Northwest Geological Society

Society Field Trips in Pacific Northwest Geology

Seattle Geology: Historic Impacts and Recent Research

June 8, 2002

William T. Laprade
Derek B. Booth
Brian L. Sherrod

Note: Some full-page images in this guide have been reduced slightly to fit on the page

This guide also includes a (partial) narrative of the field trip, taped and transcribed by John Whitmer

Seattle Geology:
Historic Impacts and Recent Research

by

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Northwest Geological Society Field Trip, June 8, 2002

Northwest Geological Society
Seattle, Washington
2002

Northwest Geological Society Field Trip
Saturday June 8, 2002
Field Trip Itinerary and Guidebook Contents

8:00 Leave Bellevue (promptly)

STOP 1 **Duwamish Head** - general geology overview, Seattle Fault introduction,
Denny Regrade, Seattle skyline, Perkins Lane
Figure: Generalized subsurface profile A-A'

STOP 2 **California Way Landslides** - landslide genesis and remediation, upper Vashon stratigraphy
Figure: Landslides by decade in the Duwamish Head area
Photo: California Avenue SW slide repair, 1998
Figure: Typical section geogrid reinforced slope

STOP 3 **Alki Treatment Plant** - Blakely Formation, Bainbridge Is. and Alki terraces
"Along the Seattle fault: Seattle to Bainbridge Island," by Brian L. Sherrod
Figure: Geology of West Seattle (from Seattle Geologic Mapping Project)

STOP 4 **Mee Kwa Mook**s - Swirled beds
Photo: Olympia beds syncline at Mee Kwa Mooks Park
Figure: Folded, interbedded silt and peat in West Seattle

STOP 5 **Duwamish River West Bank** - uplifted terrace and shell beds
[Figures illustrating uplifted terraces and shell beds]

LUNCH at Duwamish River Park

STOP 6 **East Queen Anne** - ST tunnel, till-like deposits, Ship Canal, I-5 construction
Figure: Generalized geology of north Capitol Hill and Portage Bay areas

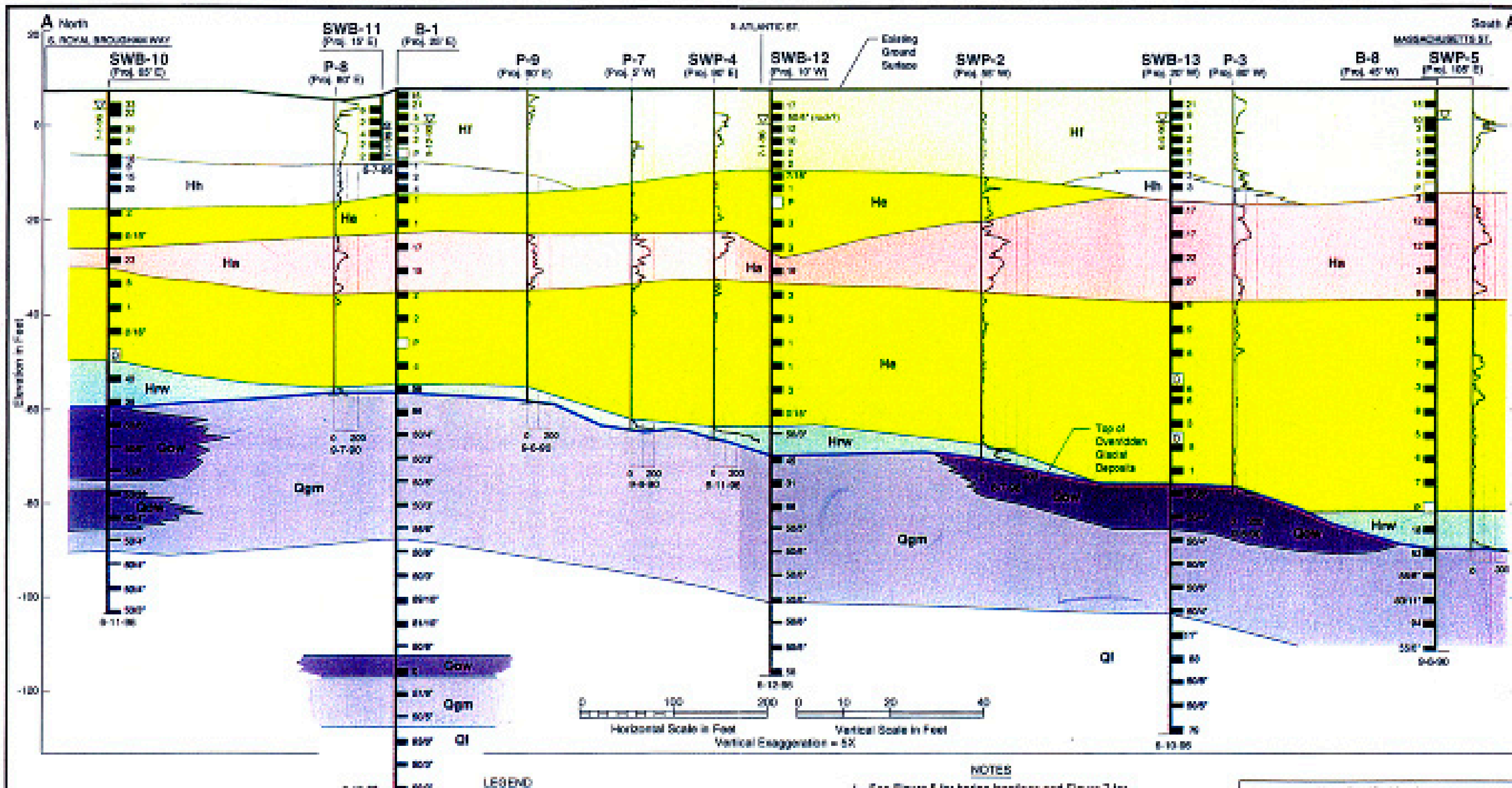
STOP 7 **Discovery Park** North Beach - till exposure, deep-seated landslide
Figure: Geology of West Magnolia (from Seattle Geologic Mapping Project)
Figure: Discovery park-South Beach and North Beach
Figure: West Point hillside stabilization
Figure: North Beach West Point treatment plant hillside retaining wall

STOP 8 **Discovery Park South Beach** - glacial and nonglacial stratigraphy, landslides
Photo: View of the South Beach bluffs, Fort Lawton, Seattle

STOP 9 **Perkins Lane Landslide** - 1996/97 landsliding
Figures: Ground and liner behavior--Mt. Baker Ridge

STOP 10 **Vasa Park** - Seattle Fault, trenching
[Figures illustrating the Seattle fault] .
6:00 Arrive at Park n Ride/McHale's Restaurant

Addendum: Field Trip Narrative



LEGEND

- B-1 — Previous Boring Location and Designation
- SWB-1 — Current Boring Location and Designation
- (Proj. 6' H.) — Offset Distance
- P — Pushed Shelby Tube Sample
- Osterberg Sample
- Split Spoon Sample
- Standard Penetration Resistance in Blows/Foot or Blows/Inches Driven
- Groundwater Level and Date Recorded
- ? — Approximate Geologic Contact
- Bottom of Boring
- 6-12-96 — Date Completed

- P-8 — Previous Cone Penetrometer Test Location and Designation
- SWP-1 — Current Cone Penetrometer Test Location and Designation
- (Proj. 80' N.) — Offset Distance
- Plot of Cone Tip Resistance (tsf) vs. Depth (See Scale at Bottom of Probe)
- Bottom of Probe
- 6-12-96 — Date Completed

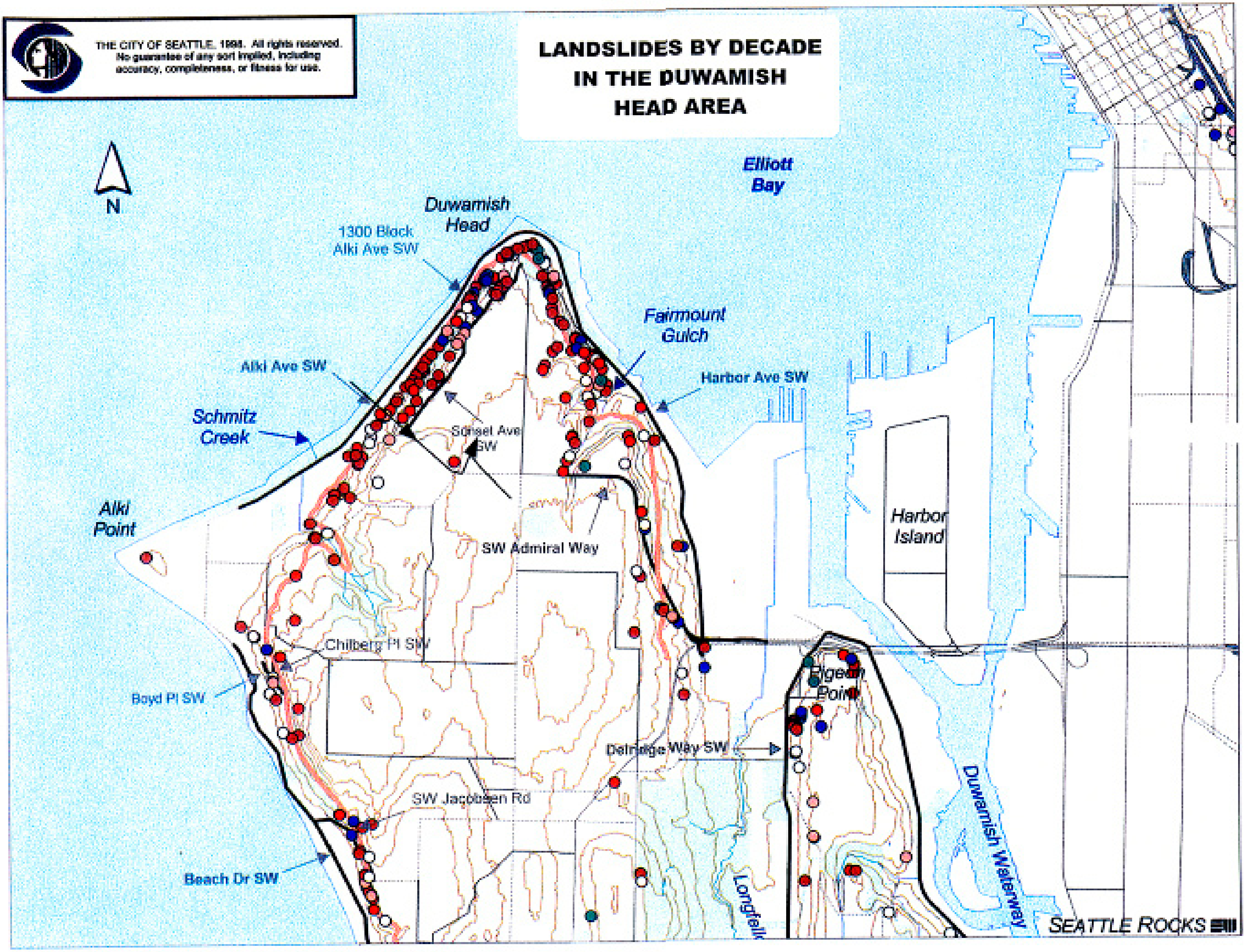
NOTES

1. See Figure 5 for boring locations and Figure 7 for geologic explanation.
2. Elevation Datum: City of Seattle
3. This profile is generalized from materials encountered in the borings and probes. Variations between the profile and the actual conditions may exist.
4. For clarity, the exploration logs shown on the profile have been abbreviated and simplified. For detailed logs, see Appendices A and D.

New Pacific Northwest Baseball Park
Seattle, Washington

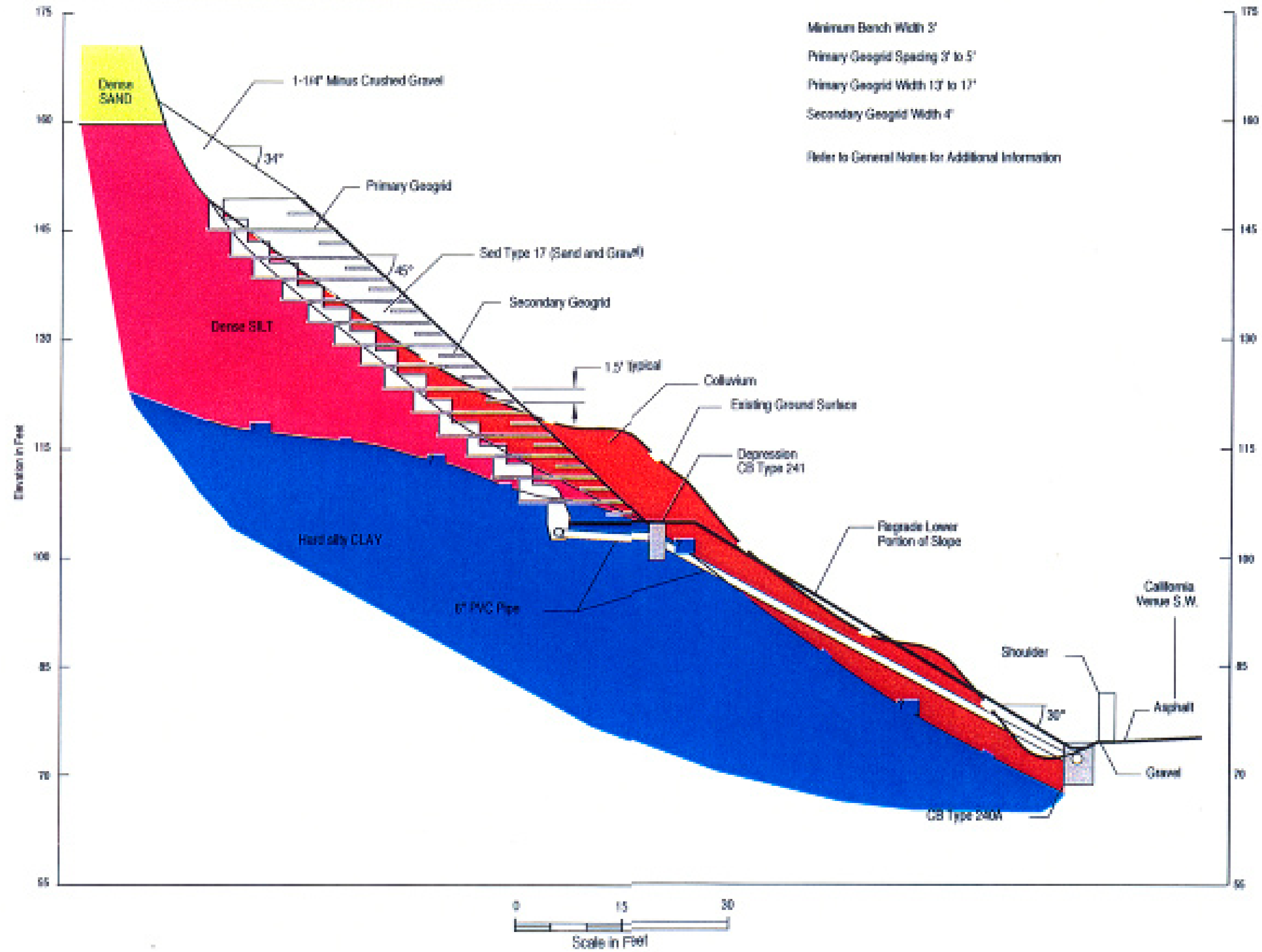
GENERALIZED SUBSURFACE PROFILE A-A'

SEATTLE ROCKS



THE CITY OF SEATTLE, 1998. All rights reserved. No guarantee of any sort implied, including accuracy, completeness, or fitness for use.
LANDSLIDES BY DECADE IN THE DUWAMISH HEAD AREA
N
Elliott Bay
Duwamish Head
1300 Block Alki Ave SW
Fairmount Gulch
Harbor Ave SW
Alki Ave SW
Schmitz Creek
Sunset Ave SW
Alki Point
SW Admiral Way
Harbor Island
Chilberg Pl SW
Boyd Pl SW
Pigeon Point
Delridge Way SW
SW Jacobsen Rd
Duwamish Waterway
Beach Dr SW
SEATTLE ROCKS


California Avenue SW slide repair, 1998



TYPICAL SECTION GEOGRID REINFORCED SLOPE

SEATTLE ROCKS

Along the Seattle Fault: Seattle to Bainbridge Island

During this excursion, you will see geologic evidence for a prehistoric earthquake on the Seattle fault. Geologists concluded that the Seattle area was struck by a large earthquake about 1000 years ago, based on diverse lines of evidence that were reported in a series of articles in Science (1992, v. 258, p. 1611-1623). The evidence, all dating to about 1000 years ago, includes sudden uplift and subsidence adjacent to a major reverse fault near Seattle (the Seattle fault), tsunami-laid sand on two historical tidal marshes in central and northern Puget Sound, several landslides that slid into Lake Washington in the same season of the same year as the tsunami in Puget Sound, a layer of graded sediment (turbidite) in Lake Washington, and a series of rock avalanche-dammed lakes in the eastern Olympic Mountains. Today, you will see sites where geologists collected evidence for sudden uplift and subsidence that accompanied this large earthquake 1000 years ago (Fig. 1).

The evidence for earthquake-induced uplift about 1000 years ago in central Puget Sound consists of geomorphic and stratigraphic features that record sudden changes in the relative elevation of sites along the coast. The most dramatic and conspicuous of these features is a raised wave-cut platform at Restoration Point on Bainbridge Island, 5 km west of Seattle (Fig. 2). Geologists proposed that uplift of this platform was the result of seismic slip on the Seattle fault, which extends westward across Puget Sound from Seattle. The northernmost fault strand crosses Puget Sound roughly along the same path as the Seattle-Bainbridgle Island ferry.

