Deschutes-Umatilla Plateau

Landscape of the Deschutes-Umatilla Plateau

The Deschutes-Umatilla province extends nearly 200 miles westward from the Blue Mountains to the Cascade Range and is 100 miles at its widest. The region slopes gently northward from elevations of 4,000 feet toward the Blue Mountains down to a few hundred feet above sea level near the Columbia River.

The surface of the province is interspersed with deeply incised canyons and broad uplands, all of which contribute to its characterization as a plateau. The Deschutes-Umatilla tableland lies at the southern edge of the larger Columbia River flood-basalt plateau that extends into the Blue Mountains, central Washington, and western Idaho. Few basalt provinces worldwide have been studied as thoroughly as this one.

Stream flows are steady as they make their way northward to enter the Columbia. The third largest river in North America, with a watershed covering 260,000 square miles, the Columbia has its headwaters on the west slopes of the Canadian Rockies and runs through Washington to Wallula Gateway where it makes a sharp bend toward the west. Along its westerly course, the river defines the boundary between Oregon and Washington before ultimately reaching the Pacific Ocean.

Originating in the Blue Mountains, the Umatilla River, Butter Creek, and Willow Creek are entrenched in their higher reaches, but in the lower stretches they are shallow and less dissected. At 90 miles in length, the Umatilla is considerably smaller than the Deschutes and John Day systems, which dominate the central and western portions of the province. From its beginning as small streams near Mount Bachelor, the Deschutes drains over 10,000 square miles and has a length of 252 miles. Supplemented by numerous springs, rainfall, and Cascade snowmelt, the Deschutes is joined by its principal tributaries, the Metolius and Crooked rivers near Madras. Because it originates in the drier Ochoco Mountains, Crooked River has a more moderate flow. From its source in the Blue Mountains, the John Day is Oregon's longest at 284 miles.

Irrigation has made the rolling topography ideal for raising wheat and other grasses.

Past and Present

Israel Russell, of the U.S. Geological Survey, named and described the Columbia River basalts in 1893 as the Columbia lava "in the precipitous walls of the coulees or canyons . . . and in the remarkable gates eroded by Yakima River through ridges" in the layers. Russell's report included the Eocene to Recent rocks of Washington, Oregon, Idaho, and northeastern California. In 1901 John Merriam of

Aaron Waters was a leading volcanologist of the twentieth century who pioneered studies of basalts in the Pacific Northwest. He was best-known for his knowledge of the Columbia River basalts, and his research, along with that of his many students, ultimately led to the subdivision and classification of the group. Waters came by his interest as a young man growing up in Waterville, Washington, where his family's ranch bordered the Columbia River plateau. His PhD in 1930 from Yale University focused on the geology of the Chelan Quadrangle, but his interests covered not only regional volcanology but geomorphology and tectonics as well. Waters' career led to teaching at several universities. He died in 1991 at age 86 in Tacoma. (Photo courtesy Condon Collection)

Recognized for his expertise on the geology of the Columbia River Basalts, Marvin Beeson's interests also included the geology of the northern Willamette Valley and especially the Portland area. Born in 1937 at LaGrande, Oregon, he completed a PhD from the University of California, San Diego, in geology and geochemistry. Accepting a position at Portland State University, Beeson remained at that institution until retirement. His recognition and demonstration that the Miocene lavas of coastal Oregon originated from vents on the Columbia plateau will be one of his most lasting contributions. He consulted in the private sector until his unexpected death in 2004. (Photo courtesy T. Tolan)

Terry Tolan grew up in Portland, Oregon, and attended Portland State University where his research emphasized the Columbia River Basalt Group and its relationship to the Troutdale Formation. After graduation, Tolan joined the Hanford nuclear waste facility, where he focused on the regional geology. Authoring numerous papers on the geology, structure, and hydrogeology of the Columbia Plateau, the northern Willamette Valley, and the Pacific Northwest, Tolan is in private practice in Kennewick, Washington. (Photo courtesy T. Tolan)

While spending 1968 to 1969 at Washington State University on sabbatical from the University of Wales, Peter Hooper developed an interest in the Columbia River basalts. He returned two years later to serve as chairman of the Department of Geology until retirement to England in 2009. As theories about the origins and composition of the Columbia plateau basalts evolved, Hooper argued in favor of their complexity. Hooper's Raiders, who combined their efforts on the basalts, are (from left to right) Steve Reidel, Peter Hooper, Victor Camp, and Marty Ross. Presently at Washington State University, Reidel has worked with geology of the Northwest for over 30 years. Vic Camp, originally from West Virginia, took his degree from Hooper, then worked in Africa and the Middle East, before accepting an appointment at San Diego State University in 1993. At Northeastern University in Boston, Marty Ross began as a graduate student with Hooper on the CRBGs before completing his PhD from the University of Idaho in 1978. (Photo courtesy P. Hooper)

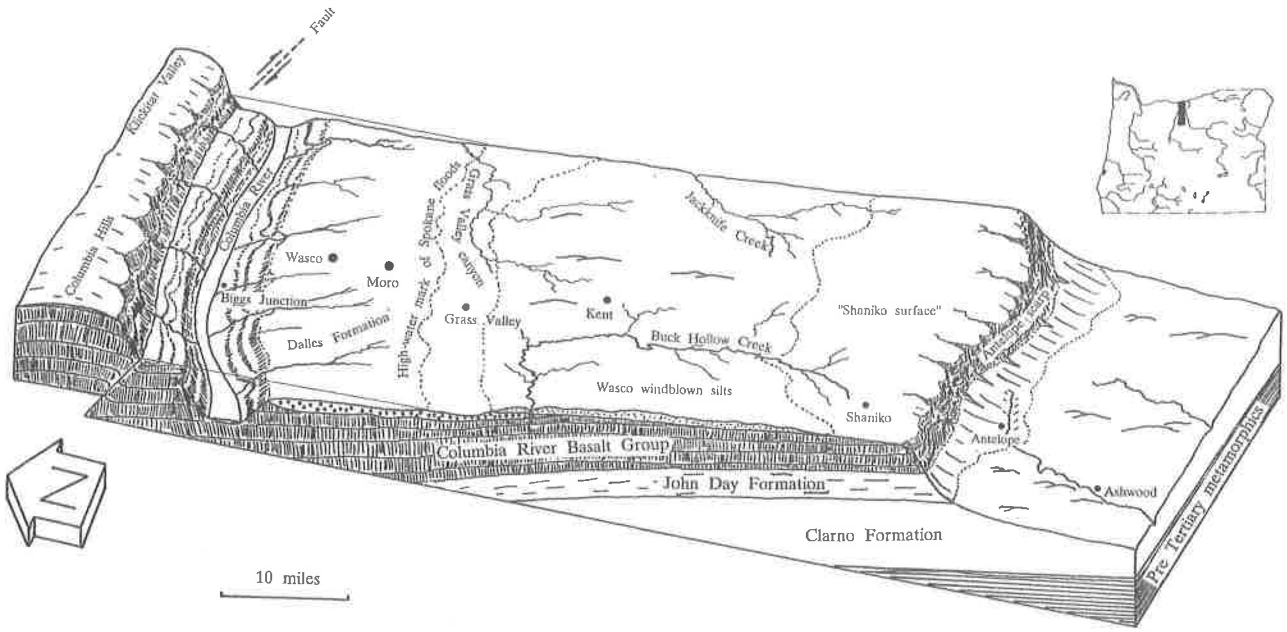
the University of California, Berkeley, limited the flows to the Miocene layer most prominent along the Columbia River and in the John Day basin. During the 1930s, U.S.G.S. Director George Smith introduced the term *Yakima Basalt* for all of the flows. This nomenclature was in use until Aaron Waters' stratigraphic revision.

Overview

The physiographic boundaries for many regions are difficult to define because much of the underlying geology and structure is obscured or has been modified by later events. This is especially true for the Deschutes-Umatilla province, where the margins are covered by thick layers of middle to late Miocene lavas. Immense outpourings Columbia River flood basalts from numerous north-trending dikes created a tableland of stacked sheet flows in Oregon, Washington, and Idaho. Other volcanic plateaus, such as the Deccan in India or the Siberian Traps in Russia, are larger in volume and areal extent, but the superb exposures, accessibility, and distinct chemical and mineral composition of the Columbia River group make them ideal for the study of flood basalt provinces. Characterized by a rapid eruptive rate rather than by fluidity, the sheet-like lavas are thought to have been triggered by interaction between a hot spot and the earth's crust.

Throughout the late Miocene and into the Pliocene, basins atop the basalt surface near Madras, The Dalles, Arlington, and McKay accumulated volcanic and fluvial sediments that preserve an assortment of fossil plant and animal remains. With the gradual subsidence of the High Cascades into a deep regional graben, the sediment source was blocked, and deposition ceased.

Pliocene and Pleistocene lavas from Newberry Crater and vents near Bend obstructed the Crooked, Metolius, and Deschutes channels before uplift brought renewed downcutting that allowed the rivers to establish the deep gorges seen today. The late Pleistocene brought stupendous floods from glacial Lake Missoula in Montana when ice dams on the Clark Fork River broke, releasing calamitous deluges that reached to the Pacific Ocean. In the course of these floods, water and sediment backed up from the constriction at The Dalles, across the Umatilla plateau, and into the Deschutes canyon as far as Maupin.



This diagram across the Columbia River just east of The Dalles shows over 50 million years of geologic history. (After Baldwin, 1981)

Overall, the province is well-watered by rivers and tributaries, however, the growth of urbanization along with demands for irrigation have brought a significance decline surface flows and a consequent drop in the groundwater table.

Geology

Paleozoic-Mesozoic

The pre-Tertiary rocks of the Deschutes-Umatilla plateau are largely covered by Miocene Columbia River basalts, although Paleozoic, Mesozoic, and early Cenozoic exposures along the margins of the province hint at older accreted terranes below. In the 1980s, four exploratory petroleum wells were drilled in the vicinity of Yakima, Washington, by Shell Oil Company. Targeted were Cretaceous and early Tertiary strata lying within anticlines, which were judged to have sufficient organic content and porosity to generate natural gas. Although the potential for hydrocarbons proved to be negligible, Eocene to early Miocene sediments were encountered.

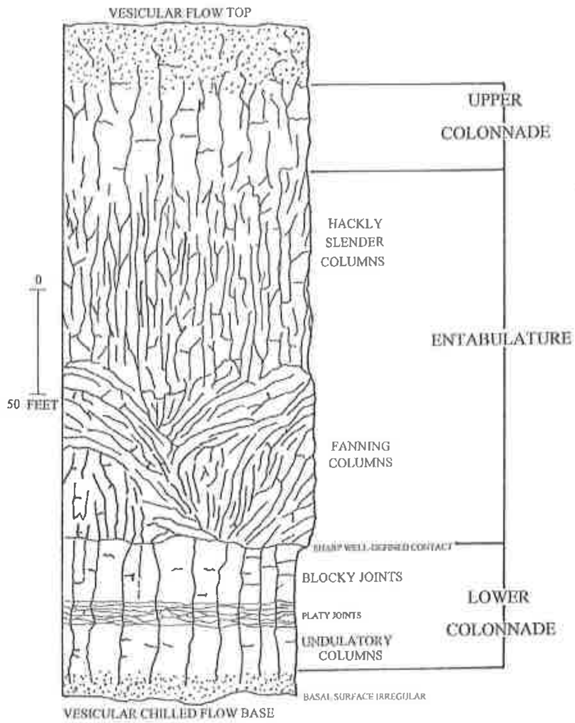
Cenozoic

Extraordinary Flood Basalts

The dark gray, fine-grained, tholeiitic (olivine deficient) Columbia River basalts that spread over adjoining sections of Oregon, Washington, and Idaho are the geologic centerpiece of this province. During the middle to late Miocene 17 to 6 million years ago, an extraordinary succession of lava flows created a broad, nearly level plateau that covered 77,000 square miles, an area only slightly smaller than the state of Washington. Over 300 separate basalt sheets were emplaced during an 11 million year period for a total volume of 56,000 cubic miles. The individual flows vary, but locally the combined layers reach 8,000 to 9,000 feet thick.

