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FIELD TRIP GUIDE # 12

The Bedrock Geology of Seattle

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Ralph Haugerud
U.S. Geological Survey
Seattle, Washington

and

Peter Haeussler
U.S. Geological Survey
Anchorage, Alaska
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I. INTRODUCTION

There is remarkably little exposed bedrock in Seattle. Why focus a field trip on such an unpromising topic? Recent concern about the Seattle fault and the consequent increased (relative to what earth scientists believed 10 years ago) seismic hazard in the central Puget Lowland have led to a number of hypotheses about the bedrock structure beneath Seattle. Conversely, what little we know about the bedrock of the Seattle area has become important for assessing fault geometry and long-term deformation rates. While there is little accessible bedrock outcrop in Seattle proper, there are outcrops along strike to the east and west, and one can reasonably expect subsurface lithologies and structures to be similar to those exposed along strike.

What rocks would be encountered in a deep test hole beneath Seattle? Why are the youngest rocks near Seattle among the most strongly deformed? The apparent basement of the eastern Olympic Peninsula is Eocene basalt of the Crescent Formation, whereas Eocene arkose and andesite crop out to the east of Seattle: is there a major N-S fault beneath Puget Sound that separates these two provinces? Some fore-arc basins (Great Valley in California, Cook Inlet in Alaska) have no exposed bedrock in their centers. Why is there any bedrock outcrop in Seattle? This trip is an introduction to these questions, with an emphasis on the evidence offered by surface rock outcrops.

The last round of extensive study of Seattle’s rock was in the 1950s and 1960s (for example, Waldron and others, 1962). Those workers are no longer active, and there now no experts on the bedrock geology of Seattle. Our credentials are limited: Haugerud has read some of the literature on Seattle and points east and is mapping Bainbridge Island. Haeussler recently finished mapping the Uncas quadrangle, SE of Sequim, which includes outcrop of Crescent Formation and overlying sedimentary rocks, and the Wildcat Lake quadrangle, west of Bremerton, which exposes sub-Crescent (?) basement. He is now mapping the Bremerton area.

Others in the local geologic community are knowledgeable on various aspects of this geology. Jody Bourgeois (University of Washington) uses the Blakeley Formation and correlative rocks to the east for teaching exercises. Liz Nesbitt (Burke Museum) is currently working on the macro-fauna of the Tukwila and Blakeley Formations. Richard Stewart (University of Washington) is working on fission-track ages for the Blakeley, and has some interesting questions about the published micropaleontology of the unit. Tim Walsh (Washington DGER) has done extensive research on the coal-bearing rocks of central King County.

Not visited on this trip, but worthy of note, are some other outcrops:

- Blakeley Formation at Alki Point is similar to that on SE Bainbridge Island. Alki outcrops are best seen at low tide. They define an open, steeply north-plunging anticline; beds are overturned at NW end of outcrop.
- Blakeley Formation outcrops along I-5 in George town would require State Patrol permission and strong nerves to examine.
- There is a good section of the Tukwila Fm along Martin Luther King Way in Tukwila, between S. Boe There is no nearby parking.
- Lapilli tuff in Seward Park was assigned to the Blakeley Formation by Waldron and others (1962).
- Waldron and others (1962) show Blakeley Formation throughout the Columbia City-Rainier Valley area.
Limited reconnaissance by Haugemd suggests that most of these outcrops have since been landscaped. Ask Liz Nesbitt about outcrops of the marine lower Tukwila Formation that are on private property along the Duwamish River.

The large Stoneway rock pit visible north of Southcenter is in crumbly-weathering, brown, massive, hornblende-plagioclase porphyry of the Tukwila Formation. Some of the rock is breccia; other rock is massive and may be flows and (or) shallow intrusions.

Some exploration might find good exposures of the Puget Group in the vicinity of Coal Creek in south Bellevue and Newcastle. There is a good Tukwila Formation outcrop—perhaps that sampled by Turner and others (1983)—along Coal Creek Parkway north of SE 79th Street.

Minard (1985) mapped Miocene sedimentary rock at the base of the west wall of the Snoqualmie valley NW of Duvall.

- Outcrops near Cathcart (lower Snohomish River valley) have long been correlated with the Blakeley Formation. Eocene (?) volcanic rocks crop out along the Bothell-Monroe cutoff (SR 522) just north of the Snohomish River.
- East of the Snoqualmie River valley, Eocene Mount Persis volcanics overlie Mesozoic sandstone, argillite, and greenstone of the western melange belt (Tabor and others, 1993). The volcanic rocks of Mount Persis may be correlative with the Tukwila Formation.

II. SATURDAY: SEATTLE—LITTLE QUILCENE RIVER—GREEN MOUNTAIN—MANCHESTER

From the Kent-Des Moines Park & Ride lot, take I-5 north about 13 miles to Exit 164B. Follow signs to ferries—right on 4th Avenue S, right on Royal Brougham Way, and right to side road beneath Alaskan Way viaduct, later turning onto Alaskan Way proper.

We are taking the Washington State ferry to Bainbridge Island, not the Victoria ferry. We hope to catch the 7:40 ferry. The crossing takes about 35 minutes.

