Evolution of volcanic landforms in the Western Cascades

Bretz Club Field Trip, Friday April 29, 2011: Gordon Grant and Fred Swanson

Below is a schedule for the field trip. This is spring in Oregon, so please bring appropriate footwear, rain gear, and some warm clothes. We will have lunch between stops 3 and 4 – this will be a bag lunch which you will make yourself Friday morning.

Tentative Schedule (weather permitting):

9:00 am Stop 0: HJ Andrews Headquarters

10:15 am Stop 1: Mona Creek
> *Overview of geologic picture: volcanic rocks (intrusive rocks associated with Blue River mining district, volcaniclastics, up to ridge-capping lava flows), hydrothermal alteration, overall topographic setting*

11 am Stop 2: Reservoir Rd
> *Hydrothermally altered volcaniclastics and dikes; glacial history affecting lower Blue River (landforms and deposits); Mazama ash in WS9 fan*

Bag lunch

1:00pm Stop 3 Foley Ridge Viewpoint off Rd 1501
> *High Cascade / Western Cascade intersection in McKenzie River context*

2:00pm Stop 4: WS3 Debris Flow and Fan histories
> *Debris flow and fan of WS2-3 interfluve*

3:30 pm Stop 5: Lookout Creek Bridge
> *Lookout Creek valley floor geomorphology*

4:00 pm Stop 6: Earthflow
> *Landforms and movement history, disruption of vegetation*

5ish pm Return to HJ Andrews, end of field trip

Optional:

5:30 pm 1 hr walking tour of HJ Andrews (*can also be explored on your own!)*
> *Lookout Creek channel and big wood changes, USGS Debris Flow Flume, Quaternary deposits exposed on south bank.*

Evolution of volcanic landforms in the Western Cascades.

This field trip will focus on geomorphic and erosional processes in an older volcanic landscape (the Western Cascades). Drawing on over 50 years of research at the H.J. Andrews Experimental Forest and surrounding area, we will examine hillslope, small watershed, fluvial, and landscape-level processes over a range of timescales. The emphasis will be on how styles and products of erosion of volcanic landscapes plus subsequent alteration by hydrothermal processes set the stage for long-term landform evolution. Stops include examples of small watersheds and their alluvial fans, debris flows, earthflow complexes, and fluvial systems. The discussion will complement Jon Major's Saturday talk on contemporary volcano erosion/geomorphology.

Stop 0 - HJA Headquarters

Discussion points: After introductions, and a brief orientation to the H.J. Andrews Experimental Forest, we'll open the discussion of the regional geologic setting, focusing on the evolution of the Western and High Cascades, themes that will be revisited throughout the day. The emphasis here will be on the styles, locations, and timing of volcanism that constructed the Cascade landscape.

A brief overview of the geologic and physiographic setting of the Cascades (From Cashman et al, 2009)

The Cascade Range extends from northern California to southern Canada. In central Oregon, the Cascade Range is 50 to 120 km wide, bounded on the west by the Willamette Valley and the east by the Deschutes Basin. The Cascade volcanic arc has been active for about 40 million years due to the convergence of the Pacific and Juan de Fuca plates, although volcanism has not been continuous in either space or time throughout this period (Sherrod and Smith, 1990). In Oregon, the Cascade Range is commonly divided into two physiographic subprovinces—the Western Cascades and the High Cascades—that differ markedly in their degree of dissection, owing mainly to the near absence of Quaternary and Pliocene volcanoes in the Western Cascades. From the Three Sisters north to Mount Hood, the young (Quaternary to Pliocene) High Cascades occupy a structural graben formed by a northward-propagating rift (Sherrod et al., 2002), which has affected both the composition of the erupted magma and patterns of groundwater flow.

The Western Cascades are composed of a thick, mixed assemblage of mafic lava flows, mostly of andesitic composition, and ash-flow and ash-fall tuffs, with minor silicic intrusive bodies and stocks, which range in age from middle Eocene to early Pliocene (40 – 5 million years). Rocks along the western margin of the Western Cascades tend to be older and decrease in age towards the boundary with the High Cascades; some intra-canyon lava flows from the High Cascades fill the upper valleys. Rocks have been locally altered by hydrothermal processes, particularly in the contact aureoles surrounding granitic stocks. The landscape has been covered repeatedly by montane glaciers, dissected by rivers, and is prone to frequent mass wasting by landslides, debris flows, and earthflows. Consequently, the topography is extremely rugged, ranging in elevation from 200 to 1800 m, with sharp dissected ridges, and steep slopes of 30 degrees or more. Stream channels range from high gradient bedrock channels to alluvial gravel to boulder-bed rivers.

In the Western Cascades, outcrops are commonly obscured by dense native coniferous forests of Douglas-fir, western hemlock, and western red cedar. Trees in this region can grow to great height (>80 m) and age (>500 years old) and are subject to episodic wildfires combined with, more recently, intensive logging on both public and private lands. At one point in the 1980's, timber harvest from the Willamette National Forest, which includes much of the Western Cascades, produced more than 20 percent of the nation's softwood timber. The legacy of this harvest remains in a distinct pattern of regenerating clearcuts of various sizes and shapes. Precipitation of up to 2500 mm/yr typically falls from November through April as both rain (below 400 m) and snow (above 1200 m), with the intervening elevations, which make up much of the landscape, constituting a "transitional snow zone."

Extending along the east margin of the Western Cascades is the modern volcanic arc of the High Cascades, a north-trending belt 30 to 50 km wide of upper Miocene to Holocene volcanic rocks. In central Oregon, the High Cascades form a broad ridge composed of a 2-3 km-thick sequence of lava flows that fill a graben formed in the older rocks (Sherrod and Smith, 1990; Sherrod et al., 2004). High Quaternary stratovolcanoes are constructed on top of the flows; they have rhyolitic to basaltic compositions and are composed of interlayered thin lava flows and pyroclastic deposits overlying cinder cones (Taylor, 1981). The location of the High Cascades at the western margin of the Basin and Range places it in a zone of crustal extension, which influences both its structural features and volcanic history. Most striking is the density of Quaternary volcanoes in the Oregon Cascade Range, with 1054 vents in 9500 km^2 (Hildreth, 2007). Sherrod and Smith (1990) estimate an average mafic magma production rate in the central Oregon Cascades of ~ 3-6 $km^3\ my^{-1}$ per linear km of arc during the Quaternary. Mafic activity has continued into post-glacial times, with 290 km^3 of magma erupted from the Cascade Range over the past 15 ka. Hildreth (2007) estimates that 21 percent of the erupted material forms mafic cones and shields, and that most of these edifices are within the Oregon Cascade Range.

The crest of the Oregon Cascade Range has an average altitude of 1,500 to 2,000 m, with several of the high volcanoes exceeding 3,000 m. The conical morphology of the stratovolcanoes is best preserved on the younger edifices—Middle Sister, South Sister, and Mount Bachelor—as the older cones have been deeply eroded by Pleistocene glaciation. The High Cascades have also been extensively and repeatedly glaciated by thick montane ice sheets but are relatively undissected by streams (drainage density is ~ 1–2 km/km^2; Grant, 1997) and generally preserve many primary volcanic features. Most winter precipitation falls as snow in this zone, with occasional summer thunderstorms contributing to the water budget. Forests east of the crest are a mix of alpine and sub-alpine firs that transition abruptly into a more open forest of ponderosa and lodgepole pine in response to the abrupt rainfall gradient just east of the crest. Much of the land is in public ownership and managed by the Forest Service and Bureau of Land Management for timber, grazing, and recreation. Of the High Cascades subprovince in central Oregon, 25 percent is in wilderness areas managed by the U.S. Forest Service. On the east side, the Pleistocene glacial record is better preserved and mapped than the west side, due to the lower rainfall (~300 mm/year), more subdued topography, and limited opportunity for fluvial erosion (Scott, 1977; Scott and Gardner, 1992; Sherrod et al., 2004).

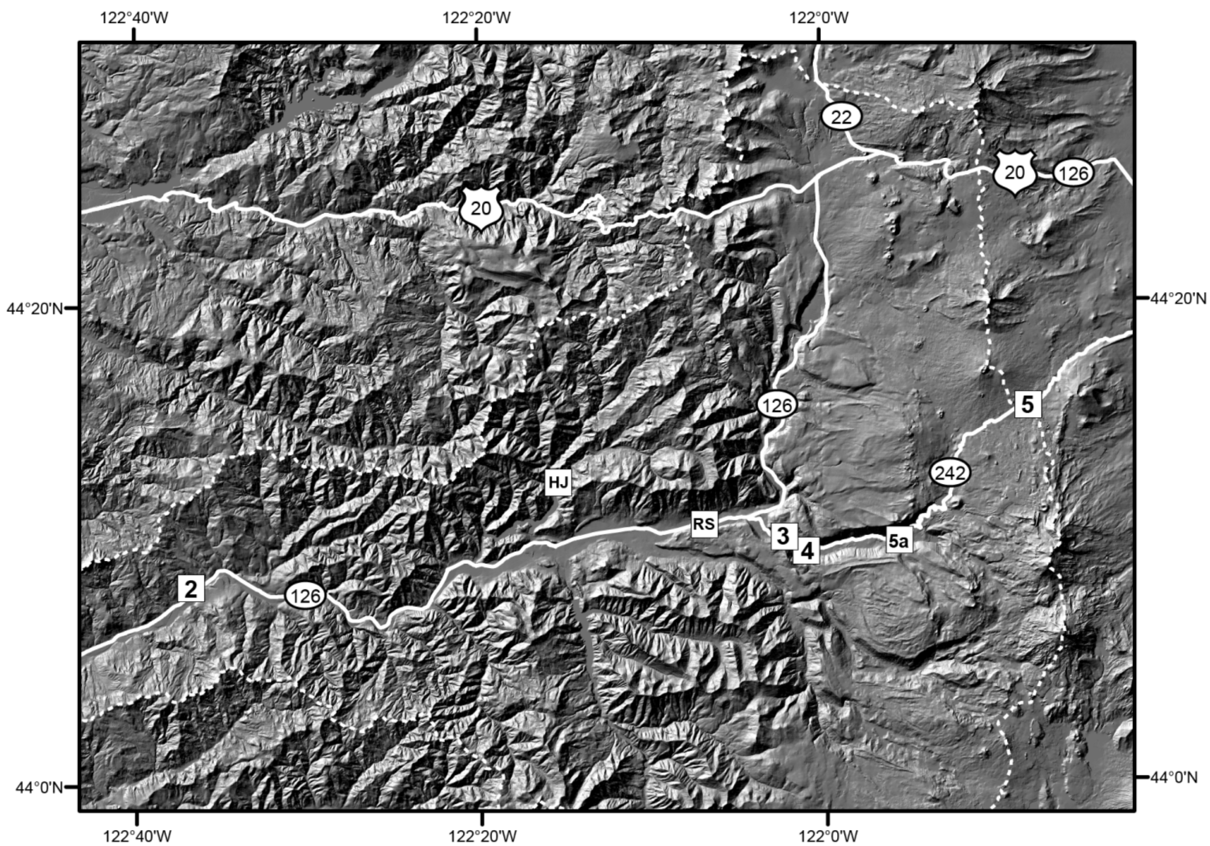


Figure 0.1 Regional scale shaded relief map (Figure 2; Cashman, et al., 2009). Note the sharp contrast in relief, steepness, and drainage density between the Western and High Cascades. Highway 126 follows the east to west course of the McKenzie River; both the highway and river turn north to follow the western bounding (Horse Creek) fault along the Western/High Cascade margin. HJ = location of HJ Andrews Experimental Forest.