We will visit sites at Duwamish Head, Alki Point, and the Duwamish Waterway south of the West Seattle Freeway. At each site, we will see evidence for a large earthquake on the Seattle fault zone about 1100 years ago..

The low-lying bedrock peninsula of Restoration Point (Figs. 1 and 2) juts eastward into the Sound from the west, mirroring Alki Point to the east. This bedrock peninsula was uplifted about 7 meters during an earthquake on the Seattle fault about 1000 years ago. The peninsula may owe its existence to bedrock that is more resistant to erosion than the unconsolidated Quaternary deposits that flank most of Puget Sound. Restoration Point appeared anomalous to Captain George Vancouver, who named the peninsula in 1792. Vancouver commented "...we arrived off a projecting point of land, not formed by a low sandy spit, but rising abruptly in a low cliff about ten or twelve feet from the water side. Its surface was a beautiful meadow covered with luxuriant herbage..." (Lamb, 1984, A voyage of discovery to the North Pacific Ocean and round the world [journals of George Vancouver]: London, the Hakluyt Society, 4 vols., 1752 p.).

To the north of Restoration Point on Bainbridge Island at Winslow, peat below the surface of a small marsh preserves evidence of subsidence about 1000 years ago. This contrast with the uplift at nearby Restoration Point is a key to inferring the source of the earthquake about 1000 years ago. We

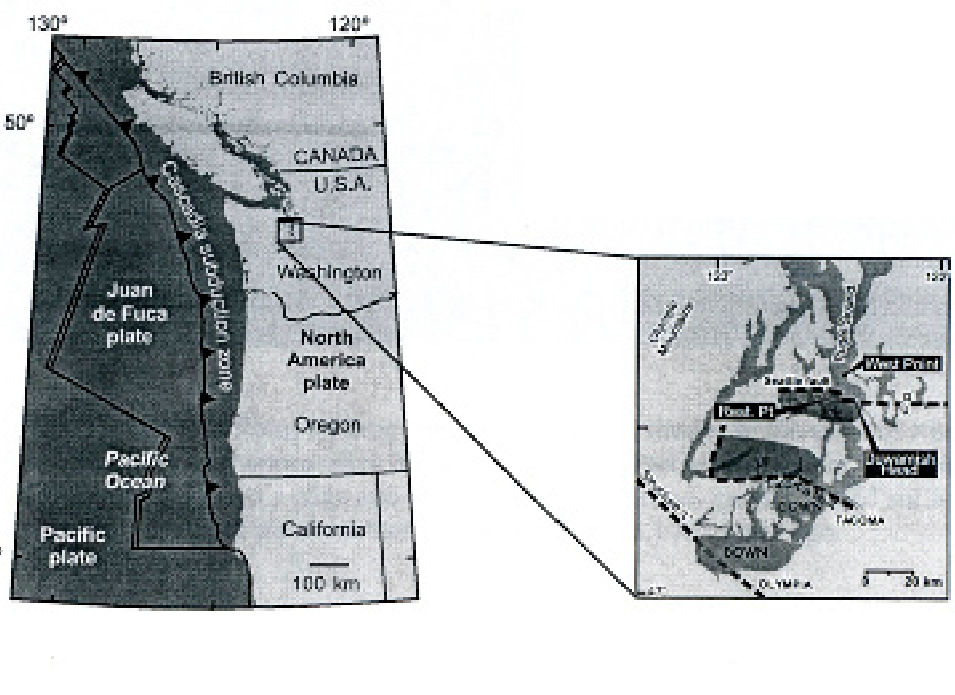


FIGURE 1. Index map of western Washington. Surface trace of subduction zone thrust shown by sawtooth line, sawteeth on upper plate; spreading centers shown by double lines with arrows; transform faults at ends of spreading centers shown by solid lines (opposed arrows show sense of offset). Locations of sites mentioned in field trip guide are shown in the inset map below.

will not visit Winslow marsh, but we discuss its importance in earthquake studies below.

Winslow Marsh-Stratigraphic Evidence of Subsidence

Winslow marsh is a small (about 1 hectare) brackish coastal marsh slightly above high tide in the sheltered cove of Eagle Harbor. A low sand and gravel beach berm borders the harbor side of the marsh. The berm ponds a small freshwater stream that flows through the marsh, forming several shallow pools of slightly brackish water that percolate through the berm. In summer and fall the surface of the marsh is commonly free of standing water, but in winter and spring several centimeters of water may stand on the surface. About 2 meters of peat and organic-rich aquatic sediments lie below the marsh surface, and record a rise in relative sea level during the past 2,000 years. Seeds, pollen, and diatoms in a clay sediment at the base of the marsh indicate that the site was a freshwater bog or swamp about 1900 years ago; similar assemblages of fossils in the overlying organic sediment indicate a stable environment of fresh to possibly slightly brackish water until about 1000 years ago. Scarce diatoms and foraminifera with brackish to marine salinity preferences in the gyttja were probably washed or blown to the site.

The marine fossils suggest that the site was only slightly above the highest tides. Peat that overlies the gyttja is dominated by fossil assemblages characteristic of brackish and saltwater tidal marshes. Within the peat, radiocarbon dated leaf bases ofTriglochin maritima, a common plant of brackish and saltwater tidal marshes in Washington, show that tidal marine water inundated the site more frequently by 700 to 900 years ago. These findings show that the elevation of this site either stayed the same or subsided slightly 1000 years.

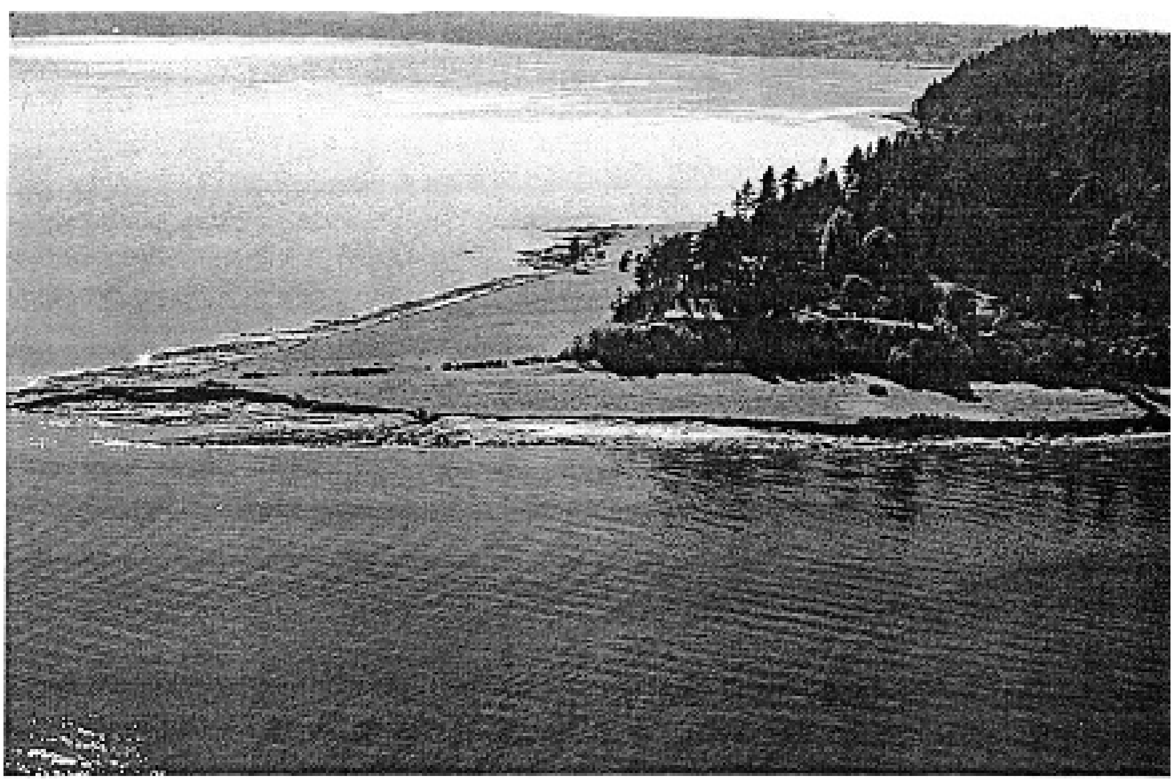
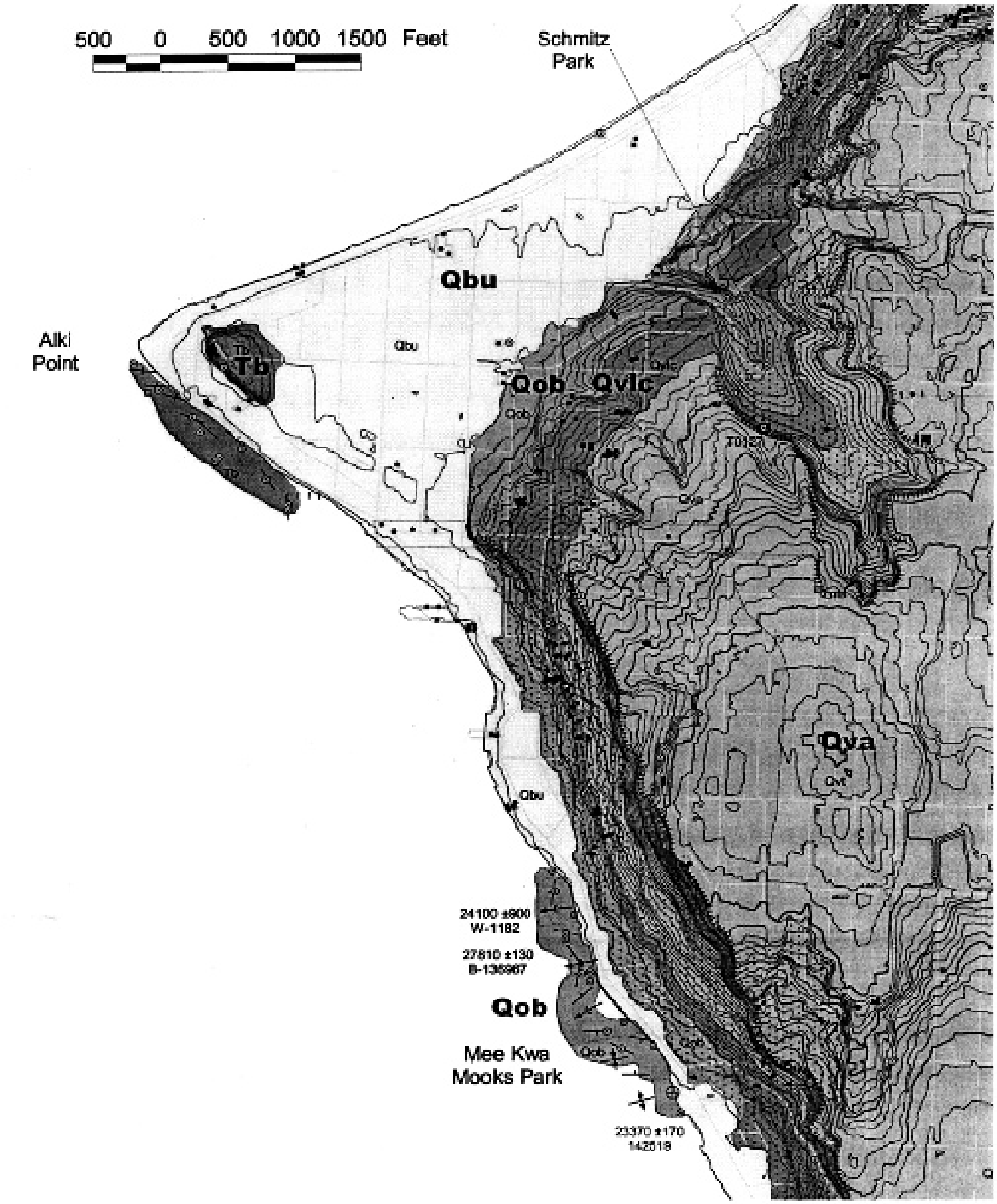
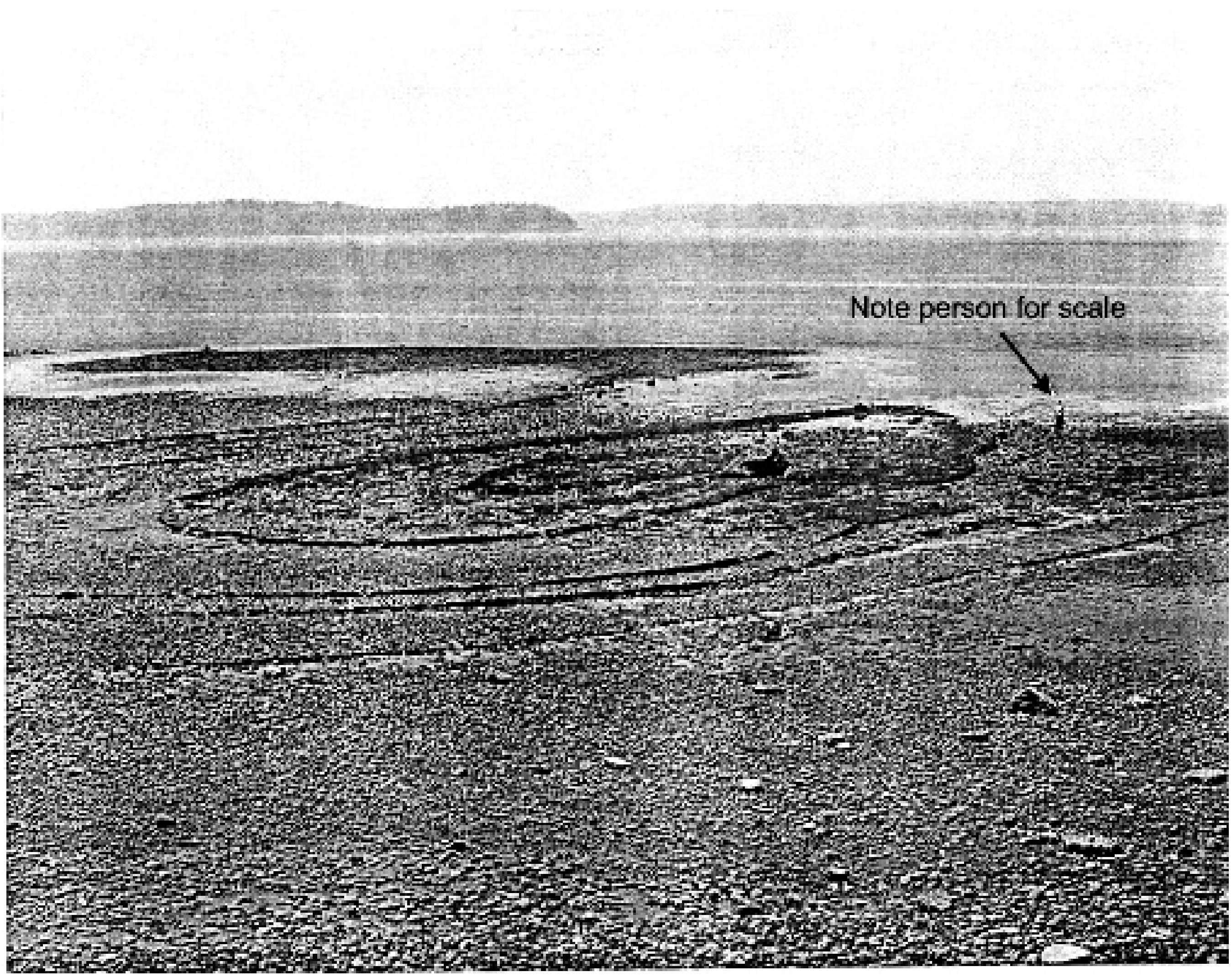
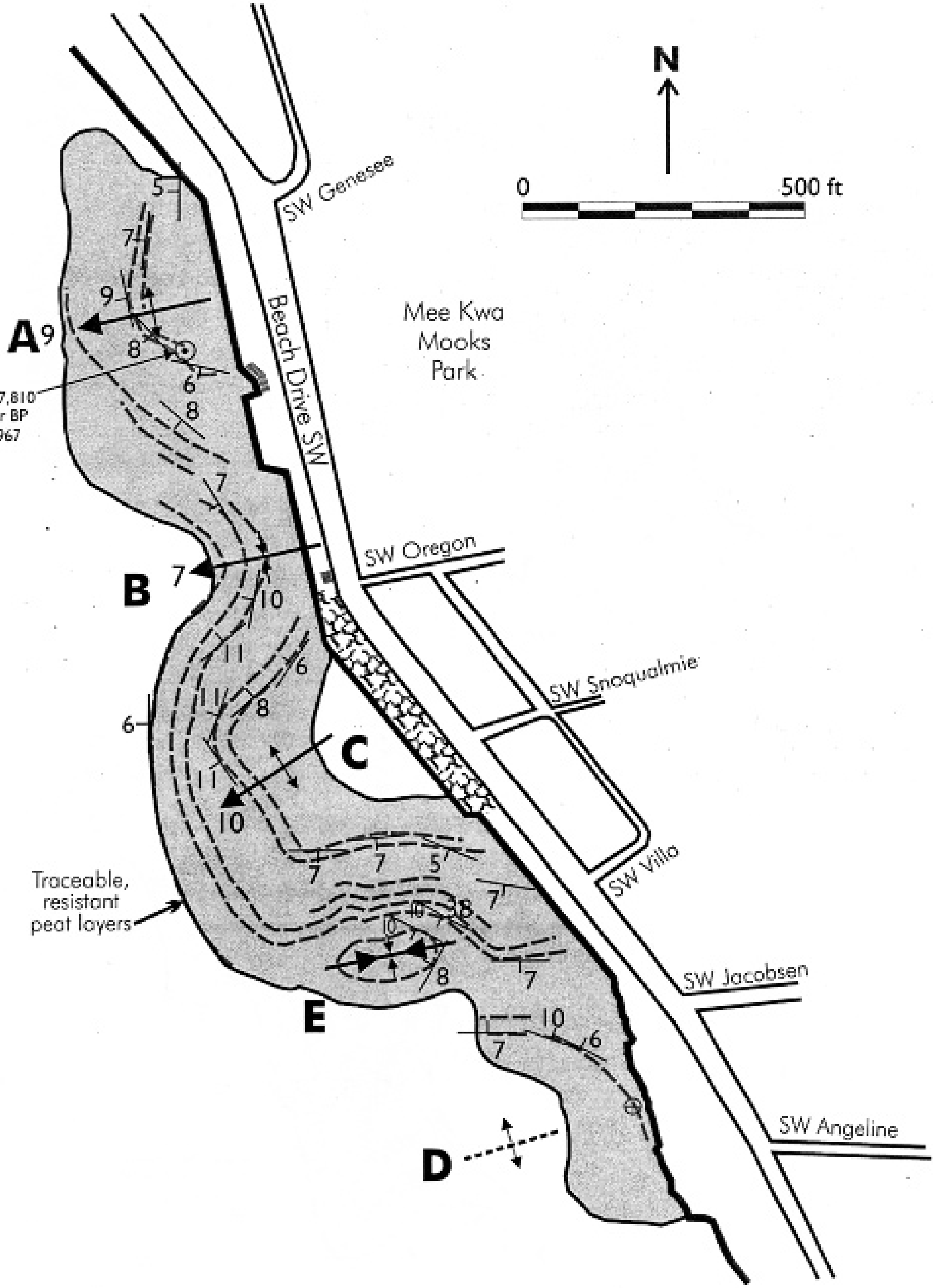


FIGURE 2. Restoration Point looking south. This view is similar to the view of Restoration Point from the ferry as it approaches Bainbridge Island. Part of the present intertidal platform is exposed between the water's edge and the low cliff. The broad, grass-covered surface above the cliff is a similar intertidal platform that was uplifted about 1000 years ago.

