VI. High Lava Plains

A. Physiography
  1. SE-NW trend, central Oregon
  2. Newberry crater forms NW boundary
  3. recent volcanic flows, arid climate, little vegetative cover

B. Geologic Overview
  1. Youthful Volcanic Eruptions
    a. cones, buttes, lava flows, lava tubes
    b. province dominated by volcanic deposits (with exception of local fluvial, lacustrine and talus)
    c. eruption cycle: 10 m.y. to recent
    d. vents along Brothers Fault zone
    e. Features
      (1) shield volcano = Newberry
      (2) tuff rings / explosion craters
      (3) lava cast forest
  2. Pleistocene shallow lakes / pluvial

C. Bedrock Geology
  1. General
    a. Oldest volcanics - Miocene lavas (10 m.y.)
    b. volcanic trends aligned with brothers fault zone (crustal conduits for eruptions)
    c. over 100 rhyolitic volcanic centers stretched throuhout the zone
    d. Brothers fault zone: clockwise shear, dextral shear (NW-SE swarm of faults)
    e. Newberry at center point of triple fault jct
      (1) to north: Green Ridge and Sisters fault zone (north of bend)
      (2) TO SE: Brothers fault zone
      (3) to SW: Walker Rim fault zone
  2. Bimodal Volcanism
    a. basalt-rhyolite association
      (1) basalts = deep source, early stage eruptions
        (a) fluid lava flows
      (2) rhyolite = shallow crust source, late stage eruptions
        (a) domes / silicics
    b. SE to NW age trend
      (1) 10 m.y. volcanics in Harney basin, sequentially younger to
      (2) < 1 m.y. volcanics at newberry
      (3) hypothesis: age trend reflecting change in subduction angle of , slowing of subduction rate, steepening of slab angle, progression of volcanics to NW
        (a) but: problem, the Cascade arc is shifting to east, antithetic to the Newberry trend
        (b) this idea is B.S.

  3. Pleistocene Lakes
    a. pluvial lake basins
      (1) Fort rock, Christmas valley
      (2) high stands = connected basins

        (3) low stands = disconnected lake basins, with potential for drainage / overflow

D. Fault-Related Geothermal Flow

E. Other Stuff
  1. Fort Rock, Hole in Ground, Big Hole = tuff rings or maars
    a. explosion craters, phreatomagmatic eruptions
    b. collapse breccia in center, ring debris around crater

  2. Newberry
    a. Newberry crater, shield volc. with > 400 parasitic cinder cones
    b. caldera lakes, obsidean flows / domes
    c. most recent activity ~2000 yrs ago, obsidean flow
    d. Mazama ash prevlalent in area
    e. Catasrophic outburst floods from caldera lakes

  3. Lava caves
    a. pliocene - Pleist lava tubes

  4. Crack in the Ground
    a. 2 mile long, up to 70 ft deep
    b. opening in lava flows as block below it faulted under weight of flows

  5. Smith rocks
    a. tuffs along Crooked River
    b. rhyolitic lavas from Gray Butte complex, silicic tuffs
    c. weathering and erosion formed smith rocks pinacles

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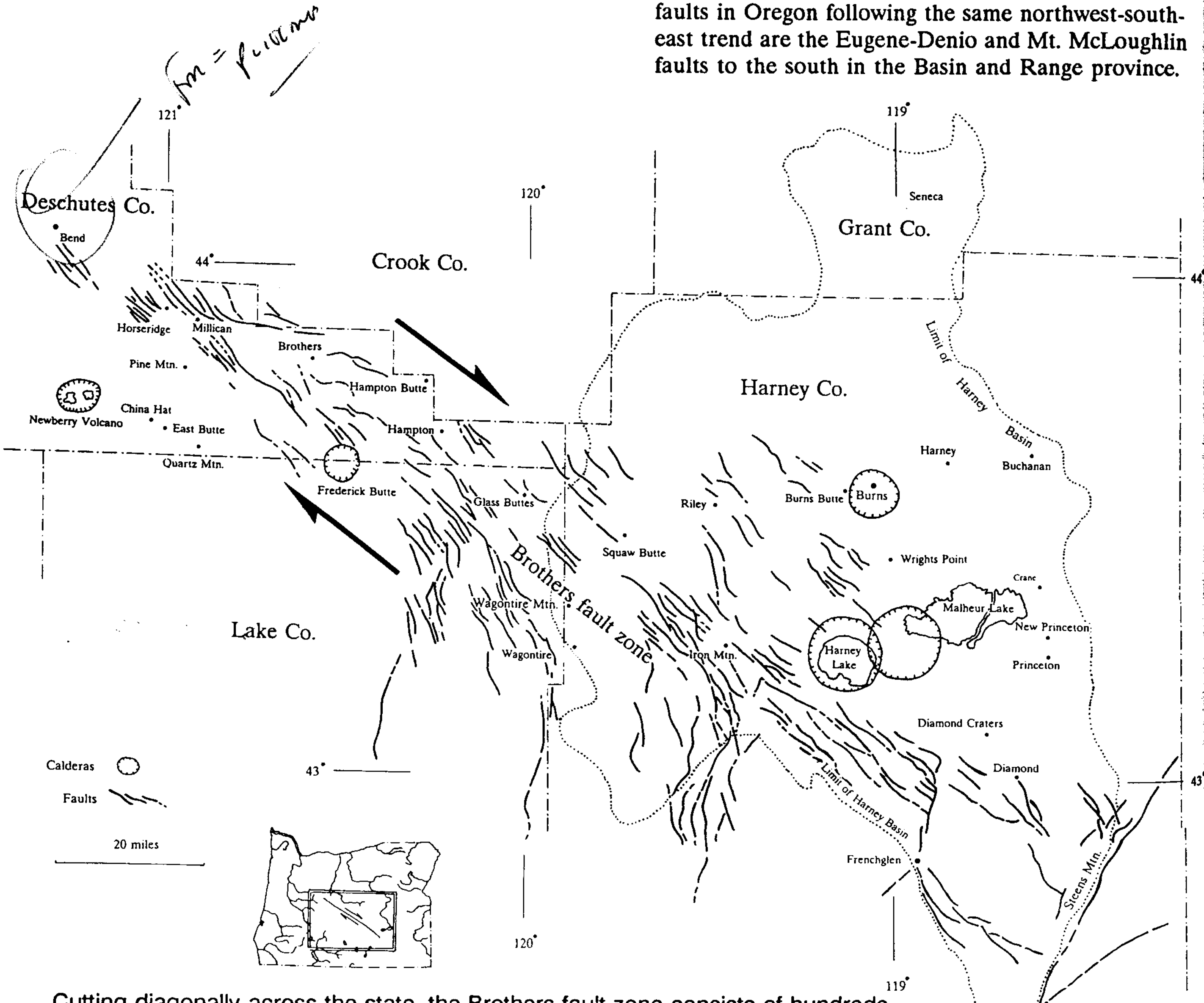
Geology

Structurally the High Lava Plains blends with the Blue Mountains to the north and the Basin and Range to the south, but its volcanic characteristics set it apart. The oldest rocks exposed in the High Lava Plains province are Miocene lavas. Five to 10 million years ago the landscape here was dotted with erupting volcanoes and slow moving thick lavas spreading over the flat surface. One eruption followed the other almost continuously for millions of years. Eruptions aligned themselves in a broad belt of overlapping faults, known as the Brothers fault zone, the dominant structural feature of the High Lava Plains and central Oregon. The zone runs for 130 miles from Steens Mountain in southeastern Oregon to Bend. Within the Brothers fault zone, individual faults are irregularly spaced a quarter to 2 miles apart with modest displacements of less than 50 feet. Over 100 separate rhyolite volcanic centers are located along the belt of faults where the silica-rich lavas have exploited the fractures and fissures as avenues to reach the surface.

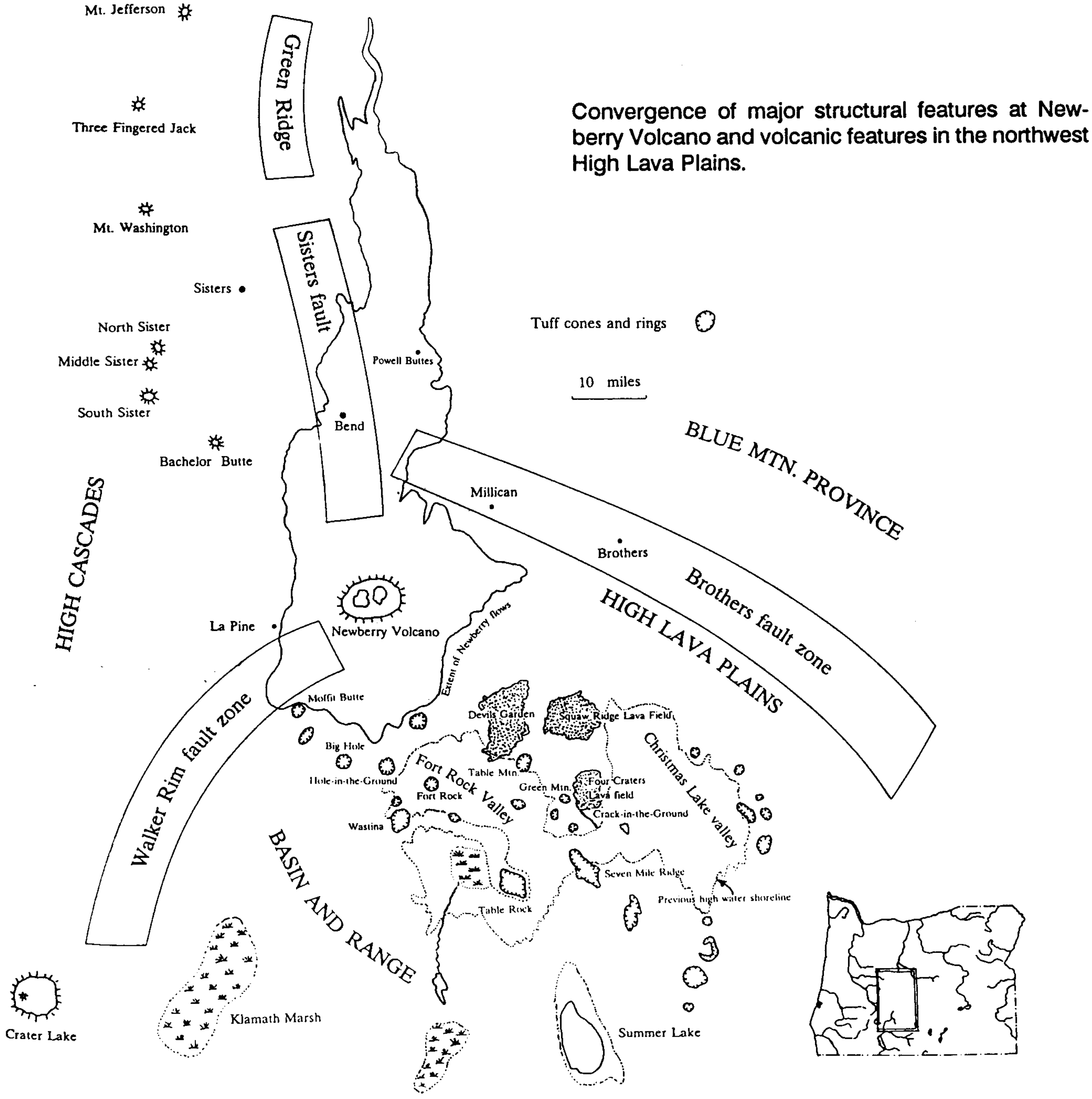
The Brothers fault zone was generated by the same forces that twisted Oregon in a clockwise motion throughout the Cenozoic era. Large tectonic blocks share a zone of weakness running north-south through central Oregon. As the blocks move relative to each other, the eastern block moved south and the western block moved north. Caught in the middle, central Oregon was distorted by wrench faulting expressed on the surface as the wide zone of faults. Most of the faults along the zone are so recent that they are easily seen in aerial photographs. Similar large-scale wrench faults in Oregon following the same northwest-southeast trend are the Eugene-Denio and Mt. McLoughlin faults to the south in the Basin and Range province.



Cutting diagonally across the state, the Brothers fault zone consists of hundreds of smaller faults above a major northwest by southeast shear. (after Walker and Nolf, 1981)

Newberry Crater, at the western edge of the province, is situated at the apex of three converging fault zones, the easterly Brothers fault zone, the northerly Green Ridge and Sisters fault zones, and the southwesterly Walker Rim fault zone. Placed at the center of these fracture patterns, it is little wonder that Newberry volcano formed as a separate, younger eruptive site well to the east of the High Cascade vents. Today a small magma chamber may be less than two miles below the caldera. Although it is often suggested that Newberry Crater may again erupt, its blanket of rhyolitic rocks tends to diminish that possibility, because silica-rich rhyolitic lavas ordinarily appear very late in the life cycle of a volcano.