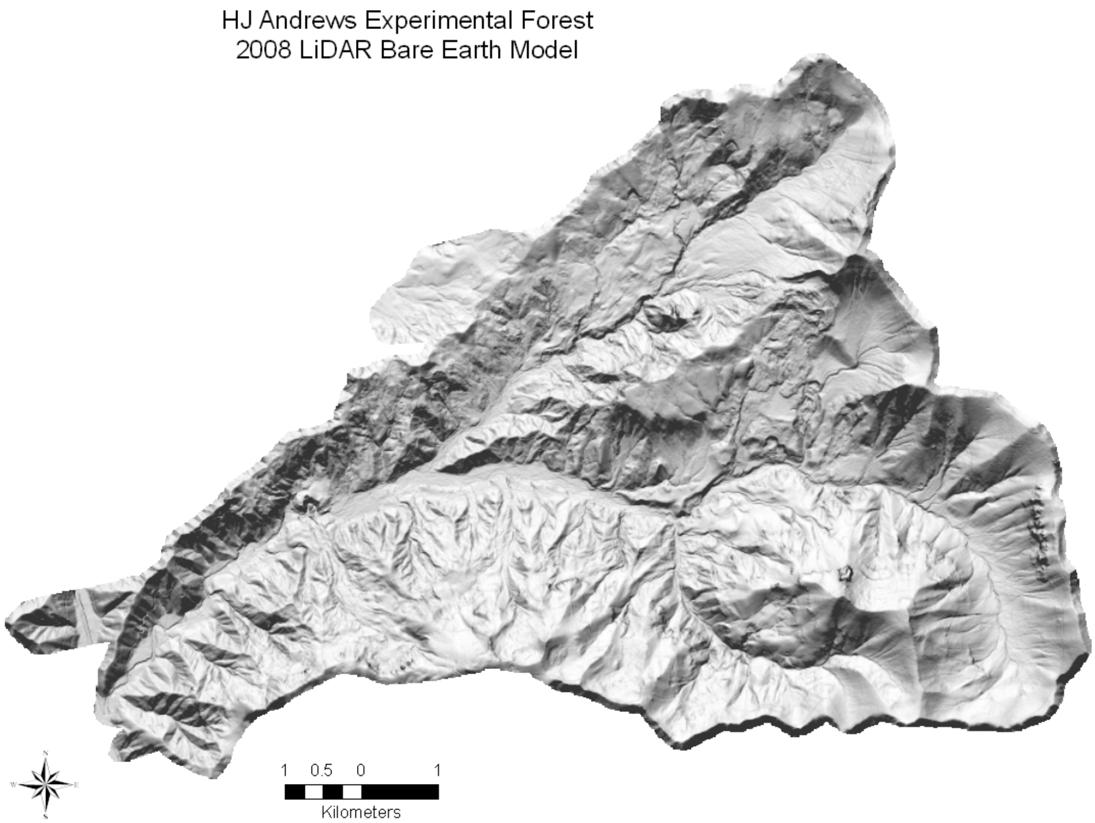


Figure 0.2 HJA map LiDAR image

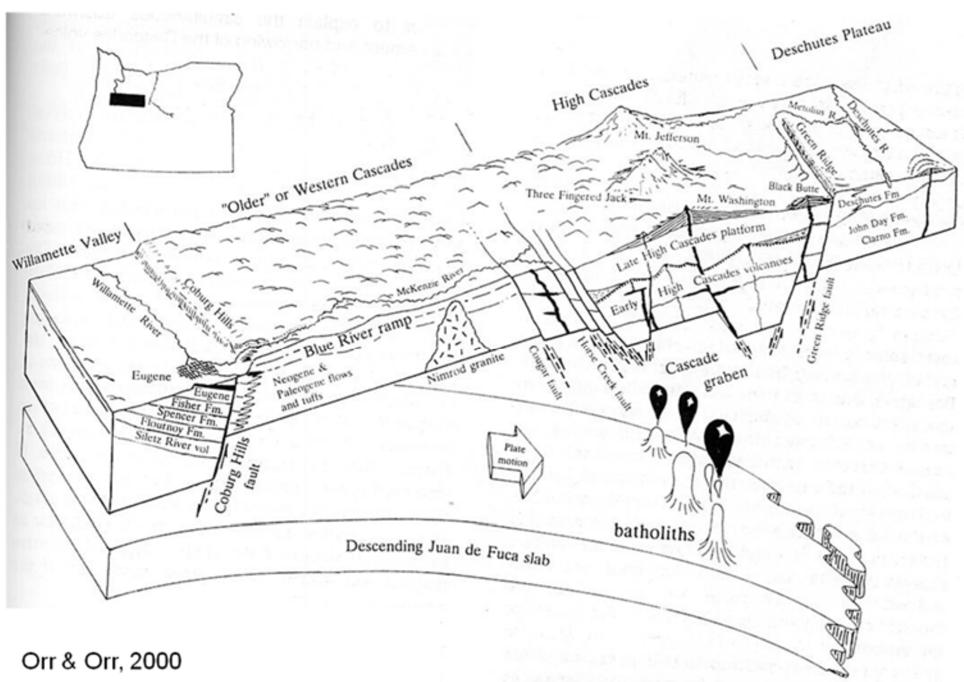


Figure 0.3 Geologic cross section showing the general tectonic setting of the Western and High Cascades. (Orr & Orr, Geology of Oregon)

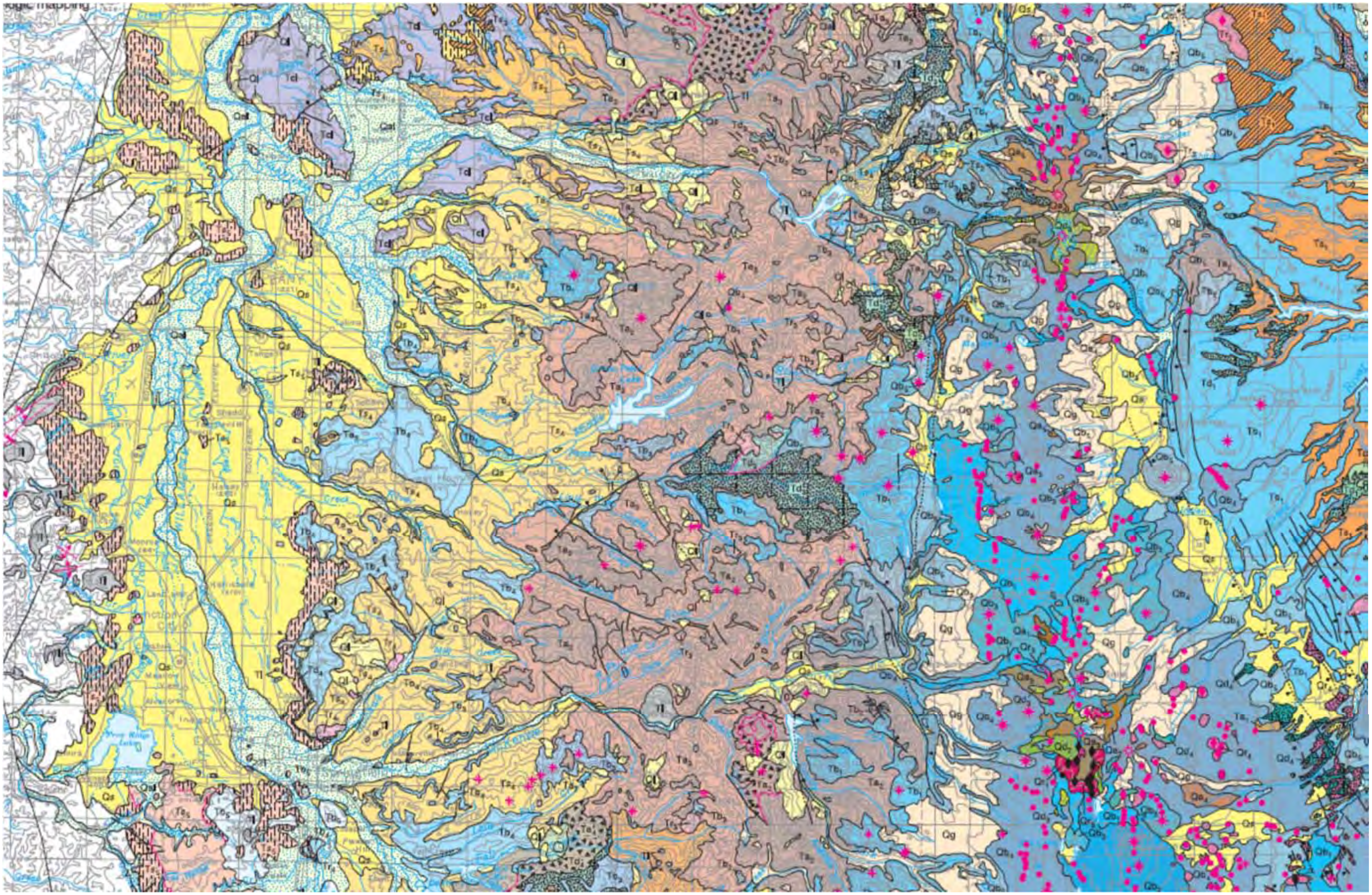


Figure 0.4 Regional geologic map of the Western and High Cascades from approximately Mt.Jefferson in the north to the Three Sisters in the south (Sherrod 2000). Available in print and digitally at http://pubs.usgs.gov/imap/i-2569/

Stop 1 – Mona Creek

Discussion points: This stop provides an opportunity (weather permitting) to look back into the Lookout Creek watershed, which is the master stream of the H.J. Andrews Forest. From this overlook, we can continue the discussion of the evolution of the Western Cascade landscape, focusing on the major volcanic "players": Tertiary volcanic sequence, intrusive rocks associated with Blue River mining district, volcaniclastics, and ridge-capping lava flows), and subsequent hydrothermal alteration. These players and subsequent tectonic history set the stage for the erosional and incisional development of the landscape, which can be interpreted from incision rates of dated lava flows. We compare these rates with recently interpreted rates of drainage development from the High Cascades to the east. We also consider how degree of drainage and topographic development drives hydrologic response of streams.

INCISION RATES

Time period	incision depth	incision rate	notes
3.3 to 2.0 m.y. ago	430 m	33 cm/1000 yrs	1
		28 cm/1000 yrs	2
2.0 to 0 m.y. ago	330 m	14-17 cm/1000 yrs	3
2.0 to 0 m.y. ago	290 m	15 cm/1000 yrs	4

See appendix 3 for derivation.

1. Kitson Ridge area, top of lava sequence to projected 2 m.y. old stream base.
2. Kitson Ridge area, base of lava sequence to projected 2 m.y. old stream base.
3. High Prairie area, top of lava sequence to modern North Fork of Willamette River. Range of values results from several measurements along outcrop length of basalt of High Prairie (unit QTbh).
4. Wolf Mountain area, unit QTb on southeast side of Wolf Creek (Waldo Lake quadrangle). Top of lava sequence to modern Hills Creek.

Figure 1.1 Incision Rates, D.R. Sherrod 1986 (UC Santa Barbara PhD. Thesis), Table 3, pg 164.