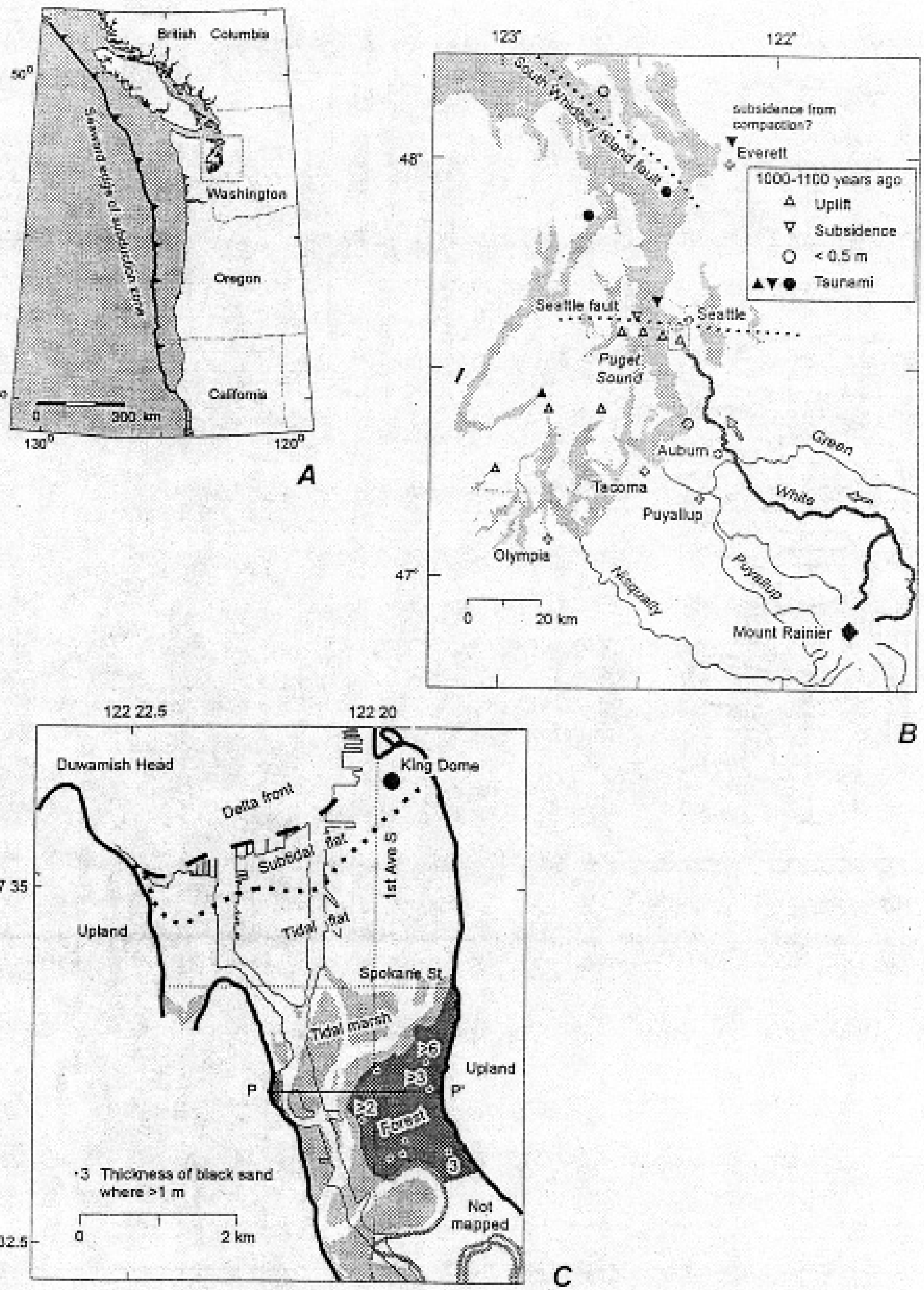


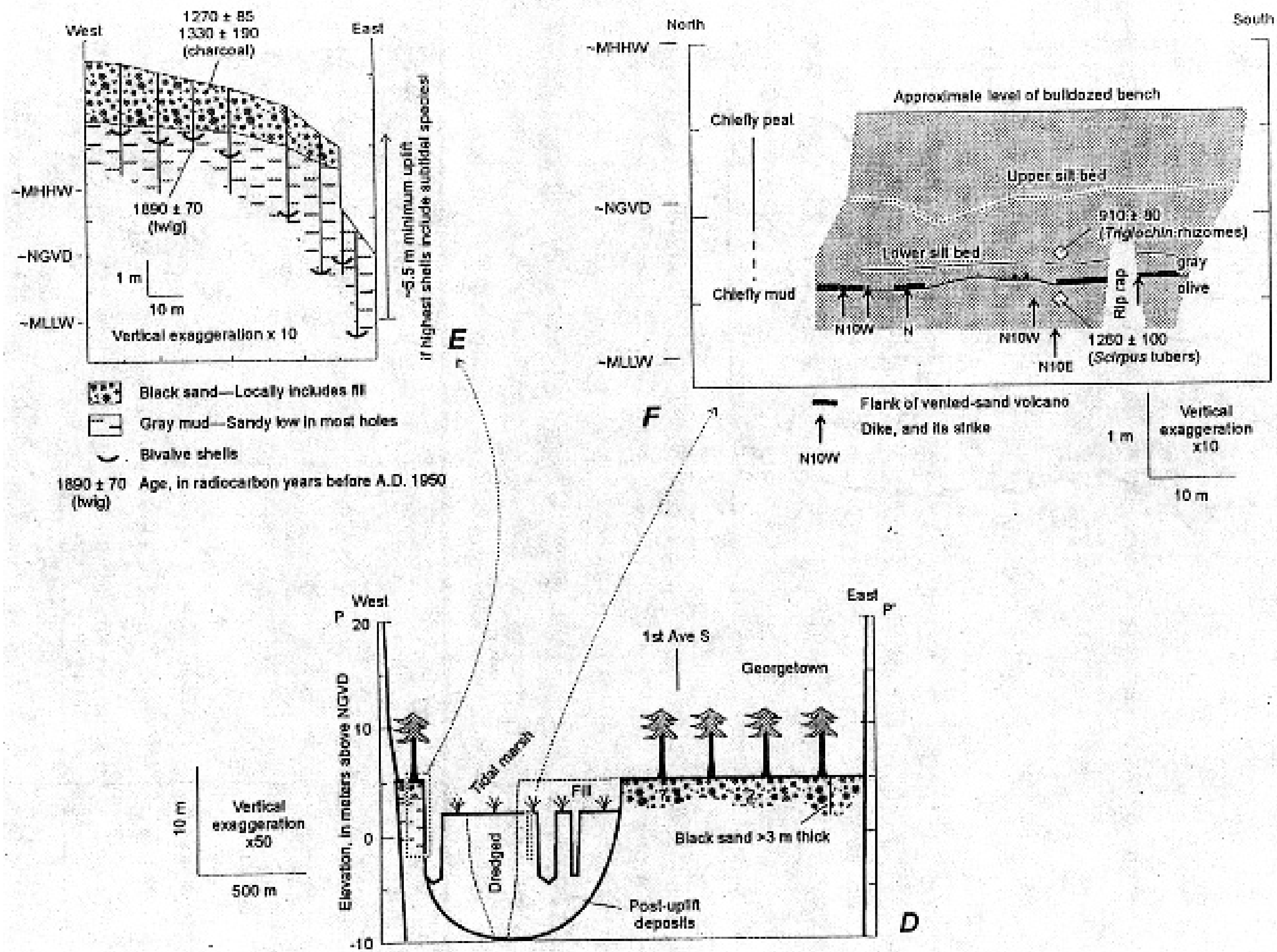
Geology of West Seattle (from Seattle Geologic Mapping Project)


Note person for scale



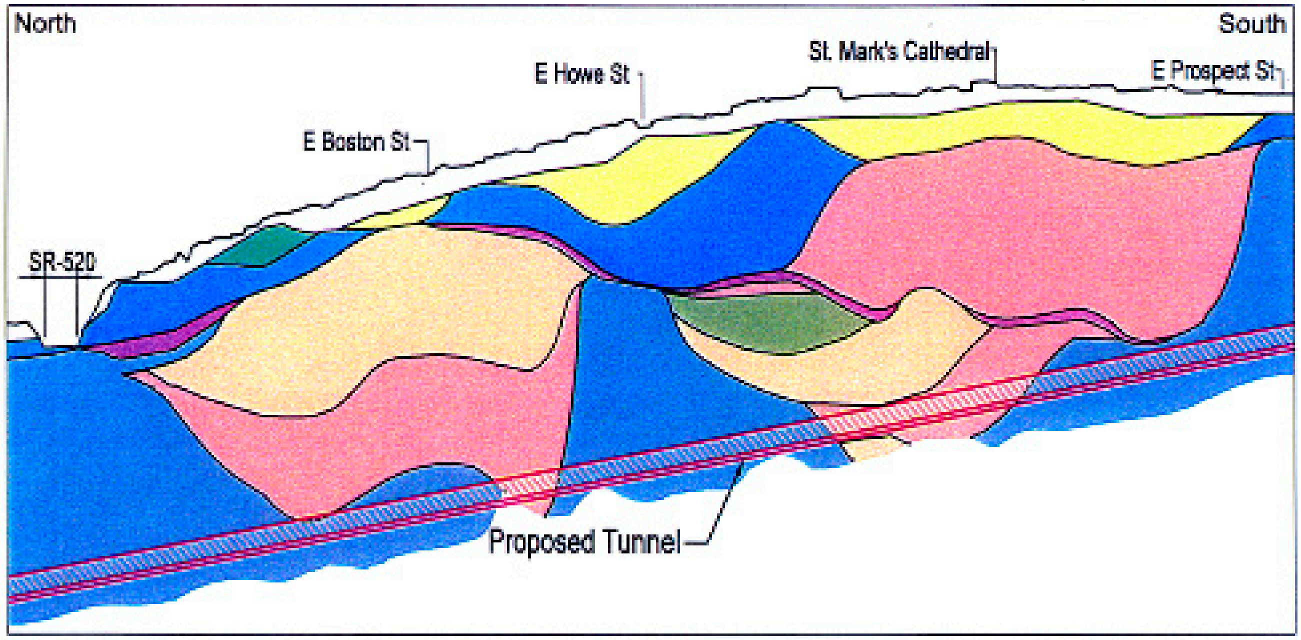
FOLDED, INTERBEDDED SILT AND PEAT IN WEST SEATTLE


British Columbia
50°
Seaward edge of subduction zone
Washington
Oregon
California
40°
0 300 km
130°
120°
A
123°
122°
South Whidbey Island fault
subsidence from compaction?
Everett
48°
1000-1100 years ago
Uplift
Subsidence
< 0.5 m
Tsunami
Seattle fault
Seattle
Puget Sound
Auburn
Green
White
Tacoma
Puyallup
Olympia
Nisqually
Puyallup
47°
0 20 km
Mount Rainier
B
122 22.5
122 20
Duwamish Head
King Dome
Delta front
Subtidal flat
47 35
1st Ave S
Upland
Tidal flat
Spokane St
Tidal marsh
>6
>3
>2
Upland
P
P'
Forest
3
·3 Thickness of black sand where >1 m
Not mapped
47 32.5
0 2 km
C

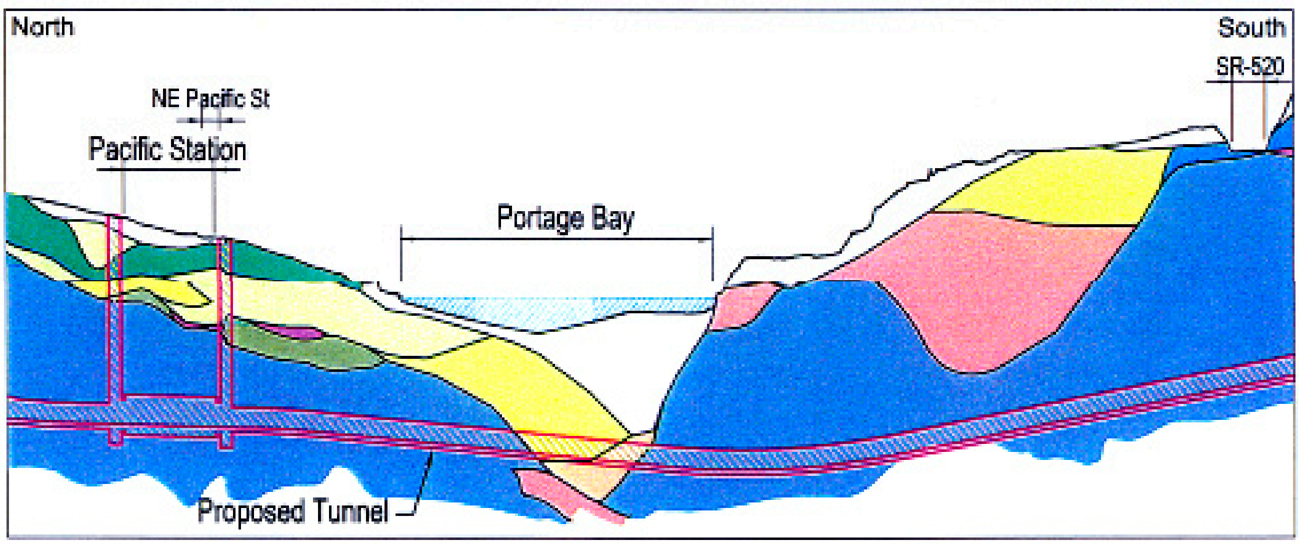


West
East
1270 ± 85
1330 ± 190
(charcoal)
~MHHW
~NGVD
~MLLW
1890 ± 70
(twig)
1 m
10 m
Vertical exaggeration x 10
~5.5 m minimum uplift
if highest shells include subtidal species
Black sand—Locally includes fill
Gray mud—Sandy low in most holes
Bivalve shells
1890 ± 70
(twig)
Age, in radiocarbon years before A.D. 1950
E
North
South
Approximate level of bulldozed bench
Chiefly peat
Chiefly mud
Upper silt bed
Lower silt bed
910 ± 80
(Triglochin rhizomes)
gray
olive
Rip rap
N10W
N
N10E
1260 ± 100
(Scirpus tubers)
F
Flank of vented-sand volcano
Dike, and its strike
N10W
1 m
Vertical
exaggeration
x10
10 m
P
West
P'
East
Elevation, in meters above NGVD
20
10
0
-10
1st Ave S
Georgetown
Tidal marsh
Fill
Dredged
Black sand >3 m thick
Post-uplift
deposits
10 m
Vertical
exaggeration
x50
500 m
D

North Capitol Hill Area



Portage Bay Area



Legend

nonglacially consolidated sediments
- Holocene and Vashon recessional sediments

glacially consolidated Vashon sediments
- Vashon till
- Vashon till-like deposits
- Vashon glacial outwash sand and gravel
- Vashon glaciolacustrine silt and clay

Pre-Vashon sediments
- Nonglacial silt and sand
- Paleosol
- Glacial till and till-like deposits
- Glacial outwash sand and gravel
- Glaciolacustrine silt and clay