Lavas of the High Plains are distinctly bimodal. That is, they have strikingly different compositions varying from dark-colored basalt to light-colored rhyolite. Basaltic lavas tend to have a deeper source in the crust and are extremely hot, while the lower temperature rhyolitic lavas are from chambers at shallow depths. In addition, basalts are generally an early stage of eruption, while rhyolites appear late in

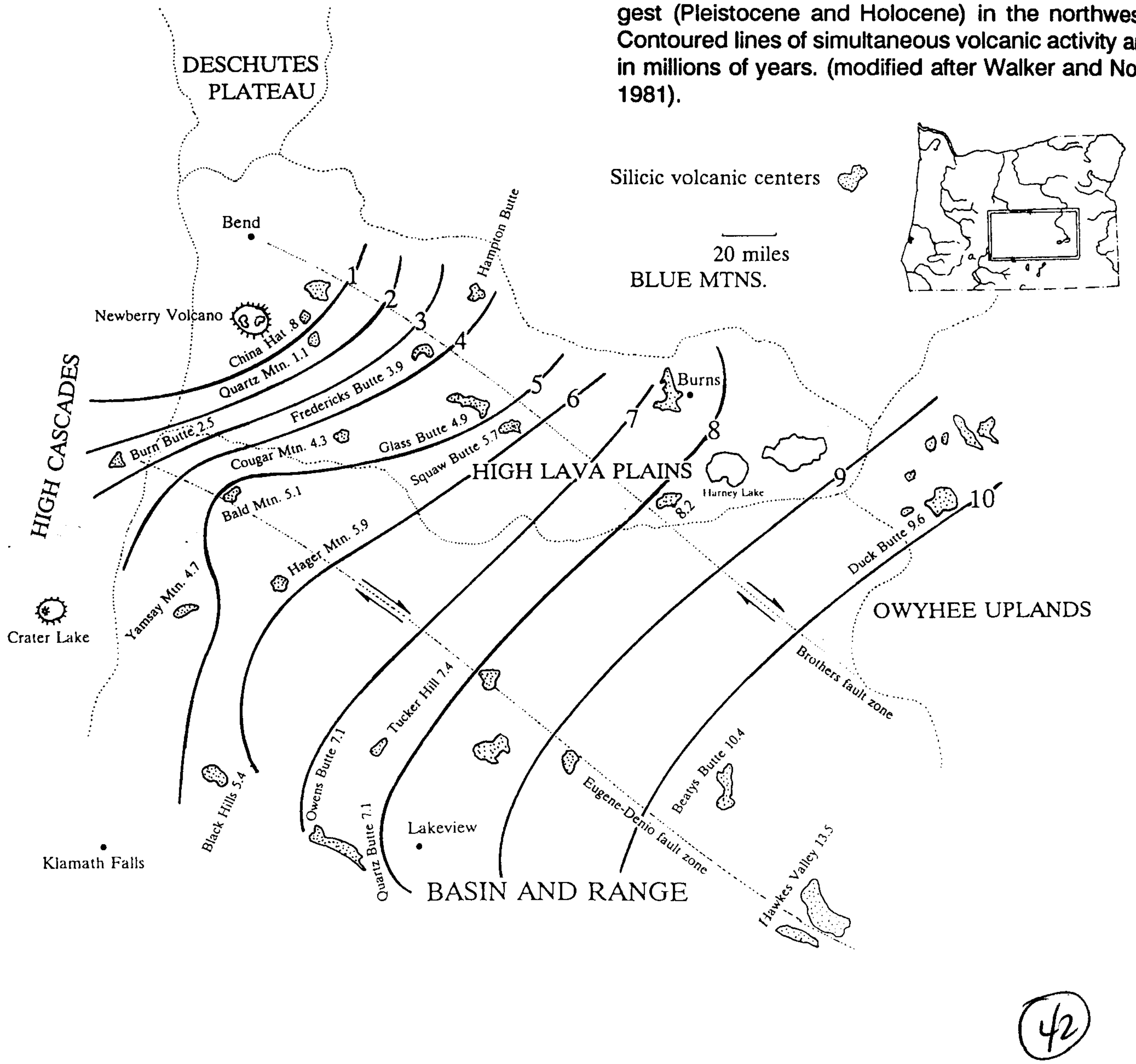


Convergence of major structural features at Newberry Volcano and volcanic features in the northwest High Lava Plains.

the cycle. In this province, the very fluid basaltic lavas predominate, but rhyolitic extrusions and domes are situated along major fracture zones. The association of basalt and rhyolite is is rare and usually occurs where the earth's crust thins because it is undergoing tension and being stretched.

Comparatively young eruptions and intrusions here between the upper Miocene and Recent occur in a broad northern belt of approximately 100 centers trending northwest across the Lava Plains and Owyhee Uplands. One of the most striking aspects of the High Lava Plains is the uniform decrease in the age of these volcanic eruptive centers geographically from east to west. Within the Harney Basin in the east, rhyolitic eruptions date back to 10 million years ago in the late Miocene, while near Newberry Crater in the west many lavas were extruded less than 1 million years ago. The eruptive zone moved steadily from the southeast toward the northwest at slightly more than one mil per 100,000 years. Such a progression of eruption might be seen as an earth crustal plate moving over hot spot, but two important aspects of local geology seem to preclude this notion.

First, it is well established that the North American plate, upon which this province rests, has moved progressively westward since well before Miocene time. The age progression should then be reversed with younger volcanics appearing in the east instead of in the west, as is the case with the Yellowstone hot spot. Additionally, another broad belt of rhyolitic and silicic domes to the south in the Basin and Range province between Beatys Butte in the southeast and



Age progression of silicic volcanic centers in the High Lava Plains and Basin and Range from the oldest (upper Miocene) in the southeast to the youngest (Pleistocene and Holocene) in the northwest. Contoured lines of simultaneous volcanic activity are in millions of years. (modified after Walker and Nolf, 1981).

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Harney Basin. The remarkable Rattlesnake ash-flow tuff, which extends to the vicinity of John Day 90 miles to the north, also has source vents in the Harney Basin. These formations are covered by alluvium and lake deposits eroded largely from the volcanic rocks of the adjacent uplands. At the outer margins of the basin, sand and gravel predominate, while silts and clays fill the center. Younger lavas from Diamond Craters along with some Pleistocene basalts cover these sediments. Within these deposits thin but well-defined layers of 6,900 year old Mazama ash lie three to six feet below the surface.

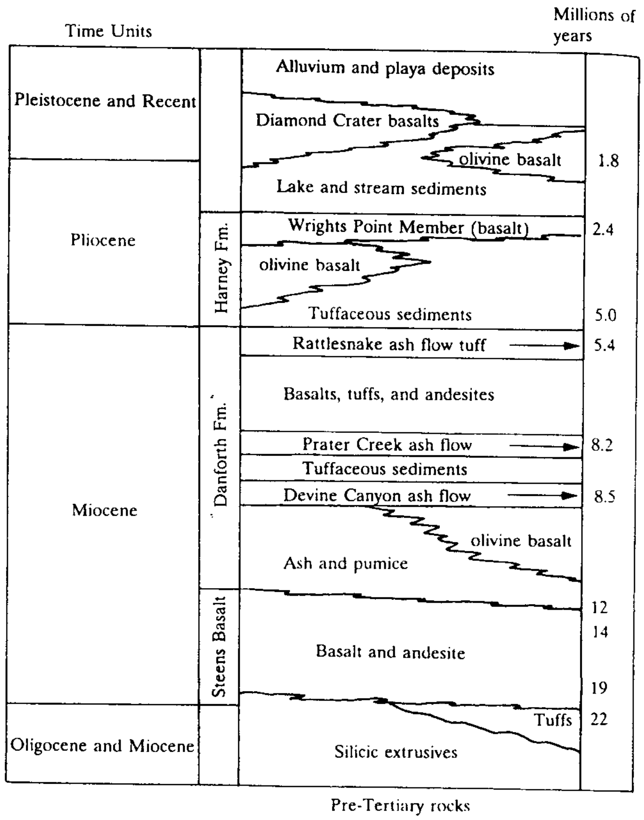
Shallow, ephemeral Malheur and Harney lakes, and smaller Mud lake which connects the two, are located in the south central portion of Harney Basin. During wetter conditions existing in the Pleistocene, a huge body of freshwater, ancient Lake Malheur, occupied the basin and extended all the way to Burns. The lake originally drained to the east along the south fork of the Malheur River and from there to the Snake River until the outlets near Princeton and Crane were dammed by a lava flow. As warmer, dryer conditions prevailed, about 10,000 years ago, the lake rapidly shrank in size creating the present series of smaller lakes, playas, and marshes. Lake Malheur, at its highest water level, was probably never more than 50 feet deep.

Even historically Malheur, Mud, and Harney lakes were not always joined. Explorer Peter Skene Ogden observed in 1826 that *"a small ridge of land, an acre in width, divides the freshwater from the salt lakes"*. About 1880 Malheur Lake topped the ridge and overflowed into Harney Lake. Today these lakes frequently double or triple in size during wet spells or decrease to virtually nothing in a dry period. Flooding during three years of record rainfall in 1984 caused the three lakes, normally covering 125,000 acres, to expand to 175,000 acres. Periods of extreme drought are not abnormal to these lakes, and prior to 1930 they became virtually dry due to low rainfall.

Malheur, Harney, and Mud lakes have been designated as the federal Malheur National Wildlife Refuge, a home for thousands of wild birds, native plants, and animals.

Geothermal Resources

Percolating from deep within the crust through cracks and fractures, heated water reaches the surface as warm springs. Scattered over the Harney Basin, almost all thermal springs are aligned along faults. Although some springs record much higher readings, the average temperature of the waters is between 60 and 82 degrees Fahrenheit. Thermal waters, ranging from 64 degrees to 154 degrees Fahrenheit issue from a number of perennial springs near Hines, Warm Springs valley east of Burns, and around Harney and Mud Lakes to the south. Water temperatures near Hines reach a high of 82 degrees Fahrenheit with temperatures diminishing outward from there. Some of the highest temperatures occur in spring waters southwest of Harney Lake where 90 to 154 degree Fahrenheit waters indicate the presence of a thermal system. Several springs here have commercial facilities, and one, Radium Hot Springs, popular since the 1890s, is the largest warm water pool in the state.



Correlation chart of High Lava Plains stratigraphic units

Features of Geologic Interest

Fort Rock, Hole-in-the-Ground, Big Hole

Distributed widely on the High Lava Plains, maars and tuff rings resulted when upward moving lava in the crust encountered underground water with devastating effects. Upon contact with the cooler water, the hot lava exploded catastrophically, creating a symmetrical, circular crater. Rocks and ash from the eruption, thrown into the air, settled close to the crater building up a high rim or tuff ring. Saucer-shaped maars are shallow explosion craters that are fed by a

VII. Deschutes-Columbia Plateau

- A. Physiography
  - 1. Columbia River Plateau
    - a. 63000 sq mi of WA, OR, ID
    - b. Okanogan to North
    - c. Cascades to West
    - d. ID batholith to East
  - 2. Rivers
    - a. Columbia, Deschutes, John Day, Umatilla
    - b. Columbia - 3rd largest river in NAM
    - c. Deschutes, trib. to columbia, heads at Mt Bachelor, flows northward

- B. Geologic Overview
  - 1. CR Flood Basalts (Miocene)
    - a. source - fissure eruptions in NE OR, SE WA, and ID
    - b. subsiding basin filled with basalt flows
  - 2. late Miocene
    - a. ash and lava flows from Cascades into Deschutes basin
    - b. subsidence / collapse of high cascades into graben
  - 3. Pliocene
    - a. high cascade volcanism
  - 4. Pleistocene - Missoula floods across plateau
    - a. loess accumulation

- C. Bedrock Geology
  - 1. Miocene
    - a. Columbia River Basalts
      - (1) stratigraphy (oldest to youngest)
        - (a) Imnaha Basalt (16.8-17.3 my)
          - i) limited to NE OR, SE WA, ID
        - (b) Picture Gorge Basalt (16-16.5 my)
          - i) limited to NE OR
        - (c) Grande Ronde Basalt (15.6-16.8 my)
          - i) most voluminous / widespread
          - ii) greater CR plateau
          - iii) flows out to mouth of Columbia / OR coast
          - iv) > 85% of total CRB volume
          - v) > 120 individual lava flows, up to 460 mi distance
          - vi) 1 my eruptive duration
        - (d) Wanapum Basalt (14.5-15.2 my)
          - i) 2nd most widespread flows
        - (e) Saddle Mountain Basalt (6-14.5 my)
          - i) intercanyon flows, limited to CR valley proper

      - (2) Eruption rates
        - (a) 10 m.y. duration
        - (b) 1 flow every 35,000 yr on average
        - (c) >100 cu. mi of basalt per flow
        - (d) velocity up to 30 mi / hr

            - (e) total volume of CRB = 42,000 cu. mi
                - i) 1 mile wide, 2 mi high around the entire earth
            - (f) thickness ranges from 1 - 3 miles to feather edge of highlands / steptoes
                - i) depocenter of CRB around Yakima

        - (3) basalt flow stratigraphy (cools from top down)
            - (a) bottom = colonnade (columnar perp. to cooling surface)
            - (b) middle = entablature (columnar in multiple orientations)
            - (c) top = vesiculated

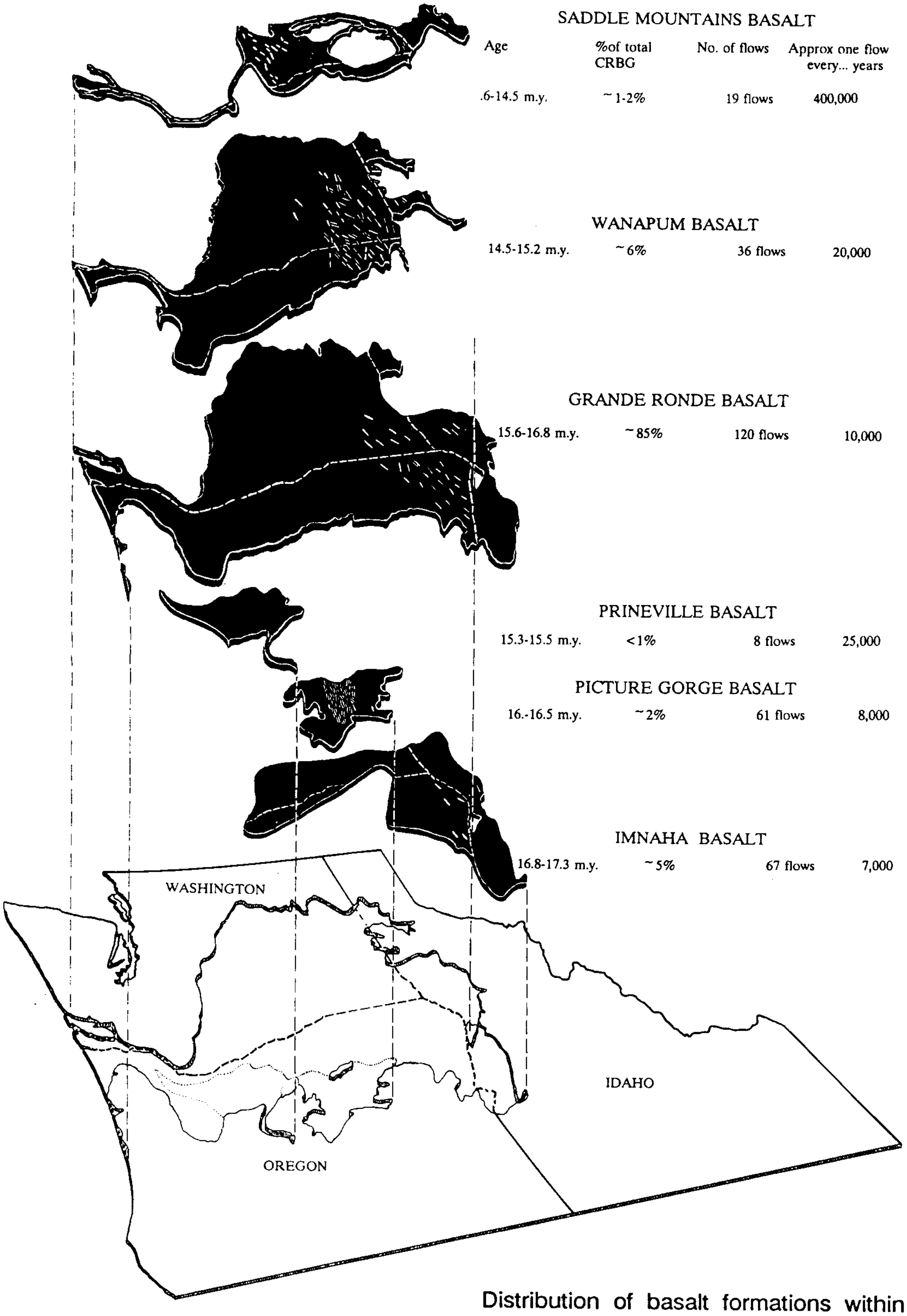
        - (4) Origin
            - (a) Chief Joseph dike swarm (NE OR / SE Wa)
            - (b) Columbia River in Miocene Time
                - i) river well south of present position
                - ii) CRB's plug / dam / divert Columbia drainage