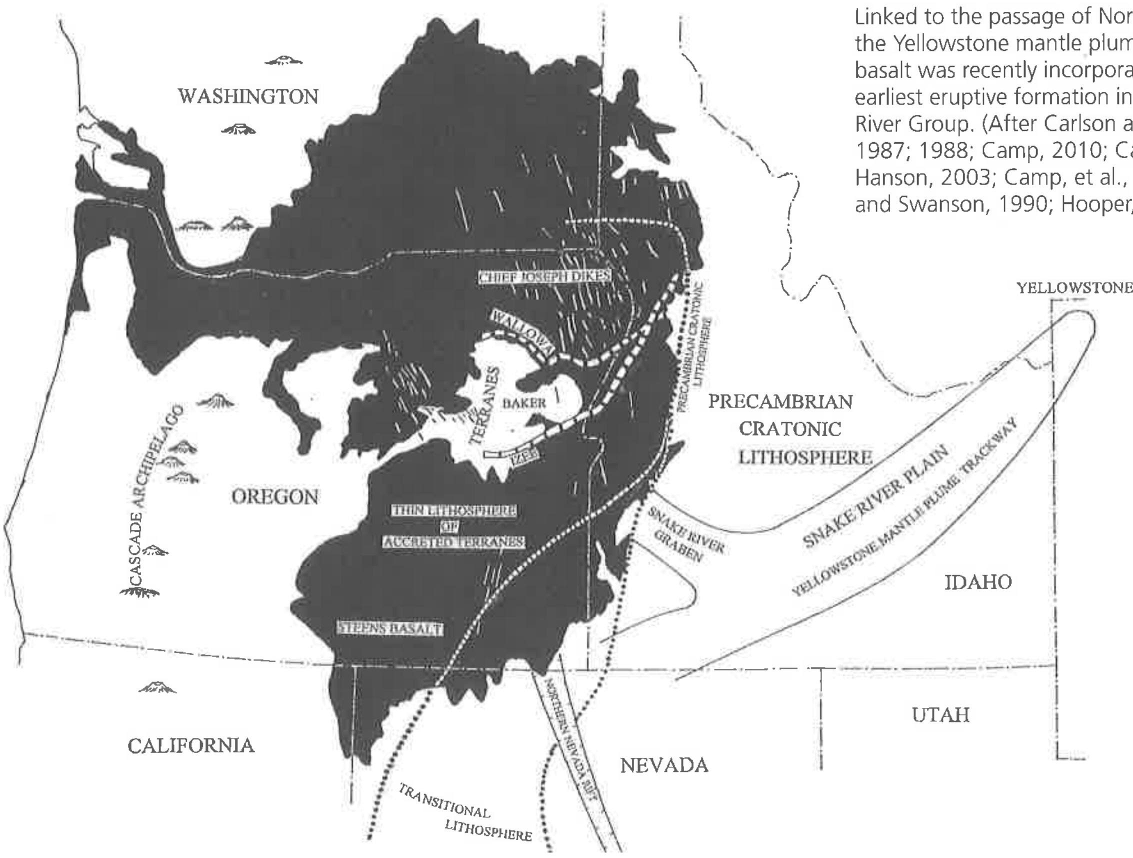
Instead of forming a central cone, the basalts moved as horizontal sheets from north-northwest-trending fractures or dike swarms. The sheet-like nature is characteristic of flood basalts and is due to the exceptionally rapid eruptive rate and not to the low viscosity of the lavas. Because of the rapidity, large volumes of material expanded over vast distances. Steve Reidel calculated that emplacement rates fluctuated from just a few weeks or months to several years and that the older flows in the central plateau were invaded and inflated by younger extrusions.

The final cooling and hardening phases produced a number of characteristic layers, each distinguished by a top, core, and bottom. The top is a ropy pahoehoe with brecciated angular fragments, and the interior most often consisted of columnar blocky jointing. The middle and base are arranged into two distinct parts, the colonnade and the



Reddish oxidized baked soils, breccias of broken angular basalts, or pillow structures where the magma interacted with water differentiate individual lava flows. In some, upper columnar intervals mimic the lowermost colonnade. (After Tolan, Beeson, and Vogt, 1984; Tolan, et al., 2009)

Dikes of the Grande Ronde Basalt display horizontal columns like stacked cordwood. (Photo courtesy Oregon Department of Geology and Mineral Industries)



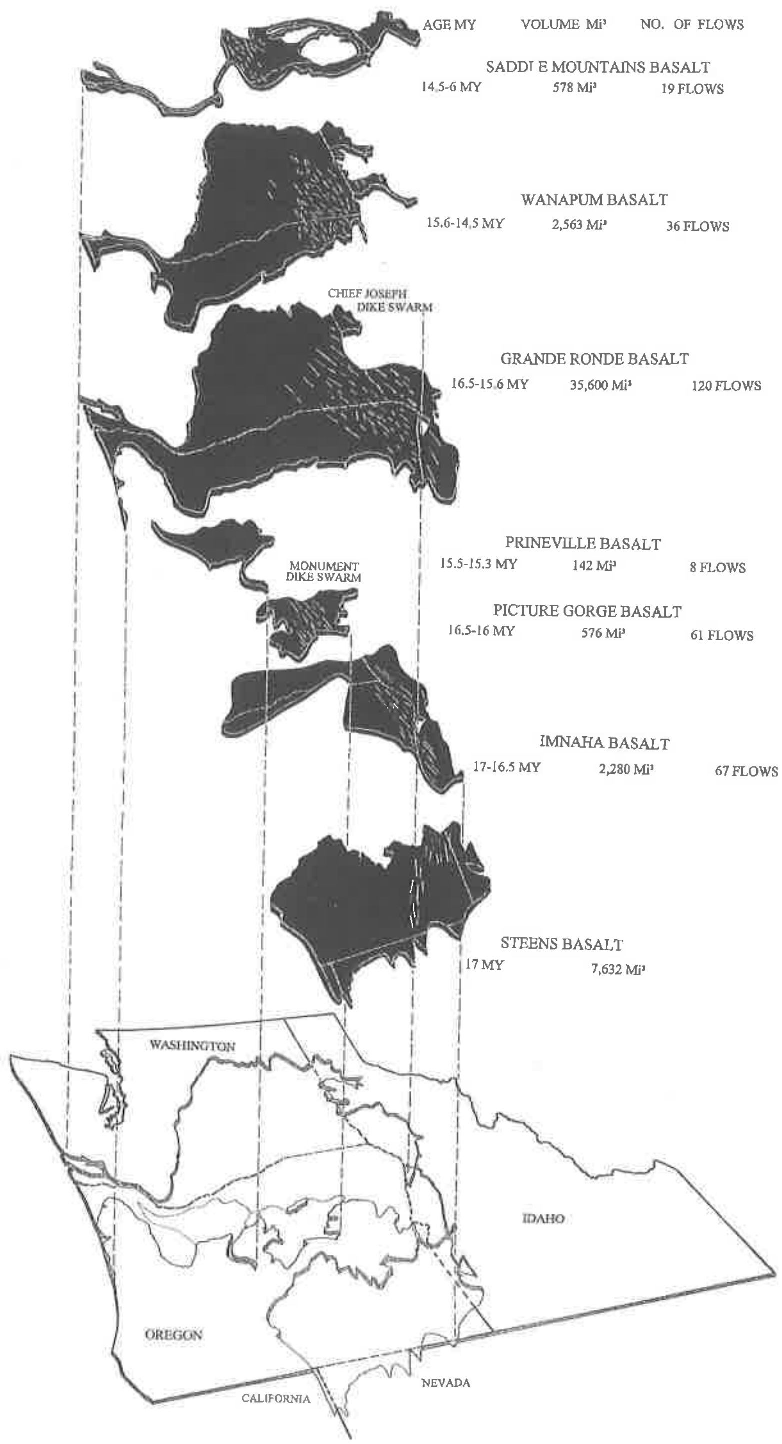
Linked to the passage of North America over the Yellowstone mantle plume, the Steens basalt was recently incorporated as the earliest eruptive formation in the Columbia River Group. (After Carlson and Hart, 1983; 1987; 1988; Camp, 2010; Camp, Ross, and Hanson, 2003; Camp, et al., in press; Hooper, and Swanson, 1990; Hooper, et al., 2007) entablature. Named after Greek temple architecture, the lower portion or colonnade is so-called because the basalt cooled and contracted into large, well-defined columns perpendicular to the surface below. The remaining upper entablature, with smaller poorly defined columns, constitutes up to four-fifths of the entire volume. Near the top of the entablature, vesicular basalt formed where gas bubbles accumulated from the molten mass. Often long, vertical tubes or pipes mark the pathways.

Individual Flows of Columbia River Basalts

Initially lumped together as the Yakima Basalts, the individual flows of the Columbia River Basalt Group are now distinguished by subtle variations in geochemistry, mineralogy, and magnetic polarity. Of the five main formations, the oldest is the Steens basalt, then the Imnaha, the Grande Ronde, the Wanapum, and the youngest Saddle Mountains. In 1988 Richard Carlson of the Carnegie Institute and William Hart at Miami University suggested that the Steens might be an early manifestation of the Columbia River series. With a flow-by-flow analysis, Peter Hooper distinguished the properties of the individual sheets, and in 2010 Vic Camp formally recognized the Steens Basalt as the oldest formation in this group.

The extent of Steens eruptions was confined to the Basin and Range and Owyhee provinces and Camp now considers them to be the equivalent of the Imnaha and Grande Ronde basalts. The widespread Imnaha issued from feeder dikes of the Chief Joseph swarm and occurs from Pullman, Washington, east to the Clearwater embayment in Idaho, and west to the Pasco basin. The 17.5-to-16.5-million-year-old Imnaha filled deep-canyons in the eroded pre-Tertiary surface to smooth out the topography.

The 120 individual Grande Ronde lavas, which were significantly younger and more silica-rich than the Imnaha, built a flat tableland. Erupting from fissures as much as 100 miles long in the Chief Joseph dike system of central Oregon, the extrusions were so rapid that the lavas did not mound up but instead spread across the uneven ground. Even though the Grande Ronde episode lasted almost 1 million years, over 95 percent of the material poured out



The distribution of formations within the Columbia River Basalt Group (After Beeson and Moran, 1979; Beeson, Tolan, and Anderson, 1989; Hooper, et al., 2007; Reidel, et al., 1989; Tolan, et al., 1989; 2009) during an interval of less than 250,000 years. The flows reached between 250 to 1,200 cubic miles in volume, and the Grande Ronde comprises more than 85 percent of the entire output of the Columbia River basalts.