0 800 1600
Scale in Feet

Generalized Geology of North Capitol Hill and Portage Bay Areas SEATTLE ROCKS

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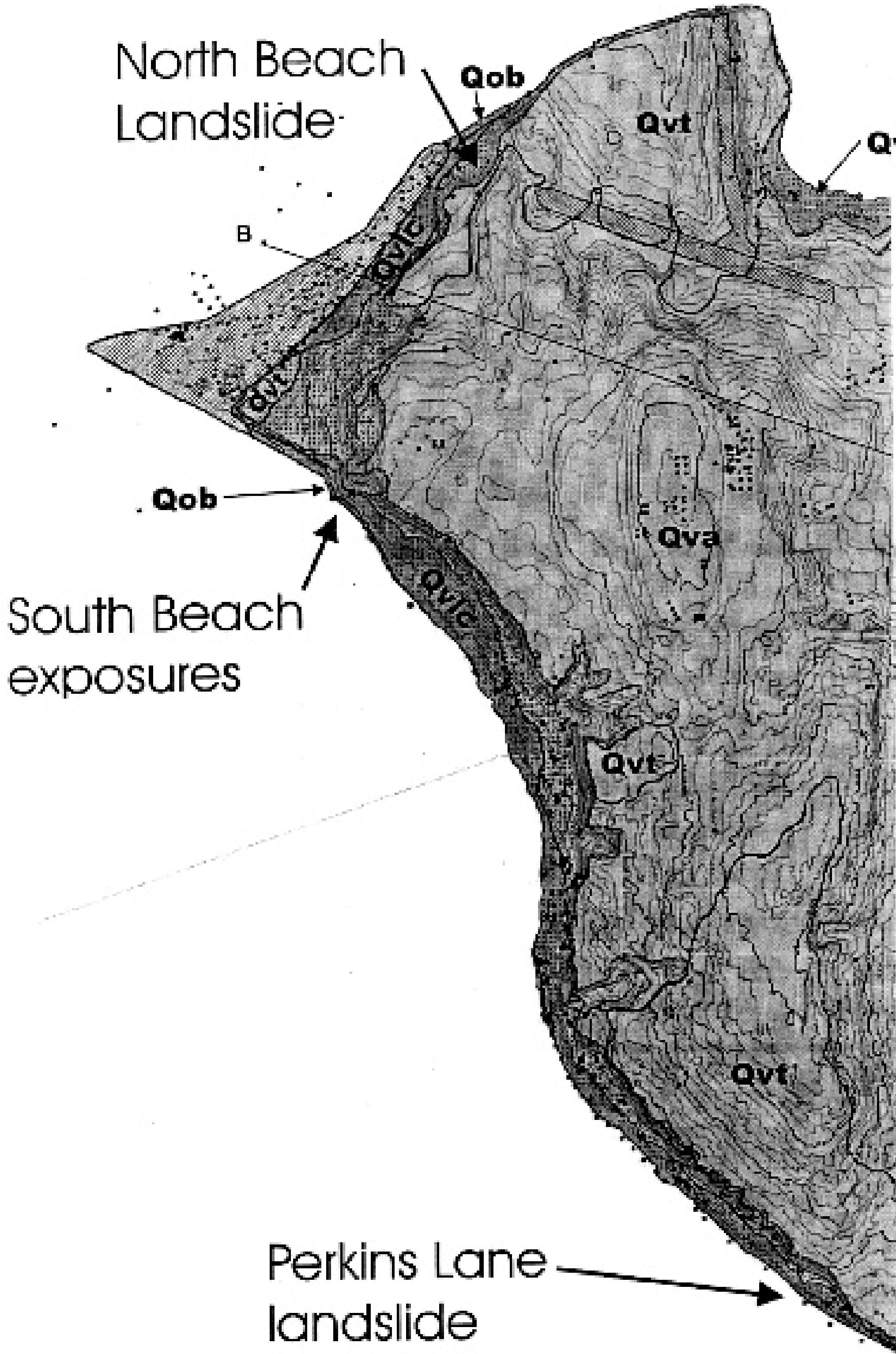
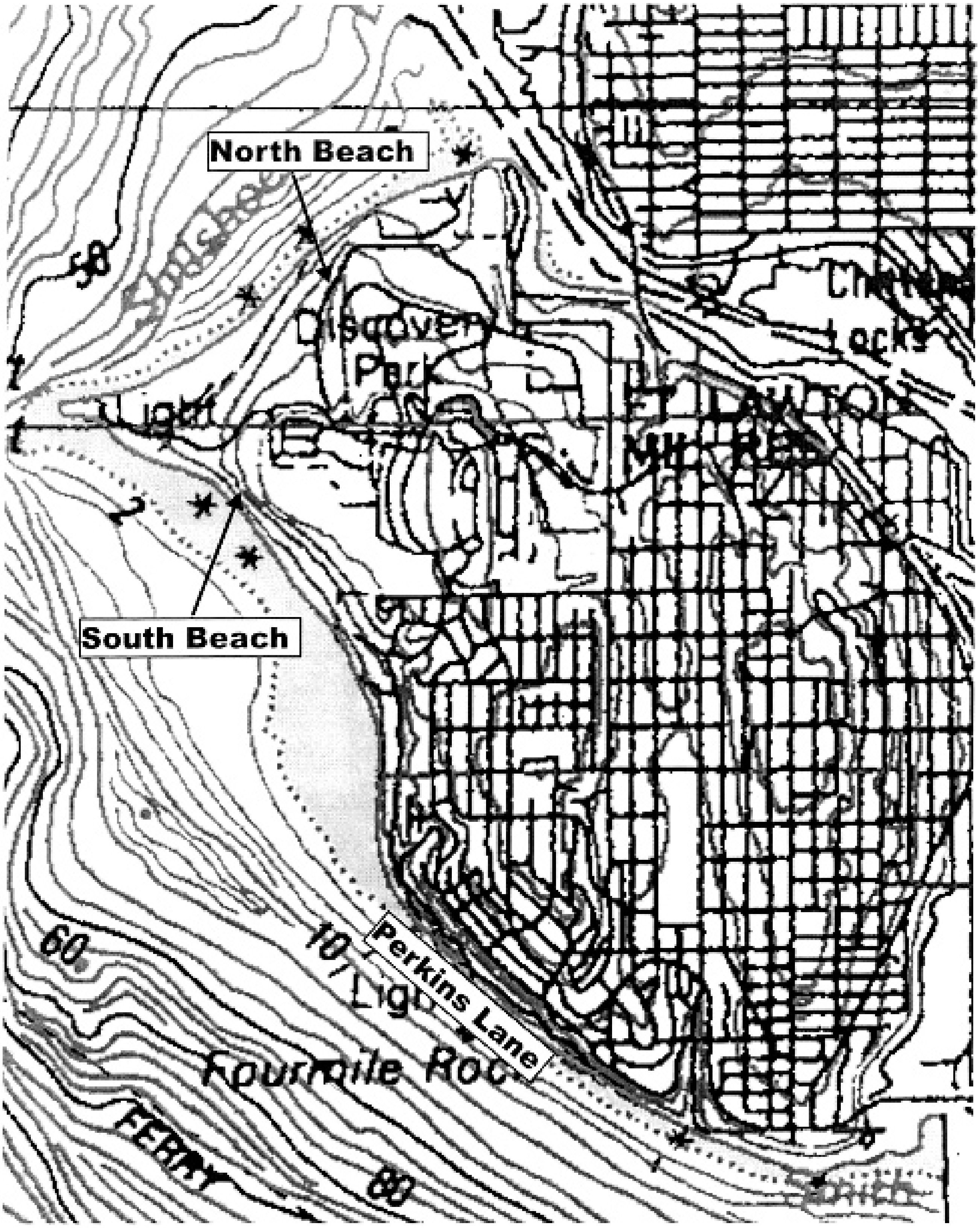


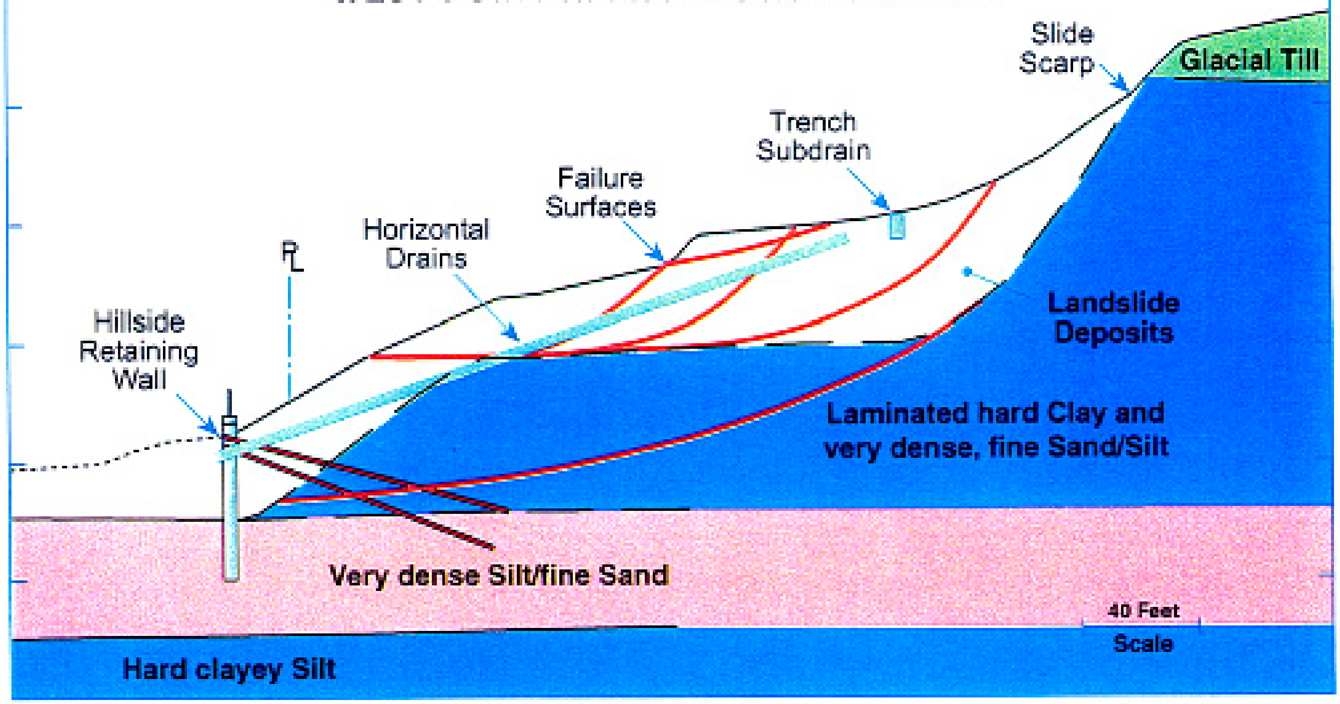
Geology of West Magnolia (from Seattle Geologic Mapping Project)

Discovery Park--South Beach and North Beach



From USGS Seattle North 7.5- by 15-minute topographic map

WEST POINT HILLSIDE STABILIZATION



NORTH BEACH WEST POINT TREATMENT PLANT HILLSIDE RETAINING WALL

Looking NE Along 45-Ft.-High Wall

From top to bottom:

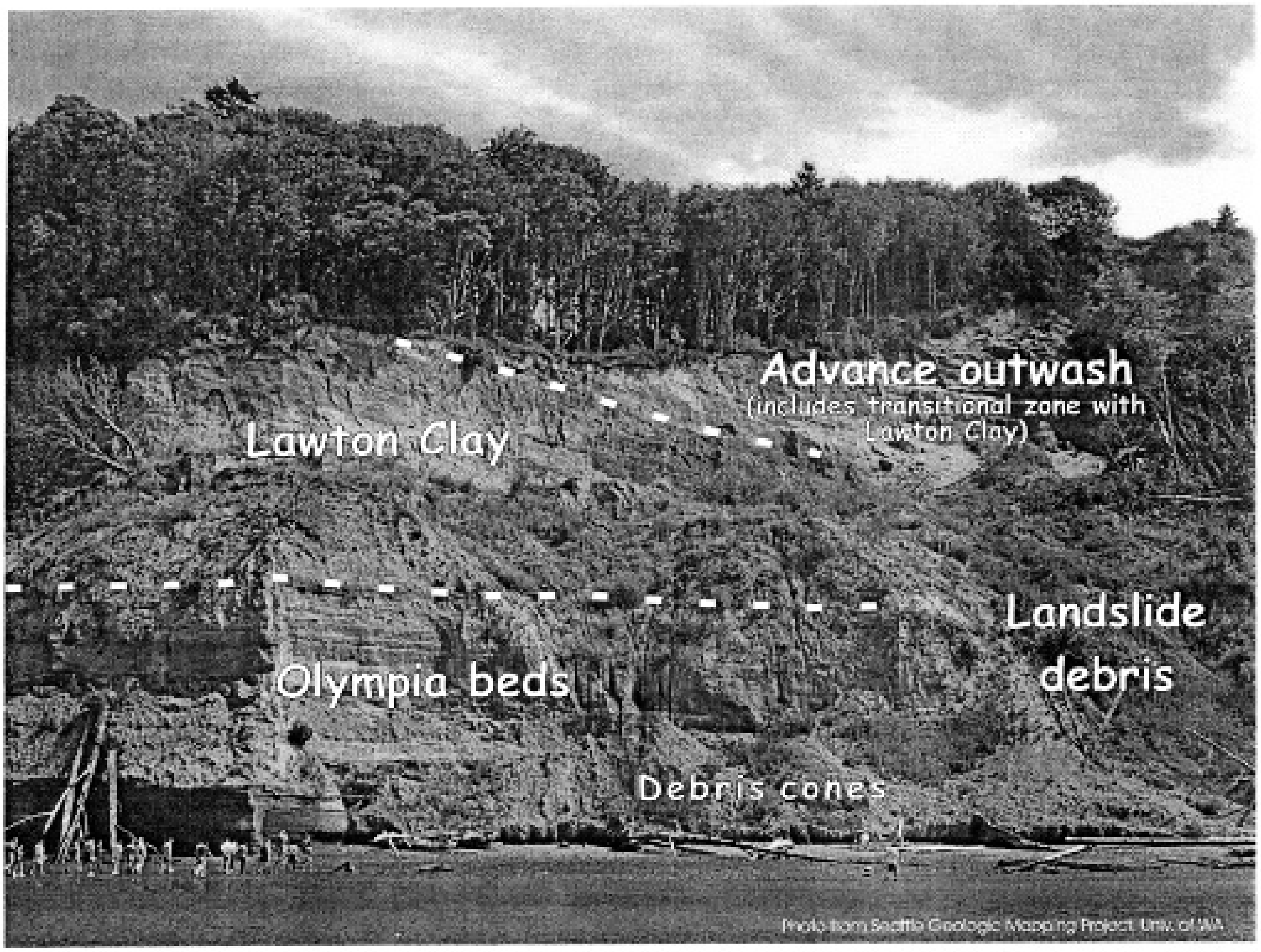
7-Ft. Catchment Wall to Retain Surface Slides