From the Bainbridge Island ferry landing, proceed up hill, straight through the first stop light, and follow State Route 305 northwest across the Agate Passage bridge to Poulsbo, about 13 miles. About 2 miles beyond Poulsbo, turn right onto SR 3 towards the Hood Canal bridge some 8 miles to the north. At the Hood Canal Bridge, drive beyond the bridge and turn left into the parking lot on the east end of the bridge (north side) to meet the remainder of our group. Continue across the bridge and west on SR 104.

West of Shine, SR 104 traverses a low-elevation plateau. Sandy, pebbly debris in road cuts suggests that the substrate is outwash. Rolling terrain and occasional erratics visible in clearcuts are inconsistent with this area being underlain by recessional outwash, so it must be advance outwash. Vashon till is here either absent, very thin, or very sandy.

At 14 miles from the east end of the Hood Canal bridge, view ahead of Big Skidder Hill, in the north part of the Uncas 7.5' quadrangle.

15 miles from E end Hood Canal Bridge, at junction with US 101, turn left, south, towards Quilcene and Olympia.

Highway 101 follows the Leland Creek spillway, a 15 km long channel that drained recessional Lake Bretz. As Vashon retreated following its maximum extent at about 17,000 calendar years BP (Porter and Swanson, 1998), ice-impounded proglacial Lake Russell drained south, via the Black Lake spillway south of Olympia, to the Chehalis valley and the sea. As pointed out by Thorson (1989), when ice retreated farther and thinned, the Leland Creek spillway opened up and the water level dropped 64 meters to stabilize as Lake Bretz. The current maximum elevation of the Leland Creek spillway is 69 meters, between Crocker Lake and Leland Lake. The Black Lake spillway is at 41 m; the difference of 92 m between the present relative elevations of the Black Lake and Leland Creek spillways and their former relative elevations is a measure of the amount of isostatic rebound in this area since Lake Bretz time.

About 9 miles from the SR 104 junction, % mile beyond milepost 292, turn right (west) onto Lords Lake Loop Road. Follow road up and to west.

High ground to west is underlain by Eocene Crescent Formation. Low country here is in younger sedimentary cover. As we drive west we are heading down section.

About the Crescent Formation

The lower and middle Eocene Crescent Formation consists of submarine and subaerial basalt flows, breccia, and interbedded sedimentary rocks. Pillow lava, pillow and lapilli breccia, amygdaloidal lava flows, dark gray calcareous mudstone, basaltic siltstone, and sandstone make up the lower submarine unit.

Tabor and Cady (1978) mapped two units within the Crescent Formation on the Olympic Peninsula. The west–eastmost (in the Uncas quadrangle) is unit Tcb, which they describe as:

basalt, massive flows, pillows, and breccia; minor diabase and gabbro. Pillows and tube structures are common, ranging from centimeters to 3 m across; some show bedding but most occur as separate pillows and pillow fragments in a tufaceous matrix. Gabbro and diabase, this probably occurring mostly as sills, are compositionally similar to basalt but with subophitic or hypidiomorphic granular texture.
Unit Tcb is basically a submarine unit. Unit Tcbb, on the other hand, has less evidence of being a submarine unit. Tabor and Cady describe it as:

*basalt flows and mud flow breccias. Flows are characterized by closely spaced, random joints and are locally are columnar jointed, or more rarely pillow-lowed. Unit includes many unmapped interbeds of sedimentary rocks, some gray foraminiferal limestone.*

Tabor and Cady map both of these units as dipping away from the core of the Olympic Mountains, with the submarine unit Tcb lying beneath unit Tcbb. This relationship is similar to that mapped on Green and Gold Mountains in the Wildcat Lake quadrangle, near Bremerton, where submarine basalts and basaltic sediments lie beneath subaerial basalts.

Calcereous nanoplankton from interbedded turbidite siltstone and sandstone at the top of the submarine unit at Bon Jon Pass, 1 km west of the Uncas quadrangle, are referred to the CP 11 zone, or early Eocene (about 50 Ma), by D. Bukry (written communication, 1998). East of the Uncas quadrangle, Yount and Gower (1991) report foraminifera referable to the Ulatisian stage (early middle Eocene) within marine siltstones and sandstones of the Crescent Formation. Most of the upper part of the Crescent Formation in the Uncas quadrangle consists of amygdaloidal basaltic flows and breccia. Breccia is monolithic, and the flows sometimes have rubbly reddish weathering surfaces indicative of subaerial eruption. However, Spencer (1984) noted on the west shore of Quilcene Bay, south of the Uncas quadrangle, there are massive basaltic flows interbedded with pillow lavas, indicating complex interfingering of environments typical of oceanic islands. No ages have been determined from the subaerial part of the Crescent Formation within the Uncas quadrangle. From the Bremerton area, 40 km to the southeast, Duncan (1982) reported an 40Ar/39Ar age of 55 Ma, and Babcock and others (1992) reported an 40Ar/39Ar age of 50.3 ± 1.5 Ma.

No fossil ages have been obtained from subaerial Crescent basalts, but the overlying Aldwell Formation has benthic foraminifera and mollusks with ages from upper Ulatisian to lower Narizian (Spencer, 1984). Therefore, subaerial Crescent Formation basalts have ages around 46-50 Ma on the time scale of Berggren and others (1995). That the 40Ar/39Ar dates on the basalt flows analyzed by Duncan (1982) were slightly older could be explained by: 1) recoil effects, because the Ar analyses were whole rock, 2) the Crescent Formation basalts may be slightly time transgressive, and 3) the Crescent Formation basalts being lower Ulatisian rather than upper Ulatisian.