    - 2. Miocene-Pliocene (post CRB)
        - a. volcaniclastics of Deschutes Fm (derived from Cascades) Pliocene
            - (1) derived from early High Cascades volcanoes (8 my - 4 my ago)
            - (2) sediment supplied, ignimbrites, ash flow, lava flows
        - b. 4 my ago - cascades graben subsidence, shut down Deschutes volc. source
        - c. High cascades built, creating rainshadow effect in Miocene-Pliocene
            - (1) climate change, rain shadow, veg. effect
        - d. Black Butte, andesitic cone, created 3.5-4 my ago, located on Green Ridge fault, likely a source for Black Butte plumbing

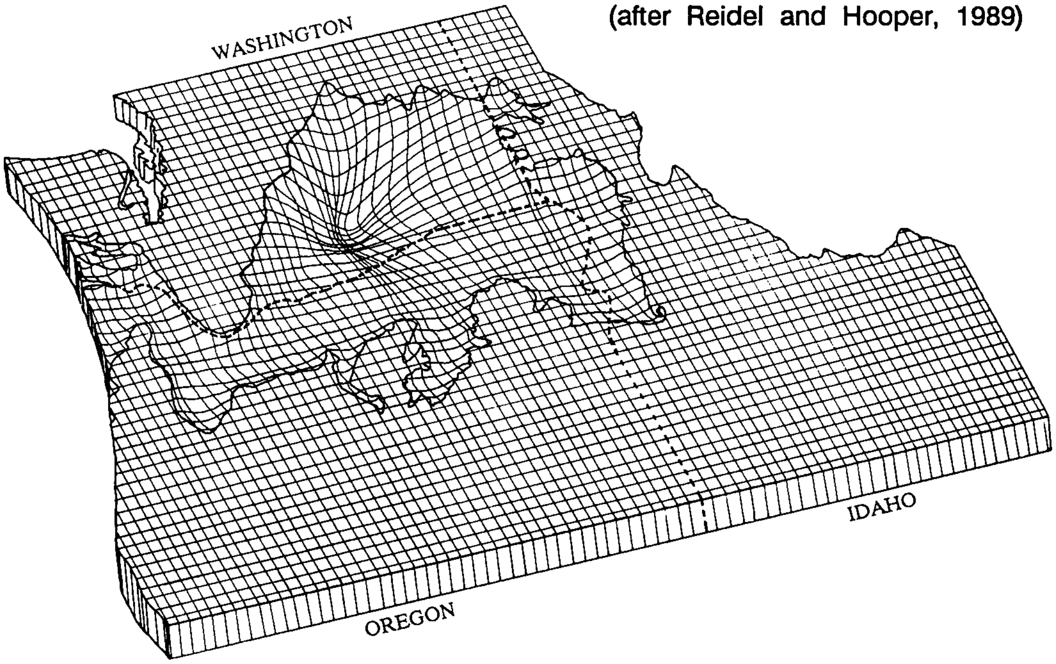
    - 3. Pleistocene
        - a. Cordilleran ice sheet
        - b. Missoula floods: backed up Deschutes, Willamette, and John Day
        - c. Loess along columbia in n-c oregon

- D. Structure
    - 1. three phase structural evolution
        - a. 17-10 my ago
            - (1) miocene basin and range extension (back arc spreading?)
            - (2) fissure eruptions in NE OR
            - (3) uplift of idaho batholith and regional westward tilting of columbia plateau
        - b. 10-4 my ago
            - (1) north-south compression
            - (2) Yakima fold belt
        - c. <4 my
            - (1) faulting in region
- E. Mining
    - 1. limited, basalt, basalt and more basalt
    - 2. local diatomite
- F. local geothermal (e.g. warm springs)

VIII. Cascades



Distribution of basalt formations within the Columbia River Group (after Beeson and Moran, 1979; Beeson, Tolan, and Anderson, 1989)

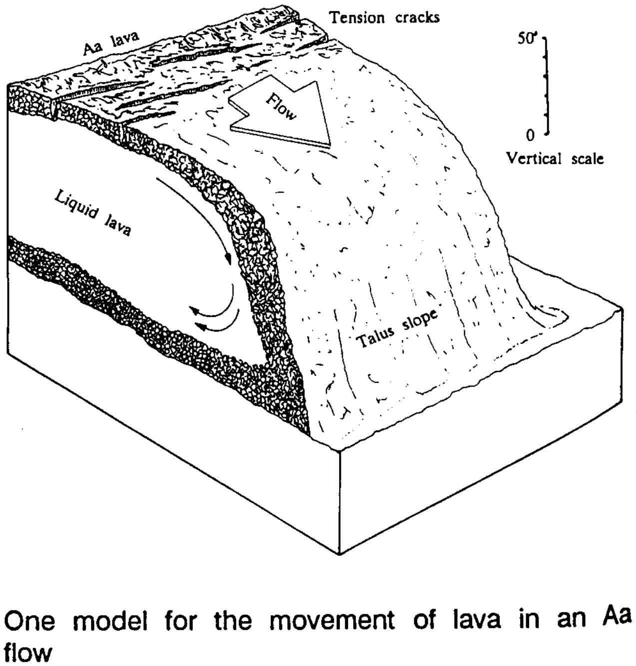


The Columbia River Basalt Group develops its maximum thickness of nearly 15,000 feet under the Columbia Plateau near Yakima, Washington (after Reidel and Hooper, 1989)

unable to push through the mound of hardened, rough rock along the edges, comes to a stop, essentially dammed up by its own cooled crust.

The relationship between the Columbia-Deschutes Plateau and the surrounding provinces is unclear because thick lavas obscure the deep crust which has not been well-studied. Crustal thickness in this province has been estimated between 15 to 20 miles. In the 1980s, a series of four wildcat wells were drilled through the lavas in the vicinity of Yakima, Washington, by Shell Oil Company. Targeted were Cretaceous and Tertiary rocks lying below the basalt along older anticlinal structures that were judged to have sufficient organic content and porosity to produce gas. Although the potential reservoir rocks were dry, rocks of the predicted formations were encountered by drilling deep beneath the basalt.

Of the four main formations making up the Columbia River lavas, the oldest is the Imnaha Basalt, followed by the Grande Ronde Basalt, the Wanapum Basalt, and finally the youngest Saddle Mountains Basalt, with the Grande Ronde composing more than 85% of the formations by volume. The Grande Ronde, Wanapum, and Saddle Mountains were formerly lumped together and designated the Yakima Basalts, but they are now distinguished by subtle differences in mineralogy and texture. Variations in magnesium oxide, titanium oxide, and phosphorus are also used to characterize individual flows.



One model for the movement of lava in an Aa flow

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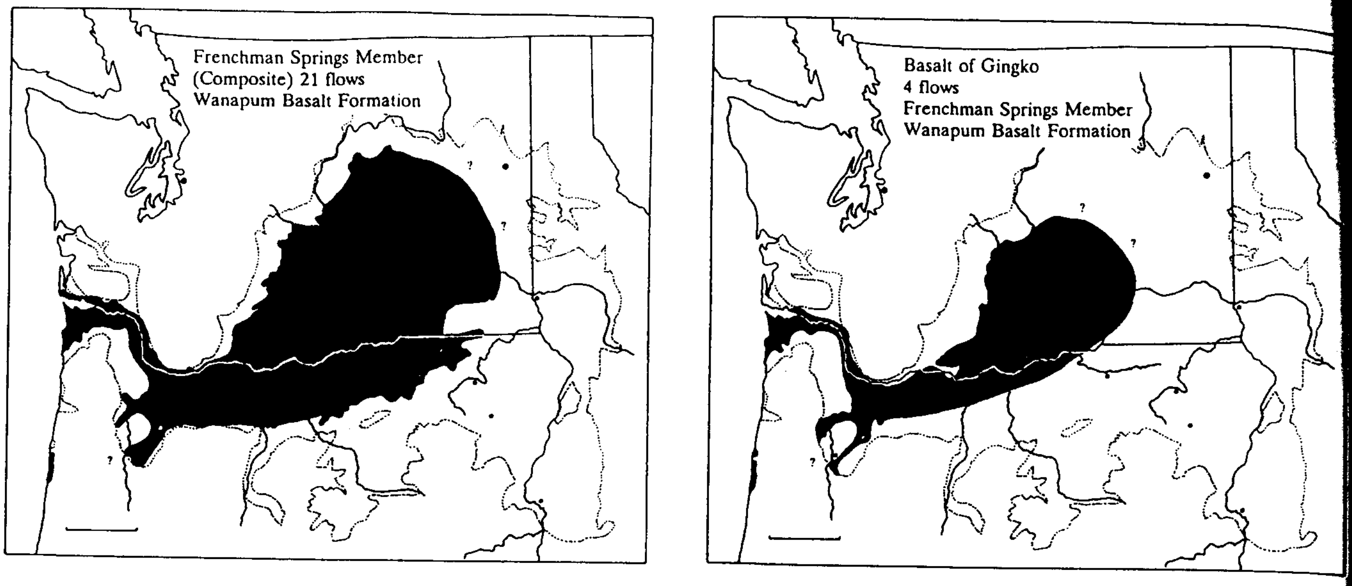
SERIES		GROUP	FORMATION	MEMBER	ISOTOPIC AGE (m.y.)
MIOCENE	UPPER	COLUMBIA RIVER BASALT GROUP	SADDLE MOUNTAINS BASALT	LOWER MONUMENTAL MEMBER	6
				Erosional Unconformity	
				ICE HARBOR MEMBER Basalt of Goose Island	8.5
				Basalt of Martindale	
				Basalt of Basin City	
				Erosional Unconformity	
				BUFORD MEMBER	
	MIDDLE			ELEPHANT MOUNTAIN MEMBER	10.5
				Erosional Unconformity	
				POMONA MEMBER	12
				Erosional Unconformity	
				ESQUATZEL MEMBER	
				Erosional Unconformity	
				WEISSENFELS RIDGE MEMBER Basalt of Slippery Creek	
				Basalt of Tenmile Creek	
				Basalt of Lewiston Orchards	
				Basalt of Cloverland	
				ASOTIN MEMBER Basalt of Huntzinger	13
				Local Erosional Unconformity	
				WILBUR CREEK MEMBER Basalt of Lapwai	
				Basalt of Wahluke	
				Local Erosional Unconformity	
				UMATILLA MEMBER Basalt of Sillusi	
				Basalt of Umatilla	
				Local Erosional Unconformity	
			WANAPUM BASALT	PRIEST RAPIDS MEMBER Basalt of Lolo	14.5
				Basalt of Rosalia	
				Local Erosional Unconformity	
				ROZA 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	
				Basalt of Palouse Falls	
				ECKLER MOUNTAIN MEMBER Basalt of Shumaker Creek	
				Basalt of Dodge	
				Basalt of Robinette Mountain	
				Local Erosional Unconformity	
			GRANDE RONDE BASALT	SENTINEL BLUFFS UNIT	15.6
				SLACK CANYON UNIT	
				FIELD SPRINGS UNIT	
				WINTER WATER UNIT	
	LOWER		PRINEVILLE BASALT	UMTANUM UNIT	
				ORTLEY UNIT	
				ARMSTRONG CANYON UNIT	
				MEYER RIDGE UNIT	
				GROUSE CREEK UNIT	
				WAPSHILLA RIDGE UNIT	
				MT. HORRIBLE UNIT	
			PICTURE GORGE BASALT	CHINA CREEK UNIT	
				DOWNEY GULCH UNIT	
				CENTER CREEK UNIT	
				ROGERSBURG UNIT	
				TEEPEE BUTTE UNIT	
				BUCKHORN SPRINGS UNIT	16.5
			IMNAHA BASALT	See Hooper and others (1984) for Imnaha Units	17.5

Basalt stratigraphy within the Columbia River Basalt Group (Beeson and Moran, 1979; Beeson, Tolan, and Anderson, 1989).

