basalt Group. *In* Swanson, D. A.; Haugerud, R. A., editors, Geologic field trips in the Pacific Northwest: University of Washington Department of Geological Sciences, v. 1, p. 1B 1 - 1B 18.

Sweeney, M. R.; Gaylord, D. R.; Busacca, A. J., 2002, Changes in loess-dune deposition in response to climate fluctuations on the Columbia Plateau, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 34, no. 5, p. A-77.

Tolan, T. L.; Reidel, S. P.; Beeson, M. H.; Anderson, J. L.; Fecht, K. R.; Swanson, D. A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group. *In* Reidel, S. P.; Hooper, P. R., editors, Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

Tolan, T. L.; Reidel, S. P.; Beeson, M. H.; Anderson, J. L.; Fecht, K.; Waitt, R. B., Jr., 1980, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653-679.

Waitt, R. B., Jr., 1980, About forty last-glacial Lake Missoula jökulhlaups through southern Washington: Journal of Geology, v. 88, no. 6, p. 653-679.

Waitt, R. B., Jr., 1985, Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271-1286.

Waitt, R. B.; O'Connor, J. E.; Benito, Gerardo, 1994, Scores of gigantic, successively smaller Lake Missoula floods through Channeled Scabland and Columbia valley. *In* Swanson, D. A.; Haugerud, R. A., editors, Geologic field trips in the Pacific Northwest: University of Washington Department of Geological Sciences, v. 1, p. 1K 1 - 1K 88.

Washington Agricultural Statistics Service (WASS), 2002, 2002 Washington Wine Grape Acreage Survey: Washington Agricultural Statistics Service [Olympia, Wash.], 24 p.

Washington State Department of Transportation (WSDOT), 2008, Washington, the Evergreen State—2008–2009 Washington State highway map: Washington State Department of Transportation, 1 plate.

Weis, P. L.; Newman, W. L., 1989, The channeled scablands of eastern Washington—The geologic story of the Spokane flood; 2nd ed.: Eastern Washington University Press, 24 p. [http://www.nps.gov/history/history/online_books/geology/publications/inf/72-2/index.htm] ■