Outcrops of Crescent Formation at Lords Lake are in the upper, Tcbb, part of the unit, and are amygdaloidal. Beyond Lords Lake, for the next 3 miles or so, outcrops along the road are massive basalt flows of Tabor and Cady’s unit Tcbb. Unless someone protests strongly, we will not stop in the upper Crescent.

*At about 4 miles from US 101, signs for Olympic National Forest. At 5 miles, pass unlocked gate. At 7/16 miles, junction.*

**Stop 1. Crescent Formation, Little Quilcene River fault.** There is a large NW-striking dextral fault with a 6-m-wide gouge zone exposed in this quarry. This fault lines up with the NW-trending Little Quilcene drainage, and thus we infer the drainage lies along the SE extension of this fault. On the SW side of the fault are pillow and lapilli breccia and calcareous mudstones. On the NE side of the fault are pillow basalts, overlain by a diabase sill(?), overlain by mudstone. This outcrop is within Tabor and Cady’s (1978) unit Tcb. If it is clear, admire the view southwest to the Puget Lowland, Seattle, and maybe Mount Rainier. Mountains and the curvature of the Earth prevent one from seeing all the way to northeast Oregon, but we are close to, if not on, the Olympic-Wallowa Lineament.

How might the NW-trending fault at this location fit into the tectonic pattern of the Puget Lowland? Of the Pacific Northwest?

*Continue up Road 28 about 1/2 mile to pullout on left. Park here and walk 100m up road to* 

**Stop 2. Sedimentary rocks in lower Crescent Formation.** What inferences about depositional environment can you draw from the bedding style here? Is there evidence that the beds are upright?

The shape of the valley here suggests this was a high-volume ice-marginal drainage channel. Key features are the wide, irregular bottom, low gradient, and minimal talus on valley walls.

*Continue up Road 28 to Bon Jon Pass (Vi mile). Take road 2810 (Road 28 is currently blocked by a washout) to northwest. 1.5 miles beyond Bon Jon Pass, roadcut on right with basalt pillows. Pull over.*

**Stop 3. Pillow basalt in Crescent Formation.**

*Continue NW on Road 2810. In 0.4 miles, pass trailhead. 0.8 miles farther, junction with Road 210. Continue left on Road 2810, about ½ mile to junction with Road 28, then another ½ mile to junction with Road 210. Continue 0.2 miles on Road 28 to junction with Road 2840. Turn right on 2840. Follow Road 2840 3 miles to junctions with roads 070 and 071 (both on left). Keep right on 2840. In another 1¼ mile, turn sharply right on Road 2845.*

**Stop 4. Lyre conglomerate.** The Lyre in the Uncas quad is mapped as having two conglomerate members, with andesite tuff and breccia lying in between. The lower conglomerate consists of chert, basalt, and conglomerate clasts, whereas the upper conglomerate also has chert, but also includes metasedimentary, igneous, quartz, and gray-
wacke clasts. The conglomerates are both clast and matrix-supported. Commonly there is no preferred orientation for the clasts, which indicates deposition by debris flows in a submarine fan environment. This outcrop is in the upper conglomerate.

In the southern part of the Uncas quadrangle, the Lyre Formation lies on the Aldwell Formation. Along the western edge of the quadrangle, and northeast of the quadrangle, the Lyre Formation lies directly on the Crescent Formation. Spencer (1984) observed the contact in the upper Snow Creek drainage, and described it as irregular and undulatory. The contact northeast of the quadrangle contains basaltic cobble and boulder conglomerate. From these observations, Spencer (1984) inferred considerable relief on the surface beneath the Lyre Formation. Spencer (1984) measured 418 paleocurrent indicators in the Lyre Formation and found a consistent south-southwest direction of transport. The base of the section has a higher percentage of basaltic clasts indicating erosion of the underlying Crescent Formation. Chert and phyllite clasts are also common in the conglomerates, and Snively and others (1993) and Garver and Brandon (1994) concluded similar clasts in the Lyre Formation at the northwestern tip of the Olympic Peninsula were derived from Mesozoic sediments on southern Vancouver Island.

There is no direct fossil control on age of the Lyre here, but it is sandwiched between the lower Narizian Aldwell Formation and the upper Narizian sandstone of Snow Creek. Yount and Gower (1991) report K-Ar ages of 35.5 and 41.0 Ma from hornblende in an andesite boulder from the Lyre, collected near Mt Zion just west of the Uncas quadrangle. These ages are younger than is allowed by Spencer’s (1984) biostratigraphy, and thus we infer some argon loss. Northwest of the Uncas quadrangle, Lyre Formation and the upper Narizian sandstone of Snow Creek appear to have been localized because it is defined and correlated. In the Uncas quadrangle, the Lyre Formation and the informally named sandstone of Snow Creek overlie the Aldwell. Perhaps the Lyre and the sandstone of Snow Creek should be combined into one formation, with the Snow Creek sandstone as a member. Spencer (1984) notes the Snow Creek unit and the rest of the Lyre Formation are related because of a conformable contact and because there is an abundance of chert and metamorphic clasts in both units, which indicates a similar source area.