In frequency, the Grande Ronde averaged one flow every 8,000 years, but the eruptive intervals slowed during the later Wanapum and Saddle Mountains times. The Saddle Mountains members were smaller and erupted within an 8-million-year interval. They were mainly confined to the central part of the plateau, where they occupied river valleys eroded into the earlier layers as intracanyon flows.

Yellowstone Hot Spot

A consensus regarding the evolution of the Columbia River Basalt Group has yet to be reached, but the various scenarios involve extension, mantle plume emplacement, or delamination of the lithosphere. Advocates for backarc spreading contend that the eruptions are related to crustal thinning, whereas others support a mantle plume or hot spot. Extensional processes in the Basin and Range stretched the crust (lithosphere) in a backarc setting to generate mantle melting and eruptions. Even though thinning ordinarily accompanies extension, the issue is whether the stretching was the cause of the massive eruptions or the consequence of the magmatic activity itself.

Present evidence favors a mantle plume (Yellowstone) accompanied by delamination of the lithosphere. As the North American plate migrated westward, it passed over a stationary hot spot, which, in turn, flattened (pancaked) when encountering the thickened Precambrian edge of the North American craton. The plume head broadened along the base of the crust, opening it to the extrusion of basalts.

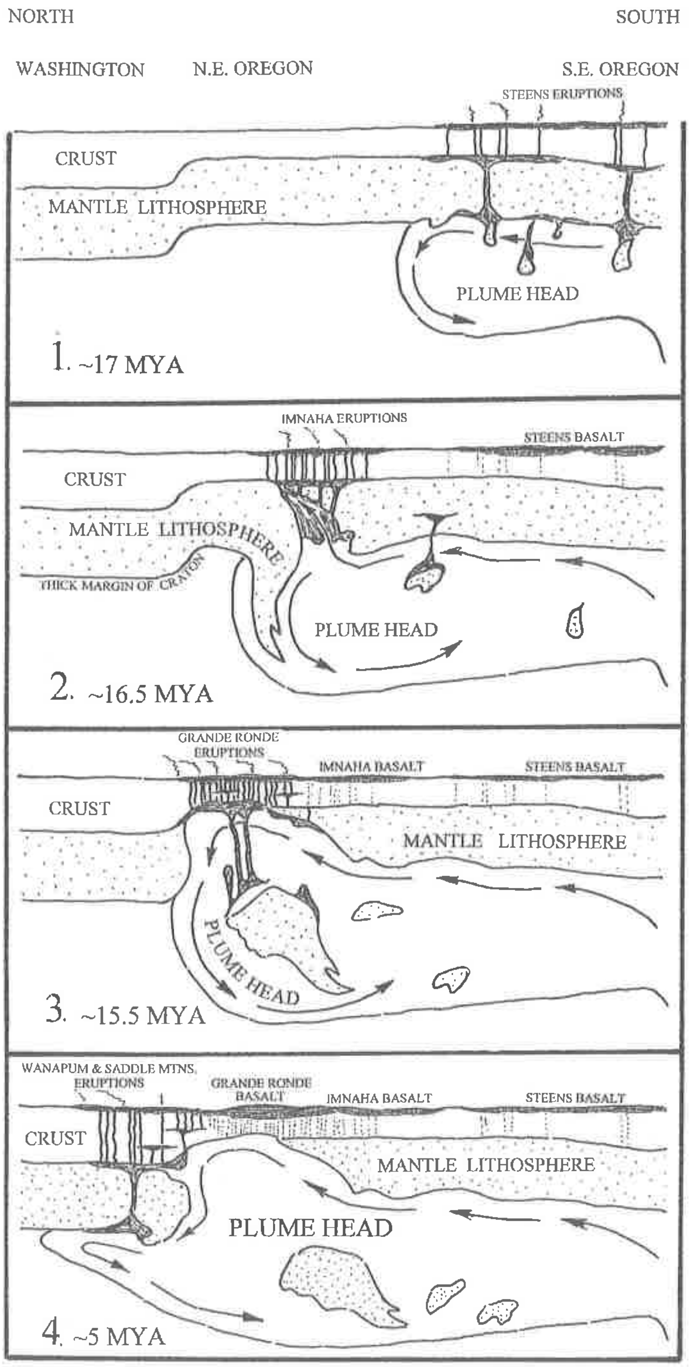
At comparatively shallow depths the plume generated the vast volumes of the Grande Ronde basalts before impact with the thickened edge of the North American craton altered the eruptive style to produce the smaller sporadic Wanapum and Saddle Mountains flows. Because of the large-scale features associated with the track, Kenneth Pierce and Lisa Morgan of the U.S.G.S. estimate that, at present, the Yellowstone plume projects at least 600 miles into the mantle.

Series		Group		Formation	Member	Age MY
Miocene	Upper	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	Lower Monumental Member	6
					Ice Harbor Member	8.5
					Basalt of Goose Island	
					Basalt of Martindale	
					Basalt of Basin City	
					Buford Member	
					Elephant Mountain Member	10.5
	Middle				Pomona Member	12
					Esquatzel Member	
					Weissenfels Member	
					Basalt of Slippery Creek	
					Basalt of Tenmile Creek	
					Basalt of Lewiston Orchards	
					Basalt of Cloverland	
					Asotin Member	13
					Basalt of Huntzinger	
					Wilbur Creek Member	
					Basalt of Lapwai	
					Basalt of Wahluke	
					Umatilla Member	
					Basalt of Sillusi	
					Basalt of Umatilla	
				Wanapum Basalt	Priest Rapids Member	14.5
					Basalt of Lolo	
					Basalt of Rosalia	
					Roza Member	
					Shumaker Creek Member	
					Frenchman Springs Member	
					Basalt of Lyons Ferry	
					Basalt of Sentinel Gap	
					Basalt of Sand Hollow	15.3
					Basalt of Silver Falls	
					Basalt of Ginkgo	15.6
					Basalt of Palouse Falls	
					Eckler Mountain Member	
					Basalt of Dodge	
					Basalt of Robinette Mountain	
					Vantage Horizon	
				Grande Ronde Basalt	Sentinel Bluffs Member	15.6
					Slack Canyon member	
					Fields Springs member	
					Winter Water member	
				Prineville Basalt	Umtanum member	
					Ortley member	
					Armstrong Canyon member	
	Lower				Meyer Ridge member	
					Grouse Creek member	
				Picture Gorge Basalt	Wapshilla Ridge member	
					Mt. Horrible member	
					China Creek member	
					Downy Gulch member	
					Center Creek member	
					Rogersburg member	
					Teepee Butte Member	
					Buckhorn Springs member	16.5
				Imnaha Basalt		17.5

Stratigraphy of the Columbia River Basalt Group (After Beeson and Moran, 1979; Beeson, Tolan, and Anderson, 1989; Reidel, et al., 1989; Swanson, et al., 1979; Tolan, et al., 1989, 2009)

Faulting and Structure

In conjunction with volcanic episodes, a north-south compression combined with east-west extension progressively distorted, sheared, and tilted the rocks of the Deschutes-Umatilla plateau. Consequently, it exhibits a suite of fractures, joints, and folds such as the Yakima fold belt, which includes the Horse Heaven anticline, the Ortley and



1. Mantle plume beneath southeast Oregon causes drip-like delamination of the mantle, generating Steens basalts.

2. As plume spreads north, the delamination of the mantle become slab-like and the plume rises to the upper lithosphere, generating the Imnaha basalts.

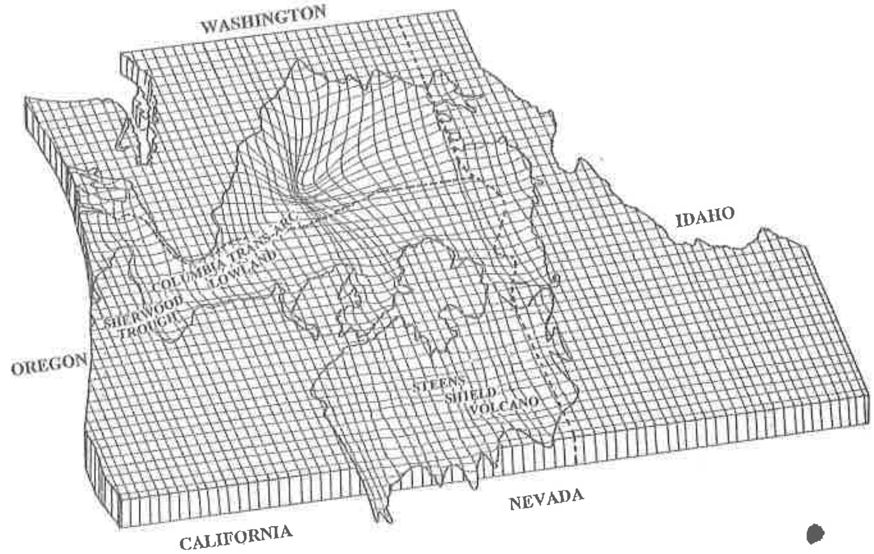
3. The slab-like delamination of the mantle fragment decouples and descends into the plume head accompanied by widespread melting to produce the Grande Ronde basalts.

4. Plume ultimately collides with the craton boundary, melting the much older crust with sporadic eruptions of Wanapum and Saddle Mountains basalts.

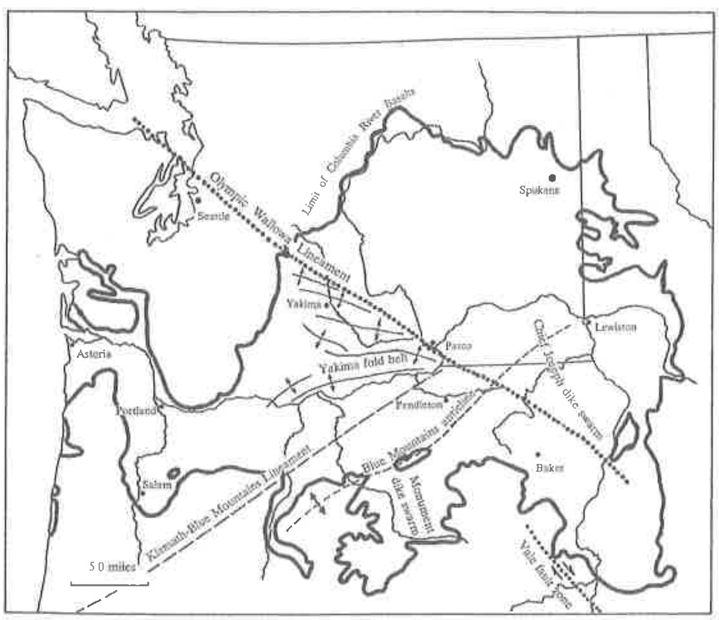
A model to explain the differences between individual formations of the Columbia River Basalt Group features a spreading plume head that peeled back the upper mantle to allow invasion of the crust with subsequent northward eruptions of the Steens, Imnaha, Grande Ronde, Wanapum, and Saddle Mountains basalts. (After Baksi, 2010; Brueseke, et al., 2007; Camp and Hanan, 2008; Cummings, et al., 2000; Hart and Carlson, 1987; Hooper, 2007; Pierce and Morgan, 2009; Waite, et al., 2006; Yuan and Dueker, 2005; Zoback, et al., 1984)

Bingen anticlines, the Mosier-Bull Run syncline, and the Columbia Hills anticline. Camp and Ross in 2004 interpreted the Yakima fold belt as thin crust, which was deformed as a tongue of the Yellowstone mantle plume spread beneath northcentral Oregon.

