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Field Trip Guidebook #25

Volcanic Deposits At Mount Baker, Washington: Tephra, Lava, Cinder Cones and A Caldera

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Figure 1. *Mount Baker rises 3065 m (10,056 ft) above Baker Lake in this mid July 2006 aerial view looking west. The Pleistocene vent, Carmelo Crater, underlies the summit ice cap; Grant Peak is the high point on the crater's rim, 14 km from the lake. Sherman Crater is 400 m below the summit on the left (south) skyline; pointed Sherman Peak rises on the southeast rim of Sherman Crater. Dark cleavers emerging above the mountain's heavy glacial cover are Pleistocene lava flows. Boulder Creek is the prominent alluvium-filled valley. The bridge at Stop 7 is at bottom center.*

Volcanic Deposits At Mount Baker, Washington: Tephra, Lava, Cinder Cones and A Caldera

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Recommended map for this field trip:

Mt. Baker Wilderness, Mt. Baker National Recreation Area, Noisy-Diobsud Wilderness, Mount Baker Snoqualmie National Forest, 2005, US Forest Service. This is a topographic-based map showing all roads used on this field trip, printed on durable water-resistant paper. It is available at the Public Service Station in Sedro Woolley, on Highway 20 just east of the Three Rivers Motel, or at the Glacier Public Service Station in Glacier on Day 2.

ABSTRACT

The glacier-clad active andesitic cone of Mount Baker is the youngest stratovolcano in the Mount Baker Volcanic Field. Indeed, it is the youngest in the Cascade arc in Washington. The earliest known eruptive activity was collapse of the rhyodacitic Kulshan caldera about 1.15 Ma. Pleistocene activity was centered at a number of basaltic and andesitic vents, now mostly eroded. The modern Baker edifice was built by eruptions focused at the now ice-filled Carmelo Crater on the summit plateau, and was largely completed by the end of the Pleistocene. Holocene activity has largely been destructional in nature, marked by flank collapses in the vicinity of Sherman Crater, which transformed into lahars, some wideranging. A single Holocene magmatic eruption is documented from the cone, and the only post-glacial lava was erupted from a subsidiary cinder cone low on the south flank of Mount Baker.

The first day of this two-day field trip will visit a variety of Holocene volcanic deposits from Mount Baker in the Baker River valley at the eastern foot of the volcano. The second day will travel to the northeast flank of the volcano for an overview of the Kulshan caldera, and to see Table Mountain andesite lava predating Mount Baker.

Stops include:

- A vestige of the Boulder Creek assemblage, a large post-glacial debris fan resulting from the final constructional activity at Baker's summit crater;
- the compositionally-zoned 8850 14C years BP Sulphur Creek lava flow (basalt and basaltic andesite), including both subaerial and subaqueous depositional facies;
- basaltic tephra set SC, which preceded eruption of the cinder cone source of the Sulphur Creek lava flow;
- a view of the Schreibers Meadow cinder cone itself (requires a short, flat hike in the meadows);
- BA tephra, product of the only documented Holocene magmatic eruption at Mount Baker proper;
- The 1845-47 Morovitz Creek lahars from collapse of Sherman Crater's east rim;
- Baker Lake reservoir, the focus of heightened eruption concerns in 1975, and certainly in the future.
- Overview and discussion of the Kulshan caldera
- Glacially eroded columnar jointing of the pre-Baker Table Mountain lava.

The field trip includes updates on recent volcanologic research at Mount Baker, and presents scenarios for likely future activity and the potential scope of volcanic hazards.

INTRODUCTION

This field trip visits largely Holocene volcanic deposits on the lower eastern flank of Mount Baker, an active, ice-mantled, 3286 m (10,781 ft) Cascade arc volcano (Fig. 1), and older volcanics on the northeast flank. Pleistocene eruptive products, including those of the 1.15 Ma Kulshan caldera and later andesite lavas, are described in detail by Wes Hildreth and others (2003). All the Holocene deposits and events described in this guide are discussed at length in an upcoming USGS Professional Paper by Kevin Scott, Dave Tucker, Jon Riedel, and Jack McGeehin (referred to herein as Scott and others, in press). The Baker River valley and the east side of the volcano afford the greatest diversity of Holocene volcanic deposits anywhere around the mountain. This flank of the volcano is relatively well served by roads. However, serious examination of volcanic exposures requires hiking and considerable bushwhacking. We regret that this field trip cannot provide nearly enough of these to satisfy anyone.

A version of the Baker River portion of this field trip (Day one) was given at the 2007 Cordilleran GSA meeting. Some aspects of the Holocene geology have been presented in a number of abstracts or papers by various combinations of the field trip authors (Scott and Tucker, 2003, 2006; Scott and others, 2003a, 2003b; Tucker and Scott, 2004, 2006, 2009; Tucker and others, 2007; Lewis and others, 2006, 2007). A detailed field guide to Mount Baker geology is currently being written by Dave Tucker for eventual commercial publication, and is the source for much of the NWGS version. For information on this future book, subscribe to posts from Northwest Geology Field Trips, www.nwgeology.wordpress.com.

For an overview of regional geology, including basement rocks, two excellent resources are the Mount Baker 30 x 60 geologic map by Tabor and others (2003) and a popular geology guide by Tabor and Haugerud (1999). Complete references are listed at the end of this field guide.

A brief flurry of scientific attention was paid to Mount Baker during the 1975 eruption scare, and a number of papers resulted from those initial studies of the volcano. Prior to the turn of the 21st Century, however, surprisingly little was known about the longer-term eruptive and geologic history of Mount Baker, nor was the existence of a 'volcanic field' recognized. Publication in 2003 of the multi-year geology, geochemical, and geochronology fieldwork undertaken by Wes Hildreth and his colleagues marked the beginning of the modern era of Baker geology. Following publication of Hildreth and others (2003), a number of studies have focused on Mount Baker volcanism, indicative of the scientific attention this beautiful, but potentially destructive, volcano deserves. More recent journal articles discuss evolution of Baker andesites based on geochemistry (Baggerman, 2008), gravity anomalies at Sherman Crater (Crider and others, 2008), fumarole gas chemistry and the causes of the 1975 activity (Werner and others, 2009), the flow of the Sulphur Creek lava into Glacial Lake Baker (Tucker and Scott, 2009) and edifice deflation mechanisms (Hodge and Crider, 2010). The 2007 GSA Cordilleran Section meeting in Bellingham included a Mount Baker symposium and produced a number of abstracts (Baggerman and DeBari, 2007; Caplan-Auerbach and Huggel 2007; Feeney and Linneman, 2007; Fountain and others, 2007; Hill and others, 2007; Juday, 2007; Mullen and McCallum, 2007; Poland and others, 2007; Ryane and others, 2007; Tucker and others, 2007; Warren and Watters, 2007). Many other abstracts dealing with this beautiful volcano have been given since 2007. The Mount Baker Volcano Research Center website, hosted by Western Washington University, features research updates, and information on the volcano. The website features on-line copies of the abstracts referred to above, and a database listing Baker journal articles. The URL is http://mbvrc.wwu.edu. Western Washington University continues to be a hot bed of Mount Baker research. Several graduate students are currently working on theses dealing with the volcano.

Mount Baker is the youngest composite cone in the Mount Baker volcanic field, which was first recognized and described in Hildreth and others, 2003. The MBVF consists of about a dozen eruptive centers, ranging in age from the 1.15 Ma Kulshan caldera (Hildreth, 1996) centered 10 km northeast of the summit of Mount Baker, to the 8850 14C BP Schreibers Meadow cinder cone on the south flank of Mount Baker. The best known and largest of the pre-Mount Baker stratocones is the Black Buttes volcano (ca. 500-300 ka). This is a glacially gutted edifice just west of the current center at Mount Baker. Black Buttes volcano was taller and more voluminous than the Baker edifice; Black Buttes lavas extend from beneath the skirts Baker lavas in almost all directions. The ca. 300 ka Table Mountain andesite lavas were rate vent to the northeast. Prior to the Kulshan caldera, the 3.72 Ma Hannegan caldera (Tucker and others, 2004) collapsed twice 25 km northeast of the MBVF. For much more detail about the geology and chronology of the MBVF, as well as the constructional phase of the Baker edifice, see the immensely readable and informative 2003 GSA Bulletin paper by Wes Hildreth and his colleagues Judy Fierstein and Marvin Lanphere.