The oldest of the formations, the Imnaha Basalt, originated from vents and fissures along the Snake and Imnaha rivers in northeast Oregon, southeast Washington, and Idaho spreading along the Imnaha River in northeast Oregon. Following this 16.5 million years ago, large volumes of Grande Ronde basalts erupted with a frequency of one flow for every 10,000 years slowing to one flow for each 20,000 and 400,000 years for the Wanapum and Saddle Mountains lavas respectively. In a process that extended less than 1 million years, Grande Ronde basalts poured from fissures and cracks as much as 100 miles long in a complex network of openings in the crust known as the Chief Joseph dike swarm that extended from southeastern Washington and northeastern Oregon along a well-defined trend. Reaching westward all the way to the Pacific Ocean, many of the 120 individual Grande Ronde lavas spread out for as much as 460 miles and are among the most extensive on earth. Lava from these separate flows was so runny that it did not mound up to form volcanoes but rapidly filled in surface depressions to produce a flat topography. Following the Grande Ronde eruptions, 36 separate flows of the Wanapum lavas poured out over a 1 million year interval nearly covering the plateau, while the Saddle Mountains Basalt, with 19 flows, was mainly confined to the central part of the Columbia basin. To

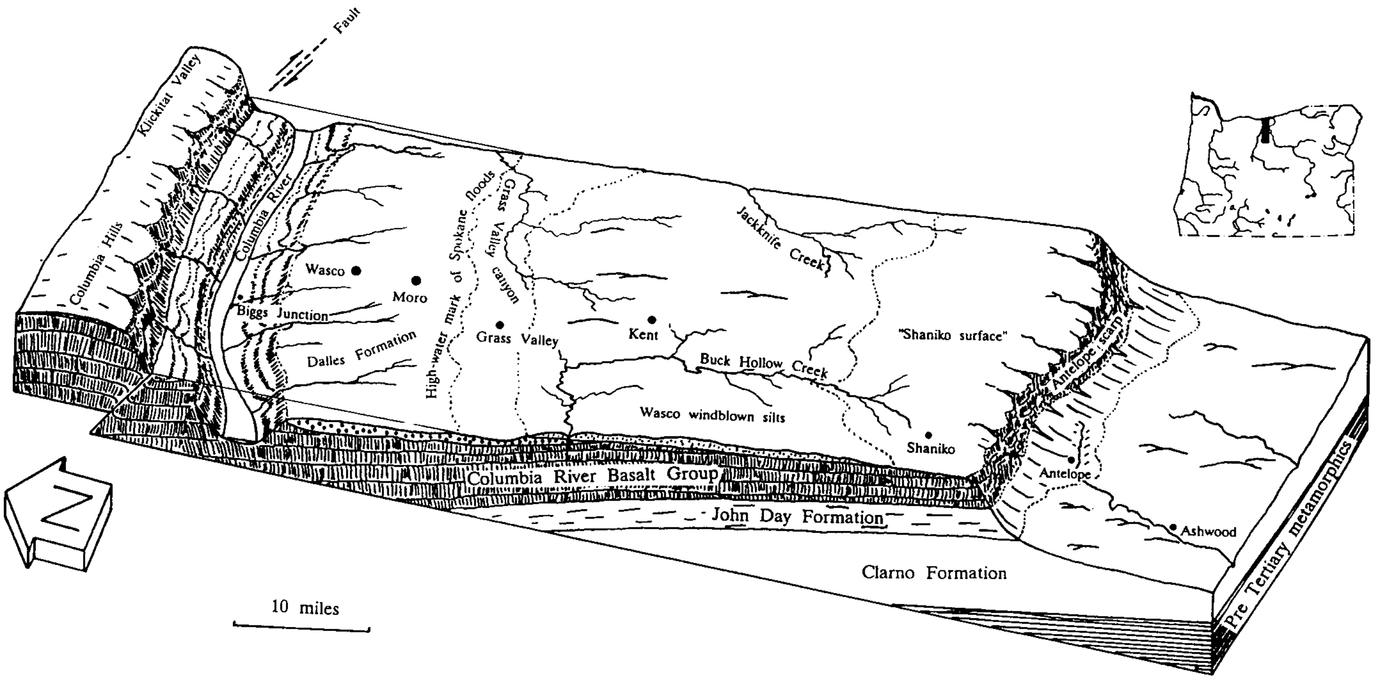
Dikes of the Grande Ronde basalt (photo courtesy Oregon Department of Geology and Mineral Industries).



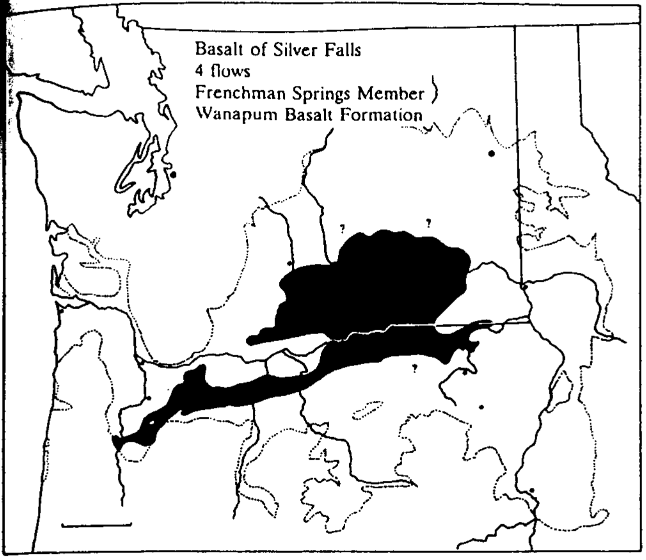
Geographic distribution of individual flows and members of the Columbia River Basalt Group (after Reidel and Tolan, 1989)

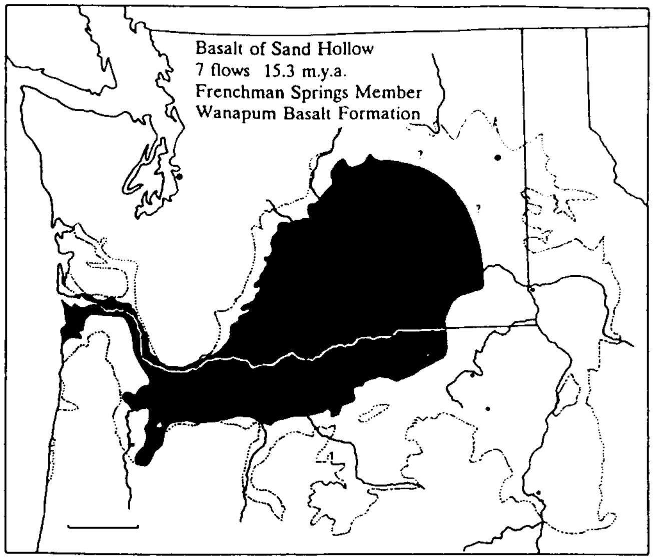
the south, widespread flows of the Prineville and Picture Gorge basalts in the Deschutes and John Day valleys correlate with the Grande Ronde Basalt, but differences in chemical composition of the three lavas distinguish them and indicate separate source magmas.

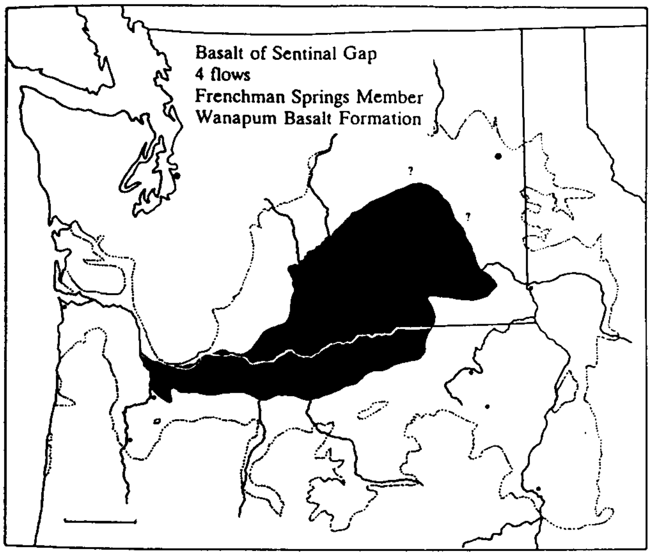
Prior to the extrusion of the Columbia River lavas, the channel of the ancestral Columbia River lay well south of its present course. Individual flows periodically swept into the canyon to plug and disrupt the drainage. As the frequent eruptions subsided, late Miocene and Pliocene compressional folding formed large-scale, east-west wrinkles that confined the river to its present course between Umatilla and The Dalles.

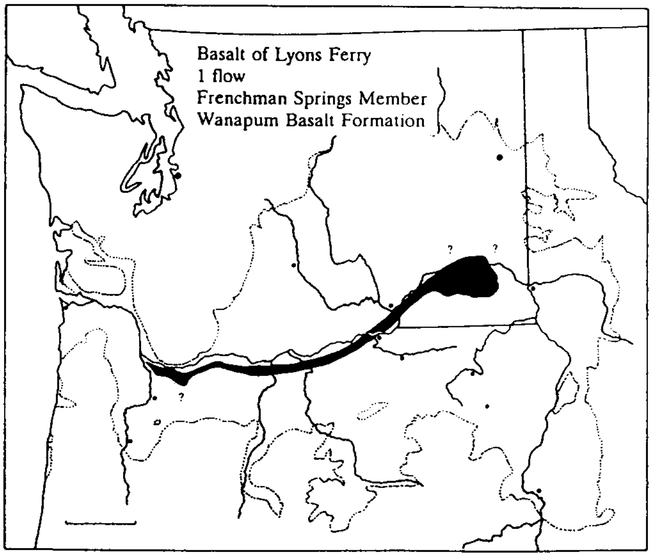


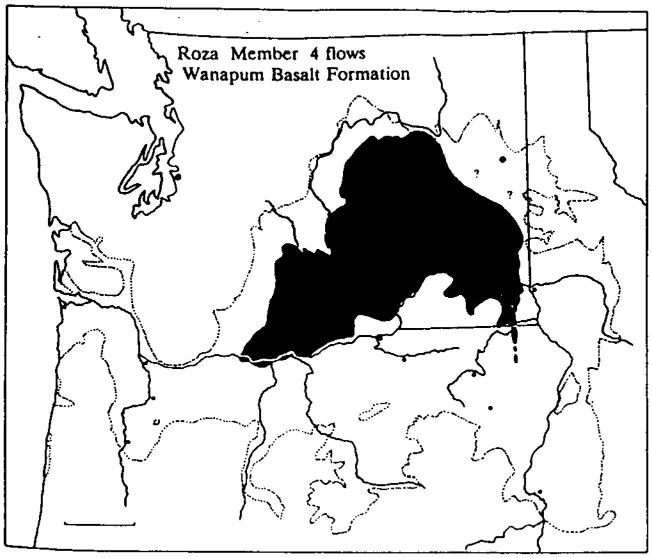
Block diagram across the Columbia River just east of The Dalles

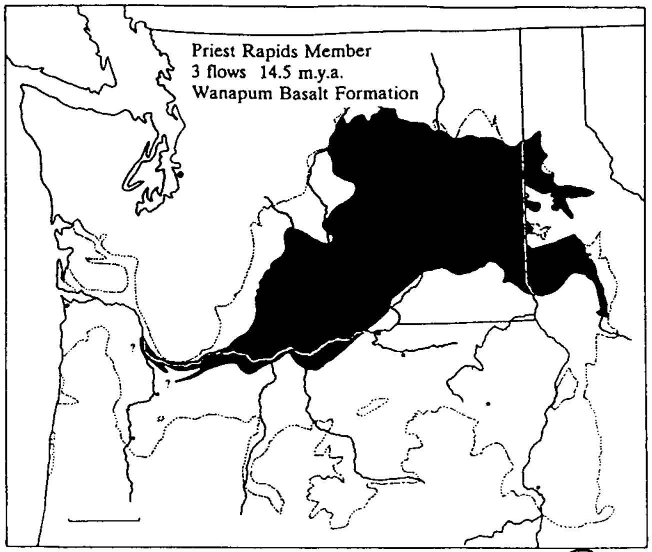

Basalt of Silver Falls
4 flows
Frenchman Springs Member
Wanapum Basalt Formation


Basalt of Sand Hollow
7 flows 15.3 m.y.a.
Frenchman Springs Member
Wanapum Basalt Formation


Basalt of Sentinal Gap
4 flows
Frenchman Springs Member
Wanapum Basalt Formation

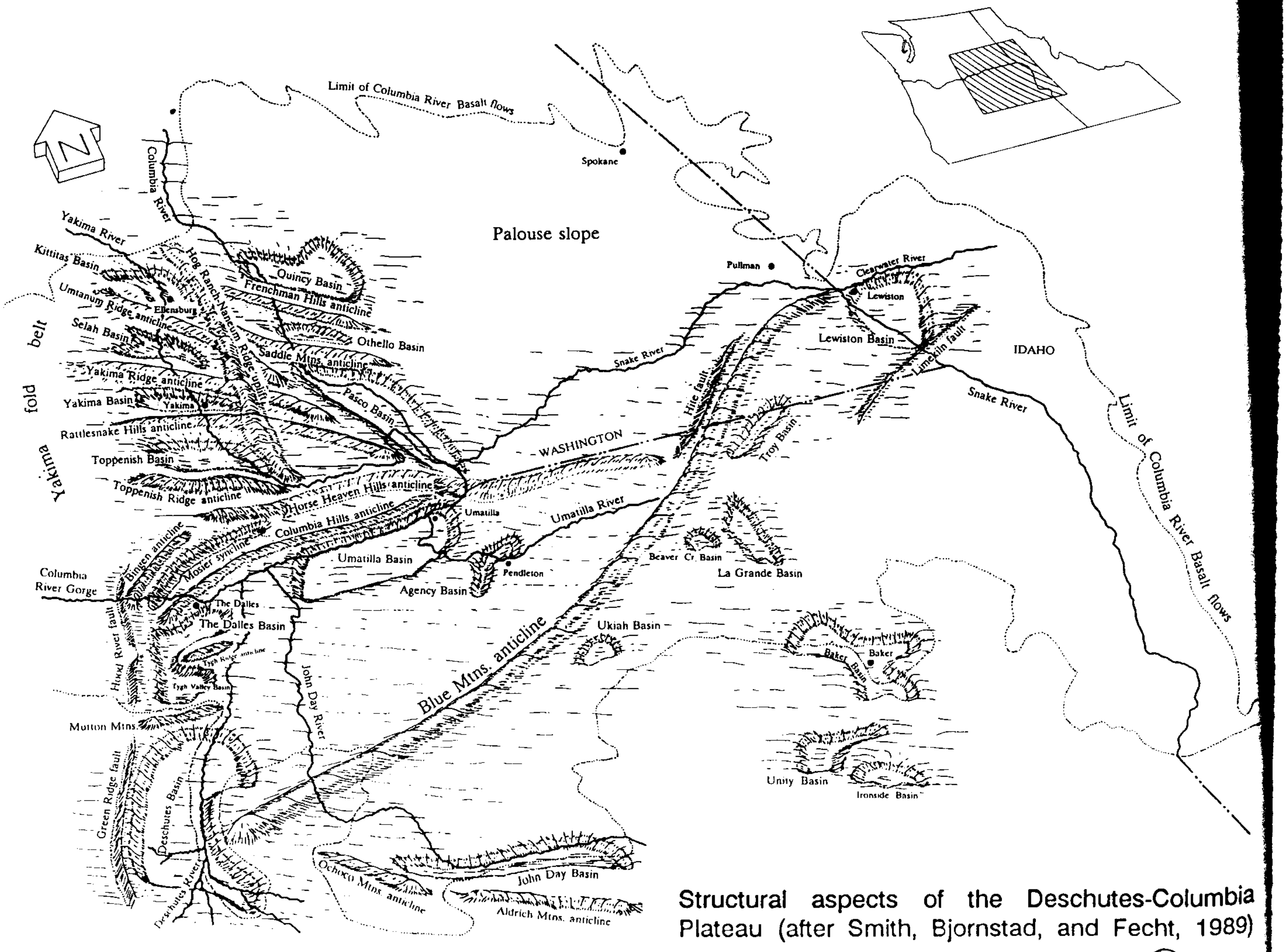

Basalt of Lyons Ferry
1 flow
Frenchman Springs Member
Wanapum Basalt Formation


Roza Member 4 flows
Wanapum Basalt Formation


Priest Rapids Member
3 flows 14.5 m.y.a.
Wanapum Basalt Formation

Because of the relative youth and thickness of the Columbia River basalts, rocks immediately below the Miocene lavas are still poorly known. In southeastern Washington small exposures of displaced rocks of the Wallowa terrane imply that this terrane extends far north of its main exposures in the Blue Mountains. Similarly, inliers of the basalt-covered Baker terrane occur well to the west of major exposures in the Blue Mountains. The extent and thickness of Cretaceous rocks as well as Tertiary Clarno and John Day formations, where they disappear under the southern edge of the plateau lavas, may be an indication that they too are much more widespread than presently known. Distinctive rock fragments found imbedded in flows of the Deschutes Formation may have been picked up by the lava as it worked its way to the surface. Although this evidence is tenuous, it suggests that accreted terrane rocks, as old as preCambrian, may be buried beneath the Cascade Range and Deschutes Basin.

