Background to Field Trip on Spirit Lake Memorial Highway, SR 504, Washington.

When Mount St. Helens erupted on May 18, 1980, over 45 km of the road that connected I-5 with Spirit Lake, State Route 504, was destroyed. The eruption destroyed approximately 570 square kilometers of timberland and resulted in the deaths of 57 people. An earthquake induced the world's largest landslide recorded in modern history, a debris avalanche, that traveled north into Spirit Lake and 22 km down the Toutle River, burying the river to depths of 20 to 200 meters. Dewatering of the massive debris avalanche caused lahars that moved down the Toutle River to the Columbia River. Between the debris avalanche, the lahars, and the blast, much of the highway was destroyed at the east end. (Pringle, 1993)

The area around Mt. St. Helens was made a national monument in 1982. Primary access to the new national monument was intended to be SR 504. It was designated a Scenic and Recreational Highway by the State of Washington. In 1985, a new alignment was planned for a stretch of 40 km from Green River to Coldwater Lake. In 1989, another 11 km extension from Coldwater Lake to Johnston Ridge was also approved. The new route is on the north side of the Toutle River, far above the flood plain and traverses steep mountainous terrain. (Lowell, 1994)

The project of building the new SR 504 has been an engineering geologist's dream for so many different examples of applied geology had to be used. It has been a designer's nightmare, a real challenge for the geotech to build a road in mountainous terrain. Geotechnical explorations included 772 test holes totaling 12,000 linear meters, 275 test pits, and 6000 m of seismic refraction line. The highway design and construction has won national awards. The first 40 km was completed in 1992 and the last phase will be completed in the fall of 1994. (Lowell, 1994)

Road Log

Mt. St. Helens Road 504, Scott Burns Leader

The field guide starts at Exit 49 on I-5, the beginning of Highway 504 and proceeds east to its end.

Mileage

0.0 Drive east on State Route 504. **0.6**

0.6 The surface we are on is a deposit of Cougar age (20,000 - 18,000 yr B.P.) lahars from Mt. St. Helens overlain by Missoula Flood silts (Pringle, 1993). **4.7**

5.3 **Stop 1: Mt. St. Helens National Volcanic Monument Visitor Center:** We will not have time to stop here, but has many excellent displays and books, and the slide show and movie are superb! Silver Lake next to the site was formed about 2500 years B.P. when lahars generated from a catastrophic draining of older Spirit Lake flowed into Outlet Creek and dammed its valley (Pringle, 1993). **3.7**

9.0 On the north side of the road, a series of Quaternary landslides in the Tertiary Toutle Formation is present for the next 3 miles. **2.0**

11.0 Coal Banks Bridge lahar deposits. An earlier bridge was destroyed here in 1980 by the Toutle River lahar. Note the series of lahars in the cliff to the south of the bridge. The top lahar lies 18 m above the river and corresponds to a peak stage of inundation during Pine Creek (2500 years B.P.). Peak discharge is estimated to have been nearly 260,000 cubic meters/sec, similar to the flow of the Amazon River today (Pringle, 1993). **8.0**

19.0 Buried A-frame house. This structure was buried during the lahar of May 18, 1980. **2.0**

21.0 **Stop 2, Sediment Retention Structure (SRS)(Toilet Stop).** Turn onto the side road. The SRS was completed in 1989. It was built to trap most of the sediment eroded upstream from the debris avalanche and the pyroclastic debris so it would not clog the channel downstream and increase flooding on the Toutle and Cowlitz Rivers. An overflow channel is on the north side to divert lahars around the dam. The life of the dam is intended to be about 45 years before filling up, but low sediment loads during the past 8 years of "drought-like conditions" has extended the estimated life. It has a capacity of 250 million cubic meters. Once filled, the spillway will become part of the permanent river channel. (Lowell, 1994) **0.1**

21.1 Toutle River Bridge: This 380 m long multi-span bridge is the point at which the SR-504 reconstruction project leaves the old highway alignment. The next 50 km is totally new road. The foundation supports for the interior pier are 30 m long driven H-piles. The abutment footings are spread footings with the south founded in bedrock and the north in an embankment. (Lowell, 1994) **4.2**

25.3 **Stop 3, Landslide in Embankment Fill.** About one year after the embankment was constructed, a sliding block failure developed downslope of the embankment after heavy rains. Over a couple of months, the landslide progressed upslope and impacted 300 m of the unpaved embankment. A

300 m long and 10 m deep shot rock shear key was constructed for remediation for $900,000. An earth berm was constructed on top of the shear key to provide additional normal load to the shear key. Since correction, no movement has been detected in the inclinometer. (Lowell, 1994) **1.7**

27.0 Hoffstadt Viewpoint (if open). We are now 25 km from Mt. St. Helens. Below you can see the end of the debris avalanche deposit formed May 18, 1980. This earthquake induced landslide is approximately one cubic kilometer and is the largest historic landslide in the world. From this point downvalley, the debris avalanche remobilized to form lahars that continued to the Columbia River. Also, remnants of N-1 dam stretch across the valley just downvalley (2 km) from the debris avalanche. Although the Corps excavated 12 million cubic meters of debris from in back of the dam when it was constructed in 1981, it was not large enough to hold the lahar of March 19, 1982, and it was breached. Failure of this dam convinced the Army Corps of Engineers to build a much larger structure, the SRS. (Pringle, 1993) **0.7**

27.7 **Stop 4, Hoffstadt Bluffs Bridge Landslide.** Immediately west of the bridge is a large Quaternary landslide indicated by the lack of talus at the base of the cliff. It is a scarp of the failure. It occurred when the base level of the valley was lower than present, and therefore, it is buttressed today by the Pleistocene alluvial and debris flow deposits. The absence of vegetation on the bluffs increases the potential for rockfall and debris flows which happen during heavy rainfalls. In 1990 during road construction, several large debris flows destroyed two large backhoes parked at the base of the cliffs. The bridge is 150 m long and the end abutments are spread footing founded in bedrock while the interior pier is set on 1.5 to 2 m diameter shafts. To the west of here glacial deposits are not present so this is presumed to be the maximum extent of the Hayden Creek Glacial (Pringle, 1993; Lowell, 1994). **2.2**

29.9 **Stop 5, Hoffstadt Creek Bridge.** The western end of the bridge represents the western limit of the lateral blast of Mt. St. Helens in 1980. All standing timber east of here was blown down. The road passes through till of Hayden Creek age (140 Ka). These deposits are all along the road to the North Fork Viewpoint. Lake deposits upstream in Hoffstadt Creek were formed when a glacier occupied the Toutle River valley in Hayden Creek time. The bridge is the largest structure on the reconstruction project. Total length is 800 m and is 120 m above the creek. It won many awards for its design. Foundation support for the bridge is either spread footings or shafts founded in bedrock. (Pringle, 1993; Lowell,

1994). **1.6**

31.5 Note the Douglas fir forest here that was replanted in 1983. Some of the trees are now 5 m tall. **1.1**

32.6 Note the screen on the north side of the road to prevent rockfall. **0.3**

32.9 Note the Brugg fence on the north side of the road to prevent rockfall. **0.4**

33.3 **Stop 6, Weyerhauser Overlook.** We have an excellent view of the debris avalanche below. Note how the Toutle River has downcut into the deposit, the main source of sediment collected downstream in the SRS. The glacial deposits disappear just uphill from the site providing an indication of ice thickness in Hayden Creek time. (Lowell, 1994) **1.3**

34.6 Note rill erosion of the fill on the right side of the road. **0.8**

35.4 We are at a higher elevation and the trees planted here in 1983 are noble firs. They do not grow as fast as Douglas firs. **1.1**

36.5 Note the paleosols in the outcrop. These can form failure surfaces for slides when they parallel the surface. **0.5**

37.0 **Stop 7, Elk Rock Lookout.** The dark fine-grained rocks here are hornfels formed by the heat of intrusions that formed the dikes of the site. This rock slope failed during the winter of 1991/2 on a low angle discontinuity located near the base of the cut. Most of the rock debris was removed back to an area in which rock bolting could occur. About 600 linear meters of post tensioned rock bolts were installed to stabilize the slope. Rockbolting was used at seven other sites on SR 504. The large rockmass in the lower portion of the cut is supported by a concrete buttress. The oversteepened colluvial slope to the east of the cut was covered by wire mesh to prevent rockfall. The highest rock cut here was resloped because of extensive zones of hydrothermal alteration and previously undetected discontinuities. This segment around Elk Rock required the construction of two VSL Retained Earth retaining walls with a combined length of 1320 m and heights in excess of 15 m. Because they were so high, FHWA has designated the walls as experimental features. (Lowell, 1994). **0.2**