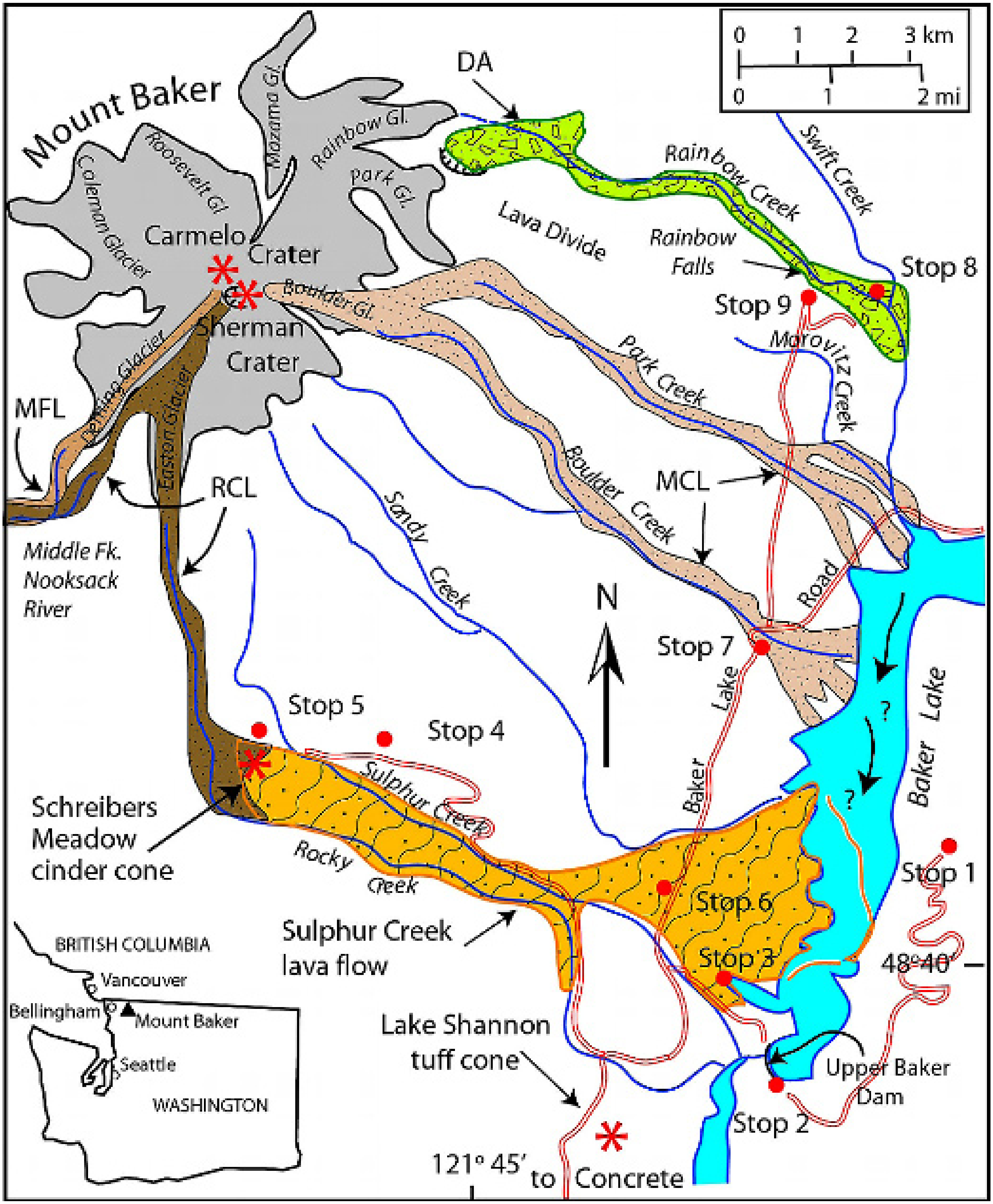

Figure 2. Mount Baker volcano and drainages on the south and east flanks, showing the route and stops on Day 1 of the 2010 Northwest Geological Society field trip. Vents are shown as starred symbols. Note that the Sulphur Creek lava crops out on the east side of Baker Lake. Arrows in Baker Lake reflect uncertainties in downstream extent of lahars in the Baker River, now impounded behind Baker Dam. Adapted from Tucker and others, 2007.

Mount Baker Holocene Eruptive Periods

We define four Holocene eruptive periods at Mount Baker (Scott and others, 2003a). These are listed from oldest to youngest, and included in Table 1. Table 1 is also available on the back of the 2010 MBVRC fund-raiser t-shirts, available on this field trip.

The Mount Baker edifice, composed of andesitic lavas and breccias, was completed in the Late Pleistocene. Thick assemblages of block-and-ash flows, lahars and their distal runouts, and associated alluvium were emplaced in drainages on the south and southeast flanks of Mount Baker (Tucker and Scott, 2004). Flows originated from the now ice-filled Carmelo Crater at the mountain's summit (Hildreth and others 2003). The best known of these assemblages is the Boulder Creek assemblage (Hyde and Crandell, 1978; Hildreth and others, 2003; Tucker and Scott, 2004), exposed 2 km upstream from the bridge over Boulder Creek (Stop 7). A cross-country day trip is required to visit these exposures. The most distal exposure known of the assemblage, though small, is visible in a road cut just north of the bridge at Boulder Creek, a brief optional stop for this trip after Stop 7.

A maximum limiting age of the eruptive period is based on the age of Vashon till, which underlies the assemblage in Pratt Creek. Vashon ice arrived in the Baker River valley via the Skagit valley, ca. 16,000 BP (Riedel, 2007). A minimum-limiting age for the Vashon, (12,200 BP) is the age of the Sandy Creek beds, volcaniclastic-free lacustrine deposits of Glacial Lake Baker which directly overly Vashon till (Scott and Tucker, 2006). The newly defined glacial lake (Scott and Tucker, 2006; Scott et al, in press) occupied the Baker River valley after recession of Vashon ice. A minimum age for the Boulder Creek assemblage is given by overlying fine ash from the 8850 BP Schreibers Meadow cinder cone (see below).

Schreibers Meadow eruptive period (ca. 8500-8850 BP).

The main event of this eruptive period was the eruption at the Schreibers Meadow cinder cone, at 1122 m elevation (3680 ft) near the south base of Mount Baker (Easterbrook, 1975). The eruption initially produced basaltic tephra (51-52% SiO_2; Hildreth and others, 2003; Tucker and others, 2007), followed by effusion of compositionally similar lava. Composition of the lava becomes andesitic closer to the cone (55-59% SiO_2; Hildreth and others, 2003), and reflects subsequent eruption of basaltic andesite lava (Scott et al, in press).

Figure 3. *'Mighty Joe' Morovits, the 'Hermit of Baker Lake' homesteaded on the creek that bears his misspelled name in 1891. This selfeducated miner and mountain guide provided original and accurate interpretations of Baker deposits. He correctly estimated the young lahar deposits in Boulder, Park, and Morovitz Creeks to have been deposited in about 1845, based on tree growth. His mention of a gorge eroded through the Sulphur Creek basalt in the Baker River, now drowned beneath the reservoir, provides the only account known to the field trip authors of the exposed thickness of the lava where it is cut through by the river. Joe also recognized that an "earlier Mount Baker" at one time existed in the headwaters of Swift Creek. Today we know this to be the 1.15 Ma Kulshan caldera. Photo courtesy Whatcom Museum of History and Art.*

The lava (Fig. 2) flowed 12 km down Sulphur Creek valley, eventually entering Glacial Lake Baker (Stop 3). This lake was formed by the end of the Vashon glaciation, dammed by glacial deposits on the north side of the Skagit River. The lake flooded the Baker River valley; its northern extent was similar to that of modern Baker Lake reservoir (Fig. 2)

The final event of the period was a flank collapse from the upslope sector of Mount Baker that yielded the Schreibers Meadow lahar (8500 BP). The lahar crossed the interfluve separating the westflowing Middle Fork Nooksack River (Fig. 2) and Sulphur Creek, flowing down both drainages, and surrounding the cinder cone in Schreibers Meadow. The meadow is named for Baker pioneer Herman Schreiber; as so often occurs, his name was misspelled when applied to the meadow where he built a cabin in 1910.

Mazama Park eruptive period (ca. 5740-5930 BP).

This mid-Holocene eruptive period is a classic example of an eruption cycle in which 1) the edifice is destabilized as magma is intruded at depth, leading 2) to flank collapses, followed by 3) phreatomagmatic eruptions as rising magma in the edifice encounters meteoric water, and culminating in 4) a magmatic eruption. The magmatic BA tephra (Stops 5 and 9; Scott and others, 2001; Hildreth and others, 2003; Scott and others, 2003a; Tucker and others, 2007, Scott et al, in press) has the greatest volume

TABLE 1.

IN A NUTSHELL: MOUNT BAKER VOLCANIC FIELD HISTORY*

3.7 million years ago • Hannegan caldera (25 km northeast) collapses twice
1 million years ago • Kulshan caldera collapse and later eruptions
300-500,000 years ago • pre- Baker volcanoes, including Black Buttes, Table Mountain
40,000 years ago • Modern Baker cone begins growing with 100 + lava eruptions

Carmelo Crater eruptive period
12,200-15,000 years ago • lava and lahars (mudflows) in southern and eastern valleys

Schreibers Meadow eruptive period
9500 years ago • Schreibers Meadow cinder cone erupts; lava reaches Baker River valley
9200 years ago • Schreibers Meadow lahar from collapse of Baker's south slope

Mazama Park eruptive period
6600 years ago • Upper south face collapses twice, generates lahars reaching Nooksack, Fraser and Baker River lowlands
6500 years ago • Eruption showers BA ash 40 miles to the east and northeast

Sherman Crater eruptive period
1843 • Large steam blast seen from Langley, BC Hudson's Bay post
1845 • Morovitz Lahar flows down Boulder, Park, and Morovitz Creeks
1850-1880 • steam eruptions reported
1891 • giant rockslide from Lava Divide roars 5 miles down Rainbow Creek
1975 • 'failed eruption'- large steam outbursts; increased heat melts crater ice
2003-2010 • increased research reveals Mount Baker's history & behavior
Today • steam and gases vent from Sherman Crater and Dorr Fumaroles

*ages are approximate calendar years. 14C ages are given in the text.

and most widespread distribution of any Holocene tephra from Mount Baker. Two of these collapses transformed into the Middle Fork and Ridley Creek lahars, the largest lahars known from Mount Baker. The time relationship of flank collapse lahars and eruptions is crucial in deciding whether the former can be grouped with the volcanic hazards directly associated with eruptions, and can therefore be similarly predicted. Emerging evidence suggests that large-scale collapses can be triggered with initial magma injection at depth well before an impending eruption (Scott and others, 2001).

Sherman Crater eruptive period (AD 1843 to present).

The period began with at least one large explosive phreatic eruption at Sherman Crater (Scott and Tucker, 2003; Scott and others, in press). The eruption was witnessed by Hudson's Bay traders at Fort Langley on the Fraser River and "covered the whole country with ashes" (Gibbs, 1874). Hydrothermally altered lapilli and ballistic blocks were ejected onto the glaciers and upper slopes of the mountain.

Hydrothermal alteration weakens the east side of Sherman Crater, which failed between 1845 and 1847 (Scott and Tucker, 2003; Scott and others, 2003b) to produce the multi-branched Morovitz Creek lahar (Stop 7). The lahar descended Boulder Glacier. Because of more extensive glacial cover at the time, it spilled over the divide into Park Creek and the lower reaches of Morovitz, Swift and Little Park Creeks (Fig. 2). We name the lahar to honor pioneer miner and climbing guide Joseph Morovits (misspelled as 'Morovitz' when applied to geographic features; Fig 3), who constructed his cabin on its deposits and who made important observations of 19th-century geological events

We suggest that the eruptive period continues today, based on the greatly increased heat flux in 1975-1976. (Fig 4.) Thermal activity has since decreased, but not to pre-1975 levels. Sherman Crater emits ca. 180 tons per day of CO_2 and 5.5 tons per day of H_2S believed to be derived from magmatic SO_2 by hydrothermal scrubbing (McGee and others, 2001; Symonds and others, 2003a and 2003b; Werner and others, 2009). Airborne monitoring of gas emissions continues, as does gas collection from Sherman Crater fumaroles (see MBVRC website for data). On the basis of activity in 1975-1976,


The Sunday Herald

Northwest Washington's only Sunday newspaper

Sunday, March 16, 1975 | Bellingham, Washington 98225 | 25 cents

Is Mt. Baker about to blow its top?

Mud, not lava, is the danger

Figure 4. Bellingham Herald headline of March 16, 1975.