Cap Beam

Permanent Anchors

8-inch-thick Shotcrete with Metal Decking

SEATTLE ROCKS



View of the South Beach Bluffs, Fort Lawton, Seattle

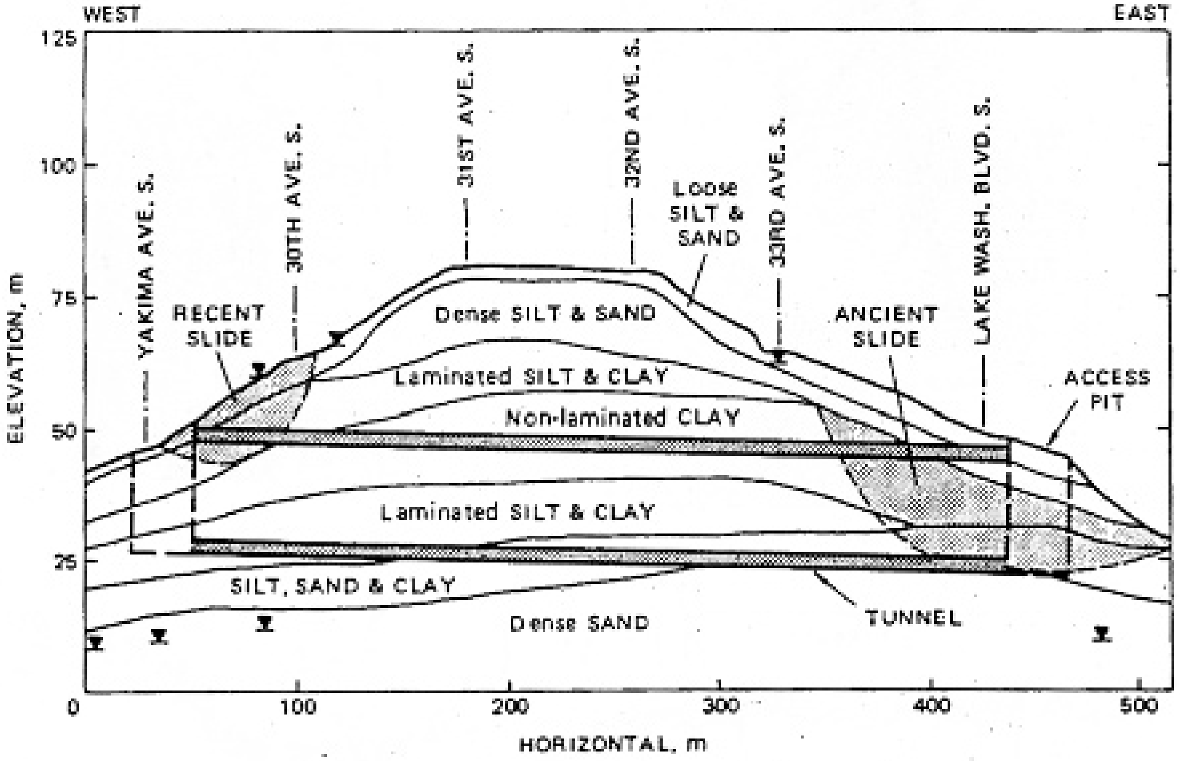


Figure 2. Longitudinal Subsurface Soil Profile

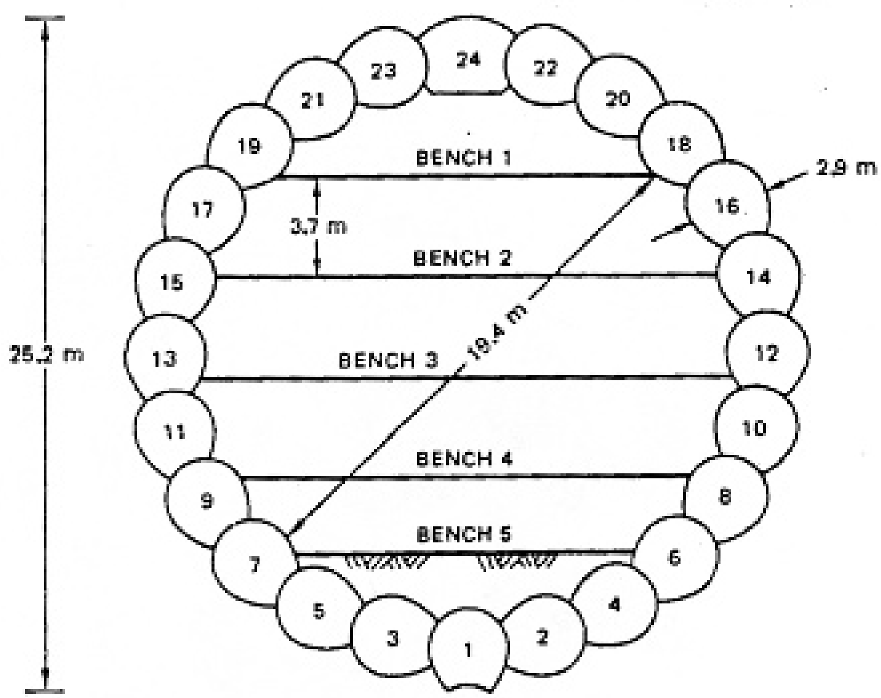
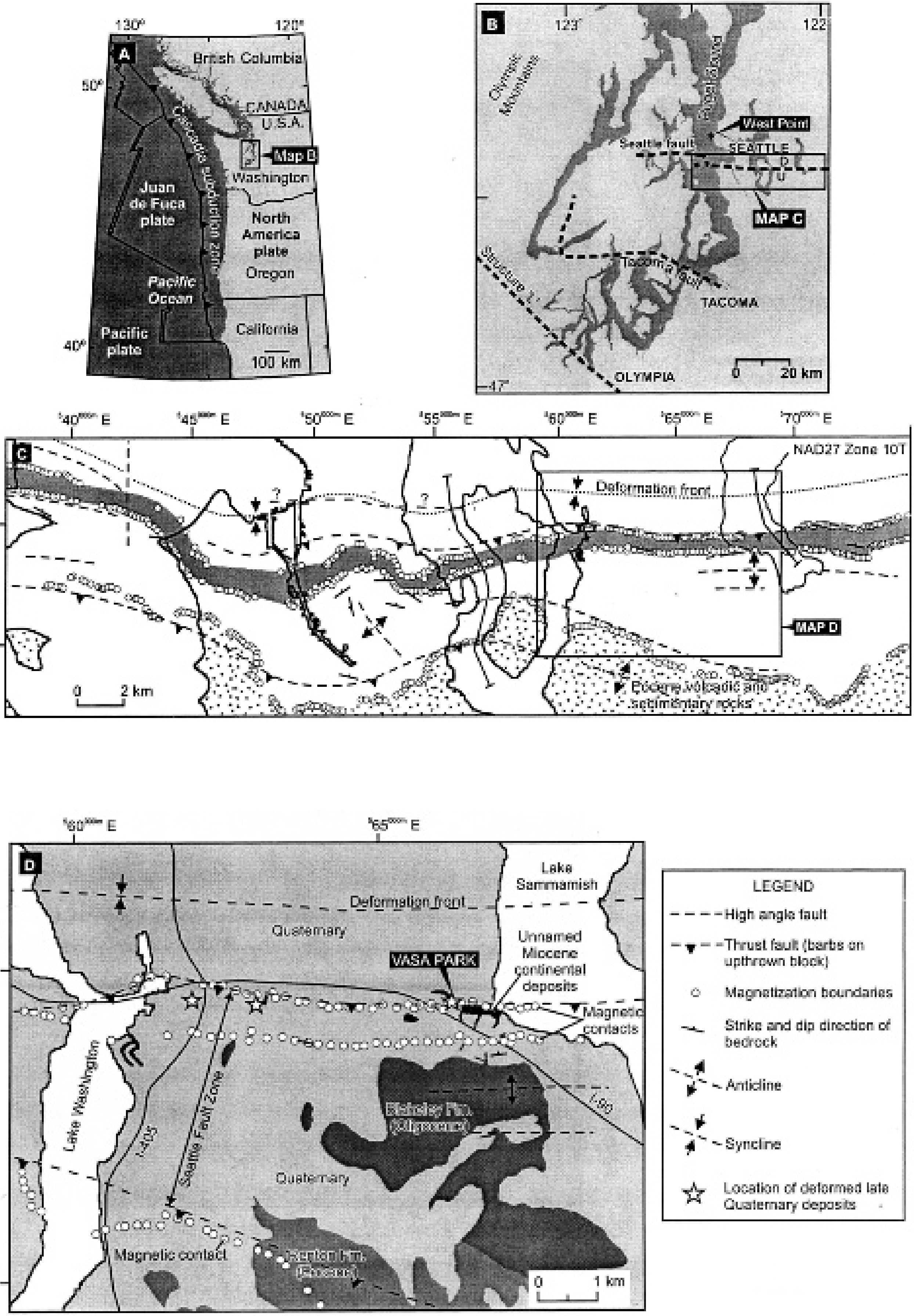
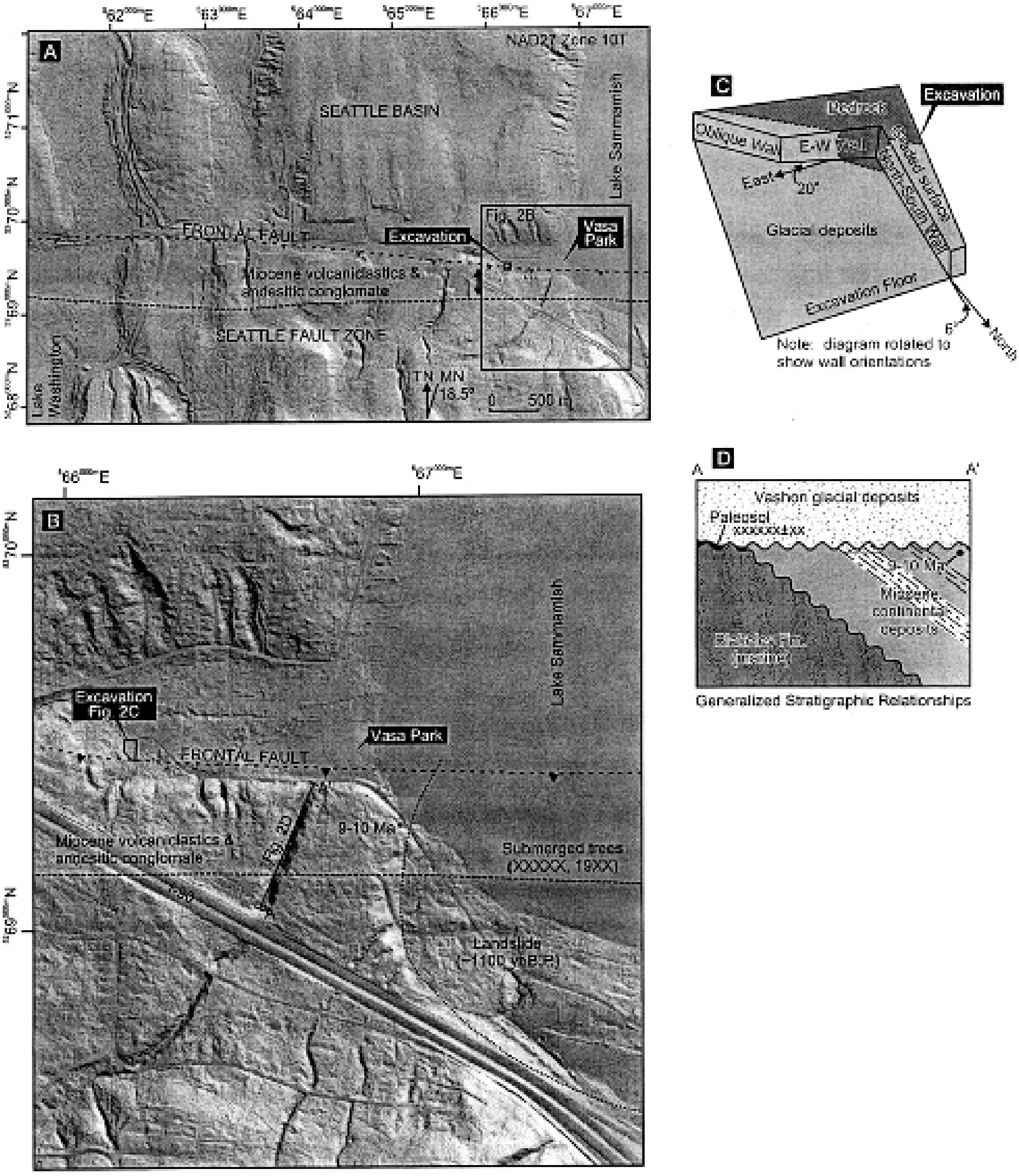


Figure 3. Sequence of Drift and Bench Excavations



A
130°
120°
50°
40°
British Columbia
CANADA
U.S.A.
Map D
Washington
Juan de Fuca plate
Cascadia subduction zone
North America plate
Oregon
Pacific Ocean
California
Pacific plate
100 km
B
123°
122°
47°
Olympic Mountains
Puget Sound
West Point
Seattle fault
SEATTLE
D
U
MAP C
Tacoma fault
Structure L
TACOMA
OLYMPIA
0
20 km
C
NAD27 Zone 10T
Deformation front
MAP D
Eocene volcanic and sedimentary rocks
0
2 km
D
Lake Sammamish
Deformation front
Quaternary
Unnamed Miocene continental deposits
VASA PARK
Magnetic contacts
Lake Washington
I-405
Seattle Fault Zone
I-90
Quaternary
Magnetic contact
0
1 km
LEGEND
High angle fault
Thrust fault (barbs on upthrown block)
Magnetization boundaries
Strike and dip direction of bedrock
Anticline
Syncline
Location of deformed late Quaternary deposits


A
NAD27 Zone 10T
SEATTLE BASIN
Lake Sammamish
FRONTAL FAULT
Excavation
Fig. 2B
Vasa Park
Miocene volcaniclastics & andesitic conglomate
SEATTLE FAULT ZONE
Lake Washington
TN MN
18.5°
0 500 m
B
Lake Sammamish
Excavation Fig. 2C
Vasa Park
FRONTAL FAULT
9-10 Ma
Miocene volcaniclastics & andesitic conglomate
Submerged trees (XXXXX, 19XX)
Landslide (~1100 ybP)
C
Excavation
Bedrock
Oblique Wall
E-W Wall
East
20°
Glacial deposits
Excavation Floor
6°
North
Note: diagram rotated to show wall orientations
D
A
A'
Vashon glacial deposits
Paleosol
xxxxxx±xx
9-10 Ma
Miocene continental deposits
Blakeley Fm. (marine)
Generalized Stratigraphic Relationships

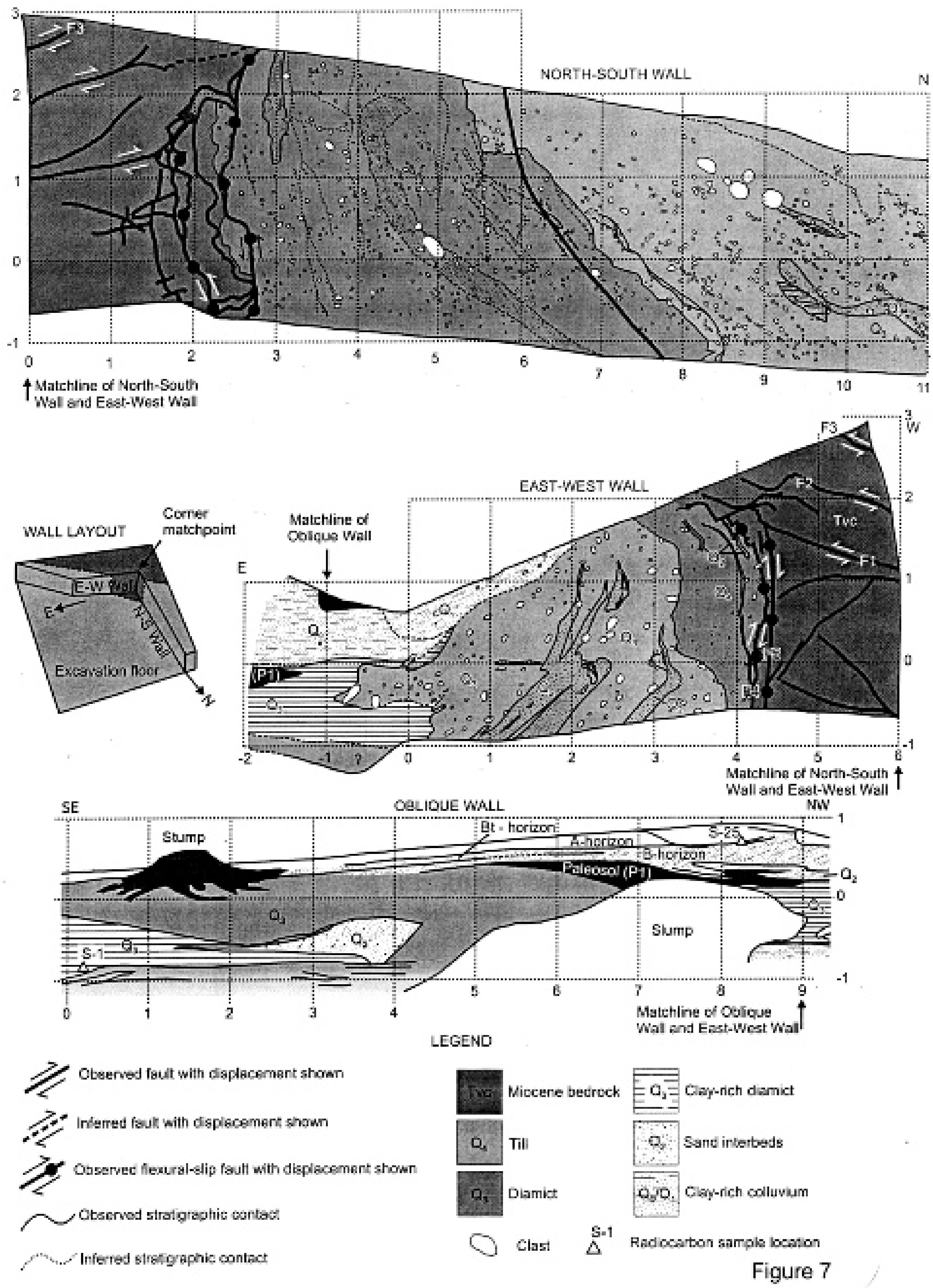
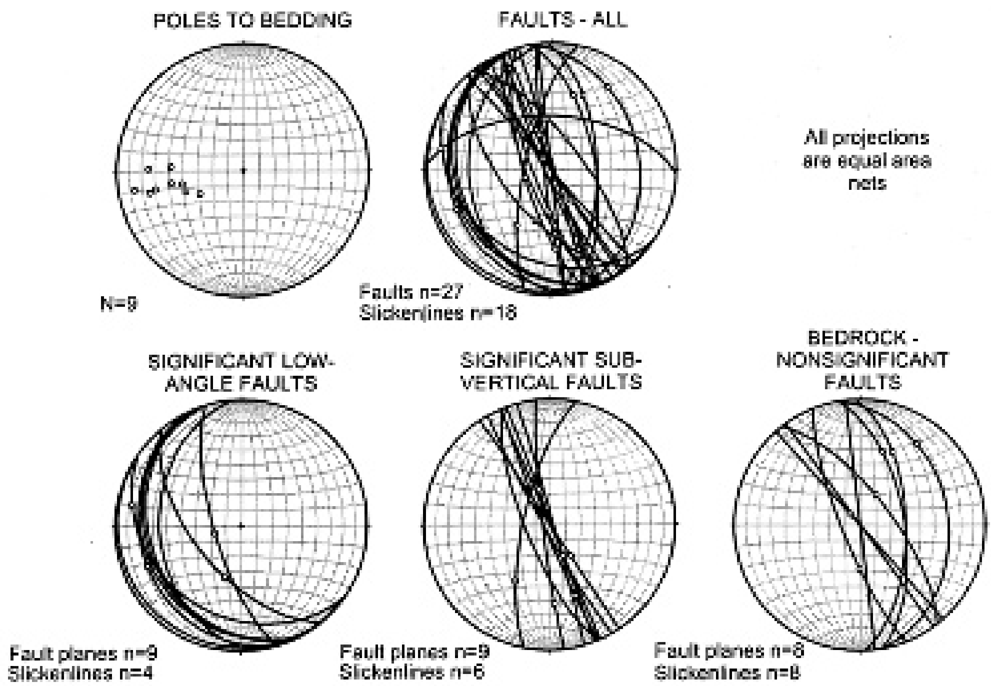
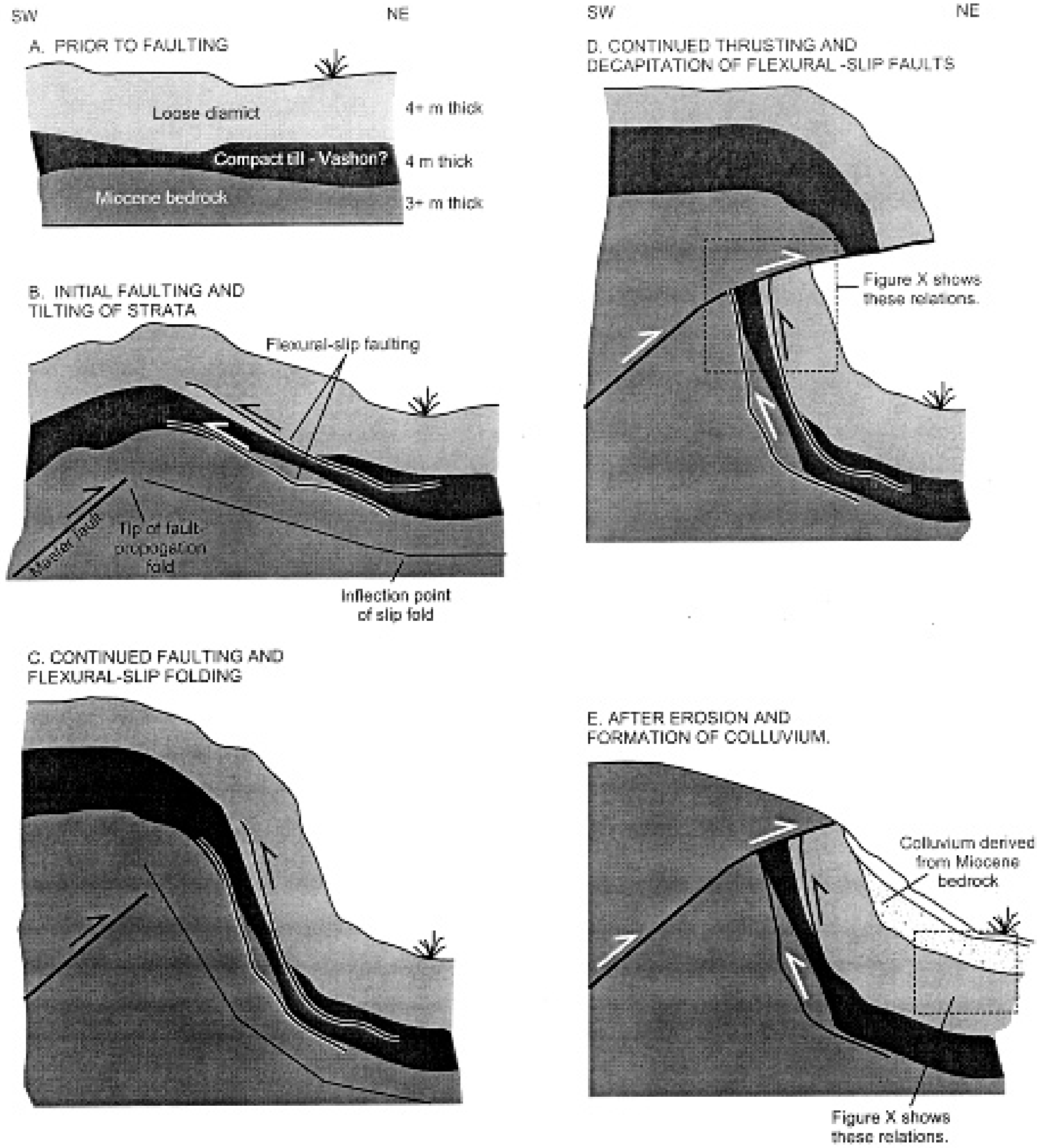