37.2 Note Mt. Adams is now in view to the east. **3.5**

40.7 **Stop 8, Castle Lake Viewpoint.** Here we have a super view of the volcano and the debris avalanche. The debris avalanche formed Coldwater Lake on the north side and Castle Lake on the south side when it dammed up their drainages. Coldwater Lake has cut its outlet down through the debris-avalanche dam to bedrock. The lake level was stabilized by the U.S. Army Corps of Engineers in 1981. The engineers have also cut an outlet for Castle Lake to keep it at a safe level. Many groundwater monitoring wells in the debris avalanche below Castle Lake help scientists determine reduced slope stability in the debris dam, especially during a major seismic event. Note the many erosional terraces formed by the Toutle River in the debris avalanche. (This viewpoint may not be open.) **1.3**

42.0 Maratta Creek Bridge. The approach embankments to this bridge were built during the 1991 construction season. The end abutments to the bridge were constructed as spread footings on the approach embankments at the same time. During the winter of 1991/2 both approach fills failed as a result of internal embankment failure. About 25 cm of vertical displacement had occurred at the abutments. Forensic geotechnical investigation indicated that failure was due to excessive lift heights and low compaction densities of the embankment. Both were closely monitored during reconstruction. The new end abutments now have the capability of being able to jack the bridge girder in the event of a settlement (Lowell, 1994). **1.5**

43.5 **Stop 9, Coldwater Visitor's Center.** This is mainly a toilet stop, but do go out to the terrace for a view of the area. The debris avalanche is 2.5 km wide here and over 50 m thick. Note the beautiful lateral moraine on the northeast side of Coldwater Lake. It is of Evans Creek Age (22,000 - 11,000 years B.P.) We are located in the Mt. St. Helens Seismic Zone which stretches for 140 km to the NW and SE. The zone shows right lateral strike slip and is capable of producing at magnitude of 6.8, with a near source ground acceleration approaching .5g. All bridges and buildings here have been constructed to withstand this potential shaking. Landslide scars can be seen on the valley walls where unstable glacial deposits have been modified. A hike down into the debris avalanche along the Crater Rocks Trail reveals many examples of mass wasting, especially raveling and slumping, in the diamicton. (Lowell, 1994; Pringle, 1993) **4.2**

44.5 **Stop 10: Coldwater Lake & Debris Avalanche:** We will stop for a chance to walk around in the debris avalanche. Toilets are here. Note how the lake has been dammed up by the debris avalanche.

47.7 **Stop F-11, Spirit Lake Outlet Tunnel, South Coldwater Canyon.** South Coldwater Canyon lies to the south of Coldwater Canyon. Before 1980, it was u-shaped, but the valley has been filled with debris avalanche material that spilled over the saddle between Johnston Ridge and Harry's Ridge. The valley floor is now 73 m above the old surface at the west end and 24 m above at the east end - all from the debris avalanche deposition. The South Coldwater Bridge rests on loose debris avalanche material that is susceptible to deep liquefaction. To build the bridge, they had to mitigate for liquefaction by deep seismic densification. A tunnel was bored from Spirit Lake to South Coldwater Canyon to drain Spirit Lake and was opened in 1985. This reduced the chances for failure of the debris avalanche dam that had elevated the level of Spirit Lake. The lake level is now stabilized at 1038 m elevation. Had the lake tunnel not been stabilized, the debris avalanche dam would probably have failed causing catastrophic flooding in the Toutle River (Pringle, 1993; Lowell, 1994). Alignment of the road has had to take into consideration the snow avalanche chutes, debris flow channels, and the large landslide on the north side into consideration. Also, the abundant hydrothermal alteration has led to small realignments in areas of intense weathering. **2.6**

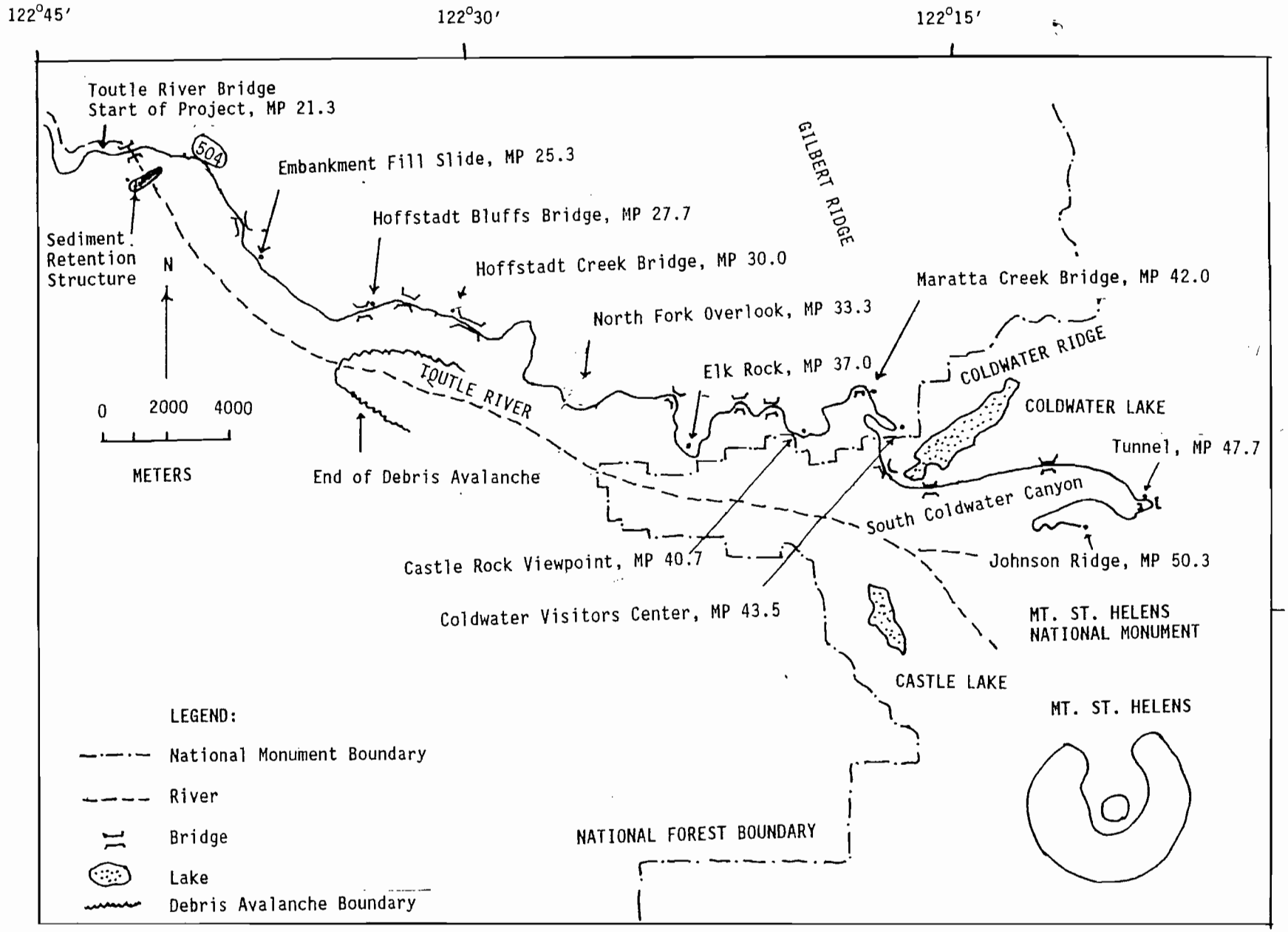
50.3 **Stop F-12, Crater Overlook at Johnston Ridge.** The view from here into the crater is one of the most spectacular in the National Monument. The ridge is named after David Johnston, the USGS geologist who was stationed here and lost his life during the 1980 blast. From the ridge we can see into the crater and see the pumice plain and the dome. The debris avalanche came down in three blocks and filled Spirit Lake, the Toutle River valley to 24 km away, and also spilled into the South Coldwater Canyon. The first slide block of the debris avalanche moved at 27 m/sec (100 km/hr), but it was overtaken by the second and third blocks which were propelled by the blast. The velocity of the following main surge reached 286 m/sec (over 1000 km/hr). (Lowell, 1994; Pringle, 1993)

Return to Portland via SR 504 and I-5.
End of Road Log.

References

Lowell, S. Badger, T, Norrish, N., and Pringle, P., 1994, Spirit Lake Memorial Highway, 45th Highway Geology Symposium Field Trip Guide, August 18, 1994.

Pringle, P.T., 1993, Roadside Geology of Mount St. Helens National Monument and Vicinity. Washington Department of Natural Resources, Division of Geology and Earth Resources, Information Circular 88.