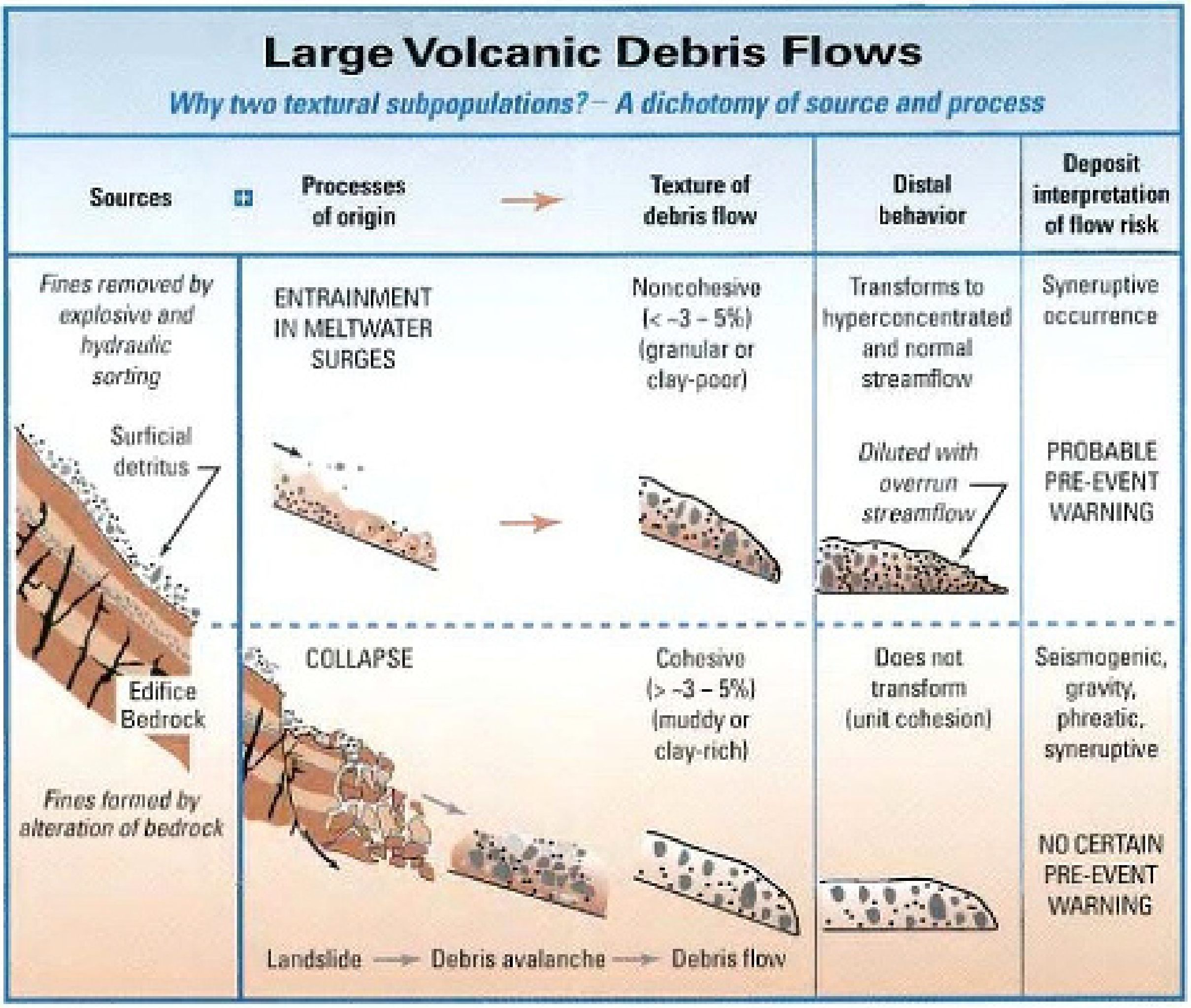

Figure 5. *The textural differences between cohesive and non‐cohesive lahars. From Scott and others, 2001.*

scientists warned that Baker could be the site of the next eruption in the Cascade arc, a role usurped by Mount St. Helens five years later. In March of 1975, levels of the reservoirs in the Baker River valley, Baker Lake and Lake Shannon, were drawn down in preparation for inflows of lahars analogous to the Morovitz Creek lahar.

Mount Baker's lahar textures reflect their origins

The chief volcanic hazard at Mount Baker is from lahars, in particular those that begin as flank collapses (Figs. 5 and 6). Flank collapses are volcanic landslides confined to one flank of a volcano; they do not remove the summit, as would a sector collapse like that from Mount Saint Helens in 1980. Lahars that begin as flank collapses are known as cohesive lahars, and deposits have a relatively clay-rich matrix; a Mount Baker example is the Morovitz Creek lahar, seen at Stop 7. The clay content reflects the degree of hydrothermal alteration common to many stratovolcanoes. Cohesive lahars contrast with noncohesive, granular-textured lahars, commonly described as syneruptive. Noncohesive lahars have an origin involving the entrainment of detrital sediment (from which much fine sediment has been previously winnowed) on volcano flanks by surges of meltwater resulting from hot volcanic flows or ash falls. Lahar deposits in the Boulder Creek assemblage (Stop 7) are examples.

This textural dichotomy in lahars is a valuable tool in reconstructing volcanic history. Both clay-rich cohesive and granular noncohesive lahars can greatly increase in volume as they flow downslope by "bulking" with alluvium and valley wall sediment.

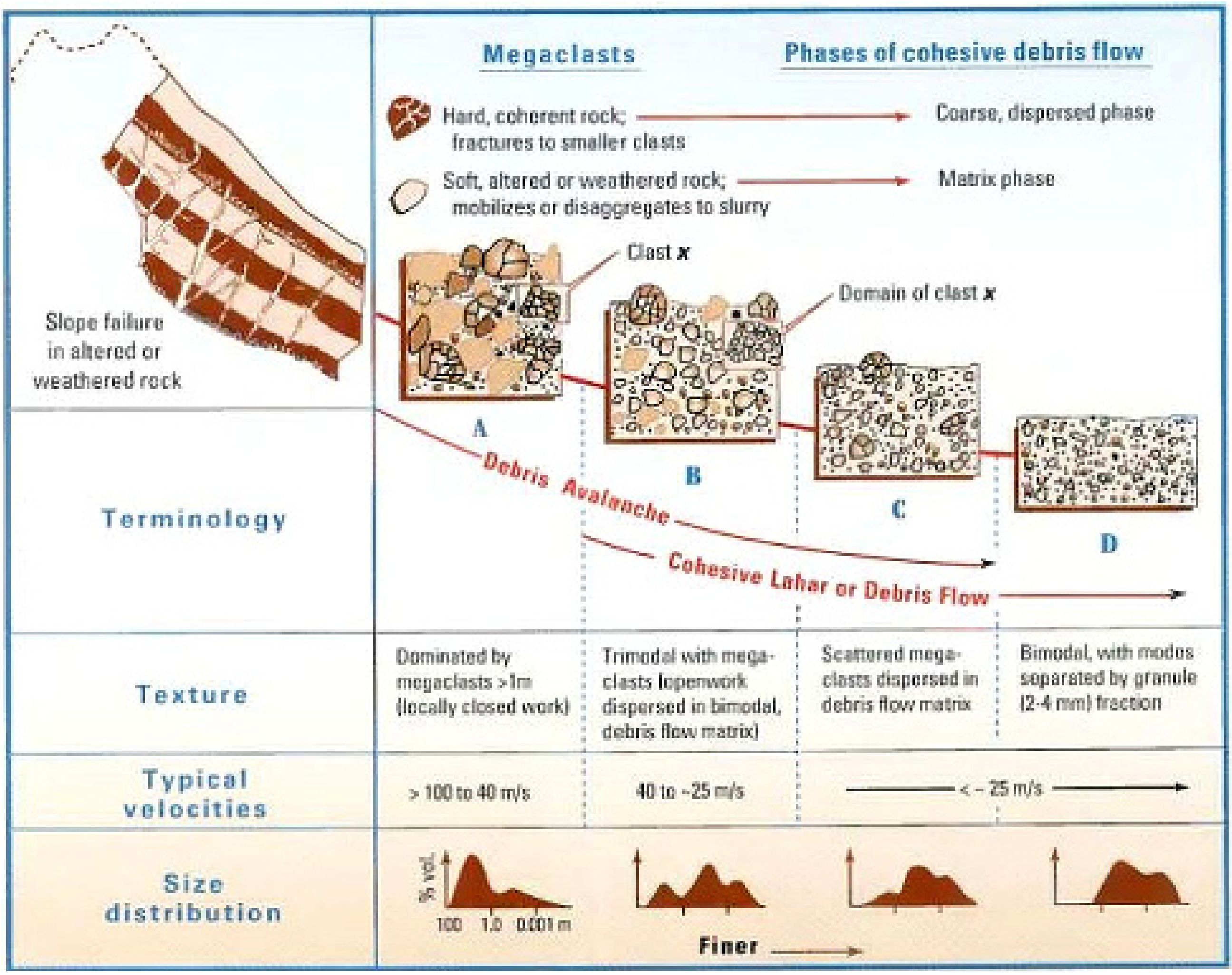

Figure 6. *How rock becomes a clay□rich, cohesive lahar. From Scott and others, 2001.*

FUTURE HAZARDS OF MOUNT BAKER

The Morovitz Creek lahar, not defined at the time of the 1975-1976 activity, is an example of the hazard that was both then and now the most probable hazard causing the greatest concern. This is a collapse from Sherman Crater that transforms to a mobile lahar displacing water from Baker Reservoir. Downstream flooding as well as wave damage to developments around the shore of the reservoir could result. What occurred in the 1970's was the correct response--evacuating lakeshore developments and campgrounds and lowering the level of the reservoir to accommodate potential lahar inflow until the activity subsided. Drawdown will logically accompany any future increase in activity at Sherman Crater. The geologic record indicates that actual eruptions of Mount Baker are small and non-explosive. Distribution of ash is determined in part by wind direction; this normally blows toward the uninhabited North Cascades mountains.

THE FIELD TRIP

Day 1: The field trip guide is presented as a series of separate destinations on roads branching off of the paved Baker Lake Road. Mileages will be given separately for each of these self-contained trips. This allows more flexibility in the order that stops are visited. Mileage logs for these individual trips are included in this guide, requiring occasional resetting of trip odometers to 0.0. Roads maintained by the US Forest Service are labeled by the FS number, e.g. FS 12, FS 1107. Stops are numbered on Figure 2. The field trip mileage log begins at the junction of Washington State Route 20 and the Baker Lake Road. This junction is 16 miles east of the town of Sedro Woolley and 6 miles west of the town of Concrete. Elevation is 194 feet.