Moreover, Tabor and Cady (1978) and Yount and Gower (1991) map the Snow Creek unit as the Twin River Formation. Spencer (1984) included the Snow Creek unit in the Lyre Formation. Haeussler et al. (1999) mapped the Snow Creek unit as a separate unit similar to the Hoko River Formation of the western Olympic Peninsula (Snively and others, 1993), thus formally avoiding expanding the Lyre Formation, and avoiding using the term “Twin River,” which has been used as a Group name to refer to several formations that range in age from upper Narizian (uppermost middle Eocene) to Miocene time (e.g. Garver and Brandon, 1994). The lowermost of the formations in the Twin River Group is the Hoko River Formation, which is similar in composition and age to the sandstone of Snow Creek, as used in this study. See Figure 2.

Retrace route 1.7 miles back down Road 2845 and turn right onto Road 2852. In about 2.3 miles, look on left of road for

Stop 5. Sandstone of Snow Creek. (Haeussler recalls outcrop somewhere in this area. Haugerud, reconnoitering for this trip, found only rubble.)

Silty sandstone and sandstone turbidites which overlie conglomerate of the Lyre Formation in this vicinity constitute the sandstone of Snow Creek. The section in the upper Snow Creek drainage is 567 m thick; foraminifera are referable to the upper Narizian stage and are “...indicative of cool to cold water temperatures and water depths in the lower bathyal zone” (Spencer, 1984, p. 135). Petrography of the sandstones indicates chert and quartz predominate, with chert being a significant proportion of the clasts (Spencer, 1984). Deposition of the sandstone of Snow Creek appears to have been localized because it is not found northeast of the Uncas quadrangle, where the Townsend Shale lies un-conformably on the Lyre Formation (Thorns, 1959) and the Snow Creek member is missing.

Continue down road 2852 about 1/2 mile to junction with Road 2850. Turn right onto 2850.

One mile from 2852-2850 junction, we leave the Olympic National Forest. A sign states “Douglas Fir Plantation
Planted 1928." The trees are no more than 2’ diameter at breast height.

Five miles from ONF boundary, turn sharply left at road junction. One mile farther, junction with Highway 101. Turn left. Take US 101 north 4 miles to junction with SR 104. Exit onto 104 and go east to Hood Canal bridge.

At east end of bridge, turn right to Bremerton. (Stop and pick up cars left here in morning). Follow SR 3 south some 20 miles.

The Seattle fault: Why bedrock crops out in Seattle

For the rest of the trip we will look at outcrops within a complex faulted anticline in the hanging wall of the east-west Seattle fault. Overall the Seattle fault appears to be a north-verging thrust that brings up older strata on the south side (Johnson and others, 1994). Uplift on the south side of the fault, and greater erosional resistance of the older bedrock, has produced the anomalous east-west topographic high comprised of Green and Gold mountains, Newport Hills, Cougar Mountain, Sauk Mountain, and Tiger Mountain.

Total stratigraphic throw on the Seattle fault is on the order of 10 km (Johnson and others, 1994). Assuming a reasonable dip (e.g. Pratt and others, 1997), overall shortening may be on the order of 30 km. Shortening is in response to overall N-S contraction of western Washington, caught in a vise between the stable (relative to most of North America) and rigid Coast Mountains of British Columbia and the north-moving, clockwise-rotating, rigid Oregon Coast Ranges block (Wells and others, 1998). The Oregon Coast Ranges are being driven north by the north-moving Sierra Nevada block, with a pivot in the Sierra Nevada. The Sierra Nevada block is dragged north by shear of the Pacific plate—not all displacement is taken up on the San Andreas fault. Net north-south contraction across western Washington is on the order of 4 mm/yr (R.E. Wells, personal commun., 2000).

When the Seattle fault began moving is not clear. Johnson and others (1994) suggested that motion began at the beginning of Blakeley time (latest Eocene or early Oligocene), as they believed that the Blakeley Formation thickens in the Seattle basin, on the north side of the fault. The apatite fission-track age reported by Haussler and others (2000) supports this inference. However, Haugerud doesn’t see the Blakeley Formation in the Seattle basin in the seismic reflection lines published by Johnson and others (1994)—and any interpretation depends on uncertain velocity corrections. Tom Brocher (personal commun., 2000) doesn’t see north-to-south thickening in SHIPS tomography. The tomography, while less precise than the seismic reflection survey, contains no unconstrained velocity corrections. An alternate view is that displacement on the Seattle fault began in Blakeley Harbor time (mid-Miocene), as the Blakeley Harbor Formation clearly thickens to the south in both reflection and tomographic profiles.

Exit for Chico Way NW. Turn right onto Chico Way, proceed about 2/3 mile, and turn right onto Northlake Way. In about 1 mile proceed right onto Seabeck Highway.

In about 3 1/2 miles, turn left on NW Holly Road.

About 2 miles farther, about ‘A mile west of the parking area for the state park, turn left at locked orange gate. We have DNR permission to drive beyond here to

Stop 6. Leucogabbro at base of Crescent Formation.

The rock column exposed on Green and Gold Mountains, referred to as the ‘Bremerton rocks’ by Clark (1989), is somewhat like that of an ophiolite with basal gabbro beneath a locally sheeted dike complex, beneath submarine basalts and volcaniclastic rocks, beneath subaerial basalts flows. Clark (1989) found more than 60 m of basal leuco-gabbro and pegmatoid. Numerous diabase and basaltic dikes intrude the upper part of this unit and are mapped separately. The overlying sheeted dike complex is approximately 150-m thick and consists entirely of dikes of diabase and basalt. The submarine volcanic unit consists of basalt flows inter-bedded with basaltic sandstone, siltstone, tuffs, and basaltic breccia. Overlying the submarine volcanic unit are subaerial basalt flows more than 180-m thick. Trace-element data from intrusive and extrusive rocks are similar, suggesting they are related (Clark, 1989).