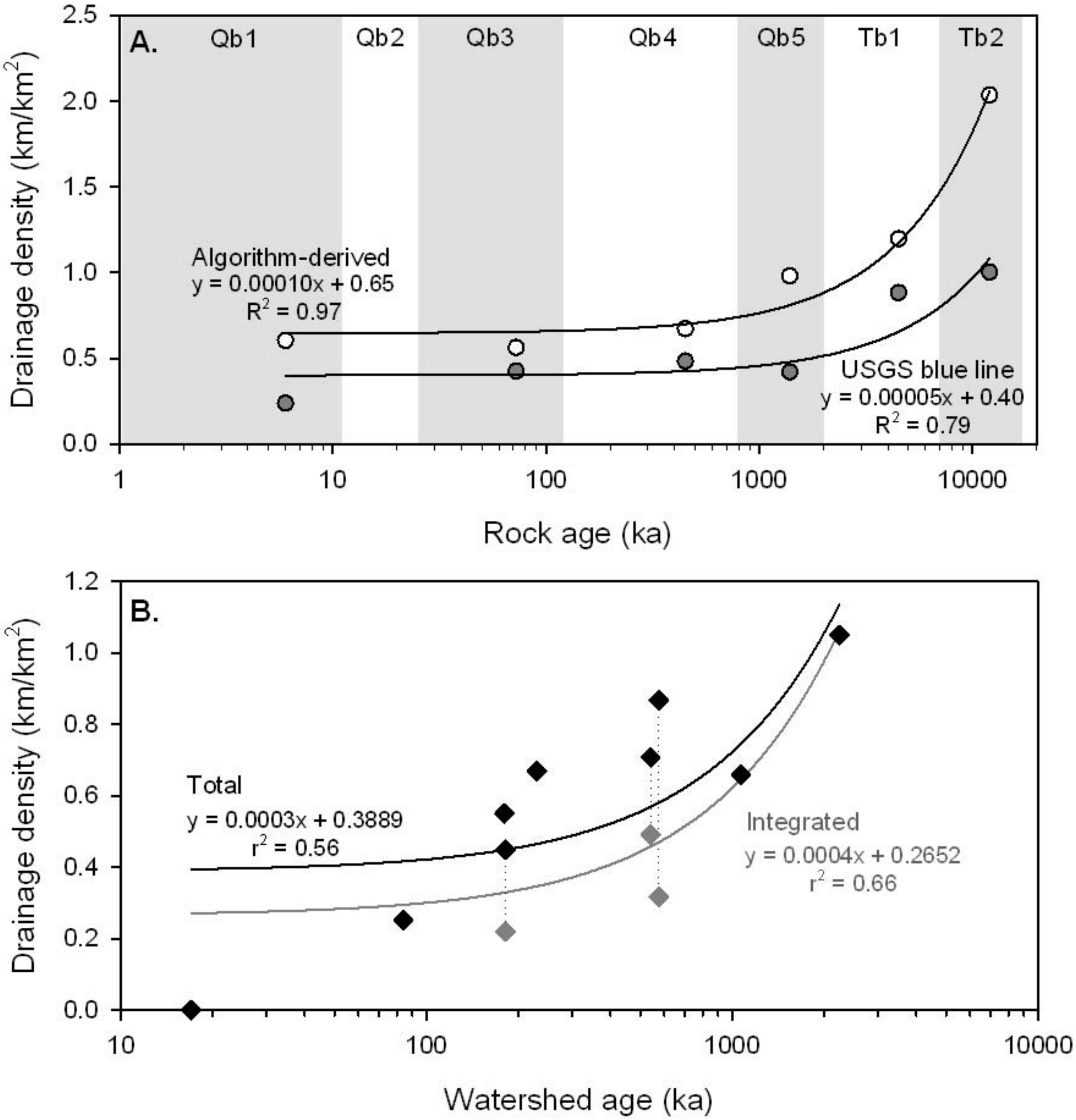
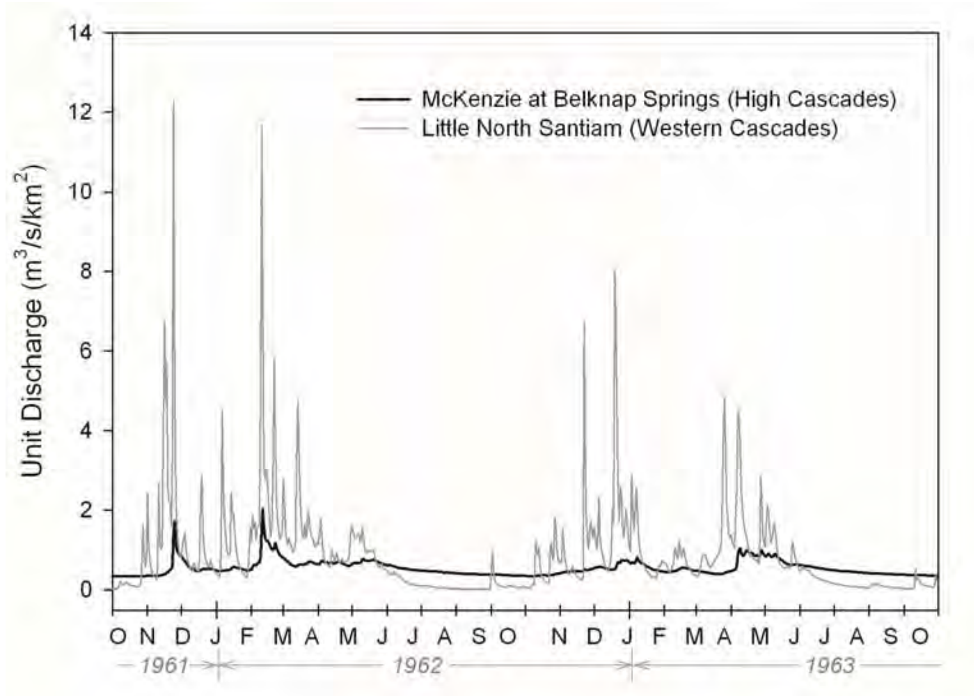


Figure 1.2 Drainage density versus rock unit and watershed age. (A) Drainage density of basalts and basaltic andesites in the north study area. Stream lengths were measured from digitized 1 : 24,000 topographic maps (gray circles) and obtained from the valley detection algorithm published by Luo and Stepinski (2008) (white circles). Shaded bars represent the range of ages for map units of Sherrod and Smith (2000), and circles represent the median age of each unit. The regression lines were fi tted through the median ages. (B) Black diamonds represent the total drainage density of each study watershed. Gray diamonds represent integrated drainage density of watersheds where integrated drainage density is lower than total drainage density. Integrated drainage density is defi ned as the length of stream connected to the watershed outlet, divided by watershed area. Lengths of streams that drain to closed basin lakes or wetlands are not counted in the integrated drainage density calculation. Dashed lines show the relationship between total drainage density and integrated drainage density for specific watersheds. (Jefferson et al., 2010).

Figure 1.3 Daily streamflow hydrographs, normalized by drainage area, for a predominantly High Cascade (McKenzie at Belknap) and Western Cascades (Little North Santiam) river. Discharge data from US Geological Survey streamflow data archive. Figure from Cashman et al, 2009.



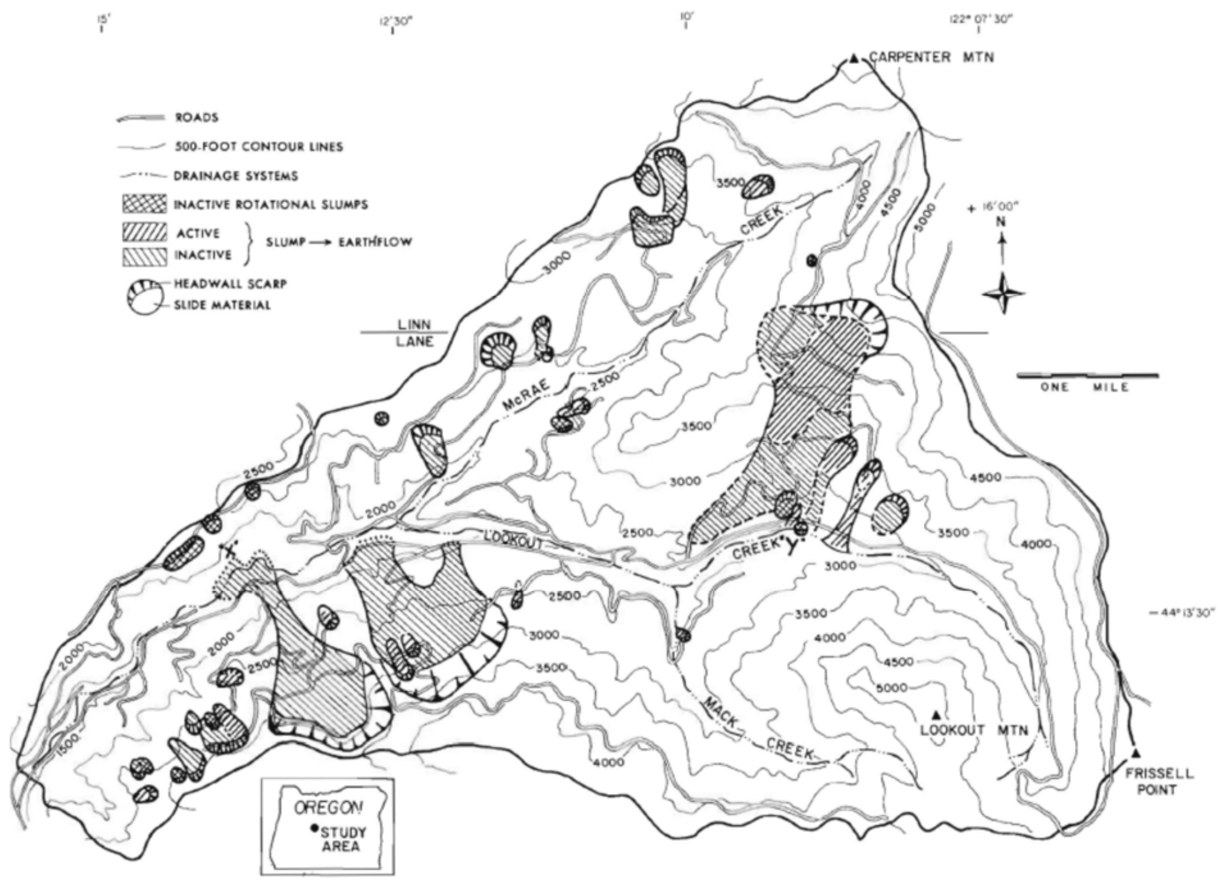


Figure 1.4 Deep-seated mass movements, H.J. Andrews Experimental Forest. Location “x” shows toe of large earthflow. Figure from Swanson et al., 1987.

Stop 2 –Reservoir Road

Discussion points: Here we get a chance to observe the bedrock geology of the Western Cascades up close, as exposed in road cuts. These are predominantly propylitically altered green tuffs and breccias cut by numerous vertical northwest-trending dikes. These zones of hydrothermally altered rocks tend to weather to smectitic and amorphous clays that promote both shallow landsliding and deep-seated earthflows, as we'll see in later stops. Immediately to the west is Blue River reservoir, one of 13 Army Corps of Engineer multipurpose projects on the Willamette River that is used for flood control in the winter, and flow augmentation and recreation in the summer.

During the Pleistocene, Blue River drained directly into the McKenzie River through the saddle dam area to the south of this stop (Swanson and James, 1975). Pre-latest Wisconsin glaciers from the High Cascades platform and from the South Fork McKenzie River basin flowed down the main McKenzie River Valley and blocked the mouth of Blue River. This ice dam formed a lake 30+ m higher than maximum reservoir level and diverted lower Blue River over a drainage divide to its present course. Drilling in the saddle dam area by the Corps of Engineers revealed more than 60 m of glacial deposits forming a natural saddle dam below the man-made saddle dam. Till, outwash, and varved and ice-margin deformed lake sediments are exposed in the reservoir area during winter low pool volumes. A wood sample from these deposits is more than 40,000 radiocarbon years old.