Mileage log

0.0 Turn north off SR 20 onto Baker Lake Rd.

1.6 Thick Vashon-aged glaciolacustrine and outwash deposits on the right, across Grandy Creek.

4.8 Grandy Lake County campground.

6.6 Burpee Hill Rd, leads to Concrete in 4 miles.

9.4 High, conical hill ahead is the vent for the 94 ± 21 ka subglacial basalt of Lake Shannon (Hildreth and others, 2003), consisting of palagonitized hyaloclastite tuff with a few thin interbedded basalt lava flows near the summit.

11.2 At the extreme north end of the outcrop on left, fragmental basalt of Lake Shannon lies against Cretaceous-Jurassic Nooksack Formation (Tabor et al, 2003). Gated road to right gives access to the vent area of the basalt, well-hidden by young brush and forest.

12.1 At the T-intersection with FS 12 stay right on the paved Baker Lake Road. FS 12 gives access to Mount Baker hiking trails and summit, and the tree-covered early Holocene Schreibers Meadow cinder cone. This is the route to Stops 4 and 5.

12.7 High roadcut cliffs in early Cretaceous to mid-Jurassic argillite of the Nooksack Formation, accreted to the continental margin in the mid-Cretaceous. This is one of the two main basement units underlying the younger volcanic rocks of the Mount Baker volcanic field. The other is the Chilliwack Group, seen later.

13.4 View ahead is of the south side of Mount Baker. The summit plateau is the ice-filled Carmelo Crater, site of Pleistocene eruptions; Grant Peak, the highest point on this crater's rim, on the right. The slightly lower point on the left is Sherman Peak (3090 m; 10,140 ft), on the south rim of Sherman Crater.

TO STOPS 1-3

13.8 Turn right on Baker Lake Dam Rd. After crossing Sulphur Creek, the road descends the fresh surface of the forested early Holocene Sulphur Creek lava flow. Fifty meters beyond the bridgeover Sulphur Creek at a pullout, a faint trail goes right (south) through brush 100 m to a lovely 10-m-high waterfall thundering over a scarp eroded through the Sulphur Creek lava flow. It is possible to climb down over the scarp of the flow and reach the stream immediately below the falls.

About a mile further down the gravel road, turn left and follow signs to the boat launch and picnic area.

15.0 **STOP 1**— Overview of the Mount Baker edifice

Park at the boat ramp on the shore of Baker Lake Reservoir. The upper part of the Baker edifice rises over 10,000 feet (3060 m) above this point (Fig 1). Sherman Crater lies in the notch just south (left) of the summit plateau, which is the ice-filled Carmelo Crater. Sherman Peak is the pointed subsummit, the highest point on the south rim.

Return to Baker Dam Road, turn left, drive 0.5 mile over the dam, park at the southern end and walk back onto the dam.

Figure 7. *The downstream face of Upper Baker Dam is 312 feet (95 meters) high.*

STOP 2—Upper Baker Dam and the response to Baker lahar hazards

This brief stop will focus on the hazard posed by lahars on the reservoirs in the Baker River valley. Upper Baker Dam (Fig. 7) impounds Baker Lake Reservoir (full pool elevation 722 feet), which lies at the receiving end of all east-side drainages on Mount Baker. During the last eruption scare atBaker, in the spring of 1975, the USGS suggested that the dam's floodgates remain open to prevent filling by spring snowmelt to accommodate a sudden volume increase should a lahar descend Boulder Creek, directly draining Sherman Crater. The lake remained at winter drawdown levels, some 40 feet below the full pool elevation (Fig. 8). This resulted in significant reduction of power capacity for the operator (now Puget Sound Energy), closure of the Baker Lake Resort and area campgrounds, and considerable loss of recreation in the valley. A lahar or seich overtopping Upper Baker Dam would flow downstream into Lake

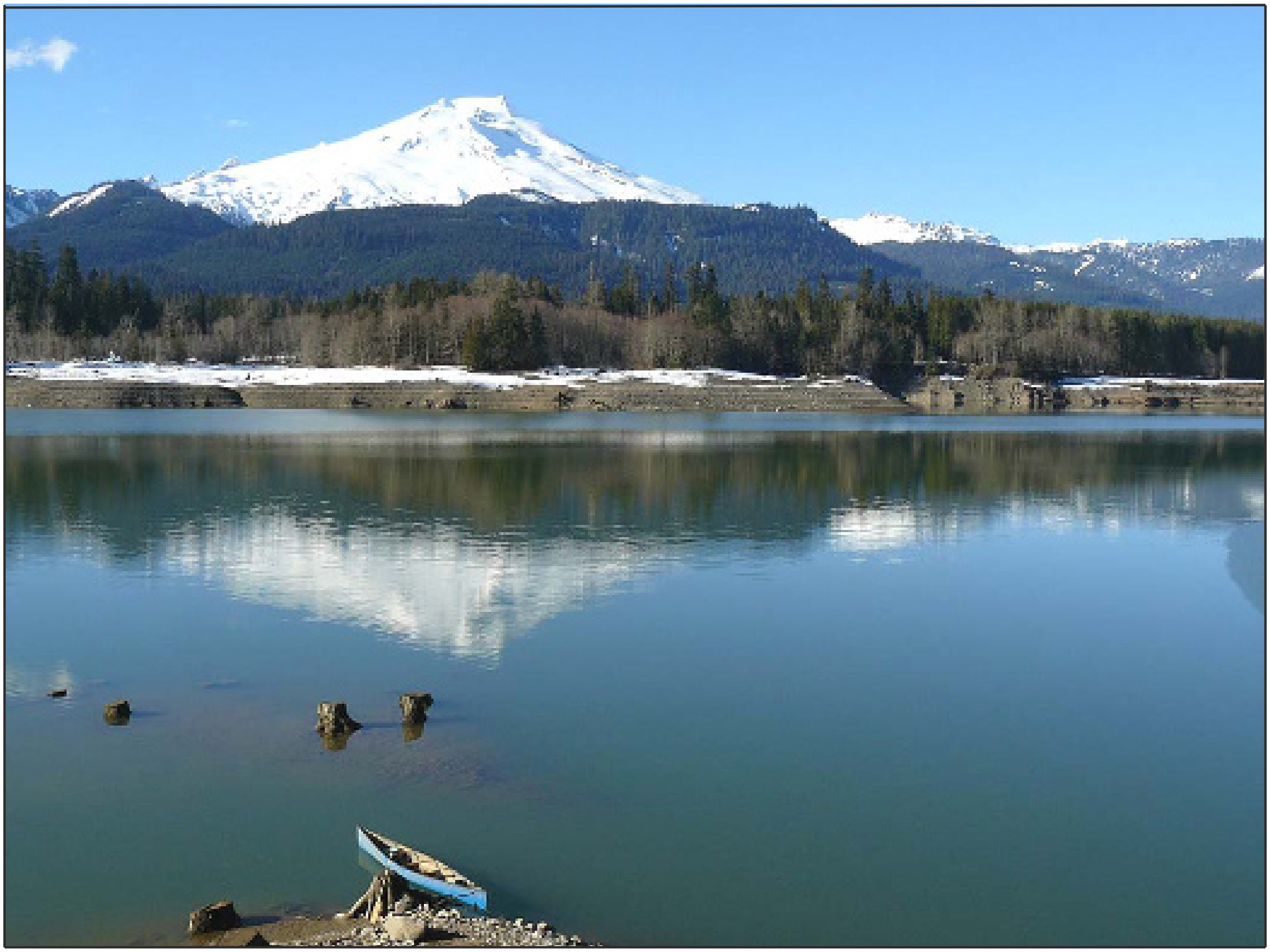

Figure 8. *During winter, water levels of Baker Lake Reservoir fall as much as 40 feet, revealing fascinating exposures of completely unvegetated subaqueous facies of the Sulphur Creek lava. The lava flowed into a large lake impounded behind glacial sediments near Concrete. See Tucker and Scott, 2009.*

Shannon (elevation 400 feet), impounded behind Lower Baker Dam immediately above the town of Concrete at the confluence of the Baker and Skagit rivers.

Return over the dam and beyond the turnoff to Stop 1.

In about 0.6 mile, turn sharp left on a spur road (may be signed FS 1106-011) leading down toward an arm of Baker Lake. Park at old quarry (elevation 790 ft). The quarry may be occupied by campers.

STOP 3—Quenched, glassy, subaqueous basalt of Sulphur Creek

Carefully scramble up the loose talus to the base of the wall of lava. Watch for broken bottles and rolling blocks. This is the ca. 8850 BP basalt of Sulphur Creek, the most mafic lava known from vents in the Baker volcanic field (51.6% SiO2, sample MB 462 of Hildreth and others, 2003). The lava issued from a small cinder cone in Schreibers Meadow, elevation 1122 m (3680 ft), 10 km further up Sulphur Creek to the northwest (Fig. 2). Lava extends another 3 km to the east, to the far side of the Baker River.

The lava invaded and displaced laminated clays deposited in Glacial Lake Baker (Fig. 4; Scott and Tucker, 2006; Tucker and Scott, 2009). The eruption initially produced basaltic tephra and lava; this was followed by basaltic andesite lava flows (55-59% SiO_2; Hildreth and others, 2003) very shortly after . Petrologic studies by Green (1988), Baggerman (2008) and Moore and DeBari

Figure 9. *Pseudopillow structures defined by quench fractures at Stop 3.*

(2008) model magma mixing conditions to produce this lava.

The black, densely vesicular, glassy, plagioclase-phyric basalt lava at this stop is pervasively jointed. At its base, the lava displays concentric, steeply east-dipping fractures separating pseudopillow structures (Walker, 1992; Lescinsky and Fink, 2000) 5-25 cm thick (Fig. 9).

Dip faces on these fractures are oxidized brown, and pitted. "Tiny normal joints" (McPhie et al, 1993) with 1-cm-spacing radiate a few cm inward from the margins of the pseudopillow fractures; the interior of the pseudopillows themselves is more massive, and jointed at 10 cm intervals. More bulbous pseudopillows can be seen at the very base at the left end of the exposure. Pseudopillow fracturing forms when a copious volume of water interacts with viscous, coherent, flowing lava. The short, closely spaced cooling joints develop normal to the quenched faces of pseudopillows isolated by the fractures. The pseudopillows are not present higher up on the 10-m-high lava face. The lava is overlain by several meters of sandy alluvium consisting of basalt scoria and rounded blocks of lava up to several meters in diameter. The texture and structure of the subaqueous lava at this location is markedly different from textures at exposures of subaerial lava only a few hundred meters to the west, where the basalt is lighter colored and much less glassy.