122°45′
122°30′
122°15′
46°15′
Toutle River Bridge
Start of Project, MP 21.3
504
Embankment Fill Slide, MP 25.3
Hoffstadt Bluffs Bridge, MP 27.7
Hoffstadt Creek Bridge, MP 30.0
North Fork Overlook, MP 33.3
Elk Rock, MP 37.0
Maratta Creek Bridge, MP 42.0
GILBERT RIDGE
COLDWATER RIDGE
COLDWATER LAKE
Tunnel, MP 47.7
South Coldwater Canyon
Johnson Ridge, MP 50.3
Sediment
Retention
Structure
N
0 2000 4000
METERS
TOUTLE RIVER
End of Debris Avalanche
Castle Rock Viewpoint, MP 40.7
Coldwater Visitors Center, MP 43.5
MT. ST. HELENS
NATIONAL MONUMENT
CASTLE LAKE
MT. ST. HELENS
NATIONAL FOREST BOUNDARY
LEGEND:
National Monument Boundary
River
Bridge
Lake
Debris Avalanche Boundary

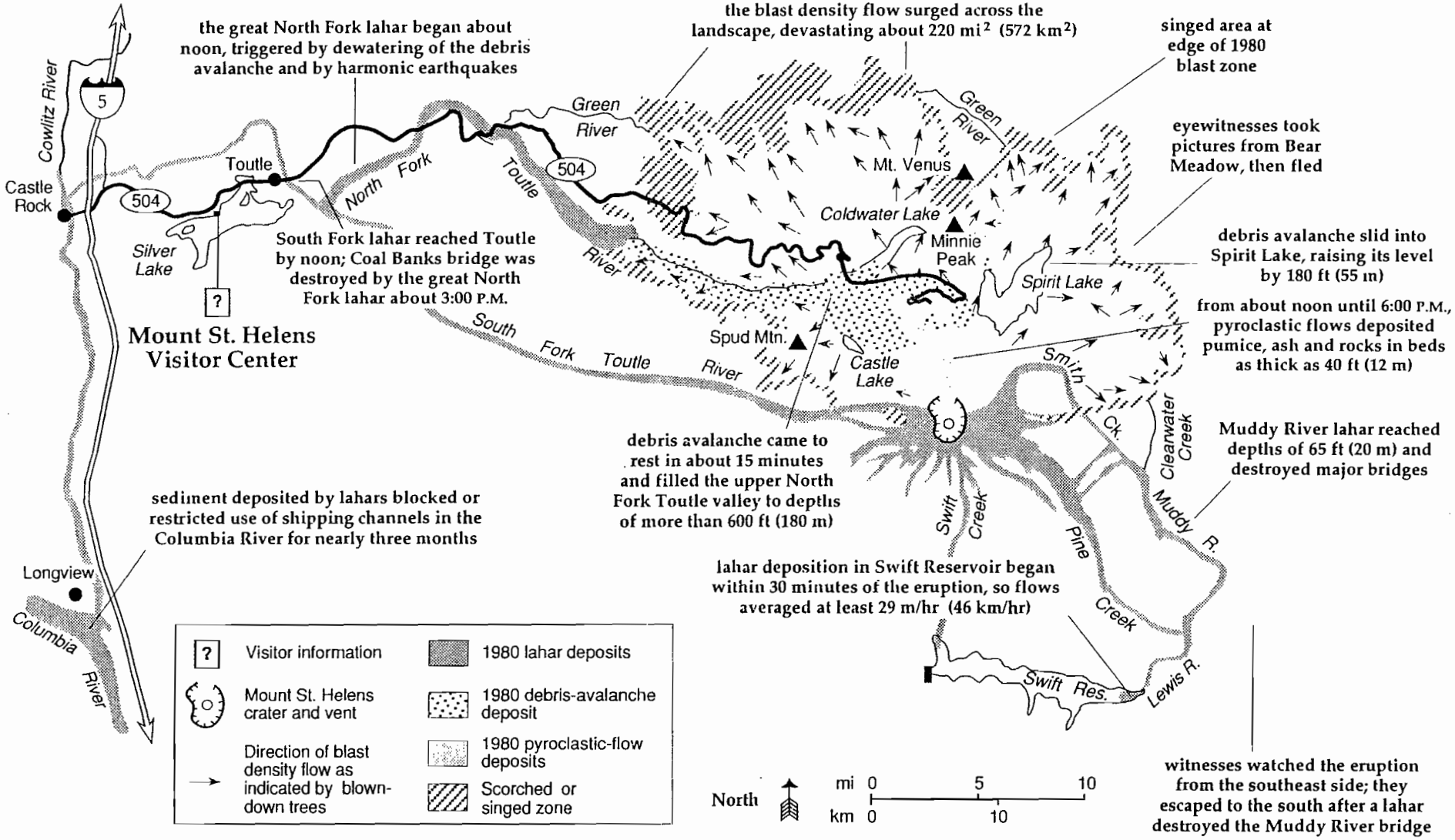


Figure 4. Generalized diagram showing the devastation caused by the climactic eruption of Mount St. Helens on May 18, 1980. The singe zone is at the periphery of the area affected by the blast. Other symbols used are identified in Figure 1. Modified by Lipman and Mullineaux (1981).

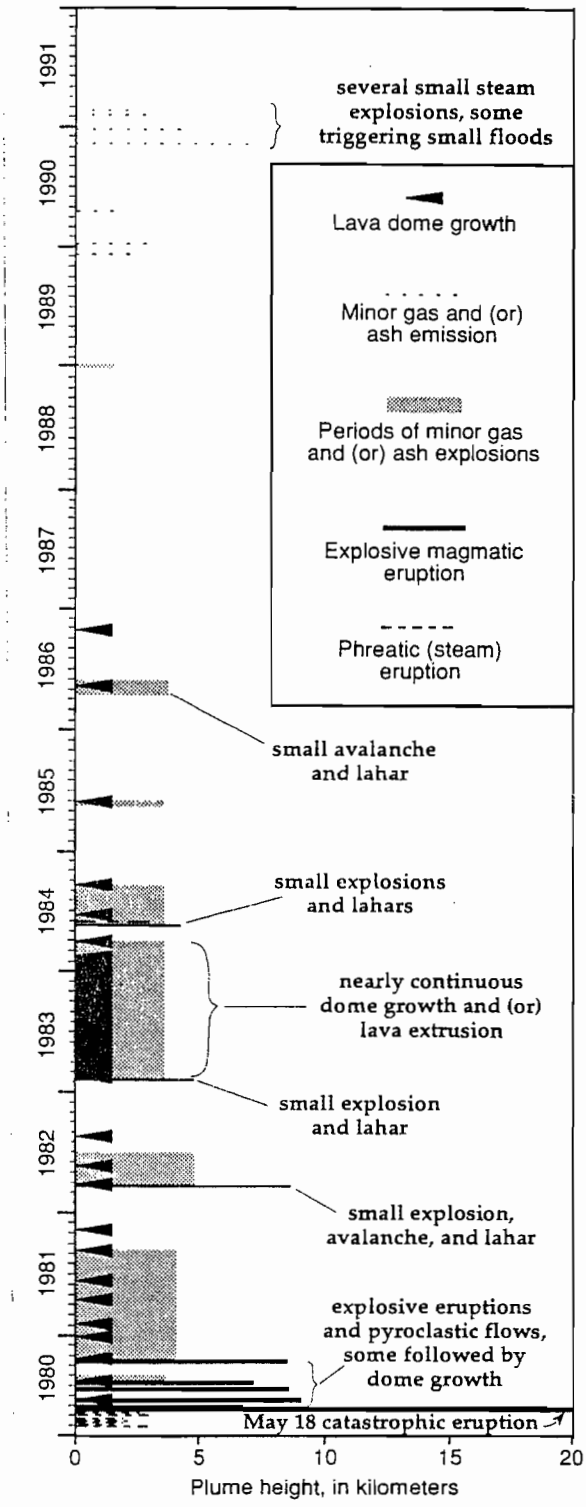


Figure 5. Diagrammatic summary of Mount St. Helens eruptive activity, 1980–1992. Modified from Tilling and others (1984).

