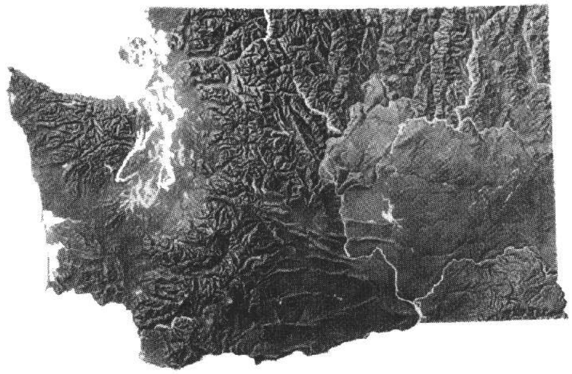
NATURAL RESOURCES



WASHINGTON GEOLOGY

VOL. 24, NO. 3
SEPTEMBER 1996

INSIDE THIS ISSUE

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

WASHINGTON GEOLOGY

Vol. 24, No. 3
September 1996

Washington Geology (ISSN 1058-2134) is published four times each year by the Washington State Department of Natural Resources, Division of Geology and Earth Resources. This publication is free upon request. The Division also publishes bulletins, information circulars, reports of investigations, geologic maps, and open-file reports. A list of these publications will be sent upon request.

MAIN OFFICE
Department of Natural Resources
Division of Geology
and Earth Resources
PO Box 47007
Olympia, WA 98504-7007

Phone: (360) 902-1450
Fax: (360) 902-1785

Internet Connections:
Library:
cjmanson@u.washington.edu
rcgg490@wadnr.gov
Subscriptions/address changes:
JHGG490@gwgate.wadnr.gov

(See map on inside back cover for office location.)

FIELD OFFICE
Department of Natural Resources
Division of Geology
and Earth Resources
904 W. Riverside, Room 209
Spokane, WA 99201-1011

Phone: (509) 456-3255
Fax: (509) 456-6115

Publications available from the Olympia address only.

Copying is encouraged, but please acknowledge us as the source.

Printed on recycled paper.
Printed in the U.S.A.

Cover Photo: Dan Scamporlina, a landscape architect with DNR, investigating the proposed location for the Capitol Trail. Because of the landslide on this slope, the trail has been relocated to the north. See related article on p. 3 and photos on p. 6, 12, 13, 14, and 15.

Washington Seismic Safety Subcommittee Organized

Raymond Lasmanis, *State Geologist*
Washington Department of Natural Resources
Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

Effective in 1995, the state legislature created the Emergency Management Council (RCW 38.52.040). According to this legislation, the council shall advise the governor and the director of the Emergency Management Division, which is now part of the State of Washington Military Department. The council, chaired by Chief Annette Sandberg, Washington State Patrol, may appoint committees, subcommittees, and working groups to develop specific recommendations. In addition, the governor is to receive an annual assessment of statewide emergency preparedness including, but not limited to, progress on specific efforts to mitigate and reduce hazards. As part of the assessment, information about progress on implementation of seismic safety improvements is specifically requested.

During a council meeting on June 13, 1996, a Seismic Safety Subcommittee was established, and State Geologist Raymond Lasmanis was appointed as chair. The chair was instructed to form a multidisciplinary committee of about 12 members "who shall provide policy recommendations" and act as advocates for seismic safety issues. This committee shall also provide to the Emergency Management Council an annual assessment of statewide implementation of seismic safety measures.

A prospective membership list is being prepared by the chair in conjunction with staff of the Emergency Management Division. The members will represent geology, seismology, emergency response, local government, structural engineering, lifelines (utilities/transportation), private industry, state government, health care, insurance, and education, among others.

Once its members have been appointed by the council, the first task of the subcommittee will be to review progress made on recommendations produced by the Seismic Safety Advisory Committee to the legislature on November 27, 1991, and published by Department of Community Development on December 1, 1991, as "A Policy Plan for Improving Earthquake Safety in Washington".

The next meeting of the Emergency Management Council is scheduled for September 19 at Camp Murray. ■

Northwest Mining Association Annual Meeting

The Northwest Mining Association's convention and international exposition will be held December 3–6, 1996, at the Spokane Convention Center. The meeting's theme is *Mining and the environment—New directions*. Two short courses are offered: Introduction to Geographic Information Systems (GIS), December 2; and OSHA Construction Safety and Health Course, December 2 and 3. For more information, contact the association at 10 N. Post St., Suite 414, Spokane, WA 99201-0772; *phone:* (509) 624-1158; *fax:* 623-1241; *e-mail:* nwma@on-ramp.ior.com.

The Upside of the Landslides of February 1996—Validating a Stability Analysis of the Capitol Campus Bluffs, Olympia, Washington

Wendy J. Gerstel
Washington Department of Natural Resources
Division of Geology and Earth Resources
PO Box 47007; Olympia, WA 98504-7007

INTRODUCTION

Geologists are often asked to make predictions about the nature of and potential for a particular geologic hazard. Rarely do they have the good fortune to have their predictions tested and validated within a short time. The storm of February 1996 provided just such an opportunity.

In 1992, as part of the Master Plan for developing the Capitol Campus and Heritage Park, the Engineering and Architectural Services Division of the Washington State Department of General Administration (GA) contracted with the Division of Geology and Earth Resources (DGER) to do a geotechnical investigation of the Capitol Campus and the surrounding bluffs.

A stability analysis of the Capitol Campus bluffs is crucial to building safe access from the campus down to Heritage Park and Capitol Lake along the proposed Capitol Trail. GA requested information on the stability of the natural bluffs as well as the fill beneath the greenhouse/conservatory structures, the location of thick soil accumulations and construction waste that might be unstable, and the location of springs and seeps that might also contribute to slope instability.

The investigation included examination of airphotos covering the years from 1965 to 1994, detailed geomorphic mapping, compilation of existing borehole data, soils testing, and computer-aided slope stability modeling.

Additional information was obtained from five new boreholes drilled at or near the bluff's edge by the Washington State Department of Transportation (WSDOT). The purpose of the drilling program was to gain a better understanding of the subsurface stratigraphy, ground water, and geotechnical conditions. With this array of information, I developed cross-sections to facilitate the geologic interpretation. Soil parameters used in the computer modeling were developed from the information acquired through field observations, drilling, and soils testing.

The report to GA (Gerstel, 1996) was nearly finished when a rain-on-snow storm event struck the Pacific Northwest from February 5 through 8. In four days, 8 in. of rain fell in the Olympia area on ground already saturated by exceptionally wet weather. The resulting slope failures along the Capitol Campus bluffs provided examples of and insight into failure mechanisms predicted by the study.

LOCATION AND SITE CHARACTERISTICS

The Capitol Campus lies on a fairly level surface about 110 ft above mean sea level (Fig. 1). Bluffs form the north and west boundaries of the West Capitol Campus. The steep bluffs fall within designated 'Landslide Hazard Areas' and 'Seismic Hazard Areas' under the City of Olympia's Critical Areas Ordinance. Wetlands occupy an area at the base of the slope between the Temple of Justice and the GA building. At the base of the north-facing slopes is a flat surface about 50 to 200 ft wide on which are several sets of railroad tracks, a gravel road to the steam plant, and a foot path. This surface is underlain by fill emplaced late in the last century and early part of this century (hatchured area in Fig. 1).