Return to vehicles, turn around and return to the Baker Lake Dam Road.

Turn left on Baker Lake Road to the junction with a gravel road signed 'Mount Baker Recreation Area'.

**SOUTH SIDE OF MOUNT BAKER-
FOREST ROADS 12 AND 13; ACCESS TO SCHREIBERS AND MOROVITS MEADOWS, PARK BUTTE AND SCOTT PAUL TRAILS, RAILROAD GRADE, AND EASTON GLACIER**

This trip begins at the junction of Baker Lake Road and FS Road 12, 12.3 miles from Highway 20, or 1.5 miles south of the Baker Lake Dam Road. Reset odometers at the junction of Road 12 with Baker Lake Road, 12.3 miles from Highway 20. Elevation at the junction is 1120 feet.

Mileages:

0.0 Begin driving west on Road 12.

0.6 Rocky Creek just below road to left.

1.8 Junction to right (snowmobile parking). Drive on to the surface of the SC lava.

1.9 First outcrop of 8850 BP Sulphur Creek lava.

2.1 Sulphur Creek bridge; the stream runs in a shallow gorge. A cross-country stroll down stream on the left bank of SC is recommended to see the deepening gorge cut into the lava.

2.2 Gated road on right. 100 yards down this road is a nice quarried section through the SC basaltic andesite lava.Optional field trip stop

3.5 Junction with FR 13. Turn right for the trailheads and to continue this road log. Almost imme diately, cross the right of way of the penstock for the Koma Kulshan Hydroelectric Com pany. This mini-hydropower project has a small dam on Rocky Creek below the base of the Schreibers Meadow cinder cone. Water is diverted out of Rocky Creek and carried in this penstock about 4.6 miles nto Sandy Creek (completely bypassing the intervening SulphurCreek). There is a small power turbine where the penstock reaches Sandy Creek, which generates 14 MW of power. The water enters Sandy Creek, which flows to Baker Lake reservoir. In thisway, water that would otherwise flow down Rocky Creek into the lower reservoir, Lake Shannon, generates power three times: at Sandy Creek, and at the powerhouse of each of the two Baker River hydroelectric dams.

3.6 The road begins to climb out of the valley; as soon as it does, leave the Sulphur Creek lava.

7.7 **STOP 4-** PROXIMAL FALL DEPOSIT OF THE SC TEPHRA

Elevation 3120 feet. For the past 0.5 mile or so, red-orange basaltic lapilli of the SC tephra has blanketed road cuts on the north (right) This is a proximal fall deposit of the 8800 BP Schreibers Meadow eruption. The cinder cone is 1.5 km to the west. Primary tephra thickness here is difficult to determine, as the tephra blanketed the steep valley slopes above and was probably immediately remobilized. The scoria along the road is occasionally 'mined' for garden landscaping by locals. Prevailing winds from the SW resulted in an elliptical distribution of the SC tephra. Great drifts of the SC tephra lie in meadows on the south flank of Mount Baker, but the tephra thins rapidly. It is only a centimeter thick 10 km NE of the vent, and peters out altogether within 15 km. It has not been found more than 5 km SW of the cone. Figure 10 shows field relations of tephras at Mount Baker.

7.9 Glimpse ahead to the neoglacial Railroad Grade moraine of the Easton Glacier.

8.2 At a very short spur road to the left you might be able to pick out the heavily forested and inconspicuous Schreibers Meadow cinder cone close by to the southwest (Fig 11).

8.3 Cross a small creek that has cut into the Sulphur Creek lava just below the road. Drive onto the surface of the lava, only 500 yards from the well-hidden cone.

8.4 Enter Schreibers Meadows and the trailhead parking area for the Park Butte and Scott Paul trails. There are toilets at the trailhead. Elevation 3364 feet.

Figure 10. *Tephra stratigraphy on the south flank of Mount Baker. Red SC lapilli are overlain by white layer O (Mazama ash). Baker phreatic OP tephra is the wispy layer of yellowish Shermanite; dark sandy magmatic BA is above.*

STOP 5—SCHREIBERS MEADOW PYROCLASTIC DEPOSITS (< 1 mile round trip trail hike)

Hike the Park Butte--Railroad Grade trail across the footbridge over Sulphur Creek. Look below in the stream bed for exposures of the Sulphur Creek lava. The Schreibers Meadow lahar (ca. 8500 BP) that swept down the flank of Mount Baker following the Schreibers eruption is sporadically visible. Thislahar banked against the cinder cone, and is locally seen atop the lava flow. It picked up considerable SC tephra and is therefore often a reddish brown color. Source area for this lahar is not known. We will stop at an appropriate trail cut to examine thin, pale, and lithic distal deposits of the 5790 BP Ridley Creek lahar (RCL), and remobilized slurries of the stratigraphically younger gray and sandy BA tephra, erupted immediately after emplacement of the RCL. Both events occurred during the Mazama Park eruptive period (ca. 5740-5930 BP). The deposits we associate with this eruptive period are:

1. Park Creek Lahars (5930 BP)- these flowed down Park Creek from flank collapse sources high on Baker's edifice.

2. Middle Fork Lahar (MFL; 5900 BP). The largest lahar known at Mount Baker flowed down the Middle Fork Nooksack and out onto floodplains of Whatcom County. At the Nugent's Corner bridge on Mount Baker Highway, 47 km from the source, the deposit is 10 m thick. This lahar likely continued in the Nooksack River into the Fraser. Thick accumulations of debris diverted the Nooksack River into a glacial outwash channel at Everson, and now flows to Bellingham Bay. The MFL is

Figure 11. *Aerial view of the twin craters of the Schreibers Meadow cinder cone. Each crater holds a small lake. Photo by John Scurlock.*

cohesive, and originated on the southwest flank of Mount Baker, just below the summit (the resulting ice-mantled scarp is now called 'Roman Wall'). It did not flow into drainages on the south or east flanks of the volcano.

3. Tephra layer OP and Ridley Creek Lahar (RCL; 5790 BP). These units grade laterally into one another. They result from a phreatic explosion at Sherman crater, which erupted the hydrothermally-altered lithic OP tephra (Fig. 10) at the same time the southern rim of Sherman Crater collapsed. Both deposits are rich in the white to pale yellow, acid-sulfate rich, hydrothermally-altered material we call 'Shermanite', conspicuous just below the surface of Schreibers Meadow and elsewhere on the volcano. Some of the ejected tephra was thick and wet enough to remobilize and flow down the volcano's slopes, joining the much more voluminous RCL. The bulk of the lahar went down the Middle Fork to the southwest, where it directly overlies the slightly older MFL. The RCL in that drainage extended at least 35 km to the confluence of the Middle and North Forks of the Nooksack, and probably at least to Nugent's Corner (47 km). A smaller volume came down the Easton Glacier and into Rocky and Sulphur Creeks, extending as far as the rough surface of the Sulphur Creek lava.

4. Tephra layer BA (5790 BP). This is the product of the largest, and youngest, magmatic eruption at Mount Baker. The dark, sandy andesitic ash is prominent in trail cuts all around the mountain, and is found 66 km southeast (Cascade Pass) and 33 km northeast(Copper Ridge). On Baker's slopes, BA forms a couplet with OP tephra (Fig. 10), as it very closely (immediately?) followed the hydrothermal explosion producing OP.

Figure 12. *Subaerial facies of the Sulphur Creek lava looks very different from the subaqueous facies.*

We interpret the Mazama Park events to represent a classic sequence of 1) gravitational destabilization of the volcano's upper slopes by shallow magma intrusion to produce the Park Creek and Middle Fork lahars, but with no attendant eruption; 2) eruption of altered material and collapse as the magma reached saturated rock beneath the volcano; 3) final magmatic tephra eruption after Sherman Crater was blasted out by OP eruption and crater collapse. The lesson to take home is that intrusion of magma can destabilize a volcano's edifice; no eruption is necessary to produce flank collapses and destructive lahars. This theme is very important to hazard assessment, and will be covered in greater depth with the publication of the USGS Professional Paper by Scott and others (currently in press).

Backtrack to the paved Baker Lake Road, reset odometers to 0.0, and turn left.

1.0 Continue past the turn to Baker Dam.

1.2 Koma Kulshan Guard Station, home of the federal interagency Baker River Hotshots fire crew, an elite fire suppression team. The Guard Station is built on the margin of the Sulphur Creek lava; low mounds behind the buildings are vegetated tumuli on the flow surface. We are very near the elevation of the shoreline of Glacial Lake Baker, where the lava entered the lake. The road shortly rises onto the flow's surface.

1.8 Shadow of the Sentinels Nature Trail (toilets) on the right. This is a barrier-free trail that wanders through beautiful old trees on the surface of the lava. There are no lava exposures along the trail. Discreetly digging an 18" deep pit into the forest soil along the trail may reveal both