: of the gaping 1-mi (1.6 km) -wide
se dome-growth episodes produced
illion and 8 million m^3) of lava. On
anied the build-up of pressure pre-

akes precede the eruption of lava at
These earthquakes are caused as the
tle rocks to the surface. When the
aks to the surface as lava, it adds to

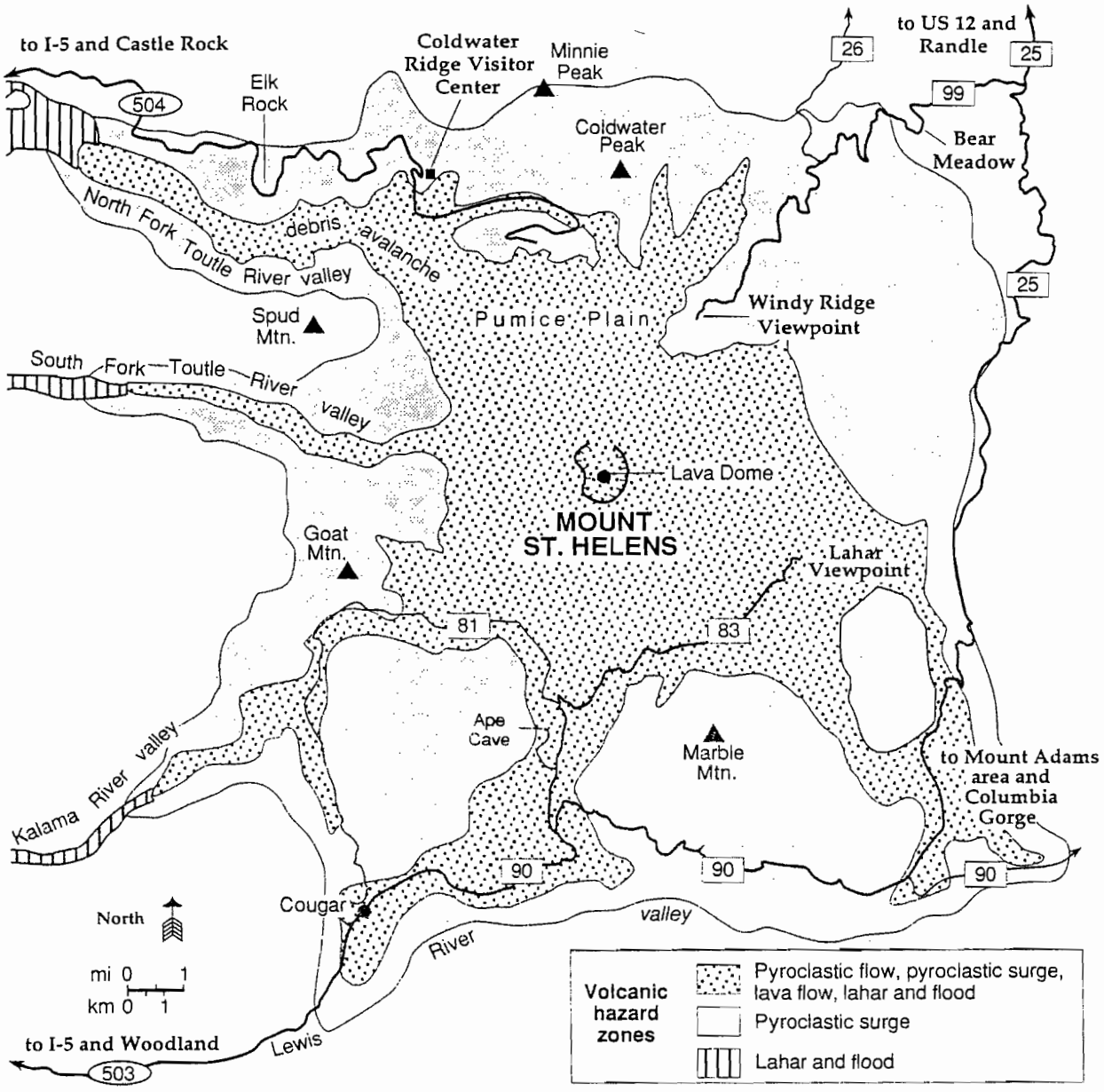


Figure 8. This preliminary volcanic hazards map, redrawn from one prepared by the U.S. Geological Survey (U.S. Forest Service, 1992), shows hazard zones close to the volcano that could be at great risk in the event of a major eruption. These areas would be evacuated and closed to the public. Such eruptive activity is typically preceded by a systematic increase in seismic activity that would give adequate warning. Symbols used are identified in Figure 1.

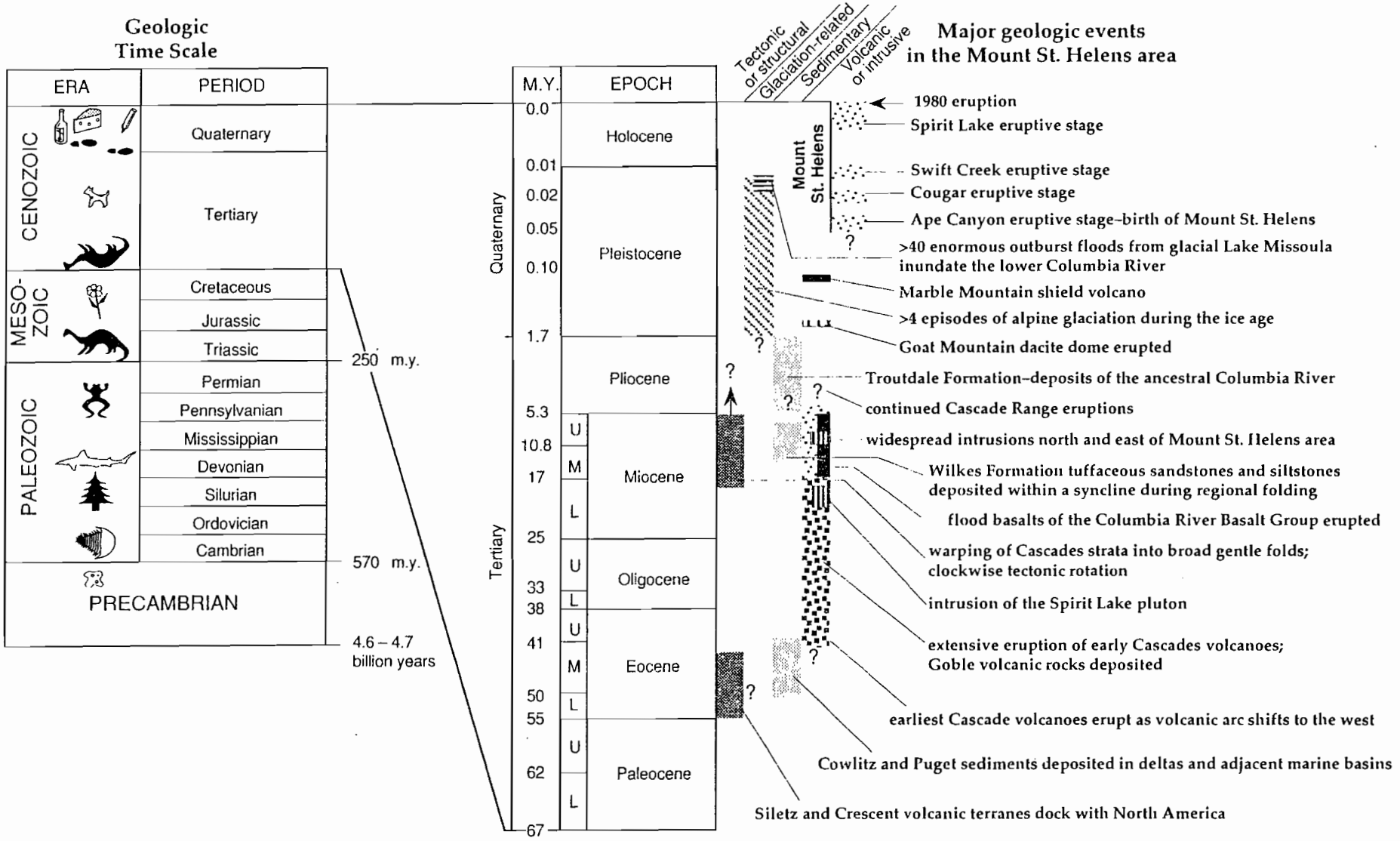
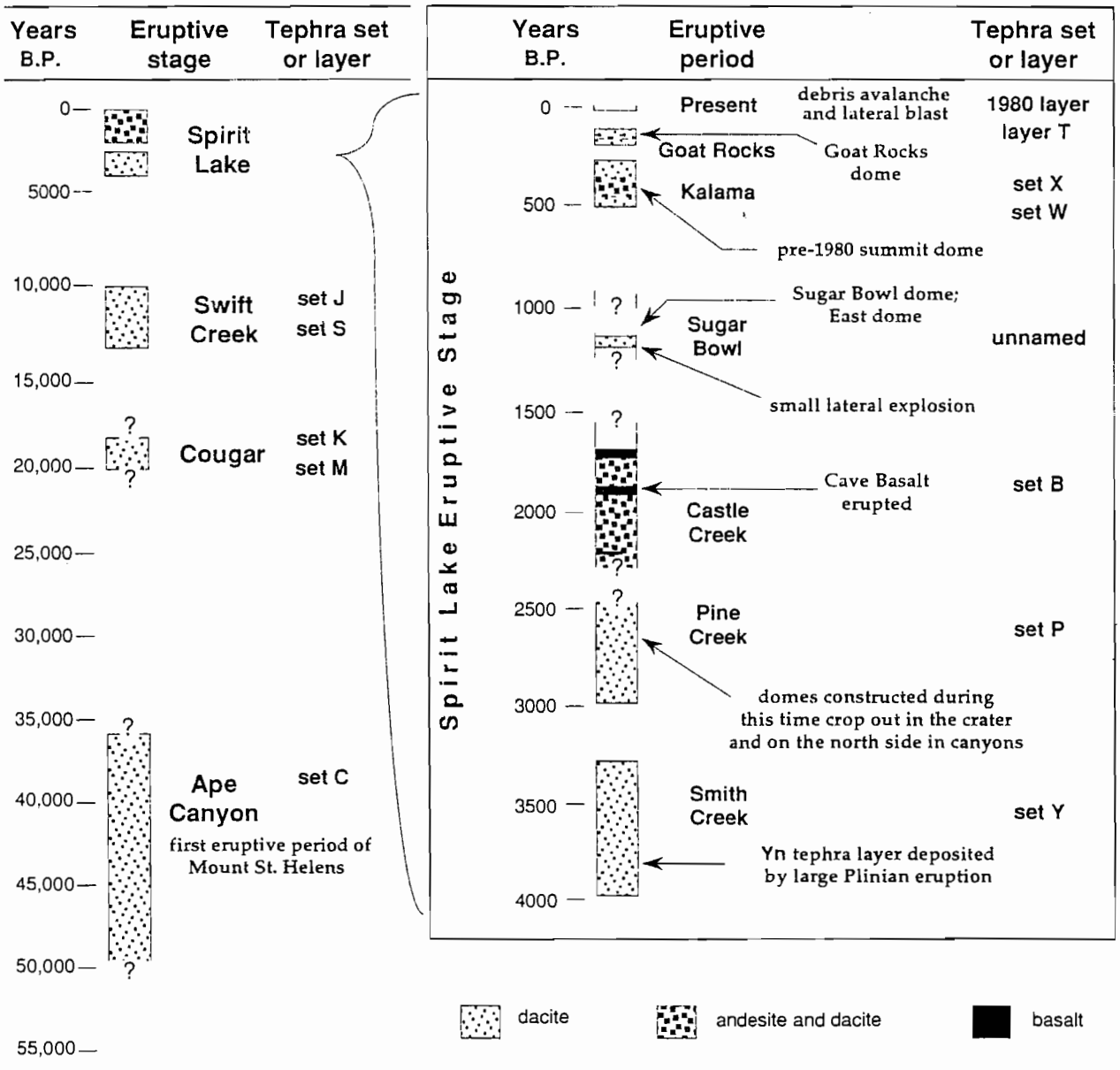