Despite the thickness and extent of the lava the plateau is not entirely featureless. Over most of western section, low wrinkles and shallow dimples d the surface. One of the largest of these is the C-shaped Deschutes basin reaching into the southwest corner o the province. During the early Miocene, the basi received lavas and ash from vents of the Columbi Plateau and adjacent volcanoes of the Western Cas cades. Intermittent volcanic activity sent lavas floodin over the vast Deschutes basin, disrupting the flow o streams and rivers. Sediment-choked streams covered 100 square miles of the basin with thin layers o waterlain tuffs, sandstones, and mudstones of the Simtustus Formation. Sedimentation was rapid, and the shallow basin filled with Simtustus deposits up to 250 feet thick. Once designated as part of the Deschutes Formation, volcanic sediments of the older Simtustus Formation are lithologically distinct from the coarse conglomerates of the younger Deschutes. Simtustus rocks are highly significant as they were laid down during emplacement of the Columbia River flows 16 to 12 million years ago.



Structural aspects of the Deschutes-Columbia Plateau (after Smith, Bjornstad, and Fecht, 1989)

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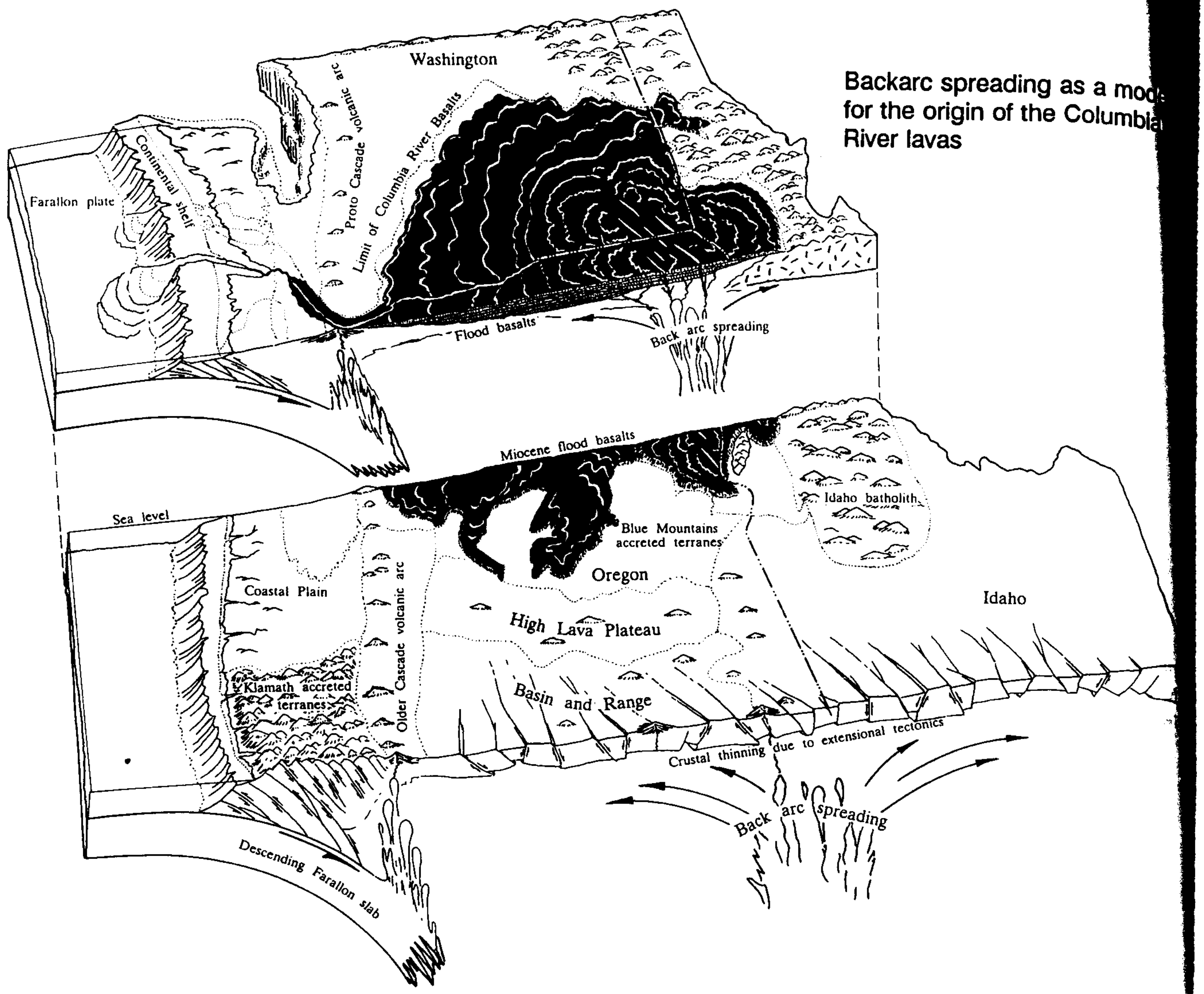

Backarc spreading as a mo
for the origin of the Columbi
River lavas

duced the northeast-southwest trending Blue Mountains anticline or arch. Where the Columbia River bisects the central plateau, a number of surface folds run east-west, corresponding to north-south compression. The Columbia River follows one of these wrinkles as it traverses the axis of a major downwarp, the 160-mile long combined The Dalles-Umatilla basins from Wallula Gap to The Dalles. Further east, the Blue Mountains anticline turns north at Meacham, Oregon, to merge and run parallel to the Klamath-Blue Mountains lineament. In Washington, the Columbia Hills and hills of Horse Heaven anticlines follow The Dalles-Umatilla syncline to intersect the Hite fault just south of Milton-Freewater.

Beneath the plateau, major structural features or lineaments converge. These extensive features can be seen in aerial photographs, but they are not obvious at ground level, and what caused them is uncertain. The Klamath-Blue Mountains lineament runs across the state in a southwest by northeast direction, intersecting the Olympic-Wallowa lineament near Wallula Gap on the Columbia River, while the Olympic-Wallowa lineament runs southeast by northwest from Puget Sound across Washington through the Oregon Blue Mountains to the Idaho border. Cutting directly across the Olympic-Wallowa lineament, the Hite fault system trends southwest by northeast.

With phase two between 10 and 4 million years ago, the spreading direction of the Pacific plate rotated 25 degrees clockwise to a more southwest by northeast direction. At this time intense compression produced a series of east-west wrinkles in southcentral Washington and in the vicinity of the Columbia River. Most of the visible folds in plateau lavas along the Columbia, including the Yakima fold belt, Horse Heaven anticline, and Columbia Hills anticline, are related to this

CASCADES

A. Physiography
- 1. western cascades (older, deeply eroded)
  - a. 1700-5800 ft el.
  - b. 60-100 in rain /yr
- 2. high cascades to east
  - a. up to 11,000 ft el
- 3. west side rivers = high discharge
- 4. east side rivers = minimal

B. Geologic Overview
- 1. late Eocene - Oligocene (~40 my ago)
  - a. coastal shoreline at present position of Willamette Valley
    - (1) shallow marine sedimentation (spencer fm, etc.)
  - b. western Cascade volcanism
- 2. Cascade arc migration
  - a. younging and shifting to east throughout late Tertiary
  - b. western cascades tilted westward, creating rainshadow to east (by 5 m.y. ago)
- 3. High Cascades Volcanism
  - a. basalts, basaltic andesite
  - b. cascade trough graben development
- 4. Pleistocene glaciation of High Cascades

C. Bedrock Geology

- 1. Eocene-Oligocene
  - a. subduction of Farallon-NAM plate
    - (1) coastline in Willamette Valley (forearc basin)
    - (2) continental shelf deposits, volcaniclastics into forearc

- 2. Oligocene-Miocene
  - a. western Cascades volcanics
  - b. volcanic arc migrating eastward
    - (1) via flattening of plate
    - (2) most voluminous volcanic production in western cascades, volume has decreased as arc shifts to east
  - c. western Cascade uplift, folding, faulting at 4-5 m.y.
  - d. Miocene arc volcanism in cascades coeval with Miocene CRB's and Steens Basalt in other parts of Oregon
  - e. Miocene westward tilting of western Cascades = creates primary rainshadow effect
    - (1) uplift and incision of western Cascades, to present day

- 3. Pliocene / High Cascades (5 m.y to present)
  - a. early High Cascade volcanism (6 - 5 my)
    - (1) basalts, tuffs, ash flows
    - (2) shiled volcanoes / cinder cones
  - b. late High Cascade volcanism (4 my to present)
    - (1) composite cones constructed on early High Cascade shield volcanic complexes

- (2) basalt = 85% of Quaternary High Cascade volcanics
- c. extension and volcanism = central High Cascades graben
  - (1) volcanic loading + subsidence
  - (2) graben development from Miocene to Pliocene (5-10 my)

4. Recent Volcanism
   - a. general absence in historic times
     - (1) Mt Hood and South Sister show most activity in OR
   - b. Juan de Fuca plate = slab dip ~65 degrees, with slab ~ 70 mi beneath Cascades
5. Pleistocene
   - a. alpine glaciation in high cascades, limited glaciation in western cascades
   - b. snow+ice+ash = lahars
   - c. cascade lakes = product of moraine dams, lava dams, or landslide dams
   - d. today: local glaciers,not widespread (Mt. Hood, Sisters)

D. Mining
1. western Cascades gold and silver districts, + sulfides
   - a. ores occur in veins cross-cutting older volcanics
   - b. hydrothermal fluids / shattered breccias
   - c. faults and fractures serve as conduits

E. Geothermal resources
1. High Cascades = thermally active, western side of High Cascades
   - a. fault-controlled springs

F. Other features
1. Columbia river gorge
   - a. cuts through cascades
   - b. long history of lava dams, ice dams, landslide dams
   - c. in general, Miocene lava flows of CRB, pushed the trace of the Columbia northward over time
2. Recent High Cascades Volcanism
   - a. Mt Hood
     - (1) 15,000 yr ago eruptions
     - (2) 1000-2000 yr ago eruptions
     - (3) 200-300 yr ago eruptions
   - b. Mt Bachelor
     - (1) 2000 to 18,000 yr ago eruptions
   - c. Belknap Crater
     - (1) 1600 yr lava flows
   - d. Crater Lake
     - (1) 6900 yr mazama eruptions
       - (a) primary silicic eruption, ash flows
       - (b) empty magma chamber
       - (c) caldera collaps / release
     - (2) 1900 ft deep lake
   - e. In general, High Cascade volcanoes <500,000
     - (1) sharp crested peaks = glaciated

IX. Coast Range

A. Physiography
1. crest elevation averages 1500 ft, highest pt = Marys Peak at 4100 ft

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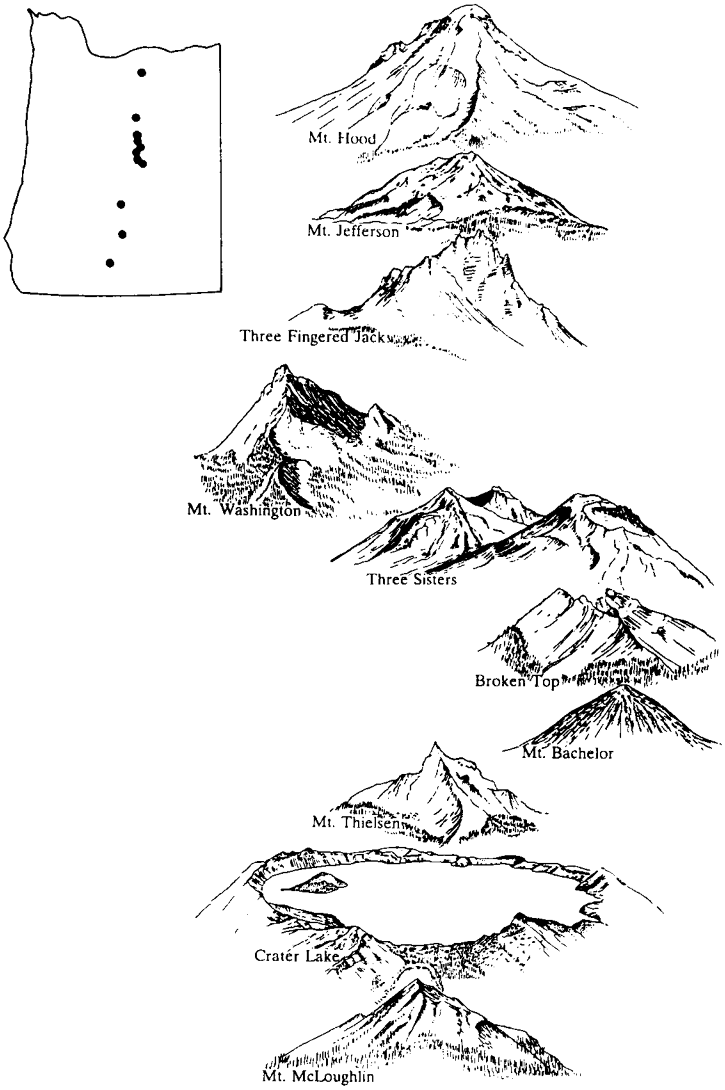