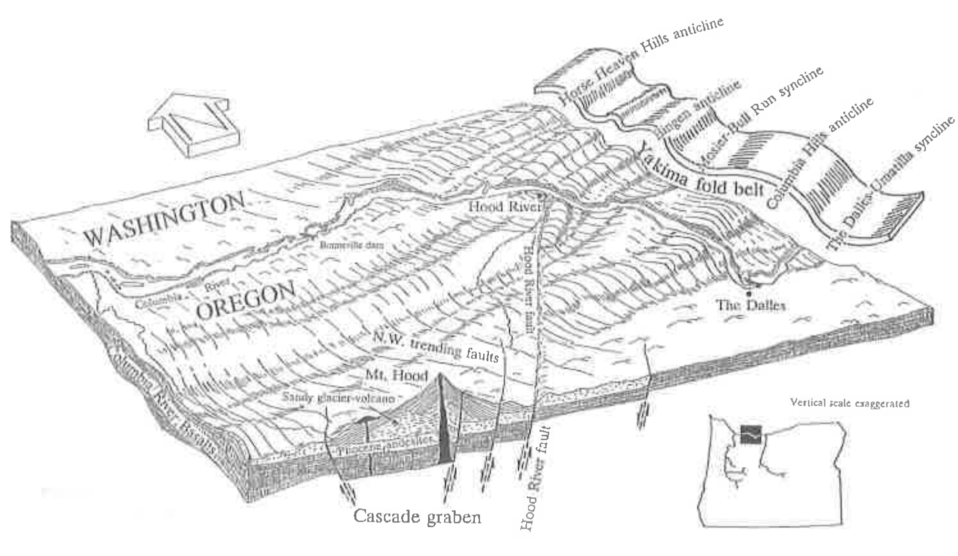
Emplacement of the individual flows was guided in part by the regional structure and subsidence. As new vents opened, the entire basalt platform was tilted gently toward the northwest by gradual uplift along the Idaho batholith. Tilting allowed the lavas to spread into central Washington, where they ponded in the Pasco basin. From that point, they moved westward through the trough-like conduit of the Columbia trans-arc lowland. Continuing eruptions were also accompanied by subsidence of the crust. Since the rate of subsidence was equal to the extrusion rate of the flood basalts, Reidel has shown that it was most pronounced during eruptions of the voluminous Grande Ronde but diminished thereafter and ceased around 3 million years ago.



A spoon-shaped mass of the combined Columbia River basalts is nearly three miles thick where it is centered in the basin beneath Yakima and Pasco, Washington, but the layers thin to a mile along the Columbia River and to a feather-edge near the Blue Mountains. This suggests that the lava filled a shallow depression, which subsided steadily. (After Beeson and Tolan, 1990; Reidel and Hooper, 1989; Reidel, et al., 1989; Tolan, et al., 2009)



Lineaments, faults and folds, and the trans-arc lowland are among the major structural features that cut the Deschutes-Umatilla province. (After Glen and Ponce, 2002; Hooper and Conrey, 1989; Tolan, Beeson, and Vogt, 1984; Tolan, et al., 2009)



Running southwesterly into the Cascades from central Washington, the gentle folds of the late Miocene Yakima belt form ridges separated by broad valleys. West of The Dalles to Bonneville Dam, the folds are exposed in cross-section where the Columbia river cuts through. (After Camp and Ross, 2004; Tolan, Beeson, and Vogt, 1984; Williams, et al., 1982)

Southwest of the Yakima basin, the Columbia trans-arc lowland was the main conduit by which the Columbia River basalts traversed the Cascades to the Pacific Ocean, a distance of 450 miles. Subsiding more than 16 million years ago, this broad southwest-northeast trending route served as a channel for the lavas as well as for the ancestral Columbia River itself. An extension of the lowland in the Willamette Valley and Coast Range, the Sherwood trough further directed the molten flows westward.

Presently at the University of New Mexico, Gary Smith grew up outside Cincinnati, Ohio, where his fascination with volcanoes was rare for a Midwesterner. That interest led to Oregon State University and on a field trip to the Cascade Mountains and Deschutes basin he saw an opportunity to work out the geologic problems. Basing his conclusions on the lithology and distribution of sediments in the Deschutes region, Smith revised the stratigraphy and named the Miocene Simtustus Formation for his PhD. Further research refined Miocene and Pliocene terrestrial sedimentation on the Columbia plateau in Washington, Oregon, and Idaho. Smith now combines teaching and administration. (Photo taken in 2010; courtesy G. Smith)

Sedimentary Basins

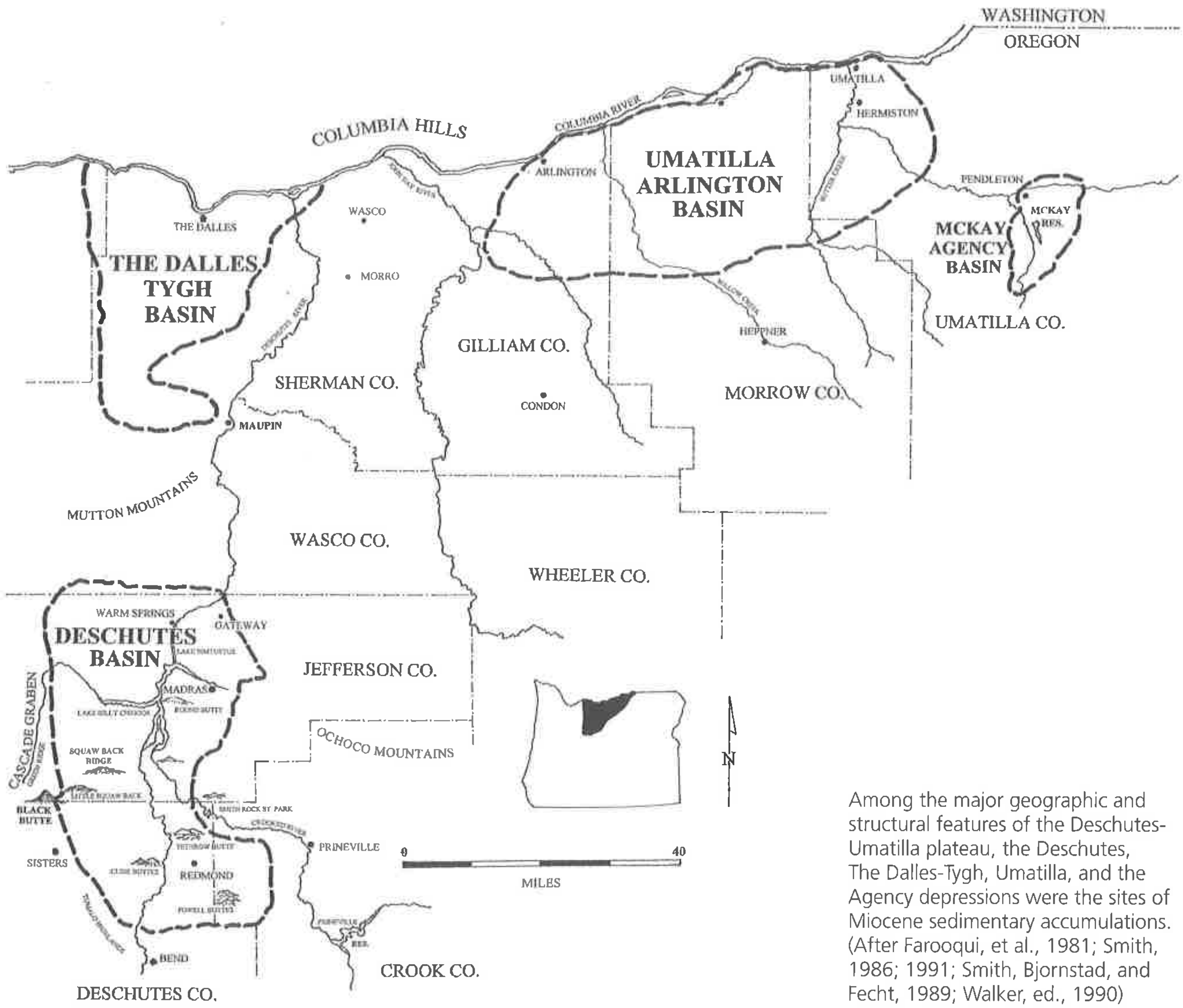
Although eruptions of the Columbia River basalts were an elemental force in shaping the Deschutes-Umatilla province, they are only part of the geologic picture. During the middle to late Miocene, enormous quantities of pyroclastic debris and tuffaceous sediments filled depositional basins, which subsided along the western and northern margins of the uplands. Richard Conrey concluded that volcanism began just prior to intra-arc rifting along the Cascades and associated each basin with a structural segment on the arc. Some of the basins were ephemeral, while others persisted, and many lie within the adjacent Blue Mountains. A network of rivers, draining the surrounding mountains, distributed volcanic detritus into the Deschutes, The Dalles, Tygh, Umatilla (Arlington), and Agency depressions where the preservation of animals and plants provides a picture of changing paleo-environments and climates. The onset of regional uplift 3 to 2 million years ago brought sedimentation to a close.

The Deschutes Basin

The Deschutes (Madras) Basin extends from Redmond northward to Madras and Gateway, east toward the Ochoco Mountains, and west to the Cascade Range. Even though most of the older strata are concealed beneath the Columbia River basalts, the John Day Formation is exposed in small buttes south and west of the Ochoco Mountains, along the eastern flank of the Mutton Mountains, and in the Deschutes canyon. The Columbia River basalts invaded between the mid to late Miocene and interfinger or are overlain by younger sediments and volcanics erupted from regional cones.

Deposited from 15.5 to 12 million years ago, thin brown and white tuffaceous silts, muds, and pyroclastics (volcanic fragments) of the Simtustus Formation represent floodplain and fluvial conditions. Near Madras, mudflows of the Simtustus entomb leaf fragments of *Populus* (cottonwood) and *Salix* (willow), which grew in a temperate climate similar to that of today. Originally included as part of the coarse conglomerates of the Deschutes Formation, sediments of the Simtustus are lithologically distinct, and the two are separated by a substantial unconformity—a gap in the rock sequence.

Following Simtustus activity, lava flows, volcaniclastic sediments (fragmented eroded volcanic rocks), and incandescent clouds of ash of the 7.5 to 3.9 million-year-old Deschutes Formation fanned out for 30 miles from vents on the eastern margin of the High Cascades. In addition to the Cascades, Cline Buttes, Tethrow Butte, and Round Butte also contributed basalts to the formation. In the central basin combined thicknesses reach 2,000 feet, thinning to 50 feet toward the Ochoco Mountains. The volcanic sources Mount Jefferson and the Three Sisters were shut off 3.5 million years ago when the 2,000-foot-high Green Ridge escarpment on the eastern flank of the High Cascade graben rose. For a time, erosion from the Ochocos continued to provide debris to the eastern portion of the Deschutes basin, but that supply also eventually ended. With the fluvial systems no longer overwhelmed by volcanic debris, streams began to incise and establish their channels.