Figure 11. Simplified version of the geologic time scale (not to scale) showing major geologic events in the southwest Washington Cascades. U, upper; M, middle, L, lower; m.y., million years. The time scale is developed from those of Salvador (1985) and Aguirre and Pasini (1985). See Tables 3 and 4, p. 25 and 28, for more detailed information on the geologic history of Mount St. Helens.

Table 3. Eruptive history of Mount St. Helens. Left columns show eruptive stages and dormant intervals; right columns show the eruptive periods and dormant intervals of the Spirit Lake eruptive stage. Only major tephra units are shown. Ash from possible earlier eruptions (100 ka–50 ka) has recently been discovered in eastern Washington (Busacca and others, 1992). Data in table from Mullineaux (1986) and Crandell (1987); redrawn from Hopson and Melson (1990) – Pringle



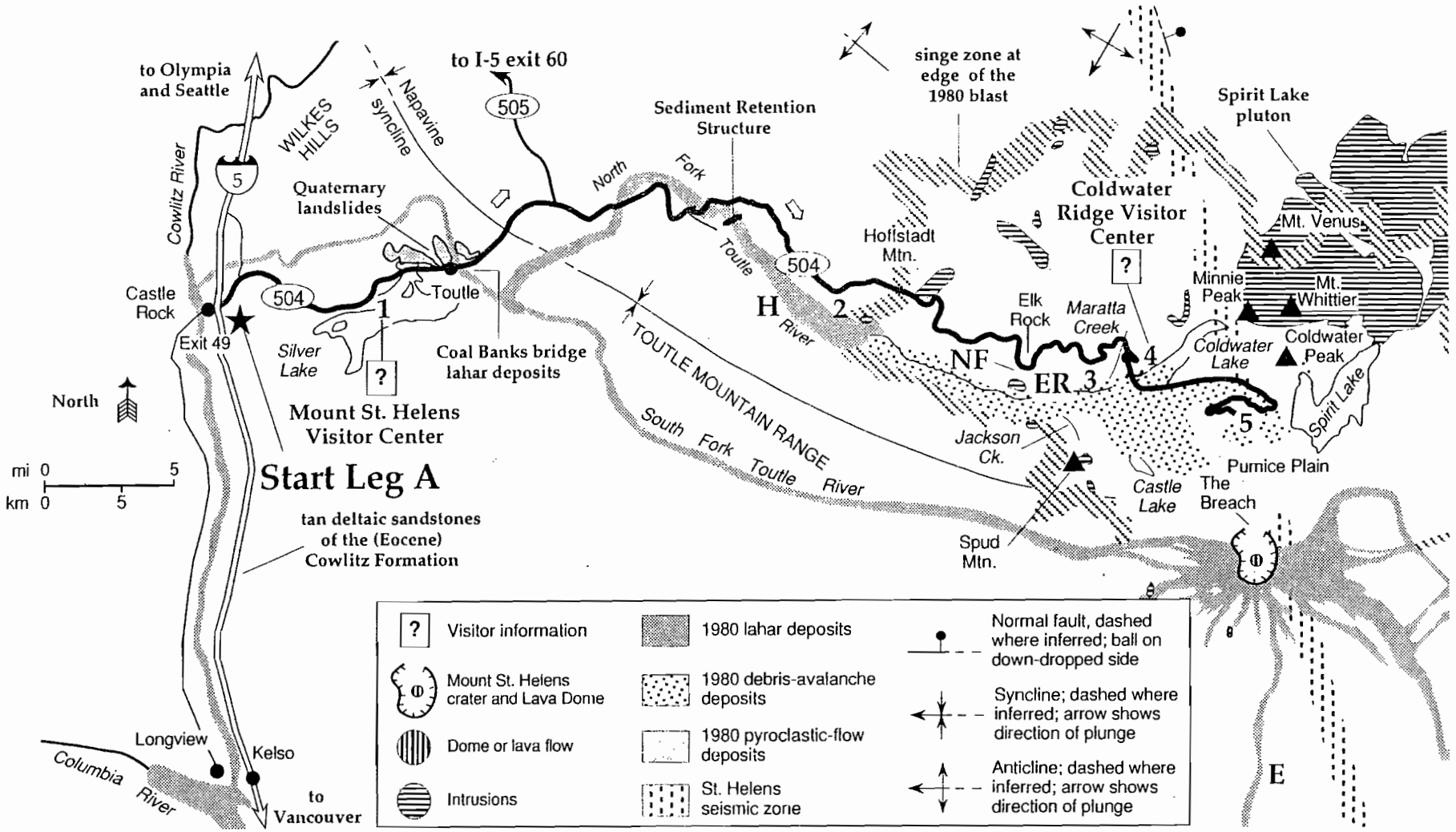


Figure 22. Sketch map for Leg A along SR 504, showing numbered road stops (referred to in text), geologic units, features, and structures, and May 18, 1980, Mount St. Helens deposits and generalized areas of devastation by the blast. E, approximate western and southern limits of glaciers of Evans Creek age (22,000–11,000 yr B.P.); ER, Elk Rock Viewpoint (monument entry); H, approximate western limit of glaciers of Hayden Creek age (140 ka); NF, North Fork Viewpoint. Road symbols are identified in Figure 1.