NORTH-SOUTH WALL
N
F3
Matchline of North-South Wall and East-West Wall
EAST-WEST WALL
W
F2
Tvc
F1
WALL LAYOUT
Corner matchpoint
E-W Wall
N-S Wall
Excavation floor
Matchline of Oblique Wall
E
(P1)
Matchline of North-South Wall and East-West Wall
OBLIQUE WALL
SE
NW
Stump
Bt - horizon
A-horizon
S-25
B-horizon
Paleosol (P1)
Slump
S-1
Matchline of Oblique Wall and East-West Wall
LEGEND
Observed fault with displacement shown
Inferred fault with displacement shown
Observed flexural-slip fault with displacement shown
Observed stratigraphic contact
Inferred stratigraphic contact
Miocene bedrock
Till
Diamict
Clay-rich diamict
Sand interbeds
Clay-rich colluvium
Clast
Radiocarbon sample location

Figure 7


POLES TO BEDDING
N=9
FAULTS - ALL
Faults n=27
Slickenlines n=18
All projections
are equal area
nets
SIGNIFICANT LOW-
ANGLE FAULTS
Fault planes n=9
Slickenlines n=4
SIGNIFICANT SUB-
VERTICAL FAULTS
Fault planes n=9
Slickenlines n=6
BEDROCK -
NONSIGNIFICANT
FAULTS
Fault planes n=8
Slickenlines n=8


SW
NE
A. PRIOR TO FAULTING
Loose diamict
4+ m thick
Compact till - Vashon?
4 m thick
Miocene bedrock
3+ m thick
B. INITIAL FAULTING AND
TILTING OF STRATA
Flexural-slip faulting
Master fault
Tip of fault-
propagation
fold
Inflection point
of slip fold
C. CONTINUED FAULTING AND
FLEXURAL-SLIP FOLDING
SW
NE
D. CONTINUED THRUSTING AND
DECAPITATION OF FLEXURAL -SLIP FAULTS
Figure X shows
these relations.
E. AFTER EROSION AND
FORMATION OF COLLUVIUM.
Colluvium derived
from Miocene
bedrock
Figure X shows
these relations.

ADDENDUM: Field Trip Narrative
Recorded and transcript by John Whitmer

Laprade: The Mercer Island Floating Bridge was completed - the first one - in 1940, connecting Seattle to Mercer Island for the first time. The original [Mount Baker Ridge] tunnel, which is on the south side of the two portals, was done by stacked drift method where there were actually seven drifts around the central core in a horseshoe-shaped tunnel. The core was then mined out from the middle after the outside had been mined. Then, they needed a new tunnel to complete the 1-90 Route from Boston to Seattle, so, starting in the early 1980's, work began on the second Mount Baker Ridge Tunnel, completed in 1989. At 65 feet inner diameter, it is the world's largest soft-ground tunnel. It also employed the stacked drift method. It had 27 drifts, each about 9'/2 feet in diameter, done with a digger shield. Each drift was cemented in & then all the soils in the core were mined out. It took about 1 '/z years to do this. During the excavation for the original tunnel, there was considerable - on the order of 2 to 3 feet - settling of soil over the tunnel. In the new tunnel, the settling was, for the most part, only in the range of a couple of inches, except that on the east side, above the portal, there was up to 20 inches. The entire area above the east portal was a large landslide area. A large cylinder pile ring had to be drilled & excavated to provide a place to get the equipment in & out while at the same time retaining the hillside.

^

The Rainier Valley was not connected to Seattle until they made the Dearborn Cut, punched through by hydraulic [water cannon] mining methods, between 1907 & 1909. This was a huge landslide area. When they made the initial Dearborn Cut, they created landslides on both the north & south sides. There actually was a slide that took out the south side shortly thereafter - still in the nineteen teens. The slide took out the southern half of the 12th Avenue South Bridge. There is a considerable amount of soft, post-glacial sediment in this valley here; some of you may recall the very high - probably 40 or 50 foot high Hilltecker [?? Phonetic Spelling -1 have no idea what the word he used really is] wall that supported this intersection that we are going over now [We are on 1-90 near its crossing over the western ramps of the Rainier Avenue interchange to just north of the Marine Hospital] for about a year because the sediments were so soft, they had to consolidate them before they could do the construction on the Rainier Valley Interchange. The south side has been completely stabilized now by this whole series of retaining walls. The north side is still unstable in some years, although it has been arrested to some degree by drainage & some of the structures at the top which have had a lot of drainage installed.

SHERROD: Just to the left here, underneath the viaduct of the northbound lanes of 1-5 [& 1-90 Off-RampJ in that small outcrop you will see the deformed beds of the Possession Lake Beds that we have mapped. Several folds & several faults have been mapped in that outcrop.

LAPRADE: [From the West Seattle Freeway Bridge]. At Harbor Island there is probably from 10 to 50 feet of fill atop deltaic sediments - bay muds, fine sands. The original bridge stood here until 1979 when a guy named Rolf Nazlund, a Puget Sound Pilot, ran into it. He was 80 years old at the time. He was apparently still mentally competent [my paraphrasing] & it wasn't his fault, but apparently something happened. The bridge was stuck for a year or more; people from West Seattle had to detour around it. They had to build a new bridge. Rolf disappeared & his wife was convicted of murdering him. The theory was always that she chopped him up & they say that there is a little bit of Rolf in everybody on Lopez Island, because she ran a Bed & Breakfast until she was convicted. The depth of the alluvial sediments is as much as 250 feet out in the middle. Right here, on Pigeon Ridge, which we are just going by on the left, there are actually glacial soils at a fairly shallow depth. We are approaching Longfellow Creek, which drains much of West Seattle & comes out here, where we are going. Just to the right is the place where much of the liquifaction occurred in the 1965 earthquake, because of all this fill. Harbor Island, which we just came over, was created by dredging the East & West Waterways of the Duwamish. At the time [1910], it was the world's largest artificial island - & it may still be.

BOOTH: The Puget Glacier covered the Puget Lowland several times in the last two million years. It is a finger of the Cordilleran Ice Sheet that grew out of the British Columbia Coast Ranges & Vancouver Island Ranges. Every time that ice advanced, it found a hole here between the Olympic Mountains & the Cascade Range. Those bedrock highs are there for reasons of large-scale tectonics that we probably won't get to in much detail today, but they are out there & you could ask any of us or each other - Eric [Cheney] would be a good person to ask, about why there is a hole between two big mountain ranges. It fortuitously enabled the ice sheet to extend farther south here than in most other areas along northwestern North America. The topography was favorable & there was an abundant supply of moisture, so we had really great opportunities for ice-sheet glaciation. The topopgraphy & most of the deposits that you see around here, with a few very notable exceptions, are products of ice-sheet glaciation interweaved with a little bit of interglacial deposits. There is not a lot of deposition going on in today's interglacial time & we assume that this was probably the case for all prior interglacials as well. Most of what we see was shipped in here & molded & left behind in the course of the successive glaciations. The most recent glaciation, which had its maximum about 16,000 years ago, is the one that has left most of the deposits that form the landscape today. We will get to more of the bits & pieces of the actual landscape here - some of the projects & how Seattle has developed over the years & how the landscape has changed, particularly over the last 100 years.

THE NEXT TWO PARAGRAPHS RELATE TO THE VIEW FROM THE PARKING AREA MIDWAY BETWEEN ALKI POINT & DUWAMISH HEAD:

LAPRADE: The panorama of the City of Seattle in front of you includes the spot midway between Duwamish Head & Alki Point where the early settlers landed. They moved later into the lower area between the new Football Stadium & downtown, in the Pioneer Square area. At one time, there was a hill where the down town is, & between there & Queen Anne Hill was another hill, called Denny Hill. Denny Hill was not quite as high as Queen Anne; it stood about 150 feet higher than the current ground level. All of the western about half of the Hill was washed into Puget Sound, using hydraulic methods - big water cannons - flushing the hillside in flumes out into deep water. The reason for the project was to open up transportation routes - they felt that downtown Seattle was too hemmed in. That was the reason for the Dearborn Cut, the Jackson regrade & all the other regrades - to open up downtown - to make ways to get in & out & to create more flat ground for development. In 1924, they decided to take down the rest of Denny Hill. The whole thing was leveled down - that whole area around where the Space Needle is & from there downtown was leveled in the Second Denny Regrade, in which they used big excavators - big shovels, & they used a conveyor system which took the material to self-dumping scows at the shoreline. That was also supposed to have been dumped in deep water, but what I have discovered is that the contractors tried to get away from things so they did not always dump in deep water & there is a shallow water area in there. Between the Space Needle & the top of Key Arena [Colliseum] is where the Mercer & Denny homesteads were. It was a swamp there; that is why you find soft ground there during excavation & drilling for the Denny-CSO Tunel & also for the Seattle Center in the 1960's. That area there, all the way up to Dravus Street used to be tidelands. Now it has been filled in. It was a dump originally & now if you play golf at Interbay, you will see vents for the methane to be released from the dump material. Over at Magnolia you can see the Marina, to the left of which are some raw bluffs between the Marina & the south end of Perkins Lane. The developed part of the Marina was fill in the beach from material excavated from the new Mount Baker Tunnel. Another part of that material from the Mount Baker Tunnel went out as counterweight, as a toe-fill to stop the sliding on 44th street, just above Lincoln Park. The interesting thing about the fill there at Magnolia is that for years some people wanted to develop a marina there. There was always opposition to it. The thing that finally resolved the issue & allowed the marina to be developed was that there was a huge landslide there - a big, deep-seated landslide that kept breaking the main sewer trunk line from downtown to the West Point Treatment Plant, resulting in periodic appearance of raw sewage floating to the beach. The slide would set down at the top & bulge up at the bottom - you could actually see where the beach was upheaving. The obvious solution was to put this great big weight on the bottom of the slide, & that is the marina parking lot, the restaurant, etc. That is what is holding the whole thing up. So that was a good compromise.

At Perkins Lane, you can see the bench coming down. From the top of Magnolia, you can see a drop off & then a lower bench. That whole lower bench, right above the raw bluffs is actually a till-like deposit that has been reworked; it has lots of sand stringers in it. That is one of the reasons for all that surfical & deep-seated sliding along that portion of Perkins Lane. The geology changes from there northward. See the profile of the stratigraphy in the Duwamish Delta on Page 2 of the guidebook. Hf = fill; hh = hydraulic fill; interbedded silts & sands; ha = alluvial fine sands & silts; e = estuarine deposits-bay mud- slightly clayey silt with fine sand. A really interesting stratum is called "reworked," hrw, sitting right on top of the hard glacial soil. Gm = glaciomarine unit; ow = outwash. Above them is a layer 5 to 10 feet thick of reworked material, a diamict of all different grain sizes. Although it looks like glacial material, it is only medium density dense. Here, the steel piles for the baseball stadium were driven to depth of 70 to 80 feet, then drilled out & filled with concrete. Much effort is underway to redefine the waterfront geology. About 50 borings have been done already. The new Alaska Way viaduct will start at Spokane Street & go north, turning just south of the Space Needle & connecting with the north end of the Battery Street tunnel. It will be viaduct to the Stadiums & cut & cover from there to Seattle Center.

CALIFORNIA STREET LANDSLIDE. LAPRADE: The department with which Bill Laprade works has already documented over 1400 landslides since 1893. The CALIFORNIA STREET LANDSLIDE occurred in 1996. It extended to within 10 feet of the brown house at the top of the escarpment. It covered California Way, which starts over there behind that condominium & goes up on a diagonal as you can see. California Way was built about the turn of the nineteenth to twentieth Century by developers who wanted to get people up & down the hill by trolley. They cut this road in & it was quite a mess. See the photograph in the guidebook. The whole hillside kept coming down on them, covering things up, & for good reason, because the lower half of the hillside is Lawton Clay - glaciolacustrine sediment. Approximately the lower half of that may be Olympia beds, but there are no good exposures of it along here. The best exposures are around the comer. About three-quarters of the way up the slide on the left you can see Esperance Sand - outwash from the last glaciation. Esperance Sand also shows up on the upper part of the slide on the right. So you get a great deal of seepage along this whole hillside, right at the clay-sand contact. When this slide occurred [1996] it kept the road blocked for much of the winter. The cross section of the slide in the guidebook shows what the slide looked like when it was fixed. They wanted to rebuild at a 2 to 1 slope. You can see with these geogrids - these horizontal lines - a plastic grid that is put in there about every two feet, then compacted, enabling them to maintain a 45° slope, which is really steep for a sand & gravel fill. We started to repair this & I believe the initial estimate was 1.3 million. It was during the second year - the contractor couldn't finish it the first year. He made the excavation along the front at the beginning of the second year. When he started to excavate, the whole thing started to move again. We knew the water level & we cautioned the contractor that it was too early, but he was real anxious to get going. In the end he had to lay off. The eventual construction cost $3 million because of all the changes required during construction. Essentially, it involved taking the whole thing down & replacing it, then building back the slope to 2:1, then putting the drainage pipes into the rebuilt part. What we were left with is a vertical face of the Olympia Beds & some of the clay, & it was dangerous to leave that exposed. So that wall that you see there only goes back about six feet; it is there just as protection - it is a facing to prevent the face from raveling & eroding & undermining the fix that was in place up above. You can see two colors of slope up there. On the right it is all grassed in. There, the soil was mixed with enough cement to stabilize it, yet not too tightly cemented to allow vegetation to grow. On the left, it is real white, with very little vegetation. That is because during the following year, the part on the left failed because there had been some old pipes put in during the WPA days. Back in 1933-34, Seattle had the biggest spate of landslides that they ever had up until 1997 & this whole slope fell apart. They had some projects that were planned & not built up in here, but they did put in about 4 or 5 finger drains back into the hillside, with pipes, & those could not be found. We found them when the slope failed, after we had done that whole fix. It failed where the pipes were delivering water to the face. We found the other ones by finding an old drawing, then measuring from where we found the original ones.