Among the major geographic and structural features of the Deschutes-Umatilla plateau, the Deschutes, The Dalles-Tygh, Umatilla, and the Agency depressions were the sites of Miocene sedimentary accumulations. (After Farooqui, et al., 1981; Smith, 1986; 1991; Smith, Bjornstad, and Fecht, 1989; Walker, ed., 1990)

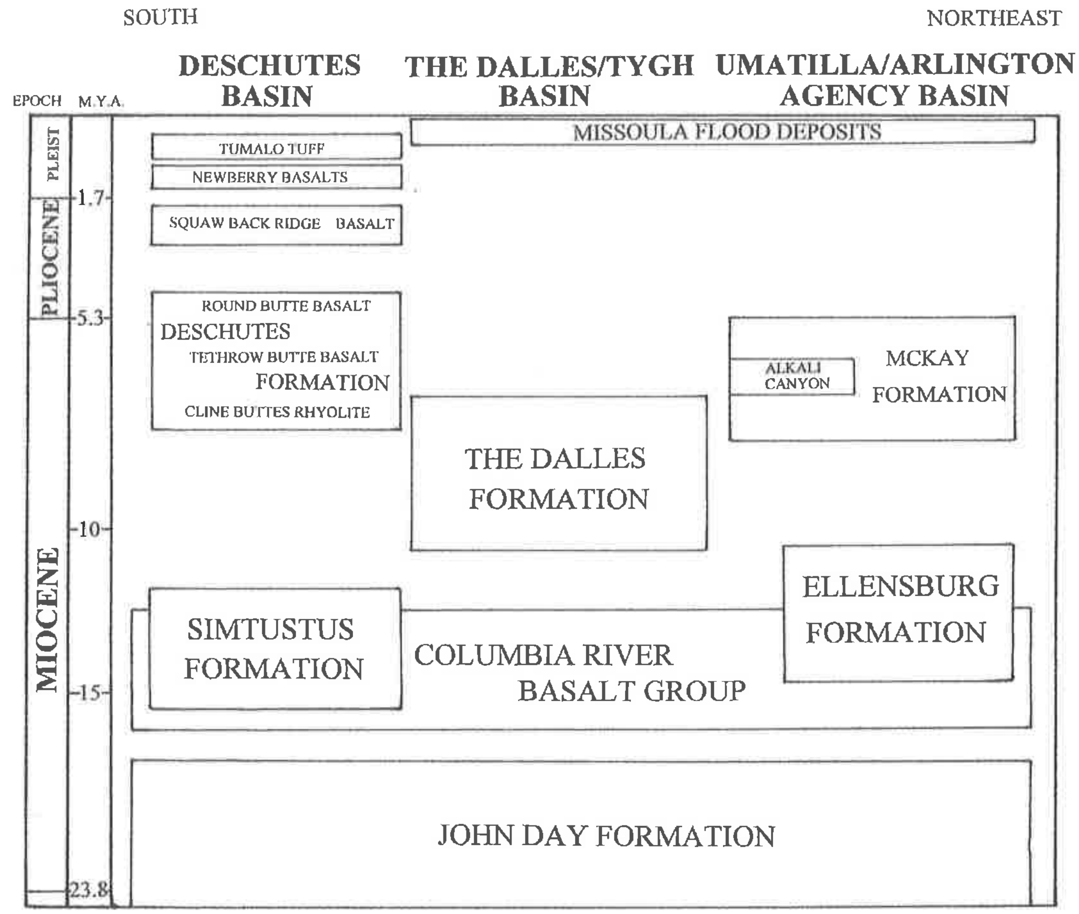
The Dalles-Tygh Basins

The Tygh and The Dalles basins accumulated late Tertiary lahars and volcaniclastic rocks that spread eastward as alluvial fans from the Cascade volcanoes. Mapped as The Dalles Formation, over 500 feet of sediments in the Tygh Valley are confined by the Mutton Mountains and Tygh Ridge. Primarily fluvial, the sediments overlie the Columbia River basalt, but their variable lithology makes a specific formational assignment difficult.

In the hiatus between intervals of the Simtustus and the Deschutes formations, tuffaceous sediments, lahars, and basalts of the late Miocene Dalles Formation can be traced eastward from the Cascades and northward from the Mutton Mountains to the Columbia River. Floodplain, stream channel, and alluvial fan deposits of The Dalles overlie the Priest Rapids Member of the Columbia River basalts and are dated as upper Miocene. Only a handful of vertebrate fossils have been recovered from rocks of The Dalles Formation exposed in creeks along the Columbia Gorge.

Umatilla (Arlington) and Agency Basins

Overlying the Saddle Mountains basalt (Elephant Mountain Member) on the Umatilla uplands, late Miocene Alkali Canyon sediments were concurrent with those of the McKay Formation in the Agency basin. Bordered to the south by the Blue Mountains in Oregon and to the north by the Columbia Hills in Washington, the Umatilla depression is drained by the steep-walled canyons of



Stratigraphy of Tertiary formations of the Deschutes Basin. (After Beebee, O'Connor, and Grant, 2002; Johnston and Donnelly-Nolan, eds., 1981; Sherrod, Gannett, and Lite, 2002; Smith, 1986; 1991; Smith, Bjornstad, and Fecht, 1989)

Willow and Butter creeks and the Umatilla River. Basaltic gravels and tuffaceous sediments of the Alkali Canyon Formation, deposited in braided streams and alluvial fans, were transported by the ancestral Umatilla River system from the Blue Mountains. The 150-foot-thick rocks indicate a drainage pattern that was much more extensive than at present.

High in the Umatilla watershed, the Agency basin is delineated by the Blue Mountains and the Horse Heaven and Reith anticlines. Confined to this area, the McKay Formation is composed of basaltic gravels interbedded with fine tuffaceous sand and silt. Up to 160 feet thick along McKay Creek, it thins considerably westward. McKay deposits are situated above the Grande Ronde Basalt and the Frenchman Springs Member of the Wanapum Basalt, and they, in turn, are covered by Quaternary wind-blown loess that often forms dunes. Fossils are common in the loose sands.

Pliocene-Pleistocene Volcanic Eruptions

A number of Pliocene shield volcanoes and cinder cones dot the Deschutes highlands at Tethrow Butte, Squaw Back Ridge, Little Squaw Back, and Round Butte. Widespread basalts from Tethrow Butte built a 165-foot-thick flatlands from Redmond to Agency Plains and Gateway. Distinctive red and black scoria from the Tethrow cinder cones also rims Cove Palisades State Park. After an initial eruptive phase, the 3.9-million-year-old Round Butte was reduced to two small summit cones. With a remarkably symmetrical profile and offering a spectacular view, Round Butte was the site of Indian ceremonies and is still regarded as sacred.

Hot ash clouds and pyroclastic fragments from sources on Tumalo Highland enveloped the region. The oldest Desert Spring Tuff, dated at 600,000 years, covered terraces in the Deschutes canyon with ash and pumice and blanketed the Bend area to depths of 60 feet. Successive 300,000-year-old showers of ash clouds (air-fall), violent surges of

The Columbia Hills to the left are the up-thrown block of a large east-west reverse (compressional) fault. Looking east up the Columbia River, Wishram, Washington, is left center and the mouth of the Deschutes River is on the upper right. (Photo courtesy Oregon Department of Transportation)

Bend Pumice, and the pink to salmon-colored strata of Tumalo Tuff serve as distinctive regional marker beds. The younger Shevlin Park and Century Drive episodes similarly inundated the Tumalo upland with volumes of lava, cinders, and ash. The source vents are no longer evident, but the build-up of debris produced the current topography.

Glaciation and Floods

In addition to a final volcanic covering, much of the Pacific Northwest experienced intervals of Ice Age flooding between 15,000 and 13,000 years ago. As continental glaciers advanced southward from Canada, ice plugged and backed up the Clark Fork River in western Montana, impounding the vast reservoir of Lake Missoula. The sudden release of waters when the barrier broke sent catastrophic floods across vast stretches of the Columbia River plateau.

Because Wallula Gap, a narrows at the big bend on the Columbia River, was less than one mile wide, it was unable to handle the 15 to 18 cubic miles of floodwaters exiting Pasco Basin hourly. A hydraulic dam, which impounded water at that point, sent the overflow into Lake Lewis north of the Horse Heaven Hills. In his readable, well-illustrated 2008 book, Robert Carson at Walla Walla University notes that this was the biggest hydraulic dam in the history of the earth. As the rushing water from Lake Missoula slowed, a five-foot-thick layer of sediments was strewn across the Umatilla basin.

Blocks of ice, stones, sand, and gravel jammed into the constriction at The Dalles to create the temporary Lake Condon to the south in the Deschutes River channel toward Maupin. Terraces along the river are composed of massive gravel layers that coincide with the water levels. Enormous rocks (erratics), that were rafted by icebergs, are common southwest of Arlington. Many mark shorelines of the ancient lake. In the Umatilla area, such stones form huge circles, having been pushed aside by farmers operating rotating irrigation sprayers.

Redirecting the Rivers

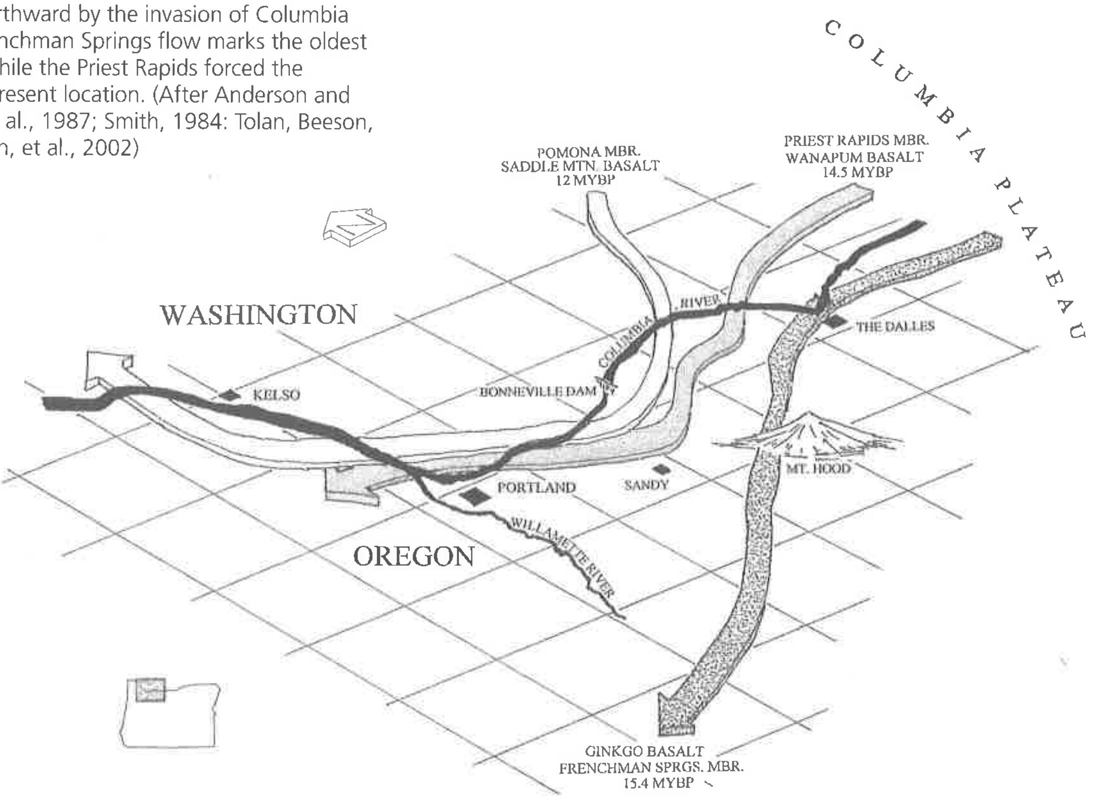
Even major rivers like the Columbia and Deschutes can be forced to change their direction with uplift of the land, faulting, and when encountering ice or lava. On the Deschutes-Umatilla plateau, volcanic eruptions played a leading role in rerouting the waterways. When moving water is impeded by lava, it works to remove the barrier, but if the dam proves to be permanent, the river bypasses the blockage along a new route. Frequently, paleo-drainages can be reconstructed by mapping individual basalt flows that invaded and occupied the channel or by tracing the presence and location of fluvial sediments and erosional patterns.