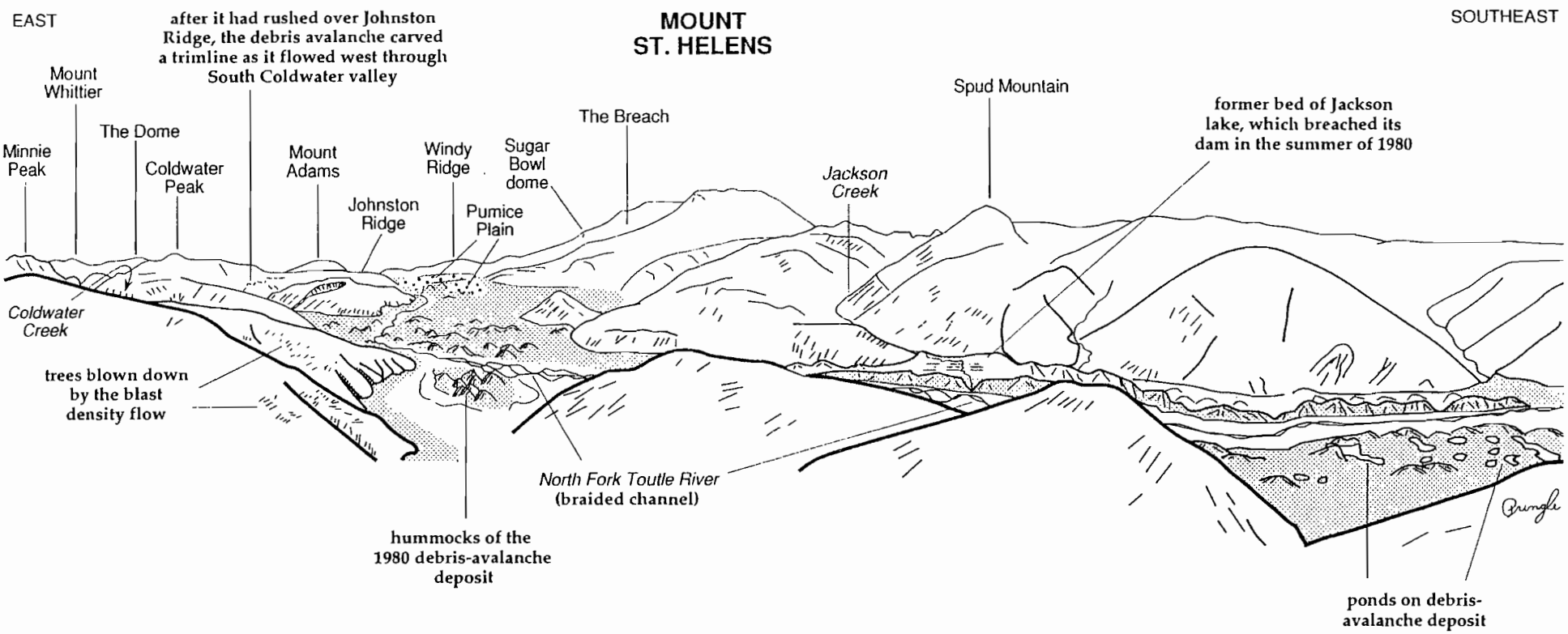


Figure 25. Panorama from Elk Rock Viewpoint, about 10 mi (15 km) from Mount St. Helens. The North Fork Toutle River has been incising and laterally eroding the hummocky 1980 debris-avalanche deposit. To the south, numerous ponds are visible on the surface of the avalanche. Jackson Creek was one of many tributary streams dammed by the debris-avalanche deposit. The Jackson lake bed is a remnant of the lake that formed behind the debris dam and breached it in 1980. Minnie Peak and Mount Whittier are composed of resistant granodiorite of the Spirit Lake pluton. The Dome, which is not a lava dome, and Coldwater Peak are composed of Tertiary volcanic rock, mostly fragmental debris. - pringle

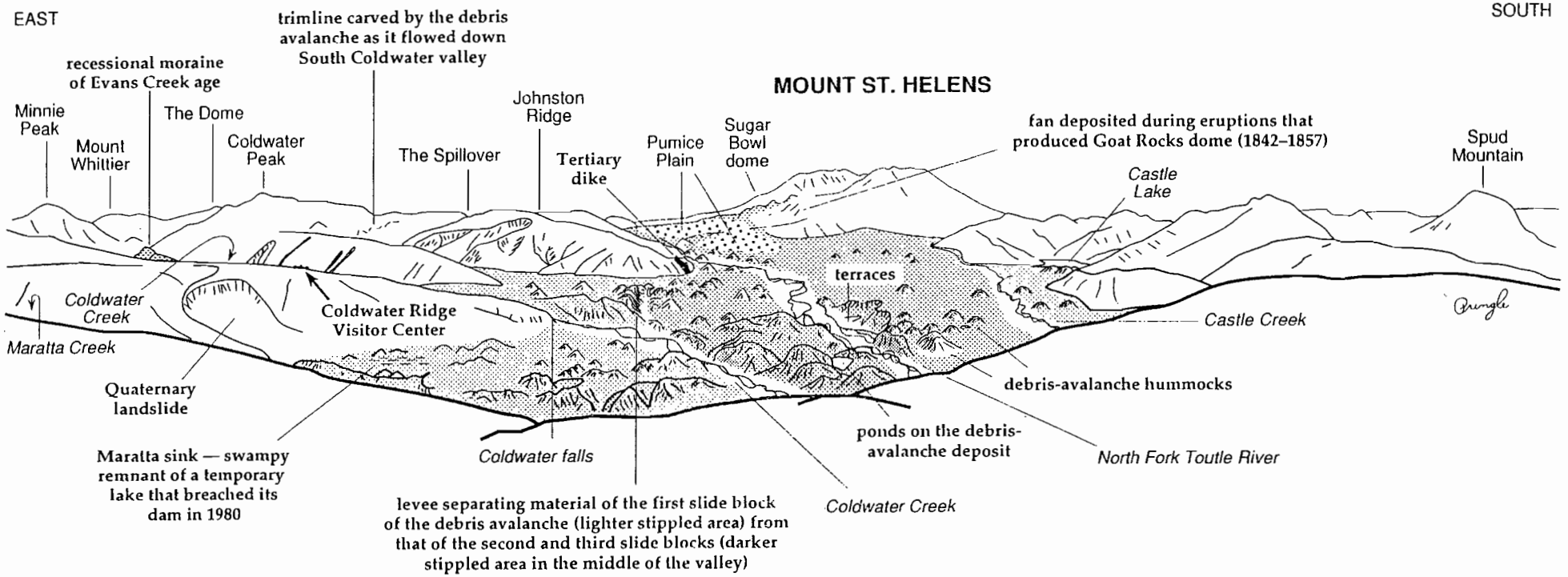


Figure 26. Panorama to the southeast from the Castle Lake Viewpoint, about 8 mi (13 km) from Mount St. Helens. This site presents a spectacular vista of the hummocky debris-avalanche deposit of May 18, 1980, and Mount St. Helens in the background. Sugar Bowl is an ancient lava dome. Goat Rocks fan is a debris fan deposited between 1842 and 1857 just downslope from Goat Rocks dome, which was removed by the May 18, 1980, eruption. Castle Lake was dammed by the debris-avalanche deposit, and Maratta sink is a remnant of Maratta lake, a dammed lake that breached in 1980. Coldwater Lake in Coldwater Canyon was stabilized by the U.S. Army Corps of Engineers at Coldwater Creek outlet. Notice the trimline on the wall of South Coldwater Creek valley cut by the debris avalanche after it had run up on, and spilled over, Johnston Ridge. A series of terraces in the North Fork Toutle River valley has resulted from both deposition by post-1980 lahars and floods and by erosion. A pronounced levee in the debris-avalanche deposit separates material deposited by the first slide block (lighter stippled area at valley margins) from that of the second and third slide blocks (darker stippled area in the medial part of the valley), which were deposited seconds later. - pringle