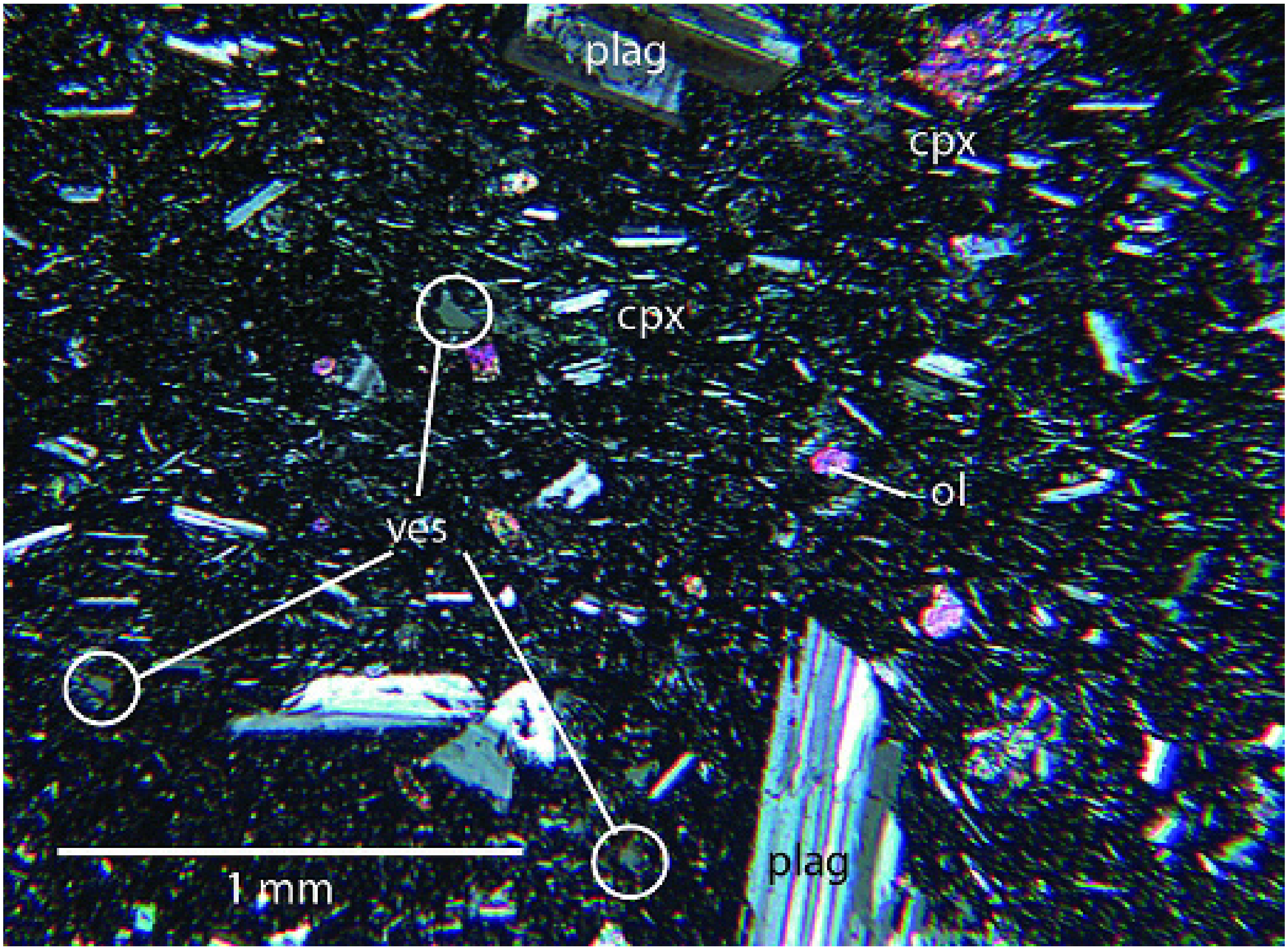

***Figure 13**. Thin section of subaerial Sulphur Creek basaltic andesite reveals olivine and plagioclase phenocrysts.*

Mazama layer O (6800 BP) and closely overlying Baker BA (5740 BP).

2.1 **STOP 6**—SUBAERIAL SULPHUR CREEK LAVA

Exposures of subaerial basaltic andesite (55.19% SiO2; Hildreth and others, 2003) Sulphur Creek lava line both sides of the road, elevation 1010 feet. At first glance, it may appear to be a rather boring lava (Fig. 12). However, it becomes much more interesting when contrasted with textures and structures of the same lava at Stop 3, 1.7 km to the southeast. The lava at Stop 6 is vesicular, and much lighter colored than the glassy subaqueous basalt. Olivine and pyroxene phenocrysts are present; plagioclase laths are much less prominent against the lighter matrix (Fig 13). Also note the compositional difference lava erupted from the Schreibers cone was initially basaltic, probably representing the initial pulse of hot magma that initiated the eruption, then becoming slightly more felsic as the eruption progressed and differentiated magma was dragged along behind. The bulk of the lava flow is basaltic andesite; basalt chemistry is only evident in the distal portion of the flow, nearer the Baker Lake Reservoir. This is the youngest lava flow in the MBVF. The lobe in Baker River extends over 11 km from the vent, with avolume of at least 0.5 km3. It spreads into a 4-km-wide fan a little to the east of this road cut. It is the largest Holocene lava flow in the Cascades north of the Big Lava Bed basalt flow in the Indian Heaven volcanic field, between Mount Saint Helens and Mount Adams. Tucker and Scott (2009) discuss in detail the composition, textures, and structures of this interesting lava, especially the subaqueous facies.

2.4 Horseshoe Cove Road (FS 1118) turns right here and reaches a campground and boat launch on Baker Lake. NWGS camping contingent will stay at the group camp site on the lake at

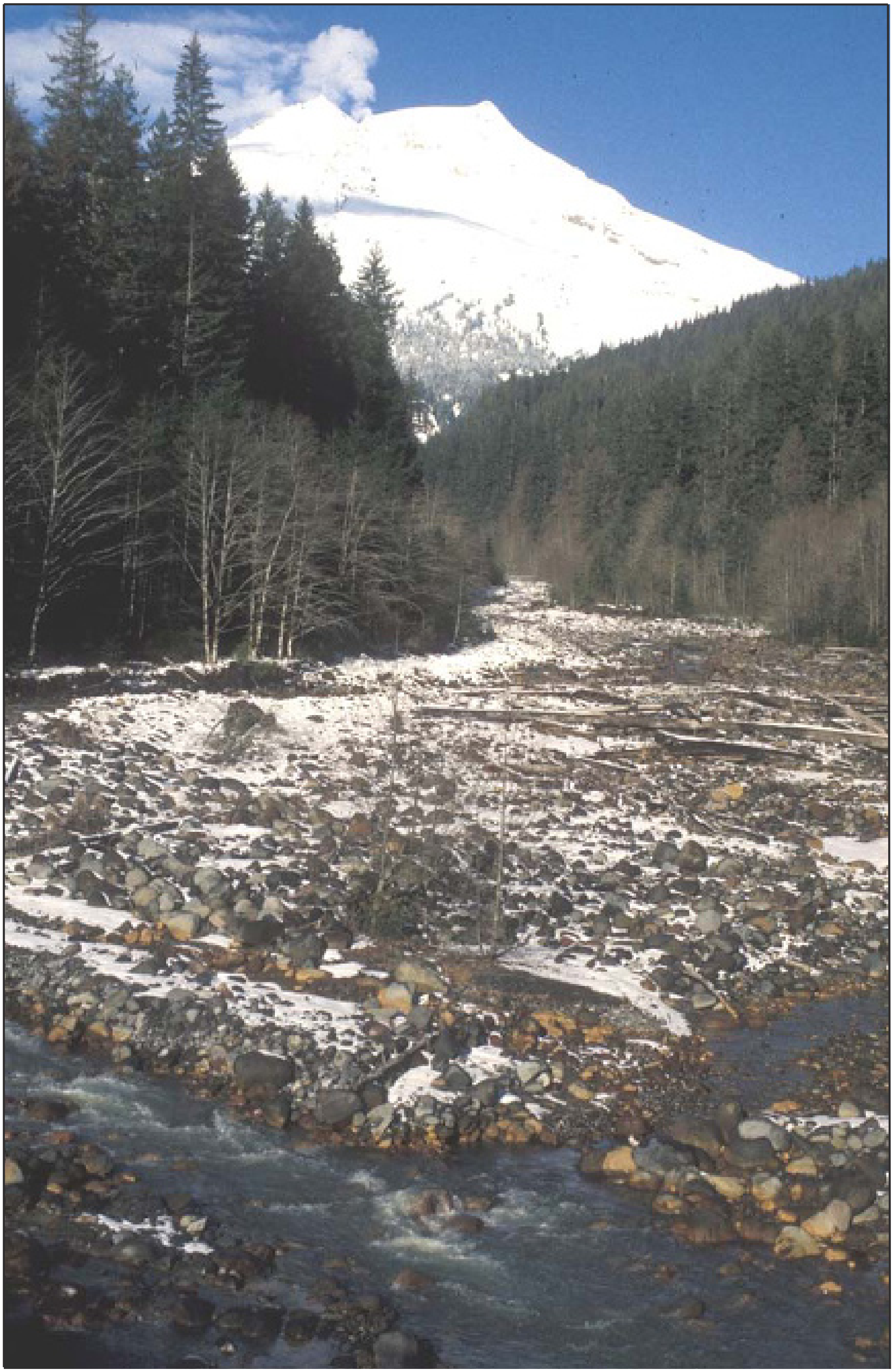

Figure 14. *Boulder Creek descends east from Sherman Crater (the notch in the summit skyline). This view of Mount Baker is from the Boulder Creek bridge, near Stop 7. A cloud of gas, mostly steam, rises from Sherman Crater.*

the close of Day 1.

2.7 Bridge across Sandy Creek, draining the Squak Glacier. This creek flows along the northern margin of the Sulphur Creek lava flow. The road begins to climb up the alluvial fan of Boulder Creek. Most of the fan is underlain by Boulder Creek assemblage of the Carmelo Crater eruptive period, with a thin veneer of younger lahar deposits on top.

3.8 South end of the Boulder Creek Bridge. Park on the left at the bridge, or in a pullout to the right. Elevation 1080 feet.

STOP 7—19TH CENTURY LAHARS OF THE SHERMAN CRATER ERUPTIVE PERIOD

If weather permits, admire the spectacular view of Sherman Crater from the walkway on the bridge (Fig. 14). Here is a great opportunity to catch a whiff of H2S. We are standing directly in the pathway of lahars generated within Sherman Crater or from collapses of the thoroughly altered and unstable east crater rim. The high point on that part of the rim is aptly named Lahar Lookout.

Access to the lahar exposures will be dependent on the current location of Boulder Creek. An idealized field trip stop is described here.

Examine the exposures in the high terrace along the right bank of the active braided channel of Boulder Creek by descending the cut bank adjacent to campsites 3-8 of the Boulder Creek campground. Alternatively, good exposures are found on the right bank of Boulder Creek about 100 m upstream of the bridge but (in 2010) this will involve 100 yards of bushwhacking. A somewhat less satisfying, but more accessible exposure of the lower of the two lahar deposits lies directly beneath the south end of the bridge. The campground is located at the head of the Boulder Creek alluvial fan, emplaced since withdrawal of Vashon ice from the Baker River valley. Trees in the campground are less than ca. 154 yrs in age, and grow on the surface of the Morovitz Creek lahar (map unit MCL; Fig. 2). The most prominent deposit in the terrace cut bank is diamict of the Morovitz Creek lahar. The matrix is highly altered. The rounded boulders of andesite that dominate the coarse or "dispersed" phase of the lahar are identical in size and composition to the bed material of Boulder Creek. At this site, the MCL deposit is composed of approximately 80 percent rounded clasts of Baker andesite, illustrating a common and dangerous behavior of lahars-- their ability to increase in volume by entraining (bulking) additional sediment with distance from source. A smaller unnamed lahar locally overlies deposits of the Morovitz Creek lahar. Thematrices of the flows are similar, and the younger flow contains a smaller proportion of entrained material (a lower "bulking factor"). Perhaps the larger MCL had already entrained most of the loose sediment, leaving little to be picked up by the smaller second flow. The first written descriptions of deposits in the Baker River valley were made by prospectors who in 1858 reported fresh inundation of the Boulder Creek fan surface by "lava", which we believe refers to the lahars. The younger flow, present only in Boulder Creek, occurred very shortly after the Morovitz Creek lahar. The two flows (Fig. 15) were initially described by Hyde and Crandell (1978), who interpreted them as lahars, but associated the matrix alteration to in situ weathering.