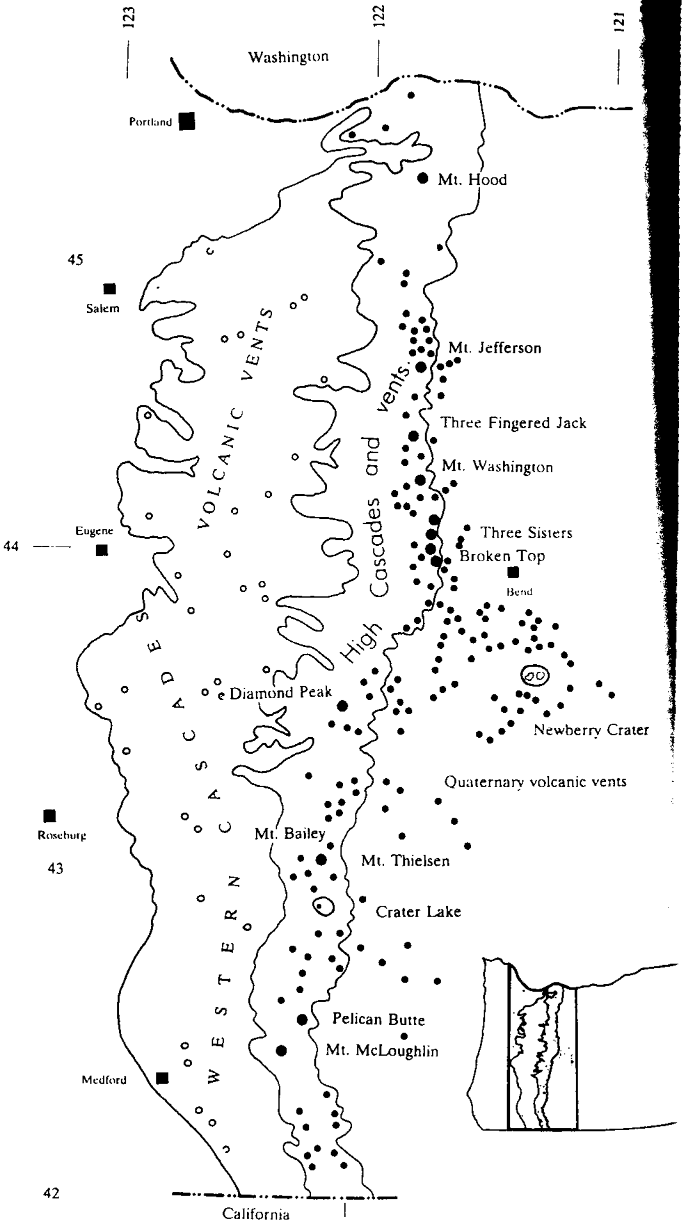
Significant volcanic peaks of the Cascade Range

less noticable, eroded Western Cascades. With extensive outpouring of basaltic lavas, the region beneath the volcanoes continued to sink, creating a series of troughs or grabens that extend most of the length of the range. Recent volcanic activity in the province took place as late as 200 years ago when black cindery lava flowed out on the flanks of the younger peaks.

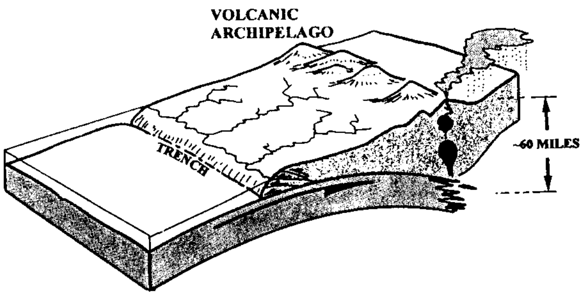
The Ice Ages of the Pleistocene brought glaciers to the range, with ice carving out glacial valleys, daming lakes, and eroding the sharp serrated crests of Mt. Washington, Three Fingered Jack, Mt. Thielsen, and Mt. McLoughlin. Glacial ice is still an active geologic agent at many of the higher elevations.

Geology

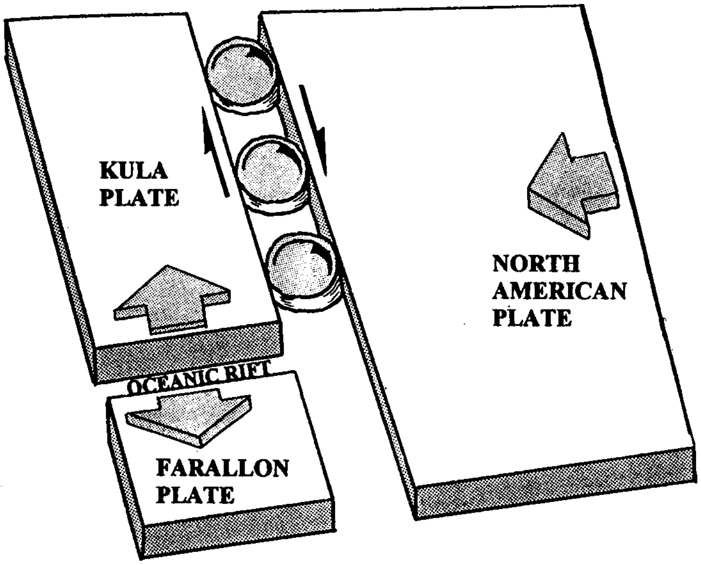
Construction of the Oregon Cascade range began with Eocene volcanism that was triggered by subduction of the Farallon plate beneath the North American crustal plate. The early volcanism took p in several stages beginning with lava flows fro volcanic chain lying immediately to the east of Pacific continental margin. As far back as 40 milli years ago, a number of small low volcanoes, irregula spaced along a northwest-southeast belt in the regi of eastern Oregon, deposited a thick accumulation andesitic tuffs and lava flows that formed the base the Western Cascade mountains. The broad width



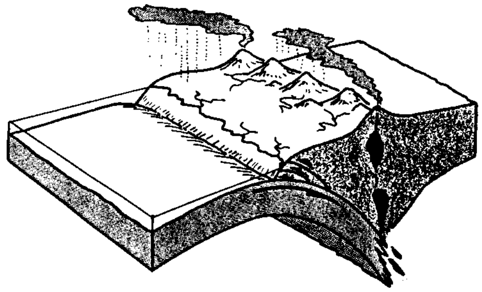
Volcanic vents in the Western and High Cascades (after Peck, et al.,1964; Priest, et al., 1983)



The distance between the subduction trench and volcanic archipelago is believed to be a function of the relative age of the crust being subducted and the rate of plate movement. Young, warm crust moves rapidly, is buoyant, and assumes a low angle of subduction with considerable distance between the arc and trench. Older, cooler crust moves more slowly, is less buoyant, and droops at a pronounced angle upon subduction bringing the arc very close to the trench.



As an alternative to the entire Coast Range block swinging like a clock hand, the "ball-bearing" model accommodates the measured rock magnetic rotations by a simple rifting mechanism [after Wells and Heller, 1988].

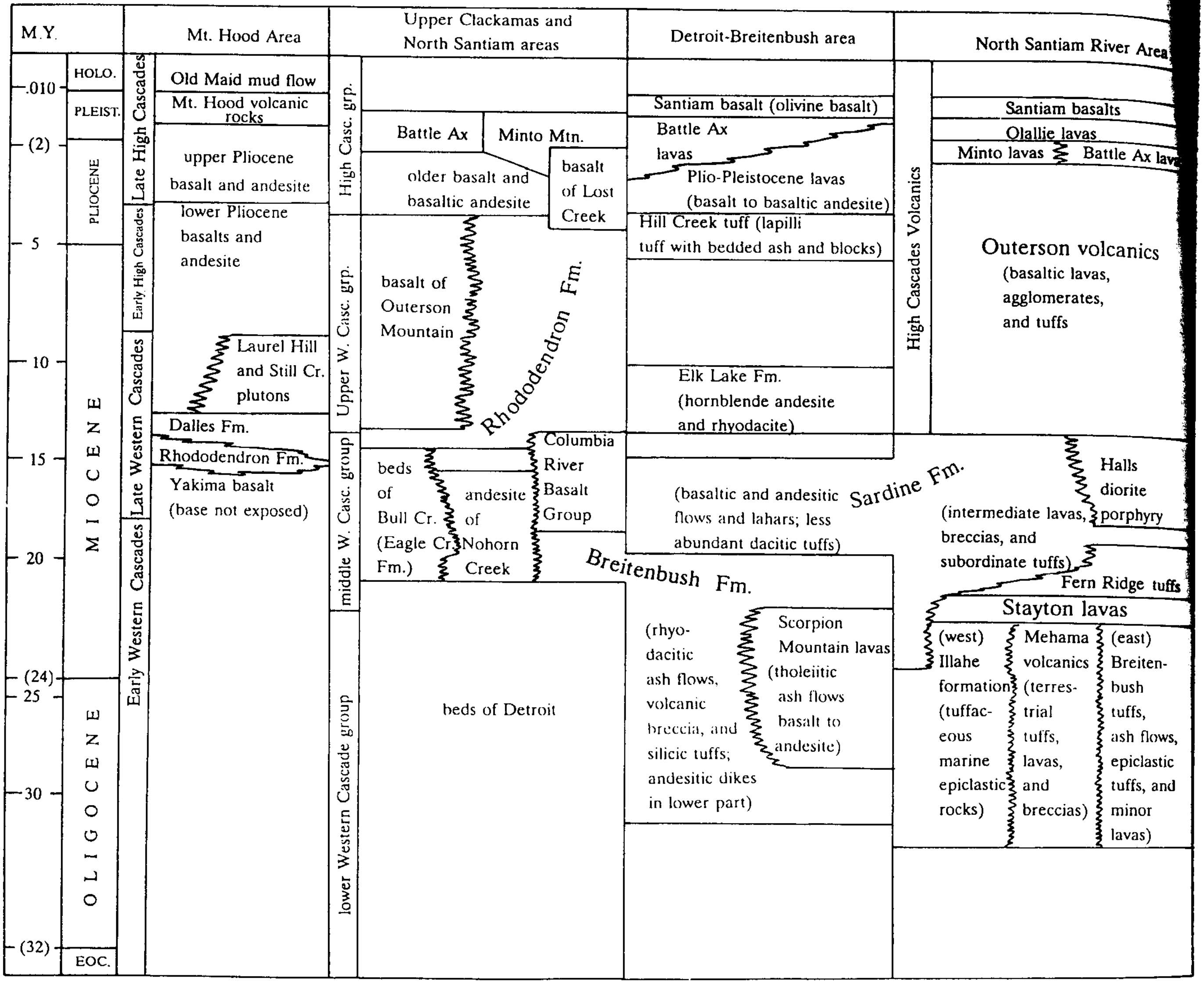


this proto-Cascade volcanic belt suggests that the underlying subducting slab was at a shallow angle and that the rate of collision between the North American and Farallon plates was rapid.

Today the origin of the Cascade range is still not well understood. One suggestion for the growth of the range is that a volcanic chain above an actively subducting ocean trench developed behind a slowly rotating Coast Range tectonic block. Breaking loose from the mainland along the Olympic-Wallowa lineament, the block rotated almost 50 degrees clockwise with a pivotal point in the northern Washington Coast Range to its present position. An alternate proposal is that Cascade volcanism was produced by a steepening subducting slab due to a marked decrease in the convergence rate between the North American and Farallon plates.

enozoic

During the Eocene and Oligocene epochs the astline angled northwest by southeast through the area of the Willamette Valley and just to the west of the volcanic vents along the Cascade archipelago. Volcanic ash from the vents was flushed by streams into shallow marine basins along the coast where thick forests of tropical to subtropical plants on the low coastal plain are now preserved as wood, leaves, and pollen. Coal-producing swamps and estuaries formed the alluvial deposits of the Colestin Formation, the oldest rocks in the Cascades. Nonmarine volcanic tuffs, sandstones, breccias, and lava flows of the Colestin reach a thickness of over 4,000 feet along the Cascades from Lane County south to California. From Eugene northward to Molalla, upper continental shelf sands and silts were the final marine sediments to be deposited along the retreating ocean shoreline. Molluscs and a variety of other invertebrates preserved in these rocks of the Eugene, Illahee, and Scotts Mills formations reflect warm subtropical to temperate waters. Broken, worn fossil fragments in some areas testify to stormy coastal conditions, while local accumulations of barnacle shells are so rich in many of these near-shore