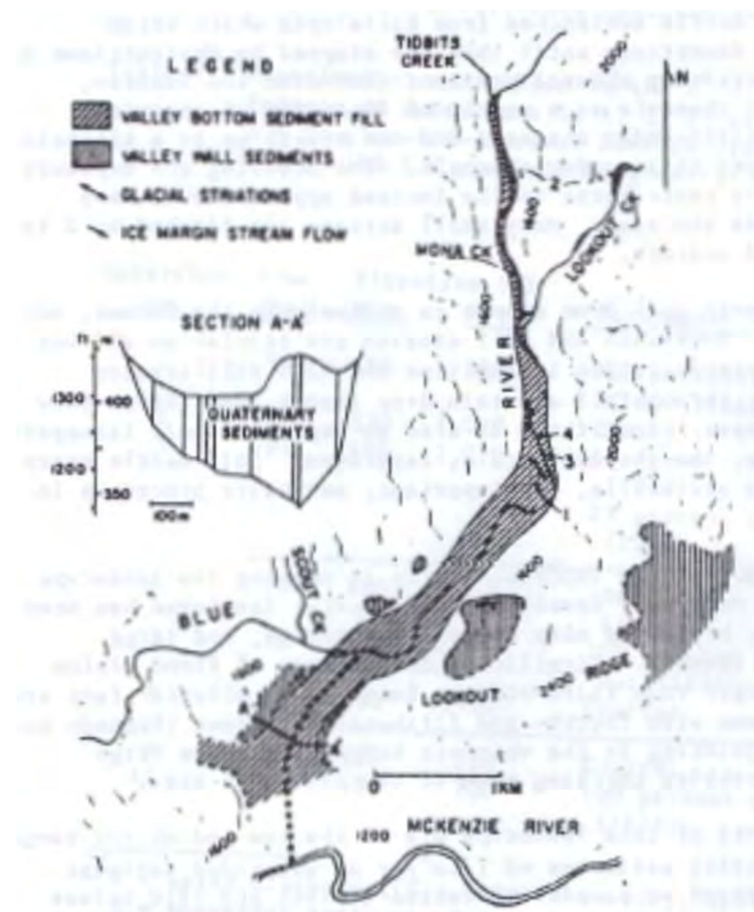


Figure 2.1 a. Map showing distribution of fluvial and lacustrine sediments realted to glaciations of lower Blue River. Location 1 notes the oocurrence of N25W-trending glacial striations. Location 2 marks sedimentary sections in the upper end of the lake, while at location 3 there are good exposures of sediments deposited in the lower portion if the lake. Wood collected from glaciolacustrine sediments at location 4 was dated at >40,000 ybp. Dotted lineshows former course of Blue River. Contour interval = 400ft. From Swanson et al., 1987.

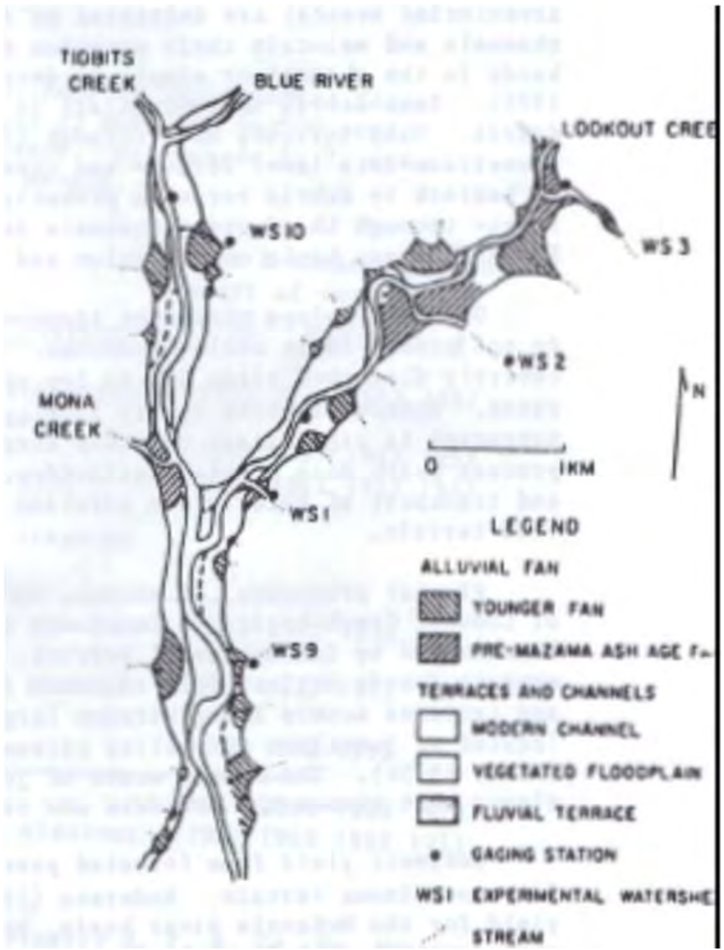


Figure 2.2. Map of post glacial geomorphic surfaces near the confluence of Blue River and Lookout Creek. From Swanson et al., 1987.

Stop 3 – Foley Ridge Viewpoint

Discussion points: As discussed in Conrey and others, 2002, Foley Ridge is a large tongue of intra-canyon basalt and inter-bedded fluvial conglomerate that partially fills the McKenzie River Valley. Its age is not directly known but inferred from correlation among intra-canyon benches along the McKenzie drainage. Older dated intra-canyon lavas occur at higher altitudes around the McKenzie River Valley (for example, Lookout Ridge which is the oldest), and all lavas of Foley Ridge have normal magnetic polarity. Thus, Foley Ridge is likely (0.6-0.8 Ma). Intra-canyon flows such as Foley Ridge offer a means of calculating the incision rates of the Western Cascades, but also interpreting paleodrainage development, since their basal gradients are assumed to represent slopes of paleochannels that were filled by lava flowing off the High Cascades to the east. Earlier intracanyon flows are now preserved as ridge-capping basalts. As documented by Sherrod (1986), paleodrainages of westward-draining streams were steeper during the Pliocene and early Pleistocene than they are today, reflecting late Tertiary uplift of the Western Cascades

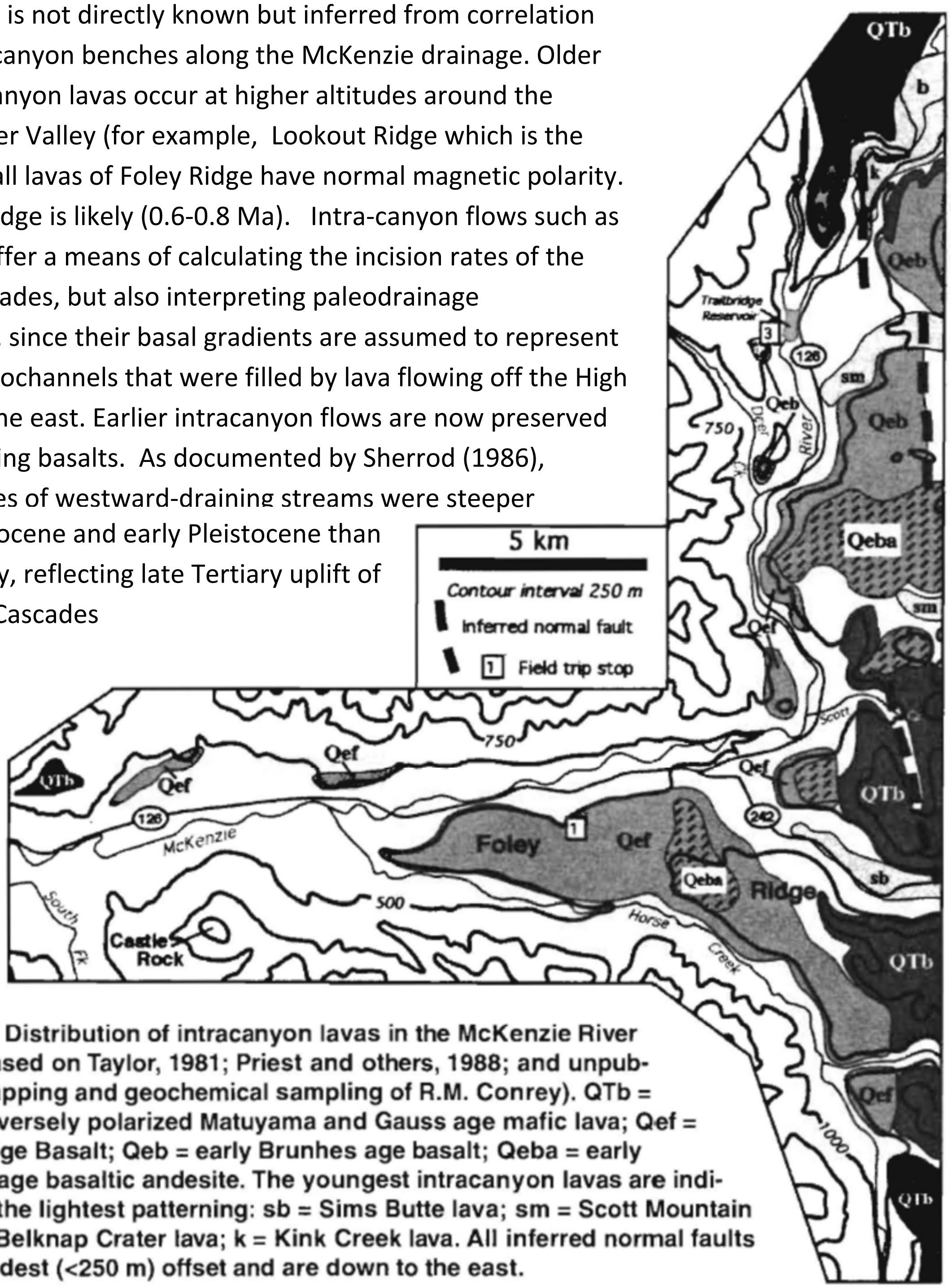


Figure. 3. Distribution of intracanyon lavas in the McKenzie River Valley (based on Taylor, 1981; Priest and others, 1988; and unpublished mapping and geochemical sampling of R.M. Conrey). QTb = chiefly reversely polarized Matuyama and Gauss age mafic lava; Qef = Foley Ridge Basalt; Qeb = early Brunhes age basalt; Qeba = early Brunhes-age basaltic andesite. The youngest intracanyon lavas are indicated by the lightest patterning: sb = Sims Butte lava; sm = Scott Mountain lava; b = Belknap Crater lava; k = Kink Creek lava. All inferred normal faults are of modest (<250 m) offset and are down to the east.