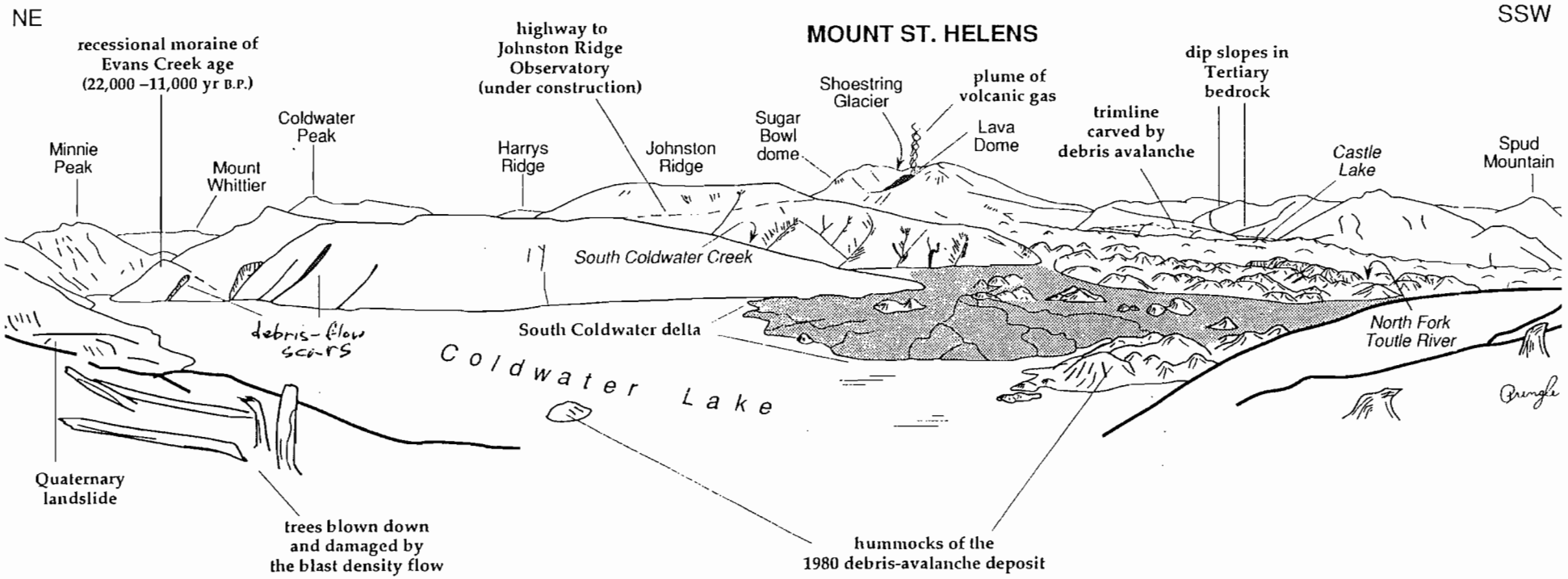


Figure 27. Panorama from the Coldwater Lake Visitor Center, about 7 mi (11 km) from Mount St. Helens. Coldwater Lake was created when Coldwater Creek was dammed by the 1980 debris-avalanche deposit. Most of the South Coldwater delta has been constructed since 1985, when a drainage tunnel through Harrys Ridge began to discharge water from Spirit Lake into the South Coldwater valley. Minnie Peak and Mount Whittier are composed of resistant granodiorite of the Spirit Lake pluton. Highlands composed of these resistant rocks were the sources of the Pleistocene glaciers that carved Coldwater valley and left the sharp recessional moraine visible on the east shore of the lake. The modern Lava Dome has been constructed since 1980 by 17 eruptive episodes during which the lava both squeezed into it and oozed out onto its surface. The debris flows that have scoured the hillslopes were likely triggered during rainstorms. The blast removed or killed the trees whose roots helped hold the soil together on the steep slopes.

Swanson, D. A., 1992, Geologic map of the McCoy Peak quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 92-336, 36 p., 2 plates, scale 1:24,000.

Swanson, D. A.; Cameron, K. A.; Evarts, R. C.; Pringle, P. T.; Vance, J. A., 1989, Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon, Seattle, Washington to Portland, Oregon July 3-8, 1989: International Geological Congress, 28th, Field Trip Guidebook T106, 60 p.

Swanson, D. A.; Clayton, G. A., 1983, Generalized geologic map of the Goat Rocks Wilderness and Roadless Areas (6036, Parts A, C, and D), Lewis and Yakima Counties, Washington: U.S. Geological Survey Open-File Report 83-357, 10 p., 1 plate, scale 1:48,000.

Walsh, T. J.; Korosec, M. A.; Phillips. W. M.; Logan, R. L.; Schasse, H. W., 1987, map of Washington—Southwest c Washington Division of Geology a Resources Geologic Map GM-34, scale 1:250,000, with 28 p. text.

Williams, Chuck, 1988, Mount St. Helens National Volcanic Monument—A pocket guide for hikers, viewers, and skiers: The Mountaineers [Seattle, Wash.], 112 p.

GLOSSARY

ablation - the loss of snow and ice from a glacier due to melting, erosion, evaporation, or sublimation.

accretion - that process by which one terrane, a fault-bounded body of rock of regional size, is attached to another having a different history. Typically accretion occurs during tectonic collision.

accretionary lapilli - a mass of cemented ash 1-10 mm in size.

alluvium - a general term for stream deposits.

amphibole - a group of dark, rock-forming ferromagnesian silicate minerals; for example, hornblende.

andesite - a fine-grained extrusive igneous rock generally containing abundant plagioclase, lesser amounts of hornblende and biotite, little or no quartz; 54-62 percent silica.

anticline - a convex-upward fold having stratigraphically older rocks in its core.

ash - see *volcanic ash.*

ash cloud - an eruption cloud of volcanic gas and fine particles.

basalt - a fine-grained volcanic rock, typically dark, that contains 45-54 percent silica.

bed load - sediment, such as cobbles, pebbles, and granules, that is transported along the bed of a river but is not in suspension.

biotite - "black mica"; a common mafic mineral.

blast - the enormous volcanic explosion and pyroclastic density current on May 18, 1980.

blast dacite - the bluish-gray to gray rocks, chilled pieces of the cryptodome, that were erupted in the blast on May 18, 1980.

blast density flow - see *blast.*

blast zone - see *devastated area.*

breadcrust bombs - volcanic bombs that have a breadcrust-like (open cracks) texture on their outer surface caused by contraction during sudden cooling.

breccia - a rock composed of coarse, angular fragments in a matrix of finer particles.

calcite - a common mineral composed of calcium carbonate ($CaCO_3$).

caldera - a large, typically steep-sided, volcanic basin produced by collapse of an underlying magma chamber.

cinder cone - a fairly small, cone-shaped volcanic vent consisting mainly of accumulated cinders and other pyroclastic fragments.

cirque - a glacially carved, horseshoe-shaped hollow at the head of a valley.

clast - general term for any fragment or individual piece of rock.

coal - a black, combustible sedimentary rock formed by compaction of plant matter.

cohesive lahar - a volcanic debris flow or mudflow that contains more than 4 percent clay minerals in its matrix.

composite volcano - a steep-sided volcano consisting of alternating layers of lava and pyroclastic debris. A stratovolcano.

conglomerate - a coarse-grained sedimentary rock consisting of rounded rocks cemented together in a finer matrix.

contact metamorphism - a type of recrystallization or change in rocks that takes place adjacent to a magma body; also known as "thermal metamorphism".

creep - slow downhill movement of surficial materials (such as soil).

crevasse - a deep fissure in the surface of a glacier.

cross dating - a method of matching tree rings that uses the known patterns or characteristics of tree rings in an area to precisely date wood or trees such as those buried in volcanic deposits or injured by volcanic activity.

cryptodome - the near-surface intrusion of magma that produced the pre-May 18, 1980, bulge in the north flank of Mount St. Helens.

dacite - a fine-grained extrusive igneous rock typically having 62-69 percent silica.

debris avalanche - a granular flow of unsorted rock debris that typically moves at high velocity.

debris flow - a moving mass of debris, typically saturated.

debris slide - a shallow mass movement of the soil layer or other geologic material.

dendrochronology - the scientific study of tree rings.

devastated area - the area of downed and singed vegetation created by the volcanic events at Mount St. Helens on May 18, 1980.

dike - a tabular intrusive rock body that forms where magma cuts across the bedding planes of other rock bodies.

diorite - a coarse-grained intrusive igneous rock having roughly the same chemical composition as andesite (54-62 percent silica).

discharge - the rate of stream flow at a given time in units of volume per unit of time (ft^3/s or m^3/s).

dome - see *volcanic dome.*

drift - a general term for any glacial deposit.

earthflow - a type of mass movement that typically takes place along well-defined failure planes and may involve more than one failure process, such as slumping and plastic flow.

faceted spur - the end of a ridge that has been ground down by the action of ice or water.

fault - a fracture along which a rock mass has been displaced.

feldspar - a common rock-forming mineral group consisting of silicates of aluminum, sodium, potassium, and calcium.

ferromagnesian minerals - silicate minerals such as olivine, pyroxenes, and amphiboles, that contain considerable amounts of iron and magnesium.

firn - a material that is transitional between snow and glacier ice.

fission-track dating - a method of determining the age of a rock based on the number of tracks recording emission of subatomic particles during radioactive deterioration.

flood basalt - plateau basalt; the lava produced by enormous fissure eruptions, such as the Columbia River basalt flows.

flow breccia - a deposit of angular rock fragments, some of which are welded together, that is produced in association with a lava flow.

fold - a bend in a rock stratum or layer.

fumarole - a volcanic vent that emits gases.

gabbro - a coarse-grained intrusive igneous rock consisting mainly of calcium-bearing plagioclase and pyroxene minerals and having roughly the same chemical composition as basalt (45-54 percent silica).

glacier - a mass of ice, mainly recrystallized snow, that is heavy enough to move under its own weight.

granite - a coarse-grained intrusive igneous rock composed of potassium feldspar, plagioclase, quartz, and some mafic minerals; more than 69 percent silica.

granodiorite - a coarse-grained intrusive rock, similar to a granite, in which plagioclase minerals are more common than potassium feldspar; 62-69 percent silica.

groundmass - the fine-grained matrix of a porphyritic igneous rock.

half-life - the time required for half of the atoms in a sample of a radioactive isotope to decay.

heavy mineral - slang for ferromagnesian or mafic minerals.

hornblende - a mafic mineral of the amphibole group.

hornfels - a fine-grained metamorphic rock formed by recrystallization.

hydrothermal activity - the migration of hot, typically mineral-rich fluids produced by magma or by reactions of magma with adjacent rocks and (or) ground water.

hydrothermal alteration - the alteration of rocks or minerals owing to contact with hydrothermal waters.

igneous rock - a rock formed by the cooling of magma.

intrusive rock - an igneous rock that solidifies under the surface of the Earth.

isotope - one of two or more forms of an element having different atomic weights.

joint - a fracture in a rock along which movement has not occurred.

juvenile material - volcanic rocks derived directly from magma that has reached the surface.