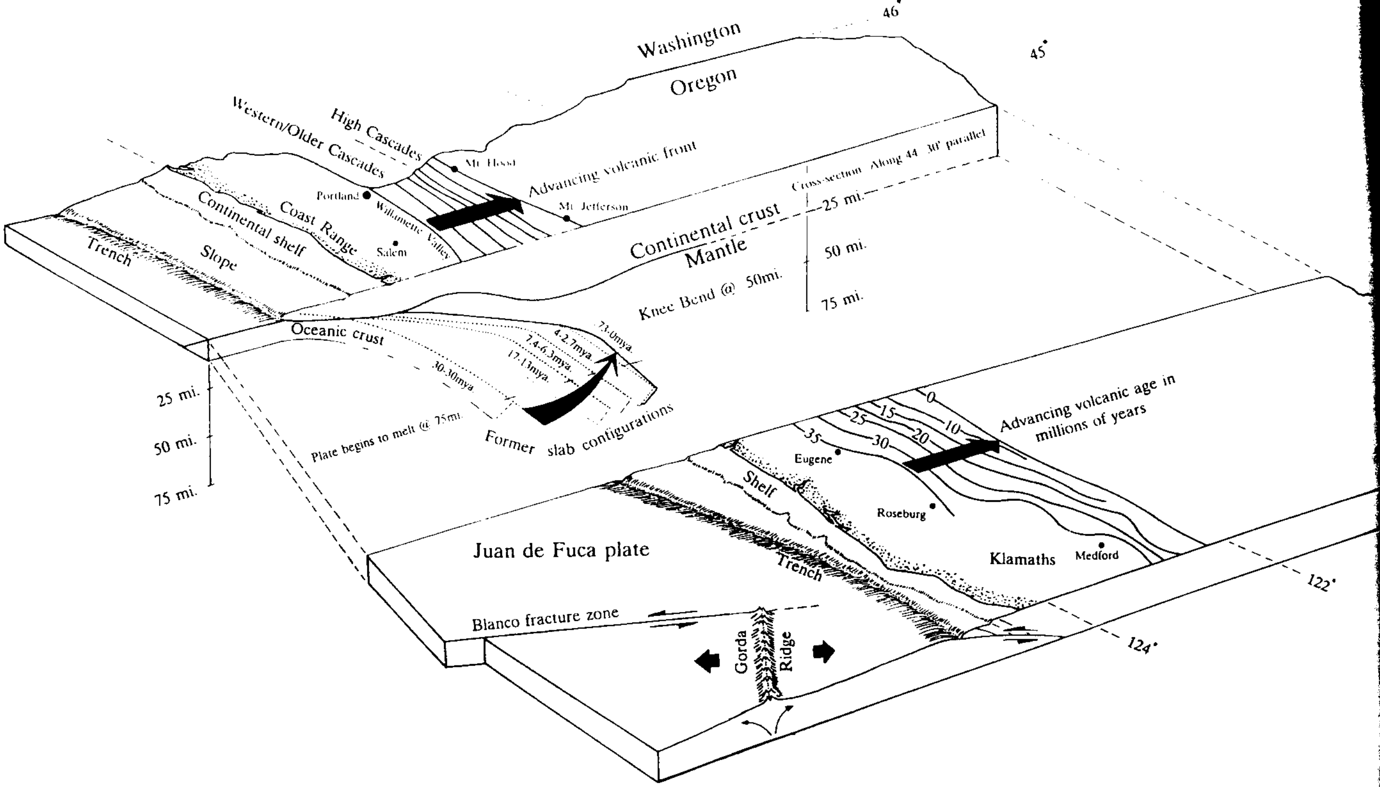


Cascades Stratigraphy (after Priest and Vogt, 1983)

sediments that they built up limestone lenses marking the old shoreline on the eastern margin of the Willamette Valley. By Oligocene time numerous eruptions of andesitic lavas and siliceous tuffs of the Little Butte Formation were interspersed with oceanic sediments along the eastern margin of the valley.

Western Cascades

A period of tilting and folding during the middle Miocene was followed by renewed outpourings of lavas throughout Oregon accompanying the growth of the Western Cascades volcanic arc. Even with a large volume of volcanic debris, the growth of the range was modest as the accumulation sank almost as fast as it piled up. About the same time voluminous quantities of the Columbia River Grande Ronde basalts began to flow from fissures near La Grande about 17 million years ago. These massive flood basalts blanketed the landscape filling in depressions to produce an even, flat platform of cooled lavas. The eruptions were synchronous in part with volcanic activity taking place in eastern Oregon in the Strawberry Mountains as well as in Steens Mountain. Concurrently in the Western Cascades violent eruptions from composite cones active between 13 and 9 million years ago comprise the Sardine Formation.The combined amount of all this volcanic material has no modern counterpart. By 7 million years ago the belt of active volcanoes had narrowed to an area only slightly wider than the present High Cascade Range.



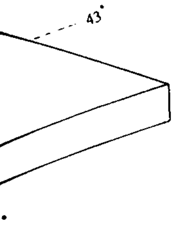
In order to explain the simultaneous eastward advancement and narrowing of the Cascades volcanic front, a popular synthesis calls for a "knee-bend" in the subducting slab that is swinging upward (after Priest, 1990; Duncan and Kulm, 1989; Verplanck and Duncan, 1987).

uplift, what was once a moist tropical climate in the eastern part of the state was transformed to the high desert environment of today. The uplift was accompanied by intensive downcutting by streams and erosion of the mountains so that today the older Cascades display deeply cut ridges of resistant lava rather than the rounded volcanoes that once existed.

Concurrent with and resulting from High Cascade volcanic activity was the formation of structural grabens, lying within the eastern margin of the Cascade range. The word "graben" derives from the German "grave" and refers to the sunken trough of earth above a collapsed buried coffin. Structurally a graben is a lowered block sitting between two faults. Beneath much of the younger High Cascades enormous, discontinuous grabens, 10 to 20 miles wide, extend for 300 miles from north to south. In the central Cascades, where volcanoes are densely clustered, both the east and west sides of the graben are well-developed. At the northern and southern borders of the state, where volcanoes are more sparce, the graben is either incomplete or only a "half" graben. Movements of the various faults that make up the east and west sides of the trough are estimated to have dropped down an average of 2,000 feet. The sinking of the grabens, which began between the late Miocene and very early Pliocene, 5 to 10 million years ago, has continued well into the late Pliocene. Collapse of the grabens followed the eruptions of volcanoes pumping out magma that left many chambers beneath the area. With the outpouring of basalts and growth of broad shield volcanoes, the heavy volcanic "loading" of the incipient High Cascades may also have contributed to the downward rupture of the grabens.

The Cascade ranges are still too young for erosion to have extensively exposed the batholiths that fed the volcanic eruptions. The siliceous composition of some of the High Cascade volcanoes, however, suggest that these chambers of magma were close to the surface because the highly viscous, molten rock, which forms the massive batholiths, has difficulty travelling upward very far into the crust before cooling. Although these intrusive bodies should theoretically be present at shallow depths beneath the High Cascades, geophysical probes of the range suggest the source magmas are deeper in the lower crust and upper mantle.

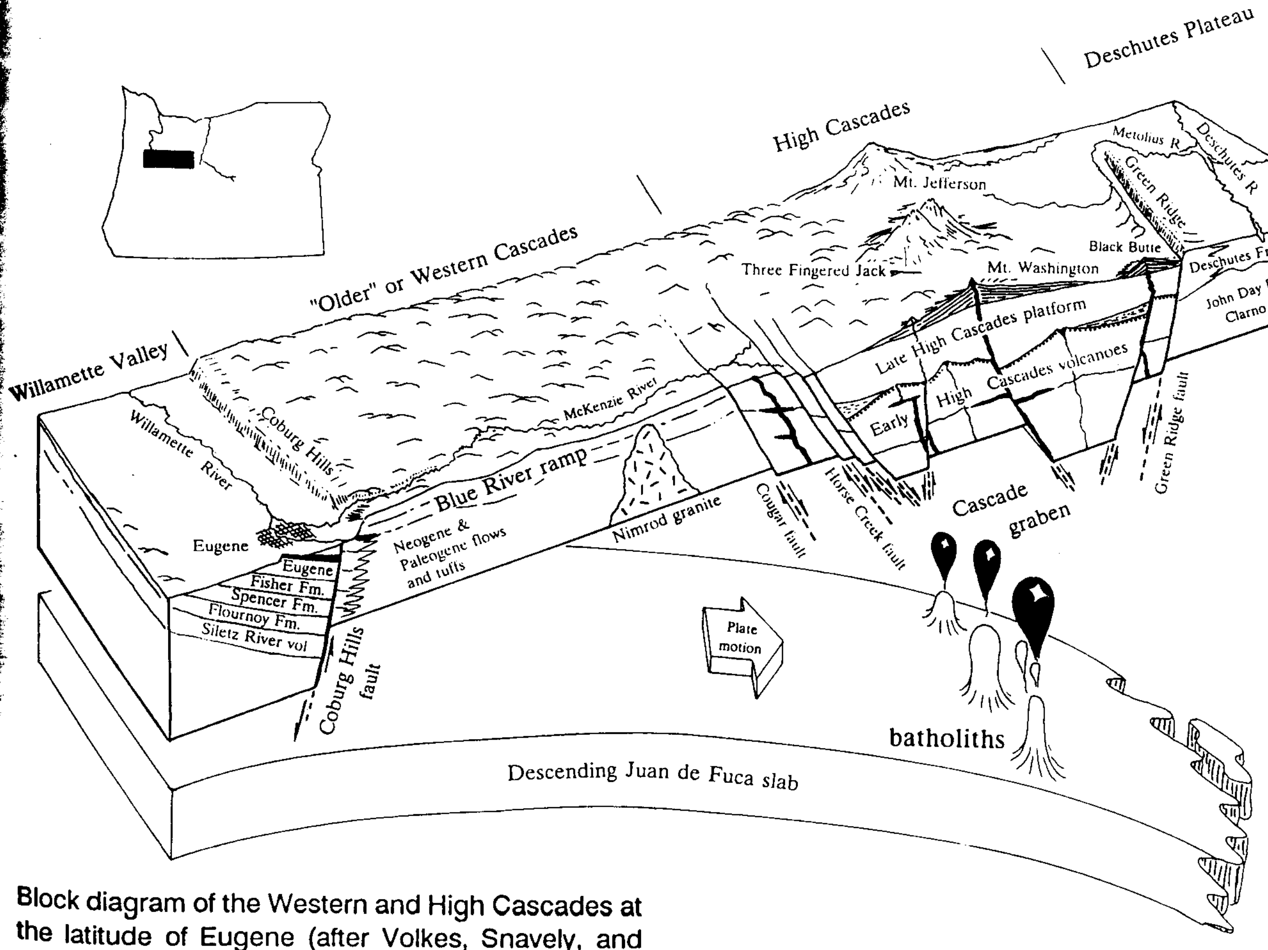
Within the Western Cascades, intrusive batholithic rocks are situated in two north-south belts running from Canada across Washington and Oregon. Having been emplaced between 35 and 15 million years ago, the western belt, through Mount St. Helens and nding near Portland, is younger. The eastern belt, hich cooled between 50 and 25 million years ago, tretches approximately 45 miles east under Mt. Adams and south through Mt. Hood and into southern Oregon.



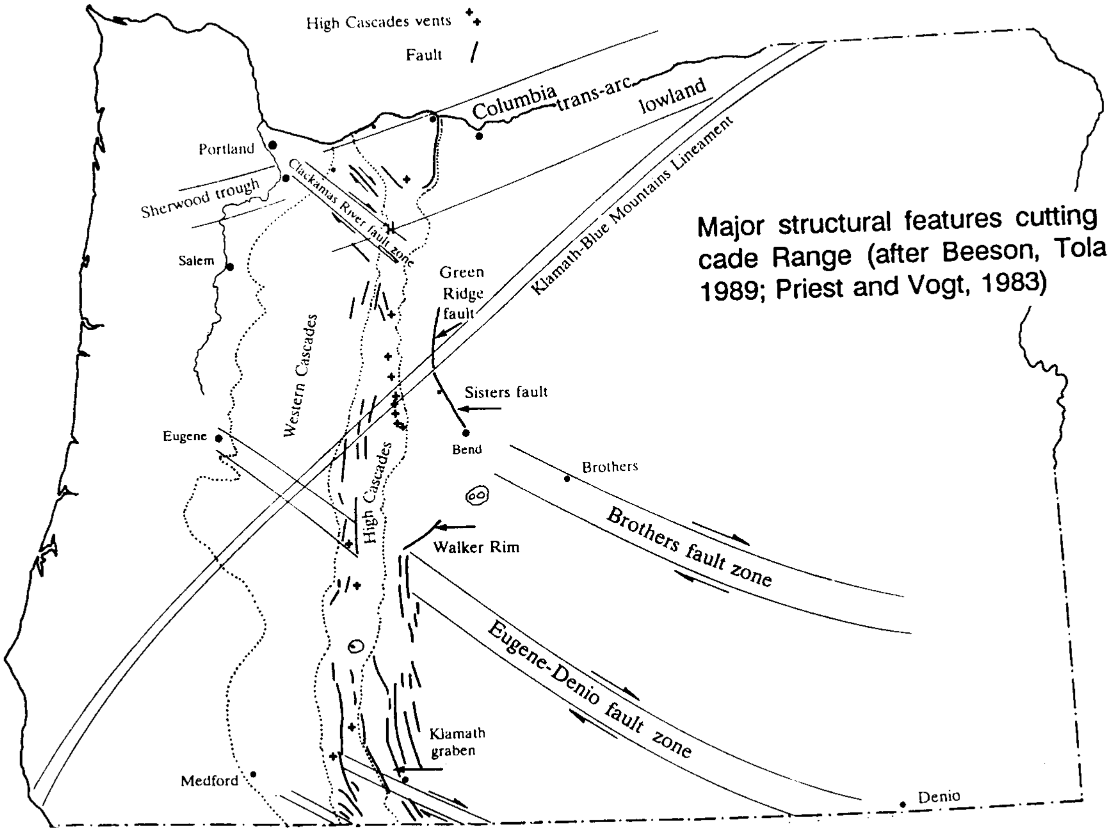
The eruptive history of Cascade volcanoes has followed a loose pattern over the past 20 million years. Since the middle Miocene, major events, each continuing for short periods of only 1 to 2 million years, have occurred at 5 million years intervals. There is evidence that these volcanic episodes in the Pacific Northwest correspond with global volcanism taking place at the same time. World-wide, shorter periods of volcanism were interspersed with longer periods of relative inactivity. The magnitude of volcanism and volume of extrusions has been decreasing steadily since the middle Miocene.