Figure 3.1 From Conrey et al., 2002

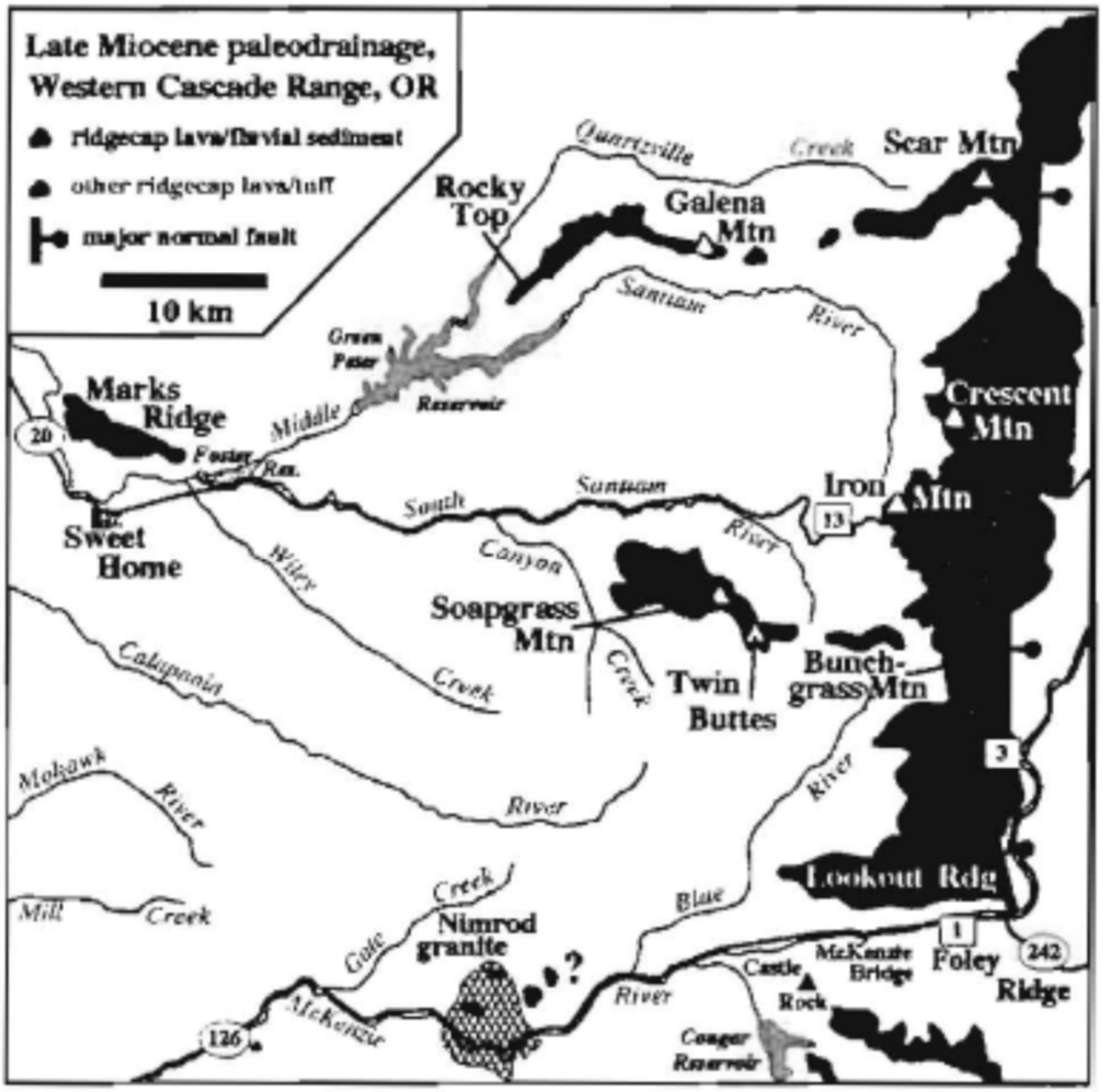


Figure 3.2 Map of late Miocene (5-8 Ma) paleo-drainage in the Western Cascades. The ancestral course of the Middle Santiam River is marked by ridge-cap deposits between the modern river and Quartzville Creek. The ancestral South Santiam is marked by ridge-caps south of the modern drainage. The ancestral McKEnzie drainage lay along Lookout Ridge; the distal end of the drainage is not know but may be marked by suspected ridge-capping mafi lava above Nimrod. The fault pattern is simplified clost to the graben. From Conrey et al, 2002, Figure 11.

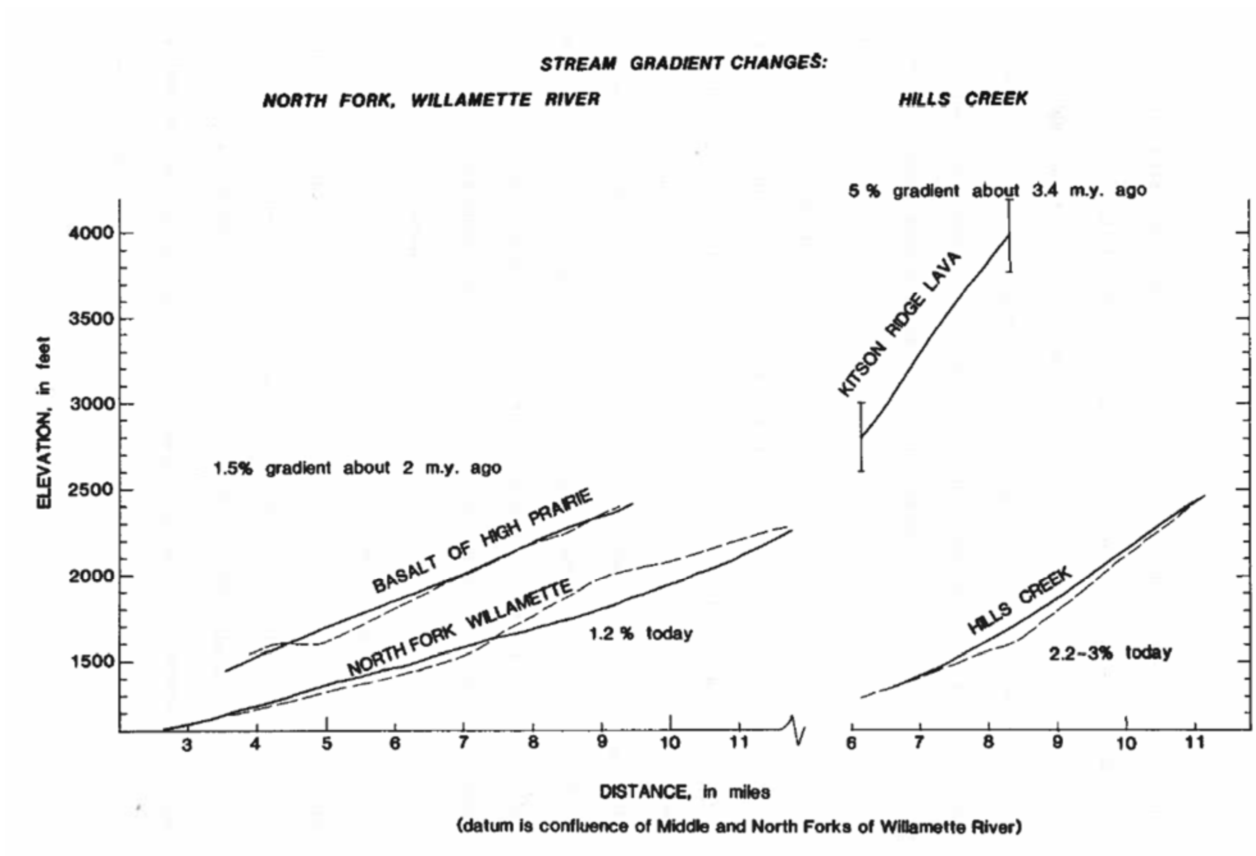


Figure 3.3 Current and former stream profiles - incision history of intracanyon flows and stream gradients. Sherrod, 1986.

Stop 4 – WS3 Debris Flow

Discussion Points: Watershed 3 was one of the original cohort of small watersheds studies that were implemented in the late 1950s and early 1960s to examine the effects of forest management activities on streamflow and sediment production among other variables (see Table). The junction between Watershed 3 and Lookout Creek has been one of the most geomorphically active sites in the HJ Andrews. Debris flows from Watershed 3 in 1964 and again in 1996 destroyed the gauge house, filled the sediment basin, and damaged the road before entering Lookout Creek and continuing downstream as a debris laden flood. This disturbance history has dominated the sediment production record over the last 40 years..

A longer-term record of sediment production from Watershed 3 is preserved in the stratigraphy of the debris fan located at the junction with Lookout Creek; this fan contains large accumulations of woody debris, some of which is radiocarbon dead. Because the channel has actively incised this fan, little sediment and wood was deposited during recent debris flows. A “live” fan that does see ongoing deposition during extreme events is located in a smaller tributary just to the west of watershed 3.

Average annual erosion rates for old-growth forested watersheds that did not experience landsliding and debris flows over the period of record (50 years) are around 20-30 t/km^2; this translates into an areal lowering rate of approximately 0.02 mm/year which is an order of magnitude less than the long-term incision rates measured from intracanyon flows. Sediment budgets from other Andrews watersheds (WS 10) that incorporate temporally-averaged sediment production from mass movements are at least 5 times greater (~100 t/km^2), and are probably a better long-term estimate.

Construction of logging roads in this steep landscape accelerates “native” geomorphic processes (i.e., landsliding and debris flows) and introduces new processes (conversion of sub-surface to surface flow; hillslope drainage diversion and capture). This new complement of processes is particularly apparent during large storms, when roads can act as both sinks and sources of sediment.

Tables from Swanson & Jones, 2002.

Table 1. Experimental watersheds in the H.J. Andrews Experimental Forest. Prior to treatments, forests were 400 to 500 yr old Douglas fir/western hemlock stands in Watersheds 1, 2, 3, 9, and 10, and 130 yr old Douglas fir stands in Watersheds 6, 7, and 8.

Basin no.	Area (ha)	Elev (m) Min	Max	Management history	Water, stream chemistry, and sediment records, start date[1] W[2]	C[3]	S	B
1	96	460	990	100% clearcut, 1962-66; prescribed burned 1967	1953	--	1957	1957
2	60	530	1070	control	1953	1981	1957	1957
3	101	490	1070	1.5 km (6%) roads, 1959; 25% clearcut in 3 patches, 1963	1953	--	1957	1957
6	13	880	1010	100% clearcut, 1974	1964	1972	1972	--
7	15	910	1020	50% selective canopy removal, 1974; remaining canopy removed 1984	1964	1972	1972	--
8	21	960	1130	control	1964	1972	1972	--
9	9	425	700	control	1967	1969	1969	1973
10	10	425	700	100% clearcut, 1975	1967	1969	1969	1973

[1] W = continuous stream discharge; C and S = composited 3-weekly samples of streamwater collected with proportional sampler and analyzed for chemistry (C): N, P, Ca, Mg, K, Na, alkalinity, conductivity, pH, particulate N, and particulate P; and suspended sediment (S); B = bedload sampling in ponding basin.

[2] Streamflow records are continuous up to the present, except for Watersheds 6 and 7, where streamflow was not measured from 1987 to 1994. Records are based on water year, October 1 to September 30.

[3] Long-term records with 3-weekly sampling interval began on this date.

Table 2. Process characterists and transfer rates of organic and inorganic material to a channel by hillslope processes (T/yr) and export from the channel by channel processes (T/yr) for Watershed 10.

Process	Frequency	Area influenced (% of watershed)	Material transfer Inorganic	Organic
<u>Hillslope processes</u>				
Solution transfer	Continuous	99	3	0.3
Litterfall	Continuous, seasonal	100	0	0.3
Surface erosion	Continuous	99	0.5	0.3
Creep	Seasonal	99	1.1	0.04
Root throw	1/yr	0.1**	0.1	0.1
Debris avalanche	1/370 yr	1-2**	6	0.4
Slump/earthflow	Seasonal*	5-8%	0	0
TOTAL			10.7	1.4
<u>Channel processes</u>				
Solution transfer	Continuous	1	3.0	0.3
Suspended sediment	Continuous, storm	1	0.7	0.1
Bedload	Storm	1	4.6	0.3
Debris torrent	1/580 yr	1	4.6	0.3
TOTAL			8.9	1.0

*Inactive in past century in Watershed 10.
**Area influenced by one event.