The Columbia River changed its channel many times during the past 15 million years when deflected by the Columbia River basalts, by eruptions from the Cascades, by regional subsidence, or by uplift and tilting of the plateau. Terry Tolan, Marvin Beeson, Beverly Vogt, and Karl Fecht have written particularly detailed accounts of the evolution of the drainage patterns.

Prior to 16 million years ago,.the ancestral Columbia River crossed Oregon and Washington through a broad low plain, flowed near Mount Hood, and entered the Willamette lowland south at Salem. Here it turned northwest, reaching the Pacific Ocean somewhere in Lincoln County, a route that can be traced by sediments as well as by the location of the basalts.

Alterations to the Columbia River pathway close to Mount Hood began around 15.6 million years ago, when the channel was impeded by Frenchman Springs flows. This member of the Wanapum Basalt forced the river toward the northwest where it followed the Mosier-Bull Run syncline. At the end of the Wanapum episode, Priest Rapids basalts filled and destroyed the route along the Mosier-Bull Run syncline, moving the Columbia River farther north to follow the Columbia trans-arc lowland. This trough allowed the Saddle Mountains basalts to enter western Washington and Oregon. For more than 10 million years the river remained in this broad route, depositing sands and gravels of the Troutdale Formation. Later Saddle Mountains eruptions failed to move it, but regional folding, uplift, and subsidence of the plateau combined with lavas from the Boring cones and High Cascade volcanoes brought a reorganization of the drainage. By 2 million years ago, the river was again forced northward close to its present channel.

Although obscured by later flows, two previous pathways of the Columbia River in the gorge can seen where they are intersected by the Columbia River today. Looking upriver from the Women's Forum State Park near Corbett, one of these is exposed in cross-section at Crown Point. In the sheer walls of the canyon below this point, a single flow of Priest Rapids can be seen. The blocky jointed 500-foot-thick Priest Rapids basalt covers a 200-foot layer of glassy, volcanic sediment emplaced before the lavas.



Ancestral pathways of the Columbia River show that it was repeatedly forced northward by the invasion of Columbia River basalts. The Frenchman Springs flow marks the oldest course of the river, while the Priest Rapids forced the channel close to its present location. (After Anderson and Vogt, 1987; Fecht, et al., 1987; Smith, 1984: Tolan, Beeson, and Vogt, 1984; Tolan, et al., 2002)

The feature known as The Island is an erosional remnant of Pleistocene intracanyon basalt flows, which projects northward into Lake Billy Chinook at the confluence of the Crooked River on the right and the Deschutes River on the left. (Photo courtesy Oregon State Highway Department)

Between the Miocene and through the Pleistocene epochs, basalt dams and fluvial debris routinely modified the drainages of the ancestral Deschutes and Crooked rivers. From 7.4 to 4 million years ago, the Deschutes River was spread over a wide alluvial plain in contrast to the narrow canyon it occupies today. Sheets of volcanics, derived from the Cascades, repeatedly pushed the channel toward the Ochoco Mountains where it followed a route similar to that taken by the Crooked River. Once Cascade volcanism had diminished, both rivers began to cut downward before Pleistocene intracanyon flows from Newberry Volcano 700,000 years ago again clogged the channels as far as Lake Billy Chinook. The Crooked River skirted the margins, while the Deschutes cut through the barricade. But it was well into the Pleistocene Epoch before the canyons were deepened to the current levels.

In a final episode about 6,000 years ago, damming of the Deschutes River by extrusions from Lava Butte impounded the water into Lake Benham. Diatoms and other plant material from sediments suggest the lake persisted until 2,000 years ago, at which time the river cut through, and the water drained, leaving the falls over the basalt. In addition to the location of Benham Falls, rapids in the river bed mark the position of the lava flows.

Geologic Hazards

As with much of the Pacific Northwest, the Deschutes-Umatilla plateau experiences its share of earthquakes, landslides, and flooding. In general, efforts at reducing risks are greatest in areas of high population and growth. Consequently, with substantial urbanization, the Deschutes River valley has seen a more detailed examination of potentially hazardous situations than has taken place near Umatilla, Arlington, or Pendleton.

Earthquakes

Along the Columbia River between Umatilla and The Dalles, periodic earthquakes have been noted as far back as the 1800s, but local seismological data is limited. In the Umatilla basin, earthquakes are concentrated between Hermiston and Milton-Freewater along the Olympia-Wallowa lineament (OWL), but in the Deschutes River valley they may be related to the eastern California shear zone (Walker Lane).

The earliest historic earthquakes were recorded at The Dalles in 1866, at Umatilla in 1893, and at Milton-Freewater in 1936. Oregon's strongest event, with a magnitude of 6.1, struck just west of Milton-Freewater. Chimneys and houses were damaged, shelved items scattered, and 75-foot-wide, 150-foot-long cracks opened. Water rose in wells and emerged from the smaller fractures in what was interpreted as liquefaction. No deaths were recorded, but costs amounted to $100,000 in 1936 dollars. With the U.S.G.S., Gary Mann and Charles Meyer attributed the quake to recent motion along the Wallula fault zone. The Wallula system is part of the northwest-southeast-trending Olympic-Wallowa lineament at the point where it emerges from the Blue Mountains anticline. Traversing the Deschutes-Umatilla plateau from northwest Washington to the Snake River Plain, the OWL or megashear is readily visible on aerial photographs but is of uncertain origin. Mann's examination of the fresh fault scarps led him to conclude that Holocene seismicity could pose a threat to local communities and infrastructure.

On the lower Deschutes River, the community of Madras shook slightly and doors rattled during November, 1942, and a year later Bend experienced a similar incident. The Maupin quake of magnitude 4.8 in April, 1976, was so strong that houses swayed and creaked, and a roaring noise was heard. Since 2006, Maupin has averaged weekly tremors registering less than 3.0 magnitude. Geologists initially suspected that the release of stress may have been from changes in water levels deep below the surface, but a more recent explanation presented by Oregon State University researcher Jochen Braunmiller and coauthors at the 2008 American Geophysical Union conference connects them to the Eastern California shear zone, which reaches from southern California into Nevada and central Oregon.

Landslides

Steep gradients, a large number of tributary streams, sediments, and human impact all can contribute to landslides, and in the Deschutes Basin a combination of sediments of the John Day Formation, overlain by lavas of the Columbia River Basalt Group, and interfingering with the Deschutes and Dalles formations lead to deep bedrock slumping, shallow soil and debris flow, creep, and rockfalls.

Slumping rocks of the John Day Formation triggered several impressive Pleistocene landslides in a 20 square mile area of the Deschutes canyon between Round Butte Dam and North Junction. Dated from 40,000 to 10,000 years ago, enormous blocks and debris, which temporarily dammed the river, can be seen at Whitehorse rapids (The Pot), Wapinitia, Boxcar, Trout Creek rapids, and near Dant. The Whitehorse landslide is the most recent of these. At Lake Billy Chinook, an ancient slide is evident in the hummocky topography at the north end of The Peninsula, and it also underlies the flat areas where the campground, boat launch, and headquarters were placed.

In 1985, John Beaulieu mapped historic slides at The Dalles including one located along the southern limits of the city. A slowly creeping slope in the clay-rich Dalles Formation became apparent after the city allowed construction that blocked springs draining from the underlying Columbia River basalts. The water began to infiltrate the unstable rocks of The Dalles, which initiated movement over a broad area despite a low regional gradient.

Flooding

Considering the low rainfall, flooding is surprisingly frequent in this region. However, precipitous valleys, blocked drainages, channel modifications, and poor building practices play a role. If sudden summer storms generate more water than a channel can carry, a flash flood over-tops the bank.

Evidence of Pleistocene flooding in the Deschutes River at Dant is readily visible. Sandy bars of coarse cobbles and scoured bedrock are an indication of the remarkable Outhouse flood, so-named because the Bureau of Land Management constructed its toilets on boulders in the channel. The powerful flood some 3,000 to 4,000 years ago took place after an exceptional rainfall, when the build-up of water was discharged at a rate two to three times higher than any on record. Similarly, the 1861 flood, which left sediments along the lower Deschutes, demonstrated an intensity far greater than those cause by the 1964

The momentous Heppner flood of 1903 devastated the small community of Heppner in Morrow County. The photo was taken near Main Street. (Courtesy Morrow County Historic Society)

and 1996 storms, when heavy precipitation and snowmelt combined to overwhelm stream channels.

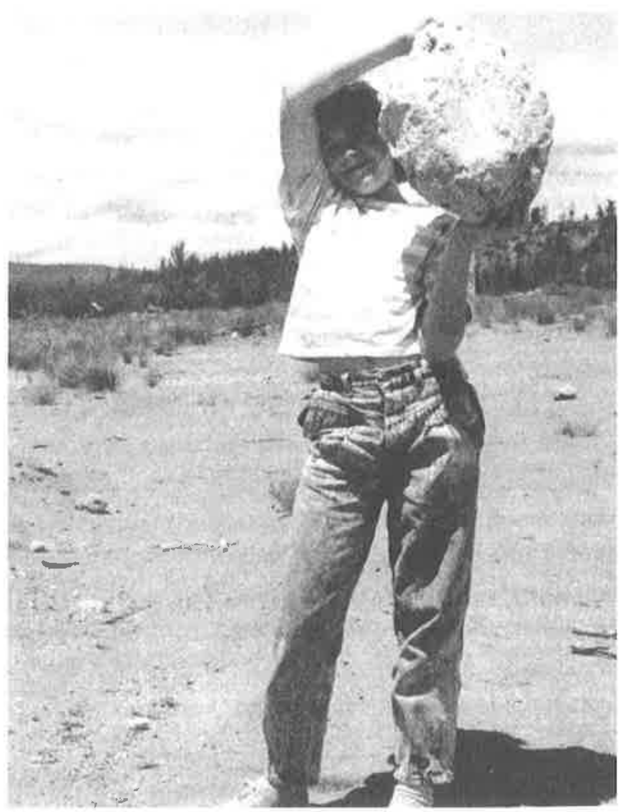
In June, 1894, what is called the greatest flood along the Columbia River, resulted from snowmelt high in the watershed. Pouring past The Dalles at 1.2 million cubic feet per second, the water overtopped the Willamette River channel, which rose over 34 feet at Portland. Undaunted residents took to boats and rafts to celebrate the Carnival of Waters.