Many of the landslides along Duwamish Head are mudflows or debris avalanches that just come down off these slopes, which are 75 to 100% slopes & they only have a colluvial depth of 3 or 4 feet. It is not the mud that causes the problems; it is the trees, which are like javelins; they just come down & wipe everything out, so you get the double whammy. He described a method by which they use a plastic material which folds together like an accordian, which they fill with sand & stack to support the slope up above where the alders are coming in. Midway up the slope of Ferry Avenue on the left side of the slide, about in line with the toe of the cribbed structure, is where the remaining WPA drains are located. They are functioning well.

BOOTH: [Responding to the question why West Seattle houses suffer more chimney damage in historical earthquakes than other areas]: That appears more related to the geometry of the bedrock & the fact that we are coming out of the Seattle Basin where bedrock is several kilometers below us across the Seattle Fault where the bedrock is rising. Therefore there will be some fairly strong density & velocity differences that are likely to lead to some kind of refraction or reflection of the seismic waves.

CHARNLEY: I was a counselor at West Seattle High School when the 1949 earthquake hit. Following the Quake & the dust settling, I took a walk around. I know why the High School & Hiawatha Playfield are there: It is because that was a peat bog. Nobody wanted to build there. That's where we build schools, right? I could outline the shore of that peat bog because of the chimneys. Within it, all the chimneys, especially those that were rectangular & aligned north-south, were down, as the shock came from the west. Of those that were aligned east-west, some were damaged & some were not. Outside of that area, far fewer chimneys came down. I could walk around an area that was about three miles & practically draw on a street map where the edge of that peat bog was.

POINTING TO A BIG CONDOMINIUM BUILDING ACROSS ALKI FROM SEACREST MEMORIAL PARK he calls attention to the superficial slide behind it. That slide was fixed about a year & a half ago; it took all summer long at a total cost of about $3 million. It was done entirely by drainage involving a 25 to 30 foot deep cut-off drain installed into the top of the Lawton Clay along the top of the bluff. There is still some sloughing off the face of the slide at the top. Oddly enough, the Park Department, which shares responsibility for this slide insists that irrigation be put into landslide-fixed areas because they want the vegetation to grow up as soon as possible. The irrigation system can be deactivated after two or three years when the vegetation is well established.

BOOTH: A question came up when we were back at the previous stop about what this flat bench is. Where we are now & where we were back at Duwamish Head - that is all fill. But as we drive forward over the next about 300 yards, you will notice that this very narrow bench that we are on here quite abruptly broadens out. Much of the Alki Beach Promenade is a very broad bench & as we make the transition past the Bon Aire Slide, a very famous landslide, we are moving off the fill & on to the uplifted beach terrace consequent to the 1100 years ago earthquake, which will be the focus of the next stop. As you look outside the bus now you will see that the hillside is falling away very rapidly to the left, & instead of a narrow strip of fill, we are on a much broader pre-settlement landform.

SHERROD: [We are east of Alki Point looking south along 63rd Street SW] The wave-cut, uplifted platform is warped into a gentle anticline here as shown by the fact that the street rises a bit here & then goes down on the other side. [A number of people express doubts about that idea, but I think he has a good point] Lidar data certainly suggests that there is deformation of the uplifted platform.

We stop at the north end of the west-facing sea wall just south of the southernmost waterfront apartment building south of Alki Point. This is an intertidal wave cut platform, cut on the Blakeley Formation here. You are standing at the leading edge of the Seattle Fault Zone, which crosses the Sound just to the north of us. These rocks are Oligocene to early Miocene in age. Across the Sound are outcrops of the same unit. Near the base of that unit, at Orchard Point, we have a tuffaceous unit that we did our fission track age on, dating it about 31 Ma. Some of the Forams from the upper part of the unit suggest that it may range into the earliest Miocene as well. This unit was deposited in shoreface areas over by Issaquah, where the unit crops out on Cougar Mountain. Those are beach deposits there. As you go west, you go offshore into deeper & deeper water. There is some argument as to how deep the water was here. You will note that a lot of these rocks do not have much left in terms of bedding. If you look at the finer-grained units, they are mostly a massive siltstone. You will also see lots & lots of burrows. Often they are resistant in the finer-grained units. They are huge. They can be this big around. This unit is extensively burrowed here & at Restoration Point, which suggests that it probably was not in real, real deep water. Farther to the west you get into progressively deeper water. The burrowing destroys the initial bedding. One thing to notice is that this is a broad platform here. It is being cut on the bedrock surface, basically between mean low low water [MLLW] which is pretty close to where we are right now. You will notice in the bedrock, there is a little notch cut there. That marks the outer edge of the modem platform. At high tide, up here where the concrete is all piled up, that marks the extreme high high waterline here. So the terrace is cut between those two points. Now a thousand years ago there was a large earthquake on the Seattle Fault that runs through here. It lifted up a platform just like this one, taking it out of the range of the tides. That is what Beach Drive & the treatment plant are built upon.

On the map [Fig. 1C, p. 20 of the guidebook is a stippled unit, representing a Miocene volcanic conglomerate which probably marks the leading edge of the Seattle Fault Zone. Rick [geophysicist who compiled the map] picks this thing up all the way from Issaquah to Dye's Inlet. This zone marks the leading edge of the hanging wall, which we are standing on, & just to the north, around the Point, you go into the Seattle Basin. The current interpretation is that there are multiple strands of the Fault Zone. This, the frontal fault, is the northernmost fault. There is another strand just south of that, which runs through Blakely Harbor. Just to the south of that is the Orchard Point Strand, which runs right through the Manchester Refueling Depot on the Kitsap Peninsula. Those strands basically make up the Seattle Fault Zone. Our current interpretation - the party line - is that this is a reverse fault system - up-to-the-south; down-to-the-north. It may be a thrust fault system - the question is, "How steep are the faults?" There is much debate over this. We have abundant seismic reflection data throughout the Sound, but in none of those reflection profiles can you see a place where you can fit a distinct fault plane. The range varies from 25° to 89° dipping to the south.

BOOTH: And also, there is the question whether it bottoms at some depth - is it thin-skinned thrusting or thick-skinned reverse faults.

SHERROD: Right. And, again, none of these reflection profiles shows any of the fault, so it is literally a geometric argument what kind of model you pick. Later, we will see some things that suggest that other things were going on. What we see on Bainbridge Island & the northern Kitsap Peninsula, where we have found surface rupture within the Seattle Fault Zone, it is not up to the south - it is up to the north & down to the south. One interpretation is that those are back-thrusts. We put this idea forward at the Seismological Society of America meeting this year. Our report was basically a field trip guide for when you take the Ferry from Seattle to Bainbridge Island - for what you see in terms of the Seattle Fault. The picture on P. 7 shows Restoration Point, looking to the south. The broad platform it shows is the analogue of this [Alki area] broad platform that got lifted up about 7 meters during a large earthquake. So the beds at Restoration Point -the same units as those here at Alki - are striking right towards where we are standing. As we walk down the beach a little way, you will actually see these beds steepening up & turning into the Seattle Fault until the strike is almost east-west in the course of about 200 to 300 yards along the beach - pretty cool!. In a few locations, they actually wobble into overturned. Between here & Bainbridge Island there appears to be a large bend in the Seattle Fault Zone. Sam Johnson, in 1999, hypothesized that a tear fault runs straight up the sound here, based on things he saw in the reflection profiles. He was saying at the time - I believe - up to 2 km. of offset. In other words, the west side was moving northward at a faster rate than this side. When Blakeley [Rick?] came out with this interpretation on the aeromagnetic data, you will notice that there is a bend in this magnetic conglomerate, but it appears to be a continuous unit from Blakely Harbor all the way over to this area. It does not appear to be ruptured & offset. The magnetic data from the Seattle area shows another structure trending north-northwest, running up the Duwamish Valley. There is also evidence in the depth to bedrock map that put together that there is another structure trending through this area that may be involved in some of this bending & faulting that you see. The full picture of what is going on here still has not emerged yet. he [I failed to get the name] thought that some of the drumlins across that structure have been offset -1 think in a left-lateral sense - not a right-lateral sense; we have never come to agreement that that is actually the case. We saw no evidence at all of lateral movement on the faults that we exposed in the trenches [the Toejam Hill trenches near Blakely Harbor, I presume]. Later on when we get to Vasa Park, we will talk about that, because we do see evidence for strike-slip motion over there.

BOOTH: Talks about 8 km. of vertical offset of Crescent Basalt seen on the Seattle Fault. In gross picture, regardless of what the geophysicists can or cannot agree to, there is on the order of 8 or more kilometers of offset from mid-Tertiary to the present between the south side of the Seattle Fault, which we call the Seattle Uplift, & the north side of the Seattle Fault, which we call the Seattle Basin. All of the questions of uncertainty are in the details & in the more recent history. To give you a sense of the scale, the Orchard Point Fault, as nearly as we can tell, makes landfall down around Lowman Beach, a little bit this side of Lincoln Park. So the Seattle Fault Zone here in West Seattle, extends from where we first talked about the bench broadening out as we left our stop on the Duwamish, down to a little bit this side of the [Fauntleroy] Ferry Dock. In that zone, we can recognize at least four individual - if not strands - at least, zones of deformation, the first being where the uplifted beach terrace first makes its appearance; the second being where we will go next, at MooKwaMeeks Park; the third a little bit south of there that we will be unable to visit, & the fourth is the Orchard Point Landfall at Lowman Beach. Most of these faults do not have clear surface expression in the Quaternary deposits. That raises the interesting question whether they were active; did they break the surface; did they have fault rupture only at depth, with propagation as folds or warps or offsets in the quaternary cover; have they been regraded off the landscape in the last 100 years? Those are some of the questions that we are all struggling with. But it seems pretty clear that there is a zone of fault-affected land here on the order of a couple of kilometers wide, with a few fairly discrete zones of deformation that may be faults - may be folds - or faults at depth & folds at the surface.

SHERROD discussing the reason for the depth of the Seattle & Tacoma Basins: The model we gave you is that this block is being thrust up relative to the block to the north, creating this big structural depression. But if you look at the gravity data for western Washington, you will notice that there is a set of these basins that ring around the Olympic Mountains - five or six, perhaps more of them. Bob Crosson has suggested that the uplift of the Crescent basalt to form a horseshoe around the Olympic Mountains caused the Crescent, a relatively durable rock, to act like a lever. Uplift on the east side of the Olympics caused the eastern part of the slab - beneath us here - to go down in the Seattle Basin - that lever creates the basin. Perhaps later on, this north-south compression creates some of the fault zones. Crosson actually thinks the Seattle Basin is going up right now, rather than down.

SHEROD: So we can get the Seattle Fault at least to Dye's inlet, but the geophysicists do not think they see evidence of it in the reflection profiles in Hood Canal. So the big question is whether it actually ruptured through Hood Canal. That has BIG implications for tsunamis, by the way. To the east, we conceptually run it to about North Bend. I like to think it is terminated by the fault that runs through Rattlesnake Mountain - in that area.

BOOTH: You can find evidence for it in the outcrop pattern & structure in the Miocene rocks just east of Lake Sammamish. That is about the last point that one can confidently show it. There has not been any geophysical investigation in the Sammamish & the Snoqualmie Valleys that I am aware of. So we do not know whether it has an expression there. Certainly the surface geology does not.

QUESTION: Where is the nearest Miocene to here?

SHERROD: Possibly at Seward Park; Definitely over by Lake Sammamish. There is none in here. If you press Blakeley on what the Miocene is doing through here, he gets kind of evasive.

SHERROD: You are standing now on the upper edge of the uplifted wave-cut platform. It is the fossil analogue of the beach you just came up from. One of the things that Bob Bucknam & I have done for several years is that we chased this terrace all around central Puget Sound & measured the back angle - the shoreline angle, which is back right there. That hill is composed of basically the Blakeley Formation that Derek has told you about. This surface is gently sloping up to that. That break in slope is probably the old shoreline - extreme high high tide.

BOOTH: On Page 9 you will see this upper knob of Tb, Tertiary Blakeley & the little faint box with two dots in it is this site, right here.

SHERROD: So, what you can do then, as a first order estimate on how much uplift occurred 1100 years ago, is measure the elevation of that notch right there. We went back & actually dug in with our shovels & found what we thought was beach gravel. It looks like a Quaternary beach gravel, just like what you see out here today. We surveyed in the top of the beach gravel out here & also surveyed in on the same line the top of the beach gravel out here where we think we got it at its highest point. The difference between the two here is 6'/2 meters. Quite a bit of uplift. Actually, that could be a minimum amount. If you account for relative sea level rise since the Event, you would probably get an extra meter of uplift - so make it T/2 meters. And there could have been transient post-seismic subsidence - so IVz meters is the minimum uplift. These estimates are based on the work of Robert Thorson, who did his dissertation back in the early 1980's, looking at isostatic uplift following the last deglaciation. His thoughts were that ___ were right on the hingeline, where most of the uplift occurred to the north of us with much less to the south of us, which is an interesting situation relationship to think that the hingeline is right at the Seattle Fault. Secondly, he thought that most of the isistatic rebound was equilibrated about the time that Mazama was erupting, 7500 years ago. Now, why would this area equilibrate so rapidly. Is there anything about this area that would allow it to equilibrate so rapidly following glaciation.

QUESTION. How long was the ice here? Booth: A couple thousand years. Enough time.

SHERROD: Enough time. The reason is that the crust & the mantle below us are a lot warmer than on the east coast, allowing this to adjust more rapidly. So isostatic rebound was all finished by the time this platform was uplifted.

BOOTH: Of course, you never know how much it really settled because it will also start to recover as the ice thins, but has not yet evacuated the area. You do not get indicators of how settled the crust was until the ice goes away & you start developing shoreline indicators, deltas, etc. Once those come in you can view the structure of the shoreline & as isostatic rebound continues, rebound is greatest in the north because the ice was thicker in the north, so you wind up taking what were originally planar features & kicking them up. It rises everywhere, but it rises more in the north than the south. Bob Thorson did a very careful [analysis] of that [process]. So we have a chance to see those marine features north of Seattle. South of Seattle, those features did not rise as much, so we assume that they have been drowned by rising sea level. So, south of Seattle, we still see features of the south-draining lakes & what is called the Leland Creek Spillway on the north [west corner of the lowland].

SHERROD: [In the trenches on Bainbridge Island] we did find post-glacial beds that contained fragments of marine diatoms, so our idea is that could represent the limit of the age of the Seattle Fault uplift event. How do we know that it was not due to isostatic rebound? Well, the first question is what is the age of the Event? The age of the uplift is best dated by a log that was retrieved from an excavation at West Point. Brian Atwater spent a lot of time working with that log trying to get enough samples to date it. He dated about six individual tree ring slices from that log & was able to use a radiocarbon calibration curve to come up with a very precise age for when that tree was killed. That tree was found in the tsunami deposit on the marshland at West Point, presumably the result of the uplift 1100 years ago. The radiocarbon dates suggest that the tree was killed between AD 900 & AD 930. That corresponds fairly well with other ages that we've got.