Recent Volcanism

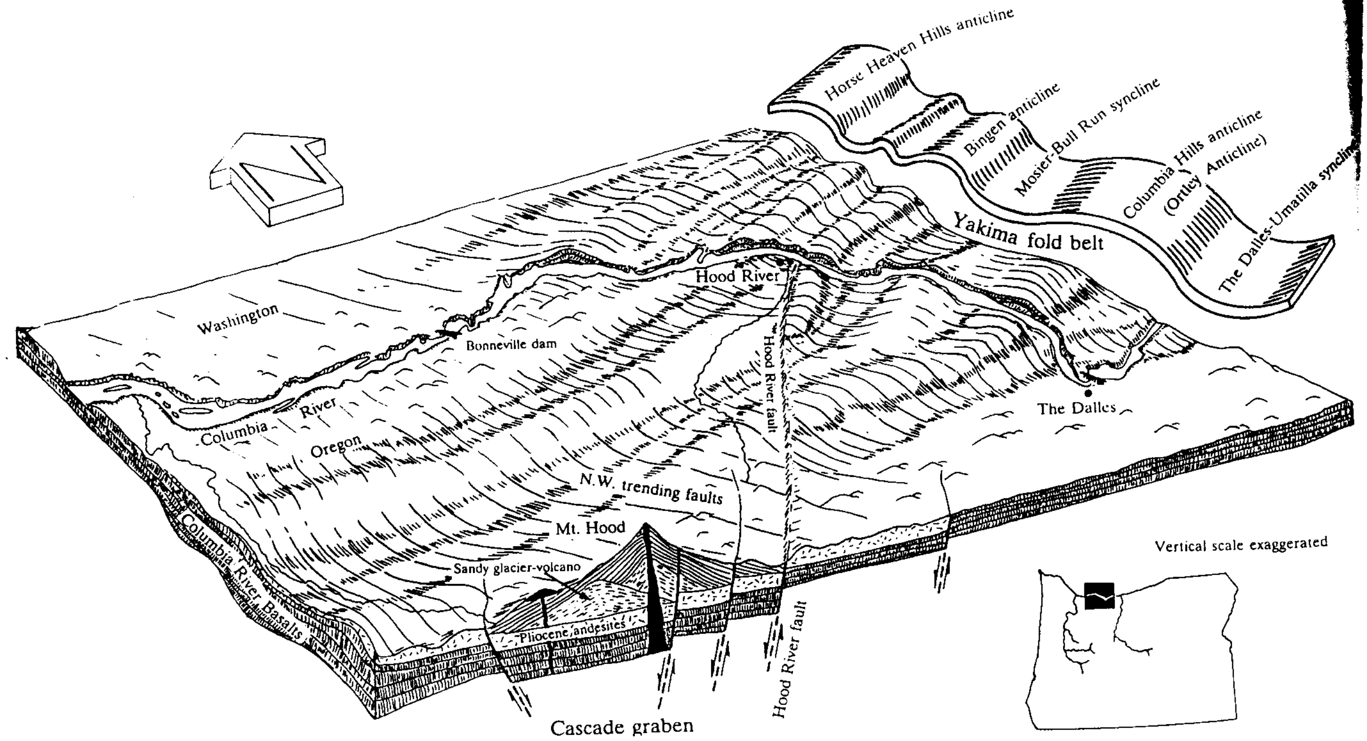
Dramatic eruptions have been absent in Oregon in the 20th century, although at least eleven volcanoes in the entire Cascade range, where it extends north into Washington and south into California, have been active historically. In Oregon Mt. Hood and the South Sister have signalled volcanic activity recently. As in the past, Cascade volcanism today is due to colliding tectonic plates. The Juan de Fuca plate



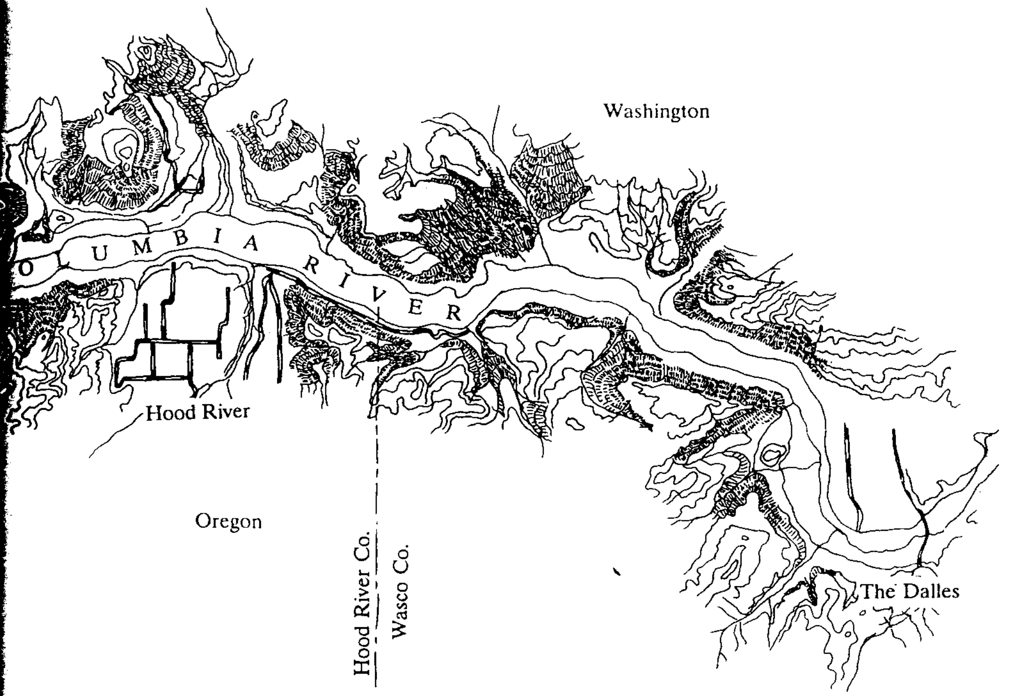
Block diagram of the Western and High Cascades at the latitude of Eugene (after Volkes, Snavely, and Myers, 1951; Gandera, 1977; Taylor, 1990)



Major structural features cutting through the Cascade Range (after Beeson, Tolan, and Anderson 1989; Priest and Vogt, 1983)



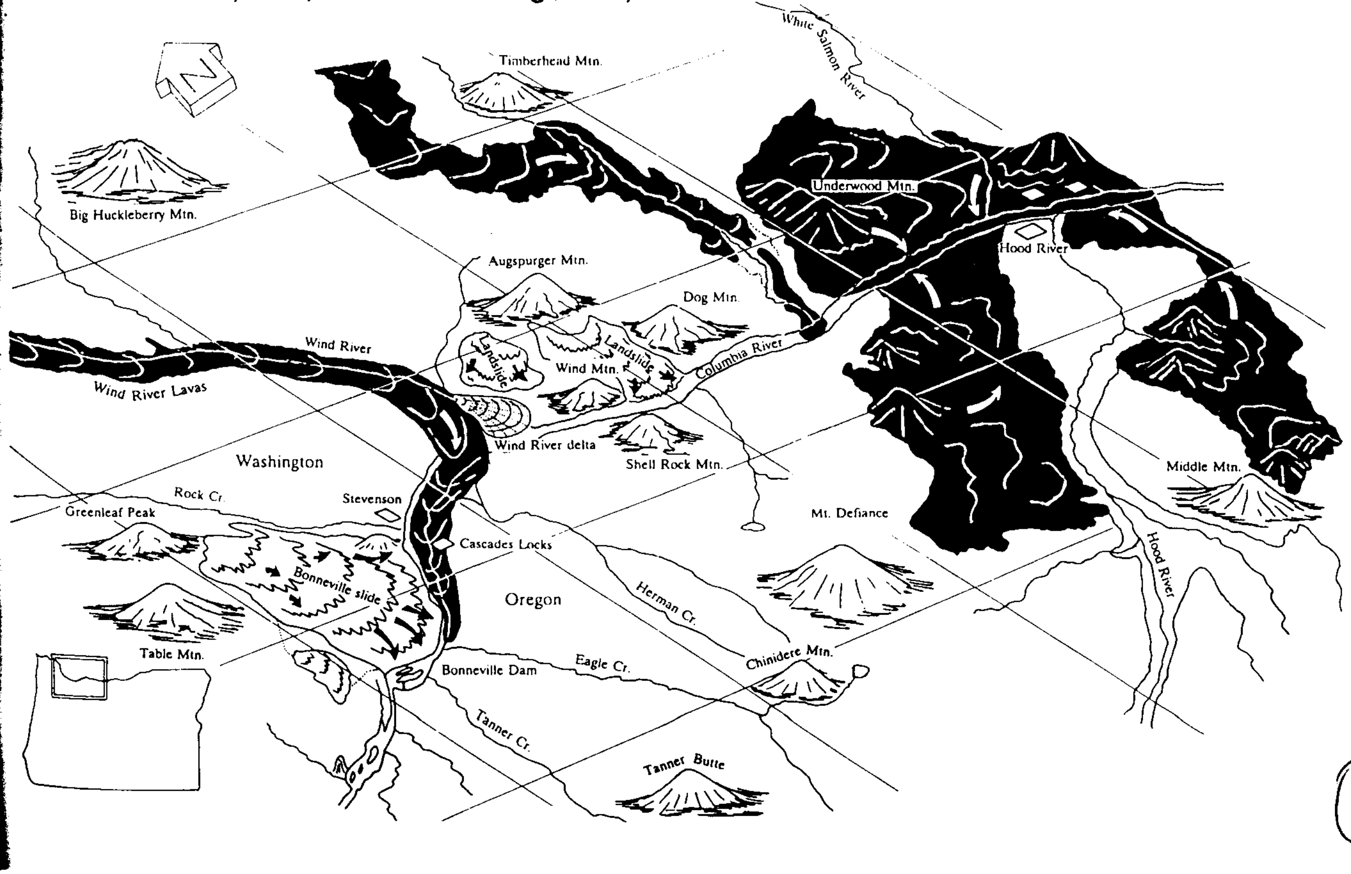
Yakima fold belt and Mt. Hood structure in the Cascades (after Williams, et al., 1982; Tolan and Beeson, 1984)



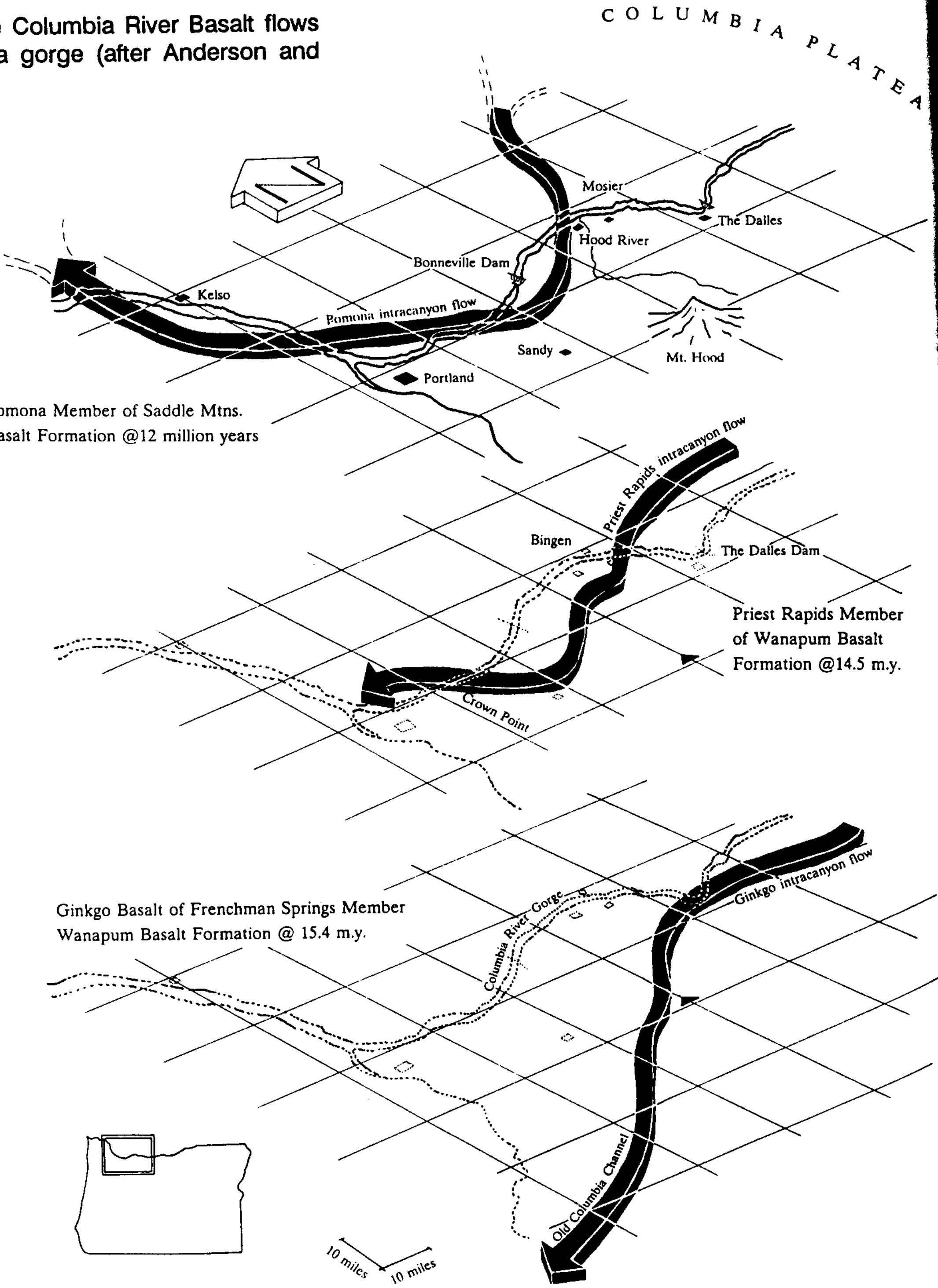
Multnomah Falls

The Columbia River gorge is lined with 71 waterfalls in 420 square miles, 11 of which are over 100 feet high. Of these, Multnomah Falls, which is the fourth highest falls in the United States, drops, in what is actually two falls, a distance of 620 feet over a projecting ledge of Grande Ronde Basalt of the Columbia River lavas. Waterfalls tend to be ephemeral features, and most of those in the gorge may have begun during recent glacial floods 13,000 years ago when high waters cut back and carried away softer valley alluvium leaving the streams to fall over the more resistant basalt.

The Columbia River gorge has been intermittently plugged by local lava flows and landslides throughout the Pleistocene and Holocene (after Allen, 1979; Tolan and Beeson, 1984; Anderson and Vogt, 1987).



Pathways of separate Columbia River Basalt flows through the Columbia gorge (after Anderson and Vogt, 1987)



Beacon Rock

On the north bank of the Columbia upriver from Multnomah Falls, Beacon Rock served as a signal to travellers that the last of the river rapids was behind them and the Pacific Ocean lay ahead. The vertical 850 foot high Beacon Rock is part of a north-south extending dike of Cascade andesitic basalt. The resistant dike intruded the surrounding Eagle Creek Formation, which was eventually eroded away leaving the pillar.

High Cascade Mountains

The snow covered Oregon High Cascade mountains offer a variety of spectacular scenery including glaciers, snow fields, thick forested slopes, cold streams and lakes, and waterfalls. The crest of the range averages a little more than 5,000 feet in altitude, but well-known peaks rise considerably higher. The High Cascades, part of a chain of volcanic peaks