The Bremerton pseudostratigraphy differs from idealized ophiolite stratigraphy in several important ways (Clark, 1989): 1) It lacks a basal ultramafic complex, 2) the Green and Gold Mountain dike complex has a thickness of about ISO m, in contrast to more than a kilometer of sheeted dikes in typical oceanic crust, 3) Green and Gold Mountain dikes are not ubiquitously, sheeted, and 4) the Green and Gold Mountain sequence is capped by subaerial basalt, whereas most ophiolites are overlain by deep marine sediments. Clark (1989) found that the geochemistry of the gabbro and basalts is transitional between normal mid-ocean ridge basalt (MORB) and enriched oceanic island basalt.

Preliminary modeling of aeromagnetic and gravity data over Green and Gold Mountains (P. J. Haussler and R.J. Blakely, unpublished work) indicate there are highly magnetic, dense rocks within a few kilometers of the surface beneath Green and Gold Mountains. Therefore, there probably is a basal ultramafic complex. Despite the differences between the Green and Gold Mountains rocks and ophiolites, the presence of the dike section on Green and Gold Mountains and the overall pseudostratigraphy of an ophiolite indicate that these rocks formed in an extensional environment.

Note the variability in grain size in the leucogabbro in outcrop and among the various rip-rap pieces on the ground. We will not go to the top of the outcrop, but it is leucogabbro all the way to the top of the quarry (there’s a bunch of vegetated benches) and the vertical exposure is probably 150 m or more. There is one 20 cm basaltic dike cutting the leucogabbro.

A Pb-Pb age on zircon of 50.5 ± 0.6 Ma was obtained from a sample from this quarry. An apatite fission track age of 32 ± 5 Ma was obtained from the same sample. Haussler and others (2000) interpret this to indicate that Green Mountain started going up at the time that Johnson and others (1994) inferred that the Seattle basin began to subside.

A short distance north of here are volcaniclastic rocks of
the upper Crescent Formation, indicating a couple of km of
down-to-the-north throw on an intervening, and unexposed,
splay of the Seattle fault.

Return east on Holly Road. Seabeck Highway, and North-lake
Way, and Chico Way. But turn right onto SR 3 and follow it
south through Bremerton to Gorst (about 7 miles from Chico
Way intersection.)

Near Gorst, at the head of Sinclair Inlet, we pass basalt
flows on the right (W) side of the road. There are nice amyg-
dules and red, oxidized horizons at the tops of lava flows. Lava
flows are very thick-commonly 10 m or so. The flows are dip-
ing to the SE.
At Gorst, go left (east) on SR 16 to Port Orchard. From Port
Orchard, continue on Beach Drive, traveling NE along the
south side of Sinclair inlet, winding around Waterman Point
and then driving south. Turn left on Hilldale Road to enter
Manchester State Park.

Stop 7. Blakeley Formation at Manchester State Park.
Very nice exposures of the Blakeley Formation here are most
easily accessed at lower tides, but the outcrops can also be
 gained by walking along the terrace-top trail and then dropping
down where access is permissible. There are wonderful sedi-
mentary structures in the rocks: beautiful flute casts, graded
bedding, channels, and debris flows. At one point there is a 3-4
m welded tuff boulder in a bed that contains large rip-ups and
a few clasts in the 30-cm size range. What brought this boulder
so far?

Fulmer (1975) divided the Blakeley into two members; we
are near the contact between his lower, conglomeratic, Orchard
Point member and his upper, finer-grained, Restoration Point
member. The difference between the two members is primar-
ily grain size. Clasts are primarily volcanic; Fulmer described
coarse basaltic clasts in a matrix of felsic glass shards, now
commonly altered to zeolite and carbonate. Other rock types
include tuffaceous brown sandstone, tuffaceous thin-bedded
siltstone, and shale.

According to Fulmer (1975) the Orchard Point mem-
er is Zemorrian and Refugian, while the Restoration Point
member is Zemorrian alone. He suggests that both units were
largely deposited by turbidity currents in deep cold water,
and that warm-water corals in the Blakeley fossil as-
semblage record remobilization of shallow-water sediments.
The Blakeley is the fore-arc basin equivalent of the
Ohanepecosh and Fifes Peak formations within the Cascade
volcanic arc. It is similar in age and lithofacies to the Lin-
coln Creek Formation of southwest Washington.

[Fulmer (1975) noted that Weaver named the Blakeley
Formation for Blakely Harbor, which has always been spelled
with only one “e”. He hypothesized that Weaver added the
final “e” to avoid conflict with an earlier recognized Blakely
sandstone unit of Lower Ordovician age. When Fulmer rec-
ognized younger fluvial strata as the separate Blakely Harbor
Formation, he removed the offending vowel.]
Retrace route to Port Orchard and Gorst. At Gorst, go north
(right) towards Bremerton. In 2 miles, take SR 304 into down-
town Bremerton, and then follow SR 303 north across Port
Washington Narrows. One mile north of bridge, turn right on
Sylvan Way towards Illahee State Park, our campsite for the
night.