Modern day flash floods on the Umatilla plateau vary in magnitude. The destructive flood in June, 1903, at Heppner in Morrow County followed excessive rainfall in the upper Willow Creek drainage. While flash floods are often anticipated, this one came as a surprise to residents because precipitation had been light in the community itself. The deep waters killed 247 Heppner residents out of a population of 1,500. This same region experienced one of the largest flash floods in the history of the United States. In July, 1964, rains in Speare Canyon, a tributary of the Umatilla River, pushed a wall of water, mud, rock, and debris that rose over 200 feet wide and 10 feet deep. Highways and homes were destroyed and one person killed above the community of Echo.

Natural Resources

Industrial Rock

With the exception of limited quantities of diatomite and pumice, the province is not rich in mineral resources. Near Terrebonne, diatomite was mined by Ori-Dri Company from the late 1950s until the deposit was exhausted in 1992. Created when lavas from Newberry Volcano blocked the Deschutes River, a Pleistocene freshwater lake accumulated a 60-foot-thick layer of diatom-rich ash. Today little remains of the beds except for waste piles from the strip mine operation. Highly absorbent,



The ease with which the young person lifts the chunk of pumice is proof of its light weight. (Photo courtesy Oregon Department of Geology and Mineral Industries) light-weight, and porous, diatomite is marketed as an absorbent to clean up spills, as a non-chemical insecticide, and as cat litter.

Near Bend 15-to 40-foot-thick tephra beds are mined by the Cascade Pumice and Central Oregon Pumice companies. Once extracted, the pyroclastic material is air dried, crushed, then screened to various sizes. Oregon is the leading national producer of pumice, which is used as a low density concrete aggregate in landscaping, roofing, and soil mixes. Reclamation of the site was undertaken by the company in 1982.

Geothermal Resources

The geothermal potential on the Deschutes-Umatilla plateau is moderate to low. North of Cove Palisades State Park, the Confederated Tribes of the Warm Springs Reservation operate a spa built around mineral springs arising from Clarno basalts. The waters reach 140° Fahrenheit and have a mild sulfur odor.

Surface and Groundwater

Surface water in the Deschutes-Umatilla province is controlled by the lengthy Columbia River system and its tributaries the Deschutes, John Day, Willow Creek, and the Umatilla. Regional groundwater sources are supplied by interbeds within the Columbia River basalts, by Miocene basin sediments, and by Pleistocene lake and stream deposits. Recharge of both surface and groundwater comes from snowmelt or rainfall or through leakage from unlined irrigation canals and sprinklers.

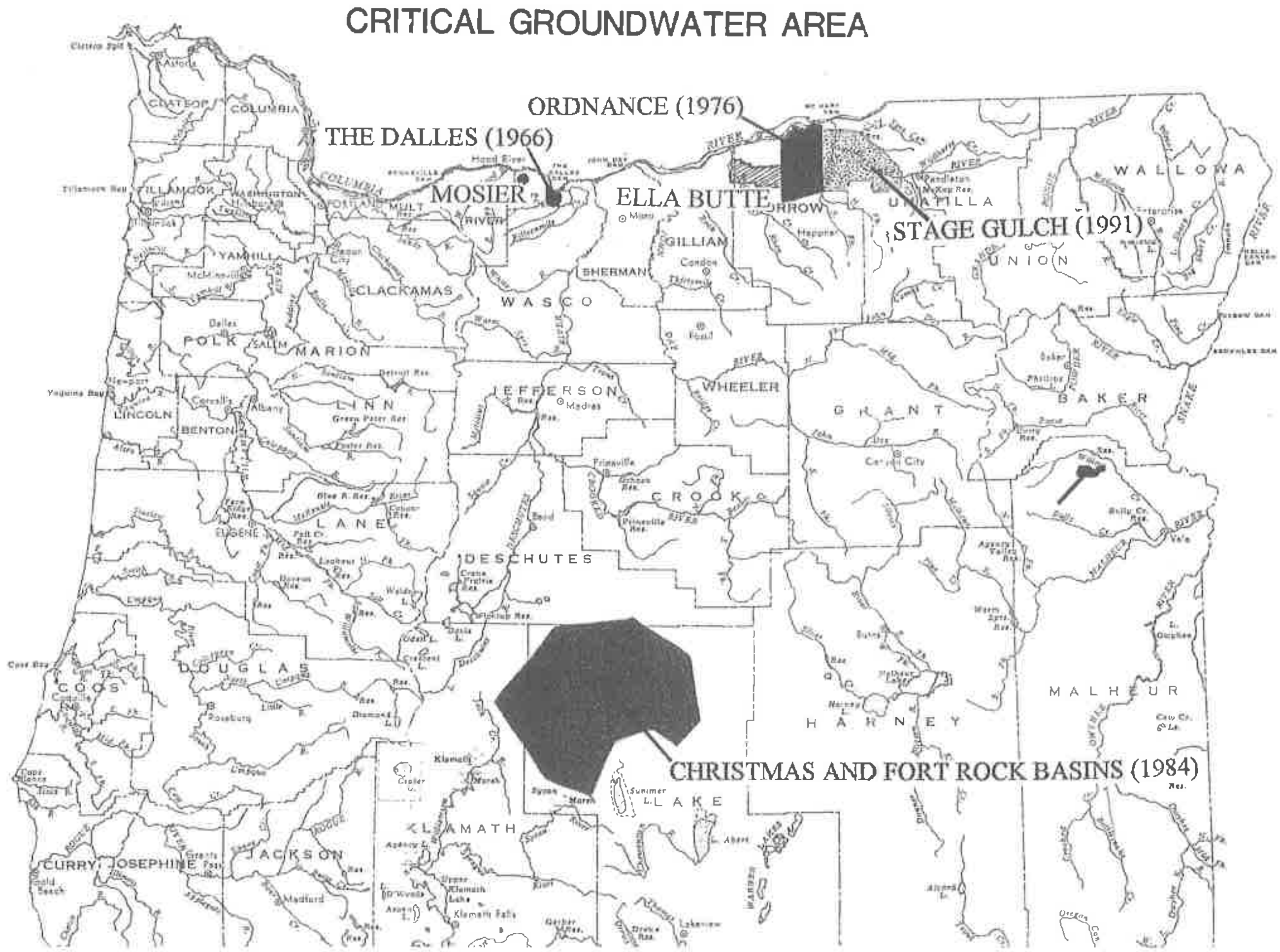
The basalts may store ample amounts of groundwater, but vertical transfer can be limited by faulting or clay seals. Consequently, the separate layers act as discrete aquifers with slow percolation and recharge. Papers by Washington consultants Terry Tolan, Kevin Lindsey, and co-authors address the regional hydrogeology of the Columbia River Basalt Group with attention to the relationship between aquifers and the flow sheets.

After monitoring water levels on the Columbia plateau for 40 years, the Washington Department of Ecology found that the aquifers began to show early signs of decline. The shallowest groundwater levels were the first to drop, but in the last 15 years drastic losses began to appear in the deeper zones. In 2010 geologists with the U.S.G.S. confirmed an 83 percent drop in water levels across the entire Columbia plateau since 1984, although they had earlier predicted there would be no long-term problems. Aquifers supplying Bend and Redmond experienced a 20-foot decline.

Attempting to rectify the shrinking water situation and rescue the local farm economy, the 2009 Oregon legislature financed a plan to pump water from the Columbia River into the aquifers, regardless of possible contamination and a limited storage capacity.

Aquifers supplying Bend and Redmond experienced a 20-foot decline. In areas where surface water appropriations have been closed for years, groundwater permits are still being granted by the Oregon Water Resources Department, and the state

In the dry climate of the Deschutes plateau, a combination of low precipitation, intensive agriculture, population expansion, and the perception that the water supply was boundless have proven to be calamitous. To sustain growth, water diversion canals, groundwater pumping, and numerous creative schemes aim to adjust water use. Near Bend, present-day irrigation canals (seen in photo) divert over 60 percent of the river's annual flow. The definitive *Waters of Oregon*, a source book by Rick Bastasch, lists 116,000 irrigated acres in Umatilla County and 37,160 in Deschutes. (Photo courtesy J. Mooney)



Designated as areas of depleted groundwater by the Oregon Water Resources Department, the shaded sections show where levels on the Columbia plateau have been dropping since the 1960s. (After Bastasch, 1997; Oregon Water Resources Department, 1988; Orr and Orr, 2005; Zwart, 1990)

legislature extended the permissible pumping period in the Deschutes basin until 2013.

Deschutes Basin. The hydrology of the Deschutes River is distinguished by two characteristics, the flow and the erosion. The flow at the mouth of the river remains relatively consistent throughout the year, with little variation in volume between the lowest in late summer and the highest in mid-winter. This is because an extensive aquifer complex receives a continuous year-round supply from the High Cascades. While there is little difference in the discharge at the mouth, the natural flows in the upper section have been altered substantially by dam construction and irrigation. Here the normal high winter-low summer situation found elsewhere has been reversed.

Another notable trait of the Deschutes River is that very little erosion occurs and only a small amount of sediment is being carried and deposited in the channel. Because the bed is primarily through hard, unweathered volcanic terrain, it is not easily broken down by fluvial processes. Behind the Round Butte and Pelton dams the build-up of debris since construction 45 years ago is minimal.

Groundwater in the Deschutes basin moves eastward from the Cascades and north from Newberry Volcano. Near Madras, the low permeability of Clarno and John Day strata forces an enormous volume of water into the more porous overlying Deschutes Formation, where it contributes heavily to streams and appears as springs. The Metolius and Opal springs are the largest two in the watershed. At a chilly 48° Fahrenheit, springs at the base of Black

Butte are the source for the Metolius River, which discharges at a remarkably constant rate of 1,500 cubic feet per second toward Lake Billy Chinook. However, in times of heavy rains such as fell during the winter of 1996, the flow soared to a record high of 8,430 cubic feet per second.

Along the Crooked River Gorge, springs emerge intermittently within a seven-mile stretch between The Cove at Lake Billy Chinook and Smith Rock. Opal Springs exits from the east bank at a temperature of 53° and at a rate of 80 million gallons a day. Opalized pebbles in the basin gave the springs its name.