Table 4. Distribution and frequency (numbers per kilometer of road length) of mass movement and fluvial features associated with roads, according to hillslope position and function of the road in intercepting or producing sediment (from Wemple and others, 2001).

Slope position / function	Road length (km)	Number: Mass movement	Number: Fluvial feature	Frequency (no./km): Mass movement	Frequency (no./km): Fluvial feature
Upper slope					
Intercepted by roads		0	0	0	0
Produced on roads		5	0	0.05	0
Total	102	5	0	0.05	0
Midslope					
Intercepted by roads		11	9	0.05	0.04
Produced on roads		41	5	0.20	0.02
Total	205	52	14	0.25	0.07
Valley floor					
Intercepted by roads		10	4	0.24	0.10
Produced on roads		10	8	0.24	0.20
Total	41	20	12	0.49	0.29

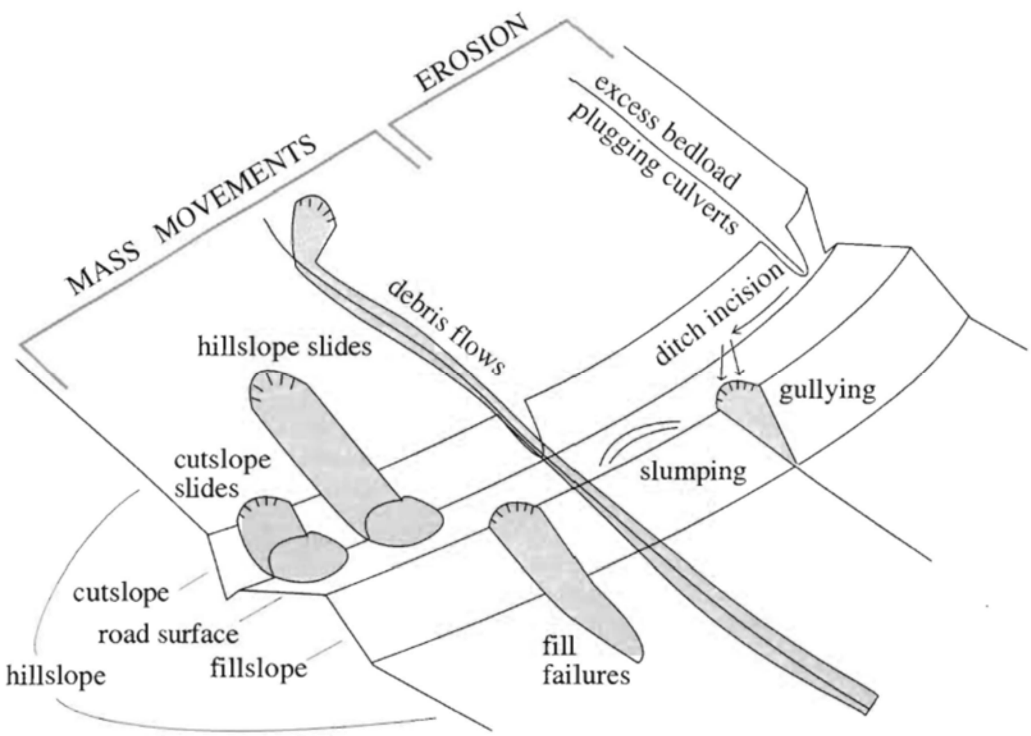


Figure 4.1 Eight types of Road failures inventoried in the Lookout Creek and Blue River watershed (from Wemple and others, 2001).

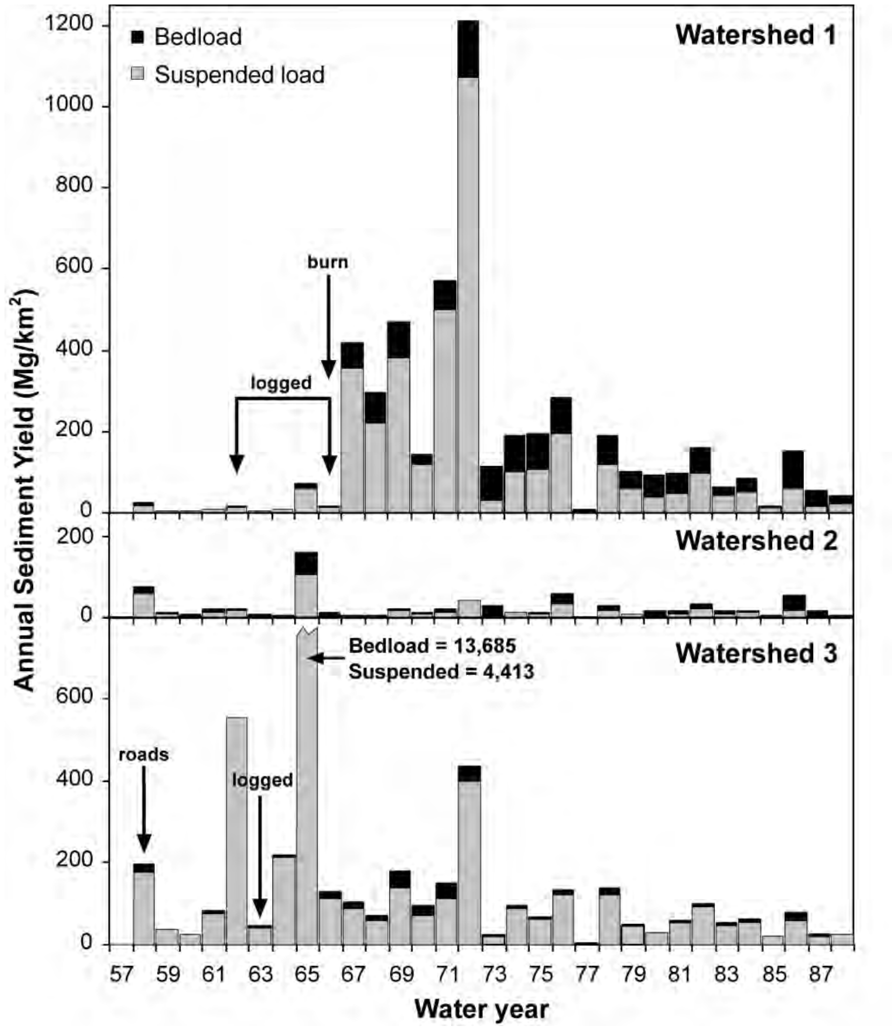


Figure 4.2 Annual sediment yields for Watersheds 1 (100% clear cut), 2 (control) and 3 (25% clear-cut and roads) for water years 1958-1988 (from Grant and Wolff, 1991).

Stop5 – Lookout Creek Bridge

Discussion points: Studies of the structure of and changes to the channel and valley floor morphology of Lookout Creek and its tributaries have been an on-going focus of investigations over the past 40 years. It has served as a type locale for analyses of channel structure and processes in step-pool mountain streams, long-term investigations of the role of woody debris in channels, controls on channel changes and the formation of valley floor surfaces and disturbance regimes, riparian ecology, nutrient dynamics, among many other topics. The Lookout Creek valley near the concrete bridge stop is distinctly wider than in upstream or downstream reaches, and reflects long-term deposition induced by a local constriction and base level control approximately 1 km downstream, where an old (at least Mazama age) earthflow dramatically reduces valley width and pinches the channel. The complex set of surfaces of different ages and origins in the reach visible from the bridge is in contrast to other reaches where a narrower and simpler set of surfaces are found, typically where the channel is constrained by alluvial fans and older terraces (Grant and Swanson, 1995). All of this reflects the important role of hillslope/channel process coupling in controlling the long-term morphology of mountain streams.

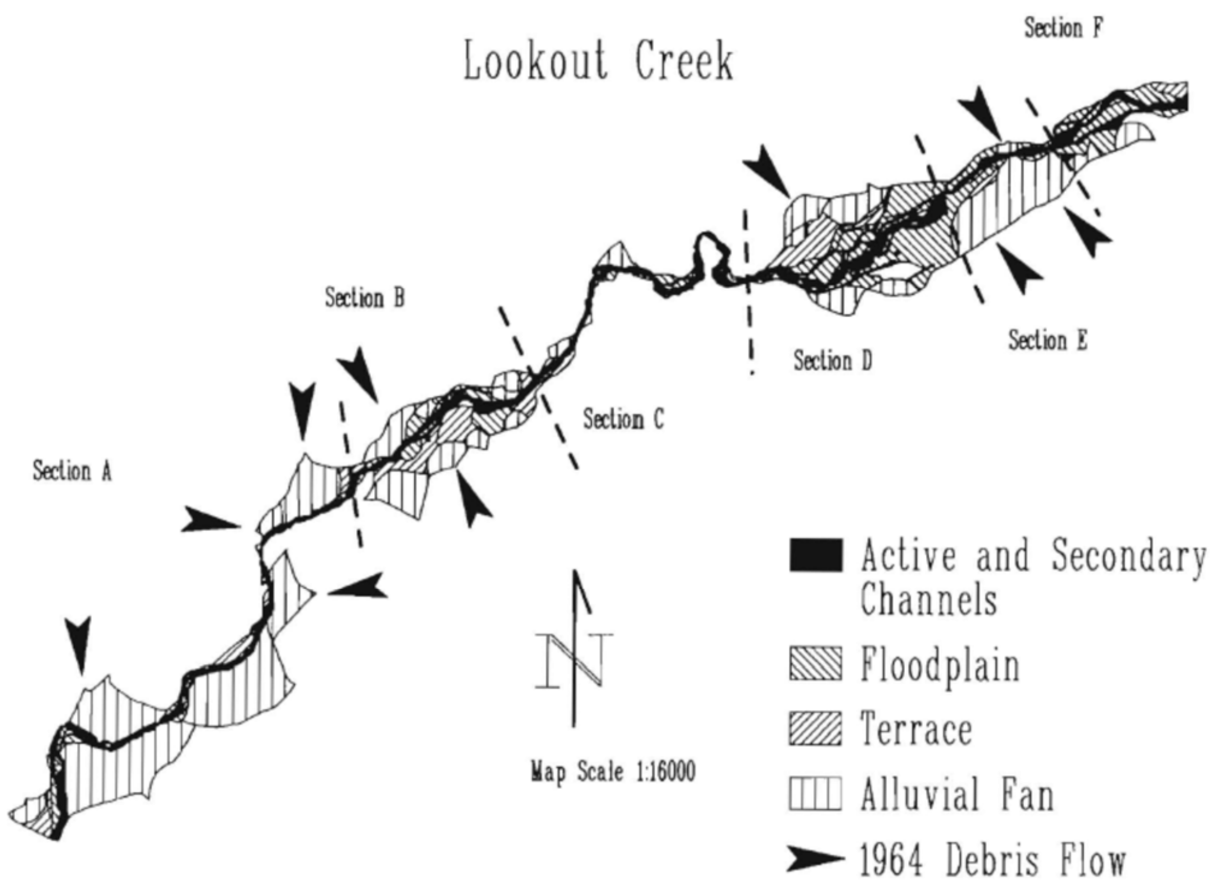


Figure 5.1 Map of Lookout Creek showing reach boundaries and locations of channels, floodplains, terraces, and alluvial fans as defined in text. Debris flows that occurred in the December 1964 storm as also shown. Bedrock outcrops occur where the stream flows against the valley wall. (Figure 3a from Grant and Swanson, 1995).

Stop 6 – Earth Flow

Excerpted from Swanson et al., 1987.