The source of these lahars was a collapse of the eastern rim of Sherman Crater, which transformed into cohesive lahars further down the slope. The vicinity of Sherman Crater is intensely altered to 'Shermanite', the clay-rich product of acid-sulfate alteration of andesite lava and pyroclastics (Fig. 16).

We interpret a very thin and discontinuous lithic tephra we call YP to the large 1843 phreatic eruption of Mount Baker; this is the eruption reported by the Hudson's Bay factor at Fort Langley, BC. Tephra YP underlies flood plain deposits of the Morovitz Creek lahar though it is not seen at this stop. A layer of wood and conifer needles separates the tephra layer from the lahar diamict. Analyses by several specialists in the composition of forest litter shed from trees killed by wildfire or insects estimate that this layer represents an interval of least 2 years. Growth rings on stumps of logged trees growing on the lahar surface date to 1847. Therefore, the lahars occurred between 1845 and 1847. The preservation of the woody layer is an example of how non-erosive a lahar can be during the relatively passive emplacement of its flood-plain facies, which accounts for the vast majority of preserved lahar deposits. The channelfacies is accompanied by intense tractive force that commonly results in large amounts of channel incision.

Figure 15. *Stop 6. The boulder-studded Morovitz Creek lahar is composed of approximately 80 percent rounded clasts of Baker andesite, illustrating a common and dangerous behavior of lahars—their ability to increase in volume by entraining (bulking) additional sediment with distance from source. The relative proportions of matrix and entrained clasts in the MCL at this site illustrate a volume increase by a factor of four. MCL is overlain by pale, shermanite-rich matrix of a much finer grained second lahar.*

Alternate Stop 7.1—Distal Boulder Creek assemblage (late Pleistocene)

The most distal exposure of the post-Vashon Boulder Creek assemblage (Hyde and Crandell, 1978; Hildreth and others, 2003; Tucker and Scott, 2004) crops out at the road junction just east of the bridge. The assemblage was deposited by block and ash flows and non-cohesive lahars of the Carmelo Crater eruptive period. The exposed deposit is only a few meters thick here, but is probably far thicker beneath the Boulder Creek fan, spreading outward from the mouth of the incised valley. At the type locality, 2 km upstream, the BCA is 85 meters thick (Fig. 17). At the distal exposure near Stop 7, the BCA sits above Vashon till, which in turn overlies Nooksack argillite at the north buttress of the bridge.

***Figure 16**. Fumaroles on the west rim of Sherman Crater result from circulation of meteoric water within the hot interior of Mount Baker. Sulphur enrichment of these emissions thoroughly alters andesitic lava and pyroclastics to clay rich, pale colored "Shermanite".*

DAY 2- Pleistocene eruptive products of the Mount Baker volcanic field

Rendezvous at the Three Rivers Motel in Sedro Woolley. Drive north on Highway 9 to the Mount Baker Highway (WA 542) east of Deming and proceed up the North Fork Nooksack River. Bedrock in road cuts is Eocene alluvial sediment of the Chuckanut Formation, followed by older, thrust-stacked, fault-bounded rock units further east- the Wells Creek member of the Nooksack Formation, and the Chilliwack Group. Proceed up the road toward the Mount Baker ski area and Heather Meadows. This portion of the trip guide is adapted from Dave Tucker's eventual guidebook to Mount Baker geology referred to in the Introduction. Figure 18 shows the latter portion of the day's trip.

Road log

0.0 Intersection with State Highways 9 and 542.

6.2 North Fork Beer Shrine and Wedding Chapel, a brew pub and pizzeria. Save it for the trip home

19.0 Enter beautiful downtown Glacier: coffee shops, restaurants, groceries.

19.2 Cross Glacier Creek, draining the Coleman and Roosevelt glaciers on the north flank of Mount Baker.

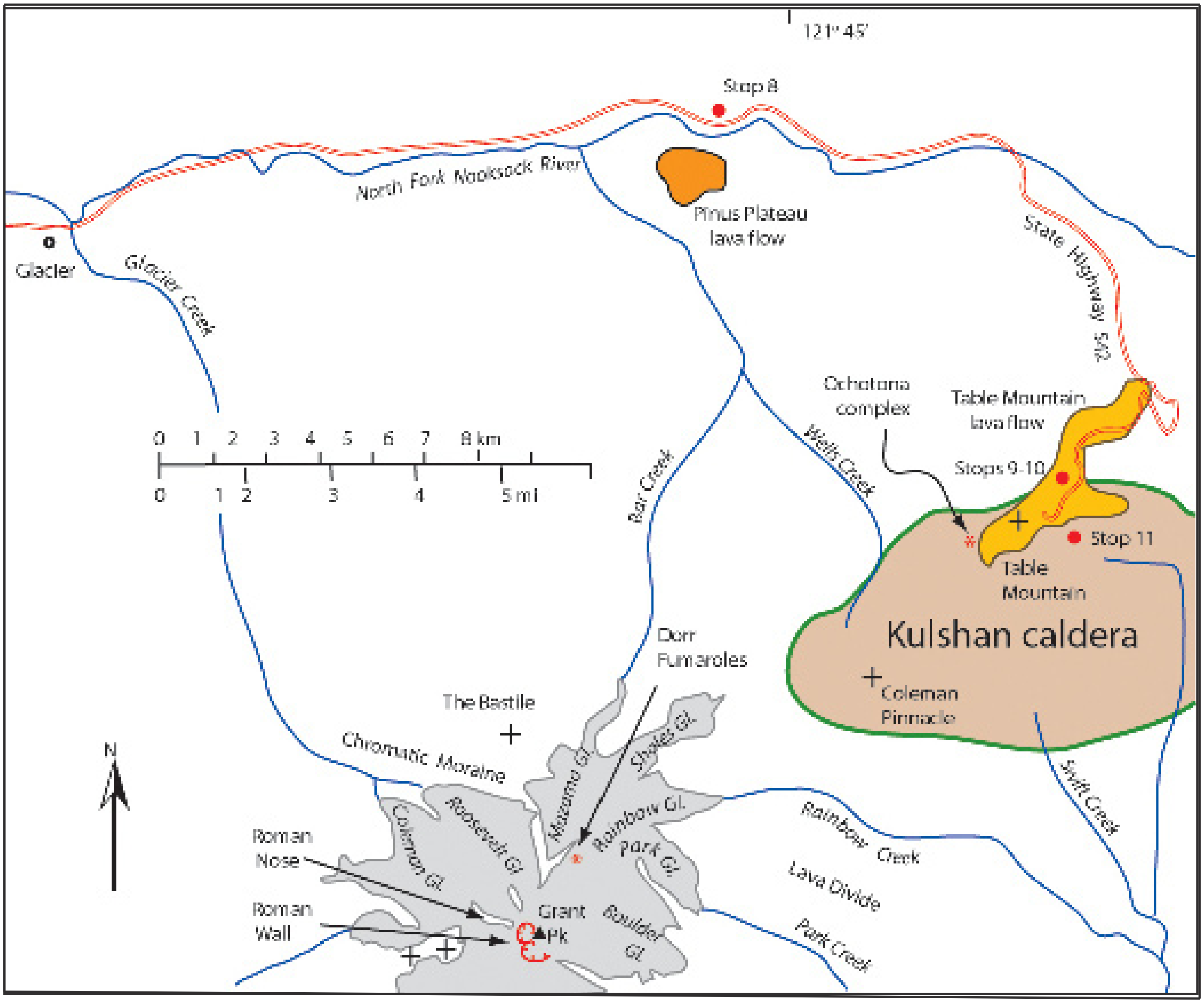

Figure 17 Map of the north side of Mt. Baker, showing the locations of stops 8-11

19.3 **STOP 8**—Glacier Public Service Station: 3-D model of Mount Baker.

The Glacier Public Service Station is an interpretive center run by the US Forest Service. It is housed in a handsome, historic stone building built in 1938 by the Civilian Conservation Corps. It features natural history displays, books, historic artifacts, and public restrooms. We will make a brief stop to orient ourselves with the large three-D model of Mount Baker.

27.9 **Stop 8**—Orphan andesite lava of Pinus Plateau

A pull- out on the north side of the road (1800 feet) allows the best views of the Pinus Lake lava flow. The high cliff (Fig. 19) across the river with spectacularly long, vertical columns is a remnant of the Pinus Lake andesite lava flow, named for a jungle-rimmed puddle on top of the mesa-like lava. The columns fall from the 300-foot-high cliff (90 m) to form an impressive talus fan reaching clear to the river. This is the first rock associated with the Mount Baker volcanicfield observed at close hand traveling up the Mount Baker Highway. Geology for this lava flow is found in Hildreth and others (2003), which was the first study of this lava despite the tens of thousands of people, including many geologists, who have driven up the valley over the decades. This is a young lava flow: a K-Ar date gave an age of 202 ±9 thousand years. The source of the lava is

Figure 18. *Rhythmic lahar deposits in the upper 1/3 of the type locality of the Boulder Creek assemblage, two kilometers up Boulder Creek from Stop 7.*

unknown, as the 'orphaned' erosional remnant is not extensive. A likely source, based on compatible chemistry and age, is the Ochotona intrusion (Fig. 18) at the southwest base of Table Mountain, about 5.3 miles (8.5 km) up Wells Creek. The cliff is the remnant of the lava flow that reached the Nooksack River valley 200,000 years ago, and the base of the flow is 400 feet (120 m) above the river. This allows us to estimate that the river has eroded another 400 feet in the time since the lava flow was emplaced here- 0.02 feet, or 6 mm per year, on average. This average is probably not truly representative, as erosion rates were higher during times when great glaciers filled the Nooksack.

The finely-layered and jointed rock in the roadside cliff is slate, which originated as fine-grained sediment interlayered in the Wells Creek marine volcanic member of the Nooksack Formation. The intersection of bedding planes and mineral alignment during mild metamorphism forms the pencil-like rock slivers.