III. SUNDAY: BLAKELY HARBOR—TUKWILA—PRESTON—
LAKE MONT—VASA PARK—SEATTLE

From Illahee State Park, return west to SR 303. Turn right,
north, and follow SR 303 north and west about 9 miles to SR 3.
Go right, north about 4 miles and take SR 305 through Pawsbo
to Bainbridge Island (about 6 miles).

On Bainbridge, about 6 miles beyond the Agate Passage
bridge, turn right on High School Road, go west 0.8 miles and
turn left on Finch Road, and south ~/i mile to a T inter-
section with Wyatt Street.

Turn right on Wyatt and follow it around to the left as it
becomes, in ~/i mile, Blakely Ave NE. Follow Blakely Avenue
south 1~/i miles and turn left on Oddfellow Road. Go east 0.6
miles and turn right on Country Club Road. About 1 mile down
Country Club Road, where the road approaches the beach, park
and descend onto tide flats.
Note that access to the beach here, and farther west at Restora-
tion Point, requires crossing private property. Contact residents
or the Port Blakely company.

Stop 1. Blakely Harbor Formation, south side of
Blakely Harbor

The Blakely Harbor Formation comprises conglomer-
ate, volcanic sandstone and siltstone, mudstone, and local
peat. Abundant logs and crossbedding within conglomeratic
strata attest to the fluvial origin of the unit. Pebbles in the
conglomerate (see next stop) are mostly basalt, suggesting
local unroofing of the Crescent Formation during Blakely
Harbor time.

Fulmer (1975) suggested a Miocene age for the Blakely
Harbor on the basis of common coal and the lack of fossils,
and stratigraphic(l) position above the Blakeley Formation.
Brian Sherrod (personal commun., 2000) has confirmed the
Miocene age with a 13 Ma fission track age from tuffaceous
layer in the lowest exposed part of the unit.

The Blakely Harbor Formation is not known to crop out
beyond southeastern Bainbridge Island.

Interestingly, where we have trenched 3-4 meters into
Blakely Harbor siltstone and sandstone they are typically
clay-rich and plastic. To this depth, at least, volcanic rock fragments are perversively altered to clay. Elsewhere in the Puget Lowland, post-Vashon weathering profiles are 1-2 m thick. Either an unusually thick weathering zone, of possible pre-Vashon age, is preserved on southeastern Bainbridge Island, or the clayey alteration is diagenetic and likely to be present at great depth within Blakely Harbor strata.

Fulmer (1975) thought the Blakely Harbor Formation was conformable with the underlying Blakeley at this point. Waldron (1967) got it more right: there is a fault here. Two different lithologies are juxtaposed across a contact that is discordant to bedding in both units. It just happens that bedding on both sides of the fault has nearly the same orientation. If the tide is low enough, go prove this to yourself. While out on the tidelifts, admire the beds of petrified chipboard.

Retrace route on Country Club road to head of Blakely Harbor, turn right and then right again on 3-T road. We have permission to park on private property and walk down to the beach.

Stop 2. Blakely Harbor Km, north side of Blakely Harbor. Most natural outcrops of Blakely Harbor Formation are conglomerate. We are stopping here to see some of this conglomerate. The conglomerate produces a strong positive aero-magnetic anomaly (Blakely and others, 1999a). The Blakeley Formation, in contrast, produces a diffuse aero-magnetic low. The combination is distinctive and allowed Blakely and others (1999b) to trace the hanging wall of the Seattle fault many km to the east.

Going north along Rockaway Beach, around the point from here, the amount of outcrop decreases, with progressively greater spacing between ribs of conglomerate and coarse sandstone. Scratching in the low-tide beach reveals that the intervening areas are underlain by fine sandstone and siltstone. The unit fines upwards, at least in this area.

Return east, continue across head of T intersection with Country Club road, and follow Blakely Avenue to head of Eagle Harbor, where it turns right and becomes Wyatt Street.

Follow Wyatt east to intersection with Madison Avenue, turn right, go 1 block to Winslow Way, turn left, and go Vi mile to ferry landing. Take ferry to Seattle.

Crossing the Sound: Is there a big Eocene fault? Yesterday and this morning we saw most elements of a coherent stratigraphy that extends from lower to middle Eocene Crescent Formation, locally with coeval igneous basement, up to Miocene fluvial strata of the Blakely Harbor Formation. Intervening sedimentary strata are marine and largely have a basaltic (Crescent), mixed-metamorphic (Vancouver Island), or volcanic (Cascade Arc) provenance. Basaltic and mixed-metamorphic sandstones are Eocene; Cascade-arc-derived sandstones are latest Eocene to Oligocene and younger. This stratigraphy is typical of much of the Oregon and Washington Coast Ranges.

We are now traveling into another geologic province. Eocene strata of the Cascade foothills, eastern Washington, north-central Oregon, and most of British Columbia are characterized by continental sandstone of granitic-metamorphic provenance, commonly micaceous arkose. Associated volcanic rocks are felsic (rhyolite, dacite, locally andesite) or locally bimodal (rhyolite-basalt). Some of us know this as the Challis province. Challis-province rocks around Seattle are the Puget Group. The change from Coast Range to Challis provinces has been interpreted as reflecting a fault (the Puget Lowland fault of Johnson, 1984), or as fundamentally stratigraphic, as basaltic Crescent-Siletz volcanics are locally overlain by arkosic Challis strata in northwest Oregon and southwest Washington. Both interpretations have merit.