SITE 4. LOOKOUT CREEK EARTHFLOW

This 900 m long and 150 m wide earthflow is moving south into Lookout Creek at an average rate of about 10 cm/yr (Figure 2, Swanson and Swanston, 1977). Bedrock is a variety of volcaniclastic materials capped by a basalt flow which is the source of blocks forming the talus slope at the headscarp. Except for two small clearcut areas, the earthflow is forested, mainly with 400 to 500 year-old trees in the lower half while most trees on the upper half were established following a wildfire in the mid-1800's.

The earthflow landscape is irregular with scattered steep (>60%) slopes, which probably represent vegetated scarps, and many low relief areas, including poorly drained depressions. Drainage pattern and channel cross-sectional geometry are very irregular. The earthflow can be divided into three active blocks in the lower half of the whole earthflow. Each block is bounded by open, lateral shear cracks and a tension crack system across the head (Figure 2). The upper half of the earthflow does not appear to have been active in the last century or so, based on straight growth of trees in that area.

Earthflow movement is monitored with (1) stake arrays (strain rhombs) across active cracks to measure relative surface movement between blocks, (2) inclinometer tubes for monitoring vertical velocity profiles, (3) crackmeters to record continuously the opening of crack systems, (4) theodolite surveys of points on the earthflow from stable reference points off the earthflow, and (5) analysis of tree rings in scar tissue on live trees being split up the middle because they straddle an active crack (Swanson and Swanston, 1977). Water inputs in rain and snowmelt and groundwater levels are also continuously recorded, so that movement-water input relations can be examined. The purpose of the work is to gain a basic understanding of earthflow behavior so we can better assess impacts of management activities on this erosion process.

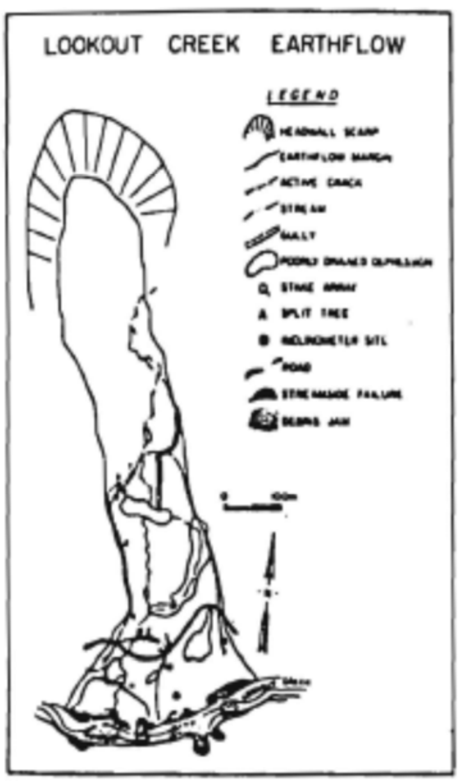


Figure 2. Map of Lookout Creek earthflow. Mapped by G. W. Lienkaemper (from Swanson and Swanston, 1977).

Comparison of crackmeter and precipitation records indicates tight control of movement rate by water availability (Figure 3). Movement at this site does not begin in the fall until nearly 90 cm of rain has fallen. Once the system is primed with water, movement continues at a slow rate until spring except for periods of accelerated movement in response to storm periods of water input in excess of about 12 cm/24 hr.

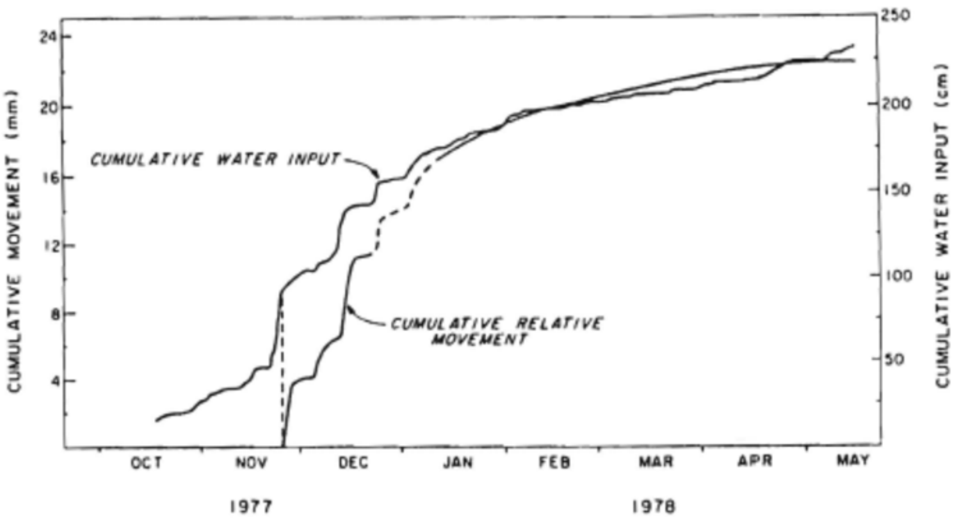


Figure 3. Cumulative water input and relative movement at crackmeter located at site 6 (Fig. 2). Movement curve is dashed for period when only total movement is known.

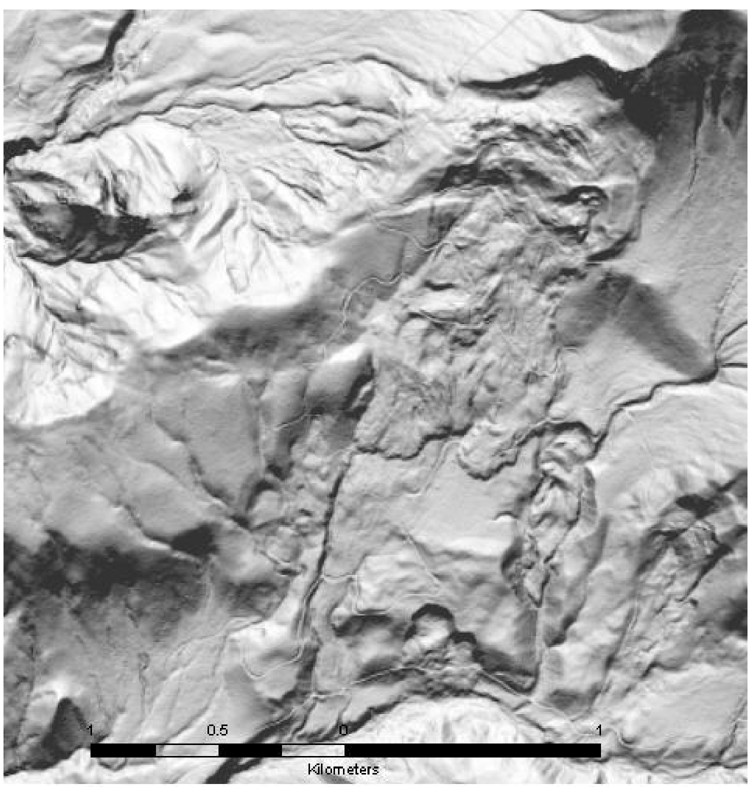
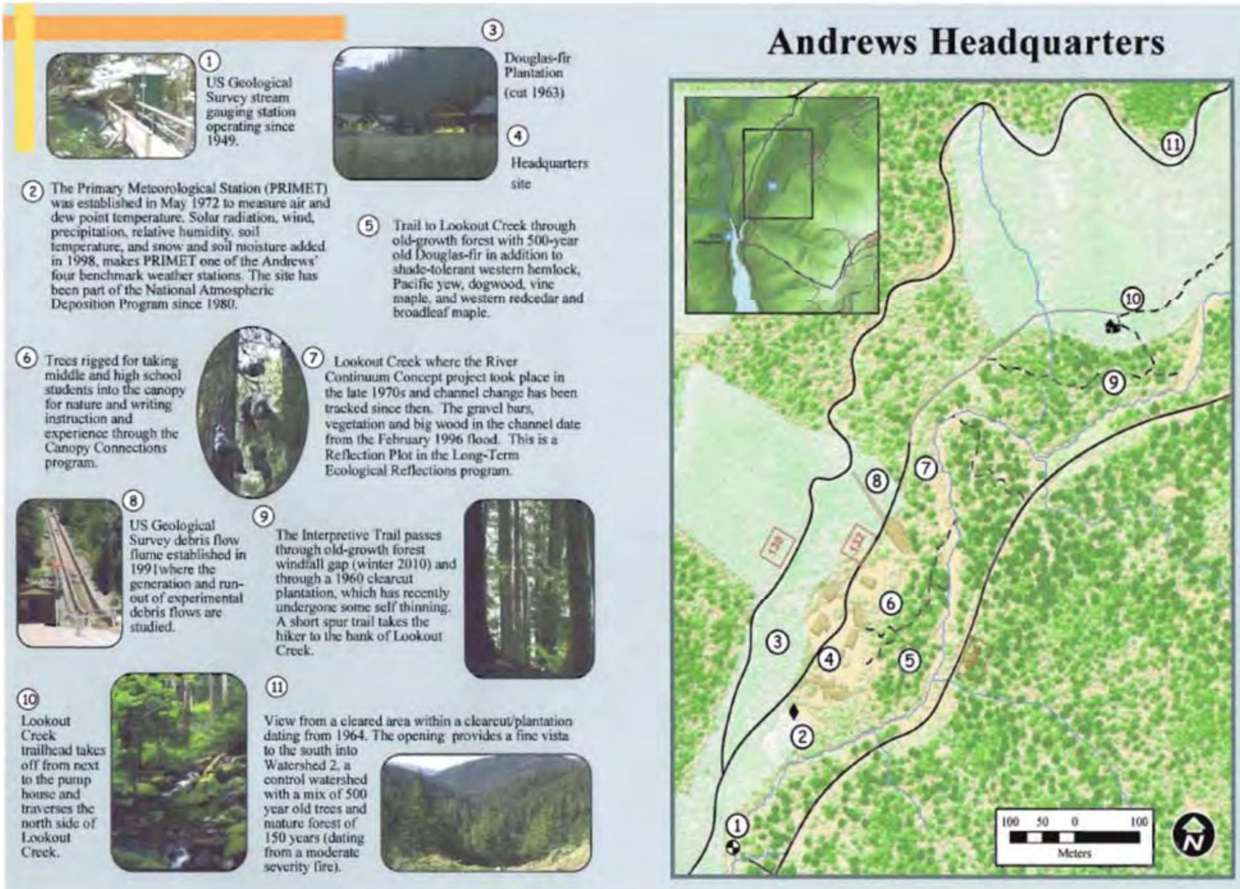


Figure 6.1 LiDAR image of earthflow complex

Return to HJ Andrews

Optional walking tour;



Lookout Creek – A Typical Western Cascades Stream

The following is taken directly from Cashman et al., 2009. pg553.

Lookout Creek near the main H.J. Andrews administration site is a classic Western Cascades stream, with a drainage area of 64 km^2. Characteristic features of this Western Cascades stream include: (1) a planform morphology dominated by coarse-grained lateral and marginal bars of flood origin, now colonized by broadleaf alders, cottonwoods, and willows; (2) a well-defined floodplain of mixed fluvial and debris-flow origin, now colonized by old-growth Douglas fir forest; (3) a well-defined channel morphology of step-pool sequences; and (4) marginal and occasionally channel-spanning large woody debris accumulations.