Figure 19. *The Pinus andesite lava as seen from near Stop 8.*

35.2 At a sharp curve to the right, 2-foot-wide (60 cm) columns march in stately, vertical ranks in a cliff of glassy, 300,000-year-old Table Mountain andesite lava. The columns are crossed by horizontal joints, formed as cool ing and contraction penetrated sequentially deeper and deeper into the flow. Most of the rest of the lava flow that reached this point, or possibly further, has been removed by glaciation- the upper surface of the exposure at this place is planed flat by ice,leaving only this scrap from near the base of the mass of frozen lava. This is the most distant mapped outlying remnant of the lava that erupted from a now-eroded source on Ptarmigan Ridge (Fig. 18). The Table Mountain lava is more easily and safely examined in Heather Meadows and points beyond.

38.4 Pullouts give great views across White Salmon Creek and the Nooksack to peaks of the North Cascades. Mostly vertical Table Mountain andesite columns are frozen in a 60 foot (18 m) cliff. Seen up close, the pale gray rock is rich in plagioclase feldspar. Sometimes you will see fresher, glassy looking clear crystals of this mineral, especially on freshly broken surfaces. Typically, the plag grains are less well defined, due to alteration of the lava. You won't need a hand lens to see small, shiny, black crystals of black pyroxene- there are several pyroxene minerals, but augite is the one found in Baker lavas. You will probably need a hand lens to see another pyroxene, the honey brown mineral called hypersthene. The assemblage of these three minerals is nearly ubiquitous in Baker andesite. In fresh samples, you may see that they often form clotted concentrations of crystals. The flow extended at least as far as the now-isolated Bagley Creek remnant, and perhaps beyond into the glaciated valley of White Salmon Creek below the highway, which flows north into the Nooksack from Mount Shuksan.

This a good place to try to visualize the changes to the topography since the Table Mountain lava flowed toward the ancestral Nooksack drainage. The surface of this gooey, viscous andesite lava flow was covered in a thick carapace of cooled rubbly blocks, hauled along clattering and clinking like broken glass on the conveyor belt-like flow as it slowly advanced a few meters per day from the vent on Ptarmigan Ridge. As the lava chilled against the floor and sides of the valley, and in contact with the air, it contracted from the outside in. The contraction generated fractures propagating into the flow interior; these fractures outline the columns.

Whether or not a Pleistocene glacier filled the Nooksack at the time of the actual lava flow, it is evident that glaciation later stripped the carapace and much of the interior jointed lava and smoothed the surface- this will be apparent higher in Heather Meadows. Imagine the erosive potential of a Cordilleran ice sheet coming down from the north, laden with the sandpaper rasp of entrained sand and rocks, crossing over the intervening ridges between here and the Fraser valley, stripping lots of rock and deepening valleys by 100s of meters.

At least four such glaciations have been recognized since the Table Mountain lavas were erupted. From oldest to youngest, these are called the Double Bluff, Possession, Fraser, and Sumas glaciations. Even after the last main Cordilleran ice sheets had withered away around 11,000 years ago, large 'orphaned' glaciers remained in the deeply eroded valleys and descended from Mount Shuksan down the broad valley of White Salmon Creek, to further eroded the toe of the Table Mountain flows.

38.8 Enter Heather Meadows Recreation Area, Mount Baker-Snoqualmie National Forest.

40.1 Picture Lake; walkways and lakeside viewing platforms. Photographs of Mount Shuksan taken from here are found in calendars, restaurants, and hotel rooms around the world. A radiocarbon date of 9410 ± 50 14C years BP was obtained by Rob Burrows, a Western Washington University graduate student (Burrows, 2000) from the bottom of shallow Highwood Lake, just across the road to the east. This age indicates that these meadows at 4100 feet (1250 m) were deglaciated at least by that time, allowing sediment to begin accumulating in lakes. Presence of sediment also means that these meadows have not been glaciated since.

40.6 Go right to 'Austin Pass' at the road fork.

40.9 The road passes the first of several road cuts in spectacularly eroded Table Mountain andesite. The smooth, gray rock knobs in the meadows undulate from under the heather like surfacing whales, and are splendid examples of glacially planed and polished lava. Most columns are skinny, only 8-25 cm (3- 10 inches) across, so we know the lava here cooled pretty quickly, perhaps in contact with (overlying?) glacial ice.

STOP 9—Tephras of Mount Mazama and Mount Baker

41.1 A road cut on the east (pullout on the west) has a nice sequence of deposits spanning much of the post-Table Mountain lava flow geology in the meadows (Fig. 20). The Table Mountain andesite forms the base of the exposure, mantled by buff-colored, weathered glacial till left by the glacier that rounded the rock knobs seen down the road. A thin layer of dark soil rests on the till, in turn mantled with 1-3 inches (3-8 cm) of a prominent, pale orange to white, fine grained layer of volcanic ash- this is the famous "layer O" or Mount Mazama ash, erupted at Crater Lake caldera 6,845 ± 50 14C years BP (Bacon, 1983; about 7,700 calendar years ago). The very fine grain sizeis a clue that this is a far-traveled ash layer, and it is- over 400 miles (640 km) from the source. Its distinctive fine grain size and palecolor make it an excellent stratigraphic marker. Another thin soil separates Layer O from a thinner ash layer, the 5790 14C years BP (ca. 6900 calendar years) OP tephra. This discontinuous whitish 'shermanite' band erupted from Sherman Crater. Like Layer O, it was washed about consid-

Figure 20. *Tephra in Heather Meadows road cut at Stop 9. Pale OP tephra underlies darker BA at root level. Buff till makes up the bulk of the exposure.*

erably while it lay on the surface, and disturbed by plant roots and burrowing animals as it was gradually incorporated in the soil and buried by subsequent deposits. Thicker lenses of these tephras were washed into depressions before burial and became anchored by plants growing up through the layer. Consequently, these ash layers vary considerably in thickness in this road cut, and sometimes disappear completely. The upper part of the stratigraphic sequence is dominated by Sherman Crater's BA tephra, the dark gray sandy layer just below the heather roots. This ash unit is somewhat layered, and really varies in thickness; it is sometimes as much as a foot thick in these meadows. It was easily remobilized when it was fresh, as you might expect of a thick sandy layer in this wet climate. BA erupted immediately after OP, and is another distinctive time marker in the soils of Mount Baker and the nearby region. Some soil has developed on top of the BA over the past 6900 or so years. These layers can be found throughout this part of Mount Baker.

STOP 10—Eroded columnar Table Mountain andesite lava

41.4 Turn right to the Austin Pass Picnic Area, after passing more exposures similar to the preceding two. The historic Heather Meadows Visitor's Center was built in 1940. The Fire and Ice Interpretive Trail makes a short loop through the meadows, and touches on the geology.

Columnar jointed lava is beautifully exposed in cross section in the glacially polished rock surface just beyond the wall built of stacked column

Figure 21. *Glacially planed and polished Table Mountain andesite lava in Heather Meadows near Stop 10. Note cross sectioned columns in foreground.*

pieces beyond the parking lot (Fig. 21). See how many of the columns actually have the stereotypical, classical six sides; how many other geometries can you find? This is the 300 ka Table Mountain andesite (Hildreth and others, 2003), erupted from vents 6 km to the southwest on Ptarmigan Ridge. These lavas are contemporary with the much larger Black Buttes center, but erupted from a separate vent (or vents).Table Mountain is a stack of 4 pyroxene andesite flows; the upper capping flow is 90-130 m (300-430 feet) thick. The eroded table is an example of reversed topography; these lavas once filled a valley bottom. The northern ring fault of the 1.15 Ma Kulshan caldera runs east-west through Herman Saddle, north of Table Mountain.

41.5 Continue up the highway from the picnic area parking lot, swinging around a curve to the left.The next rocks you come to are green Chilliwack Group submarine volcanic breccia. For safety reasons, this is not the best place to examine these rocks.

43.3 End of the road at Artist Point (elevation 5040 feet, 1536 m) with expansive views in all directions, including Mount Baker and Mount Shuksan. Trails lead east along Kulshan Ridge to Huntoon Point, northwest up the steep exposed switchbacks of Table Mountain, and west along the south flank of Artist Point to Ptarmigan Ridge and beyond to Mount Baker, or to Chain Lakes.

Figure 22. *View south from Artist Point, Stop 11. Pale intracaldera ignimbrite is prominent. Ptarmigan Dome (5600 feet), at right center, is a post□caldera rhyodacite dome. Cloud draped ridge in distance is the southern structural margin of the Kulshan caldera.*

STOP 11—Artist Point: overview of Kulshan caldera

Walk east along the trail toward Huntoon Point. The pale rocks in the headwaters of Swift Creek to the south are the nonwelded rhyodacitic ignimbrite fill of the Kulshan caldera (Fig 22). Details of this caldera-forming eruption and associated post-caldera domes are found in Hildreth (1996), and Hildreth and others (2003; 2004). The following is taken from those papers. The Kulshan caldera foundered some 1.15 Ma following eruption of lithic poor, often pumice-rich, rhyodacitic ignimbrite (71-73% SiO_2). The intracaldera fill is nowhere welded, presumably due to quenching; the eruption apparently took place through cover of glacial ice. No outflow sheets are preserved; the only fall deposits known (Lake Tapps tephra) are found in the vicinity of Sumner Washington and the southwest corner of Hood Canal, which must have been beyond the extent of the ice sheet. No base is exposed; intracaldera ignimbrite is 1000 m thick.

The intracaldera volume is 30 km3. Total volume of the eruption is unknown; allowing for extensive outflow sheets and far-flung tephra, the total eruptive volume could have been as much as 100 km3. For comparison, the calculated volume of magma erupted at Crater Lake is 50 km3. The northern structural margin lies in the valley of Swift Creek north of Huntoon Point; it then curves to the south and runs upslope from the south-trending lower valley of Swift Creek, below the crest of Mount Ann. The southern margin of the caldera is the skyline to the south. The western margin, 7.5 km from here, is hidden behind younger extrusive rocks. No volcanic lithics have been found in the caldera fill to indicate any precursory volcanic activity. Following caldera collapse, magmatic activity continued in and near the caldera, resulting in rhyodacite domes near the western margin of the caldera. These are visible to the west from the trail to Huntoon Point.

This is the end of the field trip. Return to Sedro Woolley.

Acknowledgements

Thanks to the many who have contributed to our studies of Mount Baker. In particular, Wes Hildreth (USGS) provided the groundwork for this and all future Baker geology. John Scurlock flew many photographic missions as Wing Commander of the MBVRC. Dave Lewis did essential fieldwork in the Rainbow Creek debris avalanche. And, lastly, Joe Morovits lives on.

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