Comparing stratigraphies on east and west sides of the Puget Lowland is hindered by uncertainty about the ages of various units. The major problems are: (1) Radiometric ages of uncertain reliability and (or) low analytical precision. (2) Few age constraints of any kind in several units, due to unfavorable lithologies (for example, fluvial arkose; basaltic tuff-breccia). (3) Uncertainty about the nature and extent of middle and late Eocene—Narizian and Refugian—foraminiferal stages: McDougall (1980) considered the zones in these stages to be time-transgressive and facies-controlled in the Pacific NW (Nesbitt, 1998). (4) Dependence on floral ages of dubious validity, as discussed by Turner and others (1983).

Comparison of published correlation diagrams (Figure 4) illustrates the problems. Note the placements of the Refugian-Narizian boundary.

These problems are not unique to the Puget Group. Strata of the probably-correlative Chuckanut Formation, Barlow Pass Volcanics of Vance (1957), Naches Formation, and Chumstick Formation are equally poorly dated. Also, see the discussion above on radiometric ages from the Crescent Formation.

From Seattle ferry terminal turn right and head south on Alaskan Way, SR 519. This eventually turns into East Marginal Way/SR 99.

Continue on East Marginal Way past Boeing Field to intersection, some 8 miles from ferry terminal, with Pacific Highway South (right), and S Boeing Access Road (left). This intersection may not be well signed. Look for Checker Limos on far left side of intersection; maybe you will see their stretched Humvee! Turn left onto S Boeing Access Road and then turn right. Park on right shoulder before outcrop.

Stop 3. Tukwila Formation of the Puget Group. Walk east, up-section, to see volcanic conglomerate, volcanic breccia, and tuffaceous sandstone. What is the composition? Can you find way-up indicators? Is there any alteration? Internal deformation?

Here and to the east, the Puget Group comprises, in ascending order, the arkosic Tiger Mountain Formation, the volcanic Tukwila Formation, and the arkosic Renton Formation. To the southeast, in the Green River area, the Puget Group lacks significant volcanic rocks and has not been divided. All units are largely continental. Coal in the Puget Group has been economically important. A century
 ago Renton, Newcastle, and Issaquah were coal-mining towns. The Renton Formation has also supplied clay for brick making. More recently, volcanic rocks of the Tukwila have been a major source of rockery boulders.

Immediately south of here, a thin marine section at the lowest level of Tukwila exposure contains a rich assortment of shelly macrofossils. Liz Nesbitt (1998) has most recently studied this fauna, and finds that it is very similar to the late middle Eocene fauna of the Cowitz Formation of southwest Washington. Radiometric ages constrain the Cowitz fauna to be about 39 to 41.5 Ma old (Irving and others, 1996).

A Tukwila sample from Newcastle, east of Lake Washington, yielded a 41 Ma fission track age and a 42 Ma hornblende K-Ar age (Turner and others, 1983).

Continue ahead and north on Airport Way. At first stop light, just past Associated Grocers warehouse, turn left to wards King County Airport, make a U-turn, turn right on Airport Way, and return to S Boeing Access Road east-bound. Cross BNSF rail yard, cross 1-5, and turn right onto 1-5 north.

Go north to 6 miles to I-90 (exit 164B) and take I-90 east towards Bellevue and Spokane.

Drive 19 miles to Exit 22, Preston. At end of off-ramp, turn right and right again onto SE Preston Way and park on shoulder. Walk back to intersection and down east-bound on-ramp to

Stop 4. Raging River Formation, Preston

The Raging River Formation crops out for about 6 miles along the core of a northwest-trending anticline. We are at the northwest limit of outcrop. Johnson and O’Connor (1994) divided the exposed Raging River Formation into 3 members, based on sedimentary facies and lithologies. Unit 1 records a shallow-marine transgression, unit 2 is fluvial, and unit 3 records marine shelf to bathyal slope conditions. The base of the Raging River Formation is not exposed. Exposed strata may be about 1 km thick. The Raging River Formation is overlain by prodelta (?) marine-shelf and fluvial arkosic sandstone and mudstone of the lower Tiger Mountain Formation, the lowest unit of the Puget Group (Johnson and O’Connor, 1994; Vine, 1969).

The isolated northern outcrops of unit 2 along Interstate Highway 90 are intruded by a sill (T. Walsh, Washington Department of Geology and Earth Resources, written commun., 1993) and dikes and are relatively indurated. These strata consist of gray pebble conglomerate and interbedded sandstone. Conglomerate beds are as thick as a few meters and are bounded by low-angle (<10°) erosional surfaces. Beds are internally structureless or crudely stratified and uncommonly graded. Conglomerate clasts are subrounded to rounded, poorly to moderately sorted, generally dispersed in a granular matrix, and uncommonly imbricate. The mean size of the largest clasts in a bed is typically about 12 cm. Several large blocks of conglomerate were collected and slabbed for pebble counting. A count of 1,180 clasts (fig. 10) indicates that lithic sandstone, chert, and aphanitic green or black volcanic rocks are the most common clast types.