K-Ar dating - see *Potassium-Argon dating.*

lahar - general term for a volcanic debris flow, a moving mixture of pyroclastic material and water that originates at a volcano.

lahar runout - the muddy flood caused by dilution of a lahar as it mixes with streamwater. The deposits are typically very sandy and have fewer large rocks than lahar deposits.

lapilli - volcanic particles in the range of 2-64 mm.

lateral blast - see *blast.*

lateral moraine - an accumulation of till along the sides of a glacier where it meets the valley wall.

lava - magma that reaches the Earth's surface.

levee - an area of deposits marginal to a flow that roughly records the maximum height of the flow.

lithic pyroclastic flow - a pyroclastic flow that contains a significant percentage of previously formed rock fragments mixed in with the juvenile rocks.

lithification - the process by which sediment is converted into solid rock.

mafic rock - a rock that contains more than 50 percent ferromagnesian minerals.

magma - molten rock; can contain liquids, gases, and crystals.

magmatism - the formation and movement of magma.

magnitude - a scale for measuring the energy released by an earthquake.

mass movement - the movement of geologic materials downslope under the influence of gravity.

mass wasting - see *mass movement.*

metamorphic rock - a rock whose composition and (or) texture has changed because of heat and (or) pressure.

mineral - a naturally formed solid chemical substance having a fixed crystal structure and range of chemical compositions.

moraine - a landform composed of till or drift.

mudline - the maximum level of inundation by a lahar or flood based on the height of mudmarks on trees or rocks. See Fig. 63.

normal fault - a steeply dipping fault in which the hanging wall has moved downward relative to the footwall. See Fig. 66.

outburst floods - jökuhlhaups; sudden releases of water stored in or adjacent to a glacier or in a glacial lake.

outcrop - an exposure of rock or a deposit.

outwash - stratified deposits produced by glacial meltwater.

pahoehoe - [pä·hoy'·hoy] a Hawaiian term for basaltic lava flows having a smooth or ropy surface.

phenocryst - a large individual crystal in a porphyritic igneous rock.

phreatic explosion or eruption - an explosive mixture of steam and fine rock debris produced when water contacts hot rock.

plastic flow - change in shape of a solid that takes place without rupture.

Plinian column - a strong, turbulent, and sustained vertical eruption column.

pluton - the cooled body of a large intrusive igneous rock mass.

porphyritic - a texture of igneous rock in which coarse mineral crystals are scattered among finer grains and (or) glass.

porphyry copper deposit - a type of hydrothermal mineral deposit associated with plutons that contains associated copper minerals.

potassium-argon dating - the radiometric determination of the age of a rock sample based on the ratio of argon-40 to potassium-40.

proglacial - immediately in front of or just beyond the limits of the glacier.

pumice - solidified rock froth; a porous volcanic rock that floats.

pyroclastic density current - a general name for any of the mixtures of volcanic gas and particles (including surges and flows) that move downslope on the flanks of a volcano under the influence of gravity. See Table 9.

pyroclastic flow - a mass of hot, dry, pyroclastic debris and gases that move rapidly along the ground surface. They can be caused by an eruption or collapse of a dome.

pyroclastic surge - a turbulent, mixture of gases and particles that flows above the ground surface at high velocities. It can develop from a pyroclastic flow and is highly mobile.

pyroxene - a group of mafic silicate minerals.

Quaternary - the geologic period lasting from about 1.7 Ma to the present. It consists of the Pleistocene Epoch (ending about 10 ka) and the Holocene (10 ka to present).

radiocarbon dating - the calculation of the age of geologic material by any of the methods based on nuclear decay of natural radioactive elements in carbonaceous material.

radiocarbon years - years before 1950 (by convention) based on the proportion of the ^{14}C isotope to normal carbon atoms. Typically radiocarbon years differ from "calendar years" because of variations of the carbon isotope content of atmospheric carbon dioxide through time. A calibration to adjust these ages on the

basis of tree rings (for about the last 8,000 years) has been devised; however, for simplicity, only the raw radiocarbon ages are presented in this guidebook. For the most part, these ages do not differ radically from actual calendar years. Tree-ring dates for Mount St. Helens deposits laid down since A.D. 1480, however, are given in calendar years.

radiometric age - see radiometric dating.

radiometric dating - a method of estimating the age of a rock or mineral by measuring the proportion of radioactive elements to their decay products in a rock sample.

raveling - erosion involving the movement of individual rocks and grains down a slope.

rock flour - fine rock particles produced by glacial pulverization.

rootless explosion crater - small, shallow craters produced by phreatic explosions.

St. Helens zone - a linear zone of earthquake activity that extends from north of Mount St. Helens through the volcano almost to the Columbia River.

scoria - an igneous rock containing abundant cavities (vesicles) but which does not float.

shield volcano - a large, broad volcano having fairly shallow slopes formed by the eruption of highly fluid basalt lava.

sill - a tabular intrusive rock body that forms where magma is injected between two layers of rock.

singe zone - the zone at the periphery of the devastated area in which trees were scorched or damaged but not blown down.

slickensides - striated or polished surface of a rock produced by abrasion along a fault.

slips - debris slides.

slosh line - see *trimline.*

slump - a type of mass wasting in which blocks of material fail with a backward rotational motion.

snag - the trunk of a dead tree.

stratigraphy - the study of strata, its succession and composition, fossils and other characteristics.

striation - a scratch or groove on a rock produced by the passage of a glacier or other geologic agent.

strike - the bearing or azimuth along which a fault or fold or other planar feature is oriented.

strike-slip fault - a fault in which displacement has been parallel to the strike of the fault. See Fig. 66.

suspended load - fine sediment carried in suspension by a river.

syncline - a fold that is concave upward, like a trough.

talus - rock debris, typically coarse, that accumulates at the base of a cliff or slope.

tarn - a small mountain lake that occupies a cirque.

tephra - a general term for all sizes of rock and lava that are ejected into the air during an eruption.

terrace - a long, narrow, nearly flat surface that forms a step-like bench in a slope.

terrane - a large block of the Earth's crust, bounded by faults, that can be distinguished from other blocks by its geologic character.

Tertiary - the geologic period lasting from about 67 Ma to 1.7 Ma.

thrust fault - low-angle fault (less than 45°) in which the hanging wall has moved upward relative to the footwall; typically caused by horizontal compression.

till - an unsorted glacial deposit produced directly under, within, or on top of a glacier.

transform fault - strike-slip faults that separate major geologic plates or plate segments.

trimline - boundary between the area affected by scour or scrape and undisturbed terrain that denotes the maximum height of runup or inundation by an avalanche, debris flow, flood, wave, or glacier.

tuff - a fine-grained rock composed mostly of volcanic ash.

valley glacier - a glacier that heads at a cirque or cirques and then flows into, and is confined by, a valley; an alpine glacier.

viscosity - resistance to internal flow.

volcanic arc - a curved belt of volcanoes and volcanic rocks associated with a subduction zone.

volcanic ash - fine-grained pyroclastic particles (less than 2 mm in diameter).

volcanic dome - a steep-sided bulbous mass of lava, such as the Lava Dome, that is commonly formed by eruptions of highly viscous dacite or rhyolite lava.

volcanic earthquakes - the sudden release of strain energy under or in a volcano as magma or volcanic gas pushes its way to the surface.

volcaniclastics - a general name for all fragmental material produced by a volcano.

vug - a cavity in a vein or rock. Some vugs are lined with crystals.