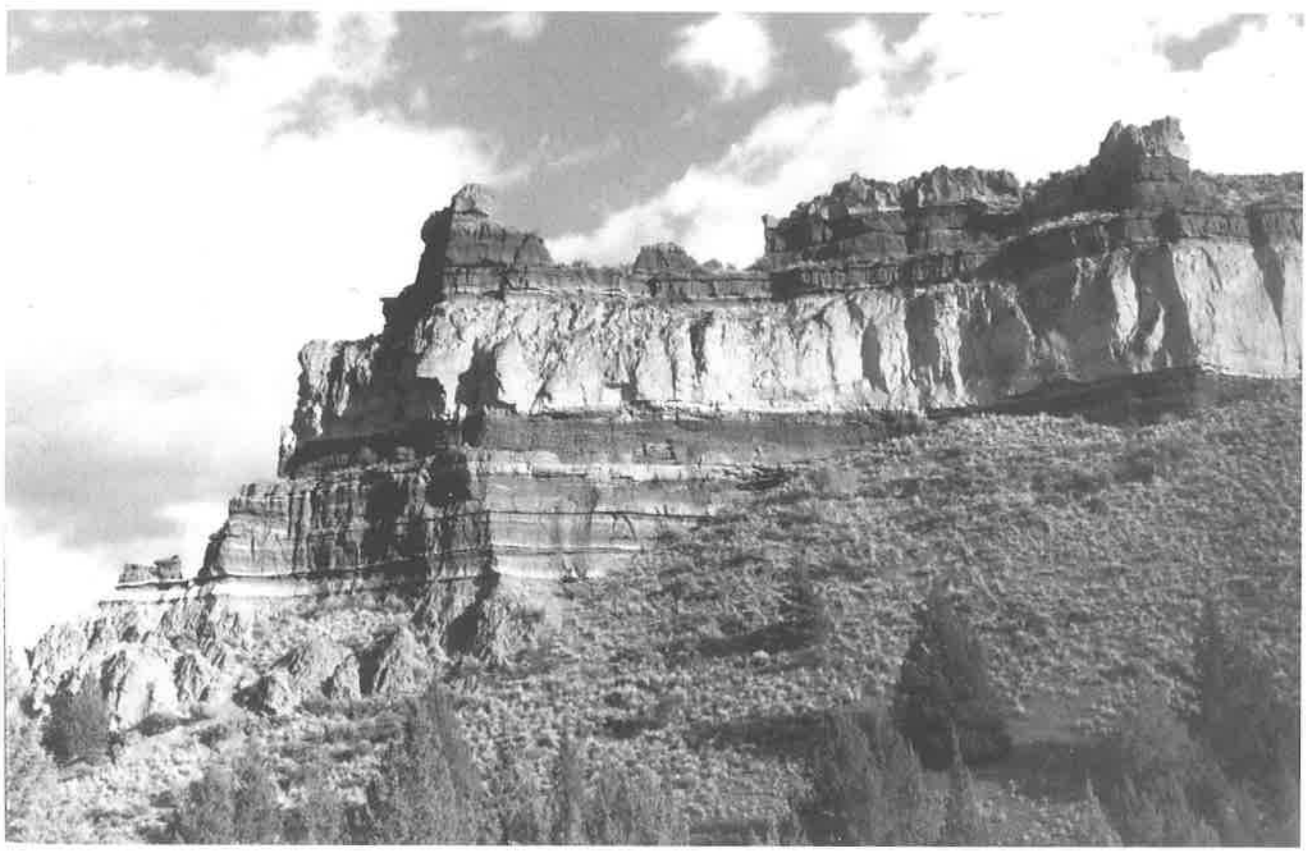
Umatilla Basin. As elsewhere on the plateau, surface and groundwater in the Umatilla basin display wide seasonal variations. The arid climate, a slow rate of recharge for both alluvial and basalt aquifers, and agriculture usage have steadily reduced the levels. Discharge peaks in the spring but diminishes to low periods in August or September. Sudden storms can temporarily elevate the amount of water in the channel, and diversions below Pendleton additionally alter the flow.

Declines in groundwater near Ordnance, Hermiston, and Stanfield, and in the Willow Creek drainage led to the Oregon Water Resources Department imposing legal limitations on withdrawal. Designation as a critical groundwater area means that the amount being drawn from the aquifer exceeds the estimated natural long-term recharge.

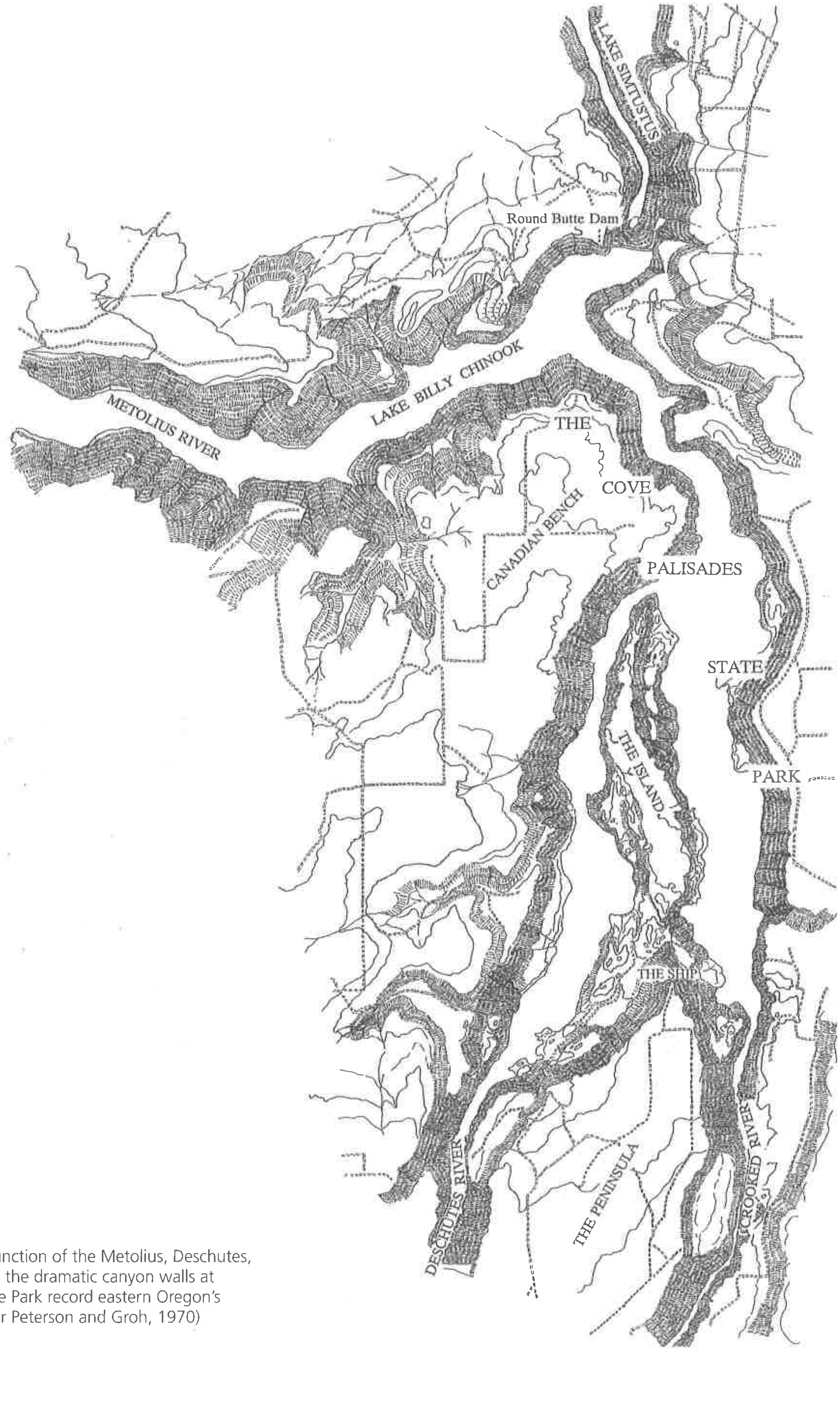
Geologic Highlights

Cove Palisades State Park

A secluded spot, just above the juncture of the Deschutes, Crooked, and Metolious rivers, was known as The Cove by settlers in the early 1900s. The site and surrounding 7,000 acres were purchased and officially designated as Cove Palisades State Park in 1940. The Deschutes River has both a State Scenic Waterway and a National Wild and Scenic River designation, and, although some sections of the banks are privately owned, most is public land.



The Ship at Cove Palisades State Park is composed of tuffaceous Deschutes Formation capped by rimrock basalt. (Photo courtesy Oregon State Highway Department)



Situated near the junction of the Metolius, Deschutes, and Crooked rivers, the dramatic canyon walls at Cove Palisades State Park record eastern Oregon's geologic past. (After Peterson and Groh, 1970)

The park includes Lake Billy Chinook and Lake Simtustus. Impounded by Portland General Electric, the Pelton Dam in 1958 backed up Lake Simtustus, and in 1964 Round Butte Dam filled the three arms of Lake Billy Chinook. These altered the complexion of the river considerably, arresting the pace of the water and decimating the migrating steelhead population. Only in 2004, when federal re-licensing came due, did PGE agree to improve fish passageways.

The geology of Cove Palisades State Park was reviewed in 1970 by Norm Peterson and Ed Groh, and updated by Ellen Bishop and Gary Smith in 1990. The emplacement of mid to late Miocene lava flows and thick fluvial sediments is recorded by colorful rocks and in scenic features such as The Ship, The Island, and The Peninsula. Contrasting yellowish-brown sands and black basalts in the canyon walls are from High Cascade eruptions, whereas the distinctive light-colored red to lighter pink and white intervals are ignimbrites of the Deschutes Formation. Ignimbrites are incandescent air-borne ash that falls to the ground to cool as a glassy layer. At Cove Palisades, an ignimbrite armors the distinctive white prow of The Ship, a high promontory at the end of the Peninsula. Dark sandstones and conglomerates of the Deschutes Formation lie below that, and ash is visible at the base. The Peninsula is made up of lavas extruded 5.4 million years ago from the Tethrow Butte cinder cones.

Distinctive iron-stained brown lavas, which erupted during the Pleistocene from Newberry Volcano, invaded and plugged the canyons as far as Round Butte dam, a distance of 40 miles from source vents. These layers can be seen in the cliffs around the park. Even though the basalts are considered to be the source for The Island, some geologists favor a yet-to-be-found fissure toward the south. Known to pioneers as the Plains of Abraham, The Island is an isolated flat mesa, which rises to a spectacular 450-foot-height above the lake shore.

Balanced Rocks

John Newberry, who accompanied a railroad exploring expedition to Oregon in 1855, examined the Deschutes basin in great detail. One of his discoveries was a cluster of precariously situated rocks on the north-facing slope of the Metolious River, where it enters Lake Billy Chinook.

Balanced rocks, each weighing over a ton, are perched atop tapering pedestals that reach to 30 feet in height. Resembling the Easter Island statues, the pedestal and top knot are Deschutes Formation ignimbrites. Both the columns and pedestals are the product of differential weathering, in which lower strata have been removed to leave the resistant cap. (Photo courtesy Oregon State Highway Department)

Peter Skene Ogden State Park

Named after one of the Northwest's first fur traders, Peter Ogden, the state park was dedicated in 1927 at the point where U.S. Highway 97 crosses the Crooked River gorge. A little over 100 acres in size, the park includes the bridge, which is 290 feet above the Crooked River at this point. The original structure over the chasm was constructed in the same year, but in 2000 a new concrete arch was opened to the east. The older bridge is now limited to foot and bicycle traffic. Pleistocene lavas from Newberry Volcano form the canyon walls in the park.

Both perspectives show the Crooked River Bridge on Highway 97 where it is 290 feet above the river. (Courtesy Oregon State System of Higher Education and Condon Collection)