Unit 2 strata are interpreted as mainly alluvial deposits. ... (Johnson and O’Connor, 1994, p. A8) Clasts in the Raging River Formation are dominantly lithic, in contrast to the arkosic debris and intrabasinal volcanic rocks of the overlying Puget Group. Johnson and O’Connor (1994) suggest the primary source for the Raging River Formation was probably subjacent Mesozoic melange of the eastern and western melange belts of Tabor and others (1993).

Benthic foraminifera from the upper part of the Raging River—Johnson and O’Connor’s unit 3—indicate a lower Narizian age (W.W. Rau, written commun., 1991, cited in Johnson and O’Connor, 1994).

Turn around and return to I-90, heading west back towards Seattle.

Outcrop north of I-90 one mile west of Preston is mafic volcanic breccia and amygdaloidal basalt of the Tukwila Formation.

Exit at West Lake Sammamish Parkway/Lakemont Boulevard (Exit 13). Turn left and go about 1 miles up Lakemont Boulevard.

At 171th Ave SE (first traffic light), turn left into Lakemont Village mall. Park towards rear and walk 700 m (about 10 minutes) to next stop. Cross footbridge over creek, turn left and walk around retention-detention ponds. Stay left of baseball field, outside fence. Take trail left and down towards Louis Creek. Trail reaches creek, follows creek for 120 m, and then crosses creek. At creek crossing.

Stop 5. Renton Formation. Booth and Minard (1992, with most bedrock data from Walsh, 1984) and Yount and Gower (1991), show this locale as underlain by Oligocene Blakeley Formation. Composition (quartzofeldspathic), bedforms indicative of fluvial deposition (crossbeds, scour at base of coarse layers), and locally abundant coal indicate that this is the Renton Formation. Look for leaf fossils, way-up indicators, detrital muscovite. There is room for improvement in existing geologic maps!

Suppose you were mapping this area at 1:24,000 or larger scale. How would you know where you are?

Return to cars. Exit shopping mall, turn left on Lakemont Boulevard and descend to stop light at SE Newport Way. At light, turn right and park on shoulder. Walk back to intersection, cross at crosswalk, and walk left some 30 m, beside and below Lakemont Boulevard.

Stop 6. Blakeley-equivalent strata. This outcrop is mostly featureless, low-density, volcanic sandstone. Get out your hand lens and look for pumice fragments. Near the south end of the outcrops, you may find a clam mold and fragments of petrified wood. The absence of visible bedding may reflect extensive bioturbation. We trust that you will agree that the rocks at the last stop are not the same unit as this.

One-half mile farther west along SE Newport Way are additional outcrops of Blakeley-equivalent strata, which...
many of us have visited with various geology classes. There is passable parking on the north (westbound) shoulder. Bedding and fossils are common.

Back at cars, make U-turn and head west on Newport Way. At Lakemont Boulevard intersection, turn right (north) and pass under I-90. Continue north along West Lake Sammamish Parkway 1.2 miles.

At SE 38th1 Street, turn left and park in Vasa Park Ballroom lot. Note that this parking lot is private. We are here with permission. The outcrops we are here to see are also on private property, which we have obtained permission to visit. We promised the residents that we would neither excavate nor collect. Please leave hammers and digging implements in the vans! If you absolutely must have samples, look for outcrops in the public right-of-way along West Lake Sammamish Parkway.

Stop 7. Miocene strata near Vasa Park. As noted by Yount and Gower (1991), the light-colored, tuffaceous, silty, sandy, and rarely conglomeratic strata here are unlike the basaltic, conglomeratic Blakely Harbor Formation. They are more like the Hammer Bluff Formation of south King County (Glover, 1941; Mallineaux, 1970) and the Ellensburg Formation of the east slope of the Cascades.

Yount and Gower (1991) reported two K-Ar ages from a single sample of air-fall tuff from this outcrop. Relevant data are reproduced here:

<table>
<thead>
<tr>
<th>Material analyzed</th>
<th>%K,0</th>
<th>% radiogenic Ar</th>
<th>Age ± 2 a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green hornblende</td>
<td>0.251</td>
<td>29.3</td>
<td>14.7 ±1.8</td>
</tr>
<tr>
<td>Brown hornblende</td>
<td>0.234</td>
<td>8.0</td>
<td>9.3 ±0.9</td>
</tr>
</tbody>
</table>

The significant conclusion that can be drawn from these data is that the analyses don’t tell us much about how old this deposit is. Hornblende should have about 1% K2O: 0.2 - 0.3% K2O suggests significant actinolite (or chlorite). The radiogenic yields are too low: either the samples were impure or the argon extraction line was leaking too much. Confllicting ages from the same sample weaken the proposition that either age is geologically valid. Nonetheless, given the position stratigraphically (?) above Oligocene rocks, poor lithification, and similarity to Miocene deposits elsewhere, a Miocene age seems reasonable.

From here, drive south on W Lake Sammamish Parkway to I-90. Go west on I-90 to 1-405 or I-5 and head south to the Kent-Des Moines Park & Ride lot.

IV. REFERENCES CITED


Irving, A.J., Nesbitt, E.A., Renne, P.R., 1996, Age constraints on earliest Cascade arc volcanism and Eocene marine biozones from a feldspar-rich tuff in the Cowlitz Formation, southwestern Washington [abstract]: Eos (American Geophysical Union Transactions), v. 88, no. 46,
supplement, p. F-814.