Channel and valley floor morphology, processes, and changes in this reach have been extensively studied and described (e.g., Grant et al., 1990; Grant and Swanson, 1995; Nakamura and Swanson, 1995; Swanson and Jones, 2002; Faustini, 2001; Dreher, 2004), and reveal interactions among fluvial processes, debris flows from upstream tributaries, growth and disturbance of riparian vegetation, and dynamics of large woody debris. In particular, this reach has been affected by repeated debris flows generated during major storms in 1964 and 1996. These debris flows entered the Lookout Creek channel approximately 2 km upstream, transitioned into bedload-laden floods that dramatically mobilized large woody debris accumulations, stripped mature and old-growth riparian forests, and deposited large coarse cobble bars that now support a young forest of alders and conifers. Stratigraphy of older deposits on which the current old-growth forest now grows reveals a similar origin. These reaches undergo a decades-long sequence of morphologic changes following large floods that is driven both by fluvial reworking of flood deposits and morphologic adjustments around large pieces of wood that fall in from the adjacent forest stand (Fig. 7.1).

7.1 Changes in Wood accumulation (black) and gravel bars (gray outlines) in Lower Lookout Creek between 1977 and 2010. Numbers denote surveyed cross section locations. Maps from 1977 through 1996 are from Swanson and Jones (2002). 2010 map from Jung-Il Seo and Kristen Kirkby (unpublished).

REFERENCES

Detailed references provided upon request

USGS briefing sheet on flume

http://vulcan.wr.usgs.gov/Projects/MassMovement/Publications/OFR92-483/OFR92-483_inlined.html

Debris-Flow Flume at H.J. Andrews Experimental Forest, Oregon

-- R.M. Iverson, J.E. Costa, and R.G. LaHusen, 1992,
Debris-Flow Flume at H.J. Andrews Experimental Forest, Oregon: U.S. Geological Survey Open-File Report 92-483

DEBRIS FLOWS

Debris flows are churning, water-saturated masses of rock, soil, and organic matter that rush down mountain slopes. They typically originate as landslides and course down stream channels when they reach the valley floor, leaving lobate deposits of debris in their wake. Debris flows commonly include 60 to 70 percent solid particles by volume and attain speeds greater than 10 meters per second (22 miles per hour). As a consequence, debris flows can denude slopes, damage structures, drastically alter streams, and occasionally cause loss of human life. They are common phenomena in mountainous areas worldwide, including the Appalachians, Adirondacks, Rockies, Great Basin ranges, Sierra Nevada, Cascades, and Coast Ranges of the United States. Typically triggered by intense rainfall or rapid snowmelt, debris flows sometimes occur in conjunction with other hazardous phenomena, such as volcanic eruptions and lowland flooding. Notable recent debris-flow disasters resulted in 150 deaths in central Virginia in 1969, in hundreds of millions of dollars of property damage and tens of deaths in California between 1978 and 1982, and in more than 23,000 deaths near Nevado del Ruiz volcano, Colombia, in 1985.

DEBRIS-FLOW FLUME

Scientific understanding of debris flows has been hampered by their unpredictable timing, location and magnitude, which make systematic observation and measurement of natural events both difficult and dangerous. Consequently, in 1991 the U.S. Geological Survey (USGS), in cooperation with the U.S. Forest Service, constructed a flume to conduct controlled experiments on debris flows. Located about 45 miles east of Eugene,

Fig.1: Debris-Flow Flume Location Map *(Modified from: Iverson, et.al., 1992, USGS Open-File Report 92-483)*

Oregon, in the Cascades Range foothills near the headquarters of the H.J. Andrews Experimental Forest, Blue River Ranger District, Willamette National Forest, this unique facility provides research opportunities available nowhere else **(fig. 1)**.

The flume is a reinforced concrete channel 95 meters (310 feet) long, 2 meters (6.6 feet) wide, and 1.2 meters (4 feet) deep that slopes 31 degrees (60 percent), an angle typical of terrain where natural debris flows originate **(fig.2).** Twelve large bolts grouted into deep boreholes and tensioned to concrete pads adjoining the flume help anchor the structure to the underlying soil and rock. Removable glass windows built into the side of the flume allow flows to be observed and photographed as they sweep past. Eighteen data-collection ports in the floor of the flume permit measurements of forces due to particles sliding and colliding at the base of flows.

Fig.2: An experimental debris flow descends the flume

To create a debris flow, up to 20 cubic meters (about 40 tons) of sediment are placed behind a steel gate at the head of the flume, saturated with water from subsurface channels and surface sprinklers, and then released. Alternatively, a sloping mass of sediment can be placed behind a retaining wall at the flume head and watered until slope failure occurs. The ensuing debris flow descends the flume and forms a deposit on a nearly flat runout surface at the flume base **(fig. 3).** The flume design thus accommodates research on all stages of the debris-flow process, from initiation through deposition. Experiments can be conducted using a variety of materials, from mixtures of well-sorted gravel and water to heterogeneous natural slope debris. Experimental materials are recycled by excavating deposits with a front-end loader, placing them in a dump truck, and hauling them back to the staging area at the head of the flume.

SCIENTIFIC OBJECTIVES

The debris-flow flume provides opportunities to make key measurements that have never before been possible. The measurement program aims to satisfy two broad objectives: (1) to test existing mathematical models and develop new models for interpreting and forecasting debris-flow behavior and (2) to develop improved technologies for mitigating the destructive effects of debris flows.

Improved models of debris-flow behavior require better understanding of how momentum is transported and energy is dissipated in debris flows. Measurements of flow-front velocities, flow-surface velocities, flow depths, vertical velocity profiles, and shear and normal forces at the channel bed help quantify the mechanisms of momentum transport and energy dissipation **(fig. 4).** Additional insight can be gained by using ultrasonic imaging to "see" into the interior of flows and by deploying "smart rocks" containing miniature computers that record the rocks' accelerations as they move downslope. Flume experiments also test the accuracy of debris-flow speed estimates made on the basis of the height of mud lines preserved on channel obstacles and at channel bends.

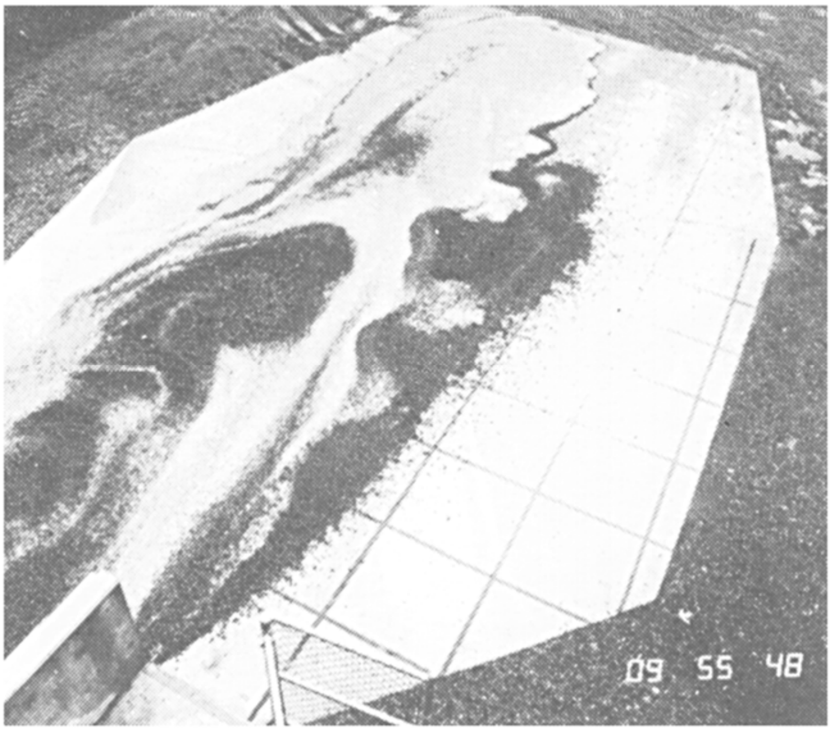


Fig. 3: Deposit formed by the debris flow shown in figure 2. A one-meter grid on the runout surface provides scale

Historically, most interpretations of debris-flow behavior have been based on reconstructions from the sedimentological record. These interpretations have seldom been verified with real-time measurements of flow dynamics. Detailed real-time measurements at the debris-flow flume constrain interpretations of the sedimentology and morphology of debris-flow deposits at the base of the flume. Such well-constrained interpretations may revolutionize sedimentologic studies of debris-flow deposits, much as flume studies of stream processes revolutionized fluvial sedimentology several decades ago. With better sedimentologic understanding and modeling capabilites, it should be possible to assess and predict debris-flow hazards with more accuracy than has been possible in the past.

Technologies for mitigating debris-flow hazards include automated detection and warning systems as well as engineering countermeasures that protect high-risk areas. For example, at Mount St. Helens in Washington, Redoubt Volcano in Alaska, and Pinatubo Volcano in the Philippines, the USGS has successfully deployed an automated debris-flow detection system. The system senses ground vibrations caused by passing debris flows and radios an alarm to receivers downstream, allowing time for evacuation of people and property. Experiments at the debris-flow flume aim to improve understanding of ground vibrations caused by debris flows and to refine the automated detection system. The flume also provides an ideal environment for testing engineering countermeasures such as structures that deflect, trap, or channelize debris flows. Experiments that assess how debris flows react to and act upon such structures can guide engineering designs. The ability to control and replicate debris flow characterisitics in the flume allows researchers to evaluate mitigative measures more systematically than if research were focused only on natural events.

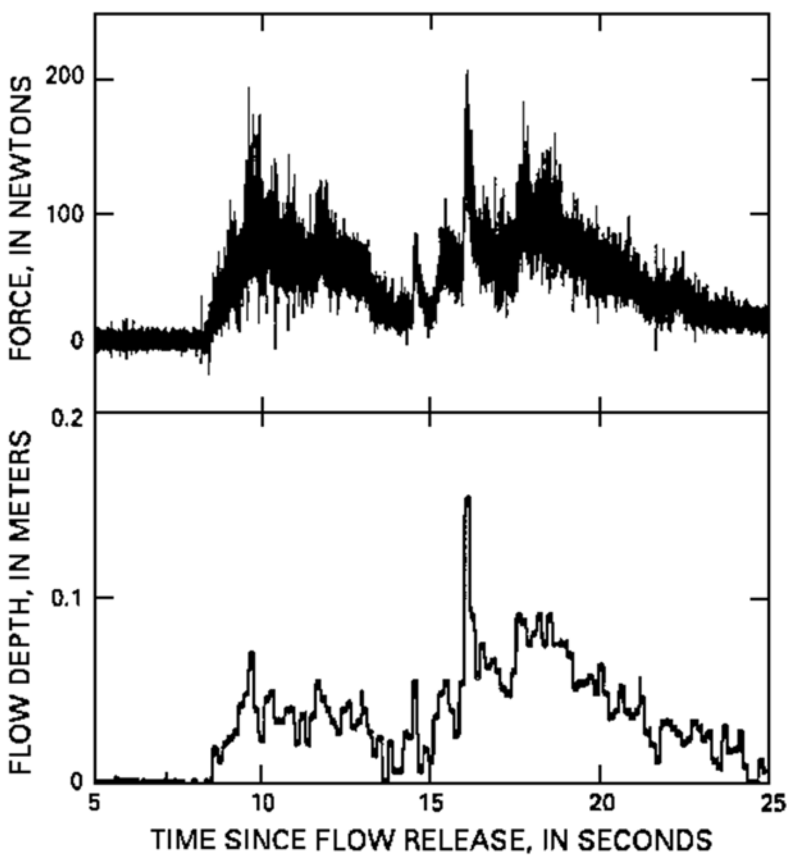


Fig. 4: Records of flow depth, measured ultrasonically, and normal force on a 0.05 square meter (0.5 square foot) plate on the flume bed as two debris-flow surges pass