BOOTH, responding to a question whether the deformation imputed to the Seattle Fault could be the result of the ice-sheet sliding over the area: The magnitude of Quaternary de-

formation in this area is extremely unusual for the entire Puget Lowland. Such deformation is seen scarcely anywhere else in the Puget Lowland.
SHERROD, AT MOO KWA MEEKS PARK: He has measured the elevation of the shoreline angle here & finds it 11 meters higher than it is to the north, just south ofAlki Point.
BOOTH: Olympia Beds do not appear south of this fold, but they come up again at Lincoln Park.
SHERROD: Bucknam described this as an area uplifted on the Seattle Fault & the uplift dies out slowly as you go to the south. What actually happened, it is almost as if a block got squirted up about 7 meters. There is about 7 meters of uplift fairly uniformly across this uplift area & then, once you cross the Orchard Point Fault, just to the south of us, the uplift dies off very abruptly. One thing we found are these back-thrusts over here on Bainbridge Island. Those are areas where the ground surface has been lifted up to the north relative to the south. One of the things we have seen over here is that just down here about 150 meters - watch this car; he will show it to you - is you drive [south] along this flat, uplifted terrace & you encounter an incline [actually a decline] where the terrace has been uplifted to the north. So you are riding along this flat terrace & then you go down on what we call the "Wow." The terrace surface has been offset, possibly by one of these back thrusts. Now I think it is a great co-incidence that you see offset of the terrace here & that you do not see Olympia Beds south of here for quite a while. The other thing is that the shoreline measurements here are anomalously high & we see the same thing over there on one of the backthrusts on Bainbridge Island. Where there is a backthrust, the shoreline angles are anomalously high - they are 10 or 11 meters. So here is a place where the terrace & the shoreline areas have been lifted up additionally, possibly by movement on these backthrusts.
South of the area described above, we ascend to the top of the escarpment on Jacobson Road, which is constructed entirely on landslide debris, as are most of the houses nearby.
The next section describes the stop in a new park on the west bank of the Duwamish River, a half-mile or so south of the Spokane Street [West Seattle] Bridge. A large sculpture representing the frame of a wooden boat is supported about 8 feet above ground. A big blue & white sign at the entrance says, "Duwamish Public Access. " Another sign recounts the history of the Indian villages here.
SHERROD: We are now in the former Duwamish delta. In fact, if you turn to Page 12, you will see some beautiful Atwater illustrations - he kindly gave us these to use on our field trips. Map C is a map which superimposes the modern Duwamish River Channel on the historic Duwamish Delta that was mapped by the Coastal Survey back at the turn of the 20th Century [i.e., 100 years ago.] Right below where it says "tidal marsh" there is a small, crescent-shaped island. That is Kellog Island, which is in view right behind us. That is the only preserved remnant of the Duwamish Delta & it is pretty screwed up. That is all we have to work with in terms of what is preserved. We are standing almost at the tip of Kellog Island as it is shown on the 100 year old map. The important thing here is that behind us is an uplifted, lower intertidal shell hash, with articulated molluscs in it. Many of them are lying on their sides with their bent noses pointing up just as they are supposed to do when they are living. Some of them were likely killed when they were lifted up. Note that here is the top of the intertidal deposit. Above it is a black sand, which is full of andesitic clasts, scoria fragments with a Mt. Rainier provenance. One of the hypotheses is that this black sand represents the distal run-out of lahar that came from Mt. Rainier about 1100 years ago. Roughly, at the same time as uplift, a lahar, called the Deadman Pass Lahar, came off Mt. Rainier & you are looking at the distal run¬out from it, we think. Brian Atwater & one of the teams at UW are doing some work on these black sands. Where we have had big exposures of it in trenches up here where we will eat lunch, it appears that the sand was in place after the uplift. We can see evidence where the tide flat was lifted up & buckled & ripped up in parts, & the sand then comes in & fills in those rip-ups. It fills in burrows, also. We think it came in after the uplift. Pat Pringle is working on that lahar up on Mt. Rainier. See illustrations on pp. 17-18.
BOOTH responding to question about how lahar got here instead of Tacoma tide flats explained the alluvial fan relationship of the White River to the Duwamish & Puyallup Rivers & stated that the White River flowed north over more time than it flowed south.
SHERROD explains that a paleontologist has found molluscs here that survive only in the lower part of the intertidal zone, right around, or below mean low low water - a sub tidal organism that cannot be exposed to aerial environment. She estimated on the basis of that mollusc, that there has been about 5 meters of uplift.
TO A QUESTION ABOUT THE WHITE DEPOSITS IN CUT BANKS SOUTH OF HERE, THE REPLY WAS THAT THEY ARE FLY ASH FROM NEARBY INDUSTRY.
SHERROD: Upstream, at Emerald Downs, when they excavated for that project, they dug up huge logs with radiocarbon dates around 1100 years ago. Pat [Pringle] worked out the chronology & correlated it with the Deadman Pass Lahar. That, in the Kent-Auburn Valley, is probably a primary lahar deposit & we are looking at the distal wash-out from it here.
DEREK observes that it is a peculiar thing that the alluvial channels which belong to King County had liquefaction & ground failure problems in the Nisqually Earthquake, whereas the channels in Boeing property did not fail under the buildings. He speculates that Boeing exercised better quality control over its contractors.
LAPRADE [as we travel eastbound on the West Seattle Bridge]: There is a big divot out of the hillside where Columbian Way goes up there. When people were trying to figure out ways to develop a canal through, a gentleman got permission & a license from the legislature to build one through there. [The divot was already there at the time, but it was smaller}. To a wisecrack about Don Charnley having been a legislator. Bill said, "I think Don approved it, yes." Well, they started the excavation, &, as you can well imagine, because that area right up there is just soaking wet - it is one of the most prolific spring areas in all of Seattle - at the sand-clay contact - they got part of the way in there & everything started coming in on them. They had to abandon it & the builder lost his license to do such & went bankrupt. That was an ill-fated try. Later on,

when we get to Queen Anne, we will talk about the Lake Washington Ship Canal, which was eventually picked over five other sites. They stabilized much of this hillside through drainage & buttressing. There were houses all along here, both where the Freeway is now & above. If you look on the old street maps; also if you climb around up above you can see old foundations & roads all through there. There is very little land sliding going on now, but it was very active in past years.

WE ARE NOW NORTHBOUND ON 1-5, JUST EAST OF THE METRO CONVENTION CENTER STATION.

LAPRADE: The proposed Sound Transit tunnel will come through right underneath the Freeway, starting at the north end of the downtown bus tunnel. The tunnel will climb from beneath the Freeway up at as sharp a grade as it can. It will have to make a loop around to the south in order to make it up to the top of the hill & then head north along Capitol Hill.

LAPRADE: [The Seattle Center - South Lake Union area] is underlain by very loose recessional deposits & Holocene deposits & then it has been filled over. One of the things that they have always wanted to do is straighten out the Mercer Mess here, but it involves a lot of money because the ground water table is very high & the sediments are very soft. No matter what you do, it adds up to a lot of money. Just off to the right, just before we go into a tunnel, is the east portal of the Denny-CSO Tunnel, a just-completed tunnel for King County Metro for sewage. It is about a 12 foot diameter sewage storage tunnel so that they do not have overflows of raw sewage into Puget Sound. They just finished the tunnel, most of which was in very old glacial soils. One of the things we discovered is that this whole south side of Queen Anne is covered with anywhere from about 10 to 30 feet of till-like material that is widely-ranging anywhere from a fairly pervious sand to a real classic till & everything in between. It appears to be a reworked till or a sub-glacially reworked till. The city's largest water supply systems - Queen Anne had five large springs that were used as municipal water supplies up until Seattle began using water from the Cedar River. This one was called the Aloha & it supplied water throughout the City because it was so prolific. It is now all put into the storm system & taken on out.

The general geology, particularly what we have learned along the light-rail alignment, which is in front of us - the development of the Freeway in the 1960's & the Lake Washington Ship Canal; & also a little bit about the land sliding on Queen Anne. Queen Anne is a good place to start. The contact between the sand & the clay is right down near the bottom of the hill. Everything above is sand; there is no till here. The only till on Queen Anne is up at the very top - up near the High School, where the big towers are. There has been a lot of land sliding all around the hill, & right in here in particular. The reason that there is no vegetation here is that this slid in 1997. It went all the way down. It undermined this house to the right & took out part of the old overlook that was here, then went down to that feeder road below, & then up onto Aurora just a little bit. This has been fixed now. There is a debris catchment at the bottom, where there are concrete posts sticking up about 8 or 10 feet to catch debris. What we are standing on was fixed. Starting over there to the left about 150 feet is our highback wall. All those little bumps along the face are tie-back anchors which go back into the hillside. They are also down below us, holding up this overlook. This area along Queen Anne is probably the thickest [colluvium] that I have seen. Because it is all sand, the colluvium is as thick as 10 feet along most of this hillside. It is marginally stable from the standpoint of debris avalanches & earthflows. This goes on all around Queen Anne Hill. You can follow the contact - as Don Tubbs has named it - between the sandstone & the clay all around Queen Anne. Much deeper-seated slides occur on the west side.

LAKE WASHINGTON SHIP CANAL: The place that was chosen for the Lake Washington Ship Canal was right through here. Lake Union was here; Portage Bay was here. There was a little Creek - I cannot remember its name - just over there, draining Lake Union on out through Salmon Bay. In the early 19th Century, they decided to put a dam across there, just before they started to put in the Lake Washington Ship Canal The Locks were finished in about 1912 & then they excavated that whole section between Salmon Bay & Lake Union, slopping all the material up onto the benches to the side of it. The wooden dam held until 1914 when they had a flood which overtopped it & flooded all the way out to the Locks. The Lake lowered about 3 meters at the time; the whole thing went down catastrophically & ruined a lot of businesses that were on the lakeshore - shipyards & such. The last piece was the connection at Montlake. There used to be a portage there, where they could get logs through, & that is where they had to make the big cut, which allowed all the water to come through from the Cedar River. At that point, the Sammamish River was connected so that everything then came through here. When it was finished, it lowered the level of Lake Washington - that is why you find a bench all around Lake Washington - that terrace of the old beach. It lowered it - I can't remember -[Charnley suggested 6 to 9 feet; I think it was 14 feet]. Wherever you find that bench it is always soft ground - silts & sands; loess & soft, silty sands all the way around. Lake Washington came down to the Lake Union level, which is controlled by the Locks.

1-5 WAS CONSTRUCTED ACROSS THE WEST SIDE OF CAPITOL HILL BETWEEN 1960 & 1966. When they started excavating for that, there was a geologist -even back then - whose name was Wegner [sp??]. He actually has written some good write-ups, cross sections & profiles - you can find them in the records - about the geology of the Freeway. There is also some good stuff in the Centennial Volume: Engineering Geology in Washington, about a number of the projects. But as they excavated that -they did not have that big row of cylinder piles - & as they excavated, the hillside started to come in on them. They had to stop construction. Ralph Peck from the University of Illinois & Mahmet Sharif from the University of Washington, were called in to do some studies. The other thing that happened was that Stan Wilson, of Shannon & Wilson, had just invented the slope indicator. He had used it in some other applications, but he had never used it very much. However, the insurer shut the project down & did not allow construction to begin again until they could be in assurance that the excavations & the hillside were going to stay in place. So slope indicators - inclinometers - were installed in a number of places along there so that they could chart whether the thing had moved. Once they demonstrated they they could hold it up, the insurers allowed construction to proceed. One of the things that they did not realize at the time - they thought that the clay would be nice blocks of hard clay - but in reality there were many joints & fractures in the clay, & also that there was a montmorillonite layer in there, from the upper weathered surface of the Olympia Beds. Don Mullineux has written a paper - he got samples from some of the places on Capitol Hill & found out that it was Montmorillonitic. They were able to put that in & essentially the upper side of 1-5 is held up by about 10 foot diameter concrete cylinder piles. Now, we come along 40 years later & we want to build a tunnel from there all the way to there, & the question is how in the world to do it. We looked at this route - in fact, people are still looking at it - as a possibility along Eastlake, but of course, there is too much stuff there already. So really, the only reasonable way - it is not reasonable from the standpoint of money - but the only easy way to do it is to go underneath. We started off by drilling holes on half-mile intervals all the way from downtown to the University district & then with several other holes in Portage Bay. The second stage involved 1000 foot centers, & then we finally got down to about 300 to 400 foot on center for the drill holes. You can see - page 14 - this is a simplified version of the stratigraphy as you look at it from the west to the east. One of the really interesting things is under St. Mark's Cathedral. Right under there, & also just to the north of there, you can see - the blue is glaciolacustrine silt & clay - how the two large cut & fill structures go all the way through the hill, as can be seen on a shaded relief map. You can line those up with the Interlaaken gulleys to the east. That is also where most of the land sliding is occurring - in those gulleys below St. Mark's Cathedral. So we have a pretty dam good idea that these things go all the way through &, in fact, in trying to find an alternate route, after we realized that we had this big bathtub of a cut & fill structure - we drilled another hole to the east to see if we could get around this thing, because in tunnelling, the best thing to be in is the dry, hard clay so you do not have to deal with groundwater or ravelling sediments. We couldn't get around it, & then we noticed that there was an east-west extension. There are multiple events, too. So the question is, "What in the world happened here?" Heck, I don't know - that is the real answer & I am open to any brainstorm that you may have. Of course, the possibility is that the ice was banked up against here & maybe there was something coming through -some kind of a channel, lateral drainage around the end of it - but it appears that it happened not only twice in two places, but multiple times in the same place. So there is something strange going on here. You have things cutting across here, but then you also have this anomaly of this lowland - the whole ship canal through this NW-SE direction, which also line up with a lot of lineaments around. We found, from looking at the Portage Bay Area is that one of the problems of trying to get underneath Portage Bay is to get underneath the trough. We could not put in any kind of a sunken structure because of the fish. So, it had to go underneath, & it had to go underneath in glacially overconsolidated soils. So that means that it is tougher to get up to the first station - the Pacific Station -as you head north up into the U. District. You cannot come up real fast & have a shallow station because the sediments there are all [??] - they are silty-fine sands & fine sandy-silts that are water-bearing & it is the worst kind of tunneling ground there is. So the idea is to stay low & try to stay [in the glacially over consolidated soils]. The other thing that you can see here is the Vashon Till-Like Deposit - it is kind of a lime green - there is a whole bunch of it on the north side of Portage Bay. In looking at the sediments, not only in specific core samples, but looking at the big picture, it is the exact same stuff that you find on the lee side of Queen Anne. It is almost as if on the lee sides of these hills, you are getting reworking, where there is less pressure. I do not know whether that is the case for sure, but it is a coincidence. You will also see, if you look at Perkins Lane, that is also where you get these reworked, till-like deposits - that is on the lee side, too. It has an engineering significance in that you think you are looking at till, but it really isn't; it has engineering characteristics that enable it to leak water - it is not impervious & also, if you want to re-use it, it is generally fairly wet because it has wet stringers in it. So it has problems that a regular till does not have. From my standpoint, any time you find till more than about 30 feet thick, you must question whether it is really till or whether it is some other, till-like deposit. One other thing: In looking at the geology of Capitol Hill, I was struck by the fact that the core of that hill is made up largely of very old glacial & non-glacial soil. A lot of it is non-glacial. It appears that the outer edge - it is almost as if the Vashon deposits are plastered up against & around this core of really old stuff. You can see this as you do corings that come down off the Hill at the south end. So it is not layer cake, as we used to show in profile, assuming that the whole Hill is made up of layers. You see it on one side on the outside - the Vashon lacustrine deposits, & you see them the other side, but they do not go through. They are just plastered on the edges. Same thing with the sand - the sand is on the side & then wraps up on the top, but it does not go all the way through. That might also account for some of the deep-seated sliding that we got, in that it is more of a rind peeling off than a typical large-unit failure. There is near-vertical till in the Montlake Cut - in fact, you can see the near-vertical cuts in the old photographs of the Montlake Cut. The other problem is the Physics Lab at the University of Washington. So this is a way to get around the Physics Lab, but it also meant that if you went around by Montlake, then you have to come up right underneath the whole campus, [from the audience: "That is hallowed ground!"]. Yes, and also it added a lot of footage to the tunnel, too. But it did not have to be as deep because it required just minimum burial. [Why not use the Eastlake Route?] Because of the grades. Also, there was a political problem. One of the whole things from the start was that they wanted to serve the two largest concentrations of riders in the whole Metro System: the University District & Capitol Hill. The thing is, that if they ever want to connect there to there, & use just Eastlake, then they do not ever pick up Capitol Hill. Of course, one of the things that is crazy is that the whole thing ends in the middle of the U. District. That is hard to justify, but they do not have the money.

We were able to get dates. Paleosol is a buried soil unit that

has organics in it, by means of which we were able to date many of these soil horizons throughout the Hill. The paleosols act as good marker beds. They are Olympia age. We did find some older ones & they were, of course, \preglacial?]
BOOTH: I would like to call your attention to the topography here & remark on the fact that if you fill in the holes with your eyes, there is a remarkable landscape level - & it is not perfect, & it certainly goes down, but it does not go up much above that level. While you are at it, you might also note that it is not a completely filled-in plane because there are big holes in the way, like Lake Union, Lake Washington, Puget Sound & a few other minor discontinuities. But by & large, when the ground comes up, it comes up to a particular elevation & then it stops. If we were to see more today - if the clouds were not here, we would see that there is more topography, but in every instance, that higher topography is bed rock. There are the Newport Hills, the Cascade Range, the Olympic Mountains - bed rock. What we are seeing here is something else - we will just kind of leave it at that. Now we will go over to the other side of the hill [North Beach of Discovery Park].
[After bushwhacking through dense alder we came to a startling abrupt escarpment, 30 feet or so high, capped with pavement of an abandoned street].
BOOTH: The other side of this road is at that other chain-link fence, not unlike the one here [at least 150 feet away}. The road used to have a little dip in it. I do remember that little dip. That little dip got bigger from year to year &, as I recall, it finally got to the point where the road was cut somewhere out in the middle there. Golly, I am trying to remember which set of landslides - it might have been 1990, January. The really exciting removal of the road was in the 1995-97 winter. It has expanded modestly since then. This is a head scarp that was previously cut into till. I think it is very likely, although I have never really gotten up close & personal with it, it seems likely that it is water reworked & has more quasi-fluvial features along the lines of what Bill described earlier & that we will see, over at Perkins Lane as well. It is a fairly thick deposit. There are a few spots behind us where you can see it fairly up close. It is a bit sandier - it has more lenses scattered through it than we see in much of the till that we see around here. I would guess that it has a fair amount of drenching [?] in it as well that has helped support the head-cutting. Underneath, the till is overlying the advance outwash sand & the sand is overlying the Lawton Clay, so the basic mechanism for land sliding is undermining of this till by failure of the advance outwash sand. That is occurring because ground water percolates down through these uplands, mainly in areas of Magnolia that do not have a till cap - & that is the vast majority of Magnolia. Even where there is a till cap, it does have a finite permeability - in round numbers about 12 inches a year. Over time you can move a lot of water through a large area if it stays saturated during the year. As that water percolates down through the sand, it perches on the clay. Rising water tables mean rising buoyancy forces, which means that the sand is making less grain to grain contact, becoming weaker & able to fail. So what we see is the typical failure mechanism in this part of the world - sloughing & block glide of the sand over the clay, not because it has been lubricated, but because it has been buoyed up by higher pore water pressures which mean lower effective pressures - grain-to-grain failures. The sand migrates over the clay, then disintegrates & slops away. That process leaves both a bench at the top of the clay because the sand is retreating backward more rapidly = = =

I RAN OUT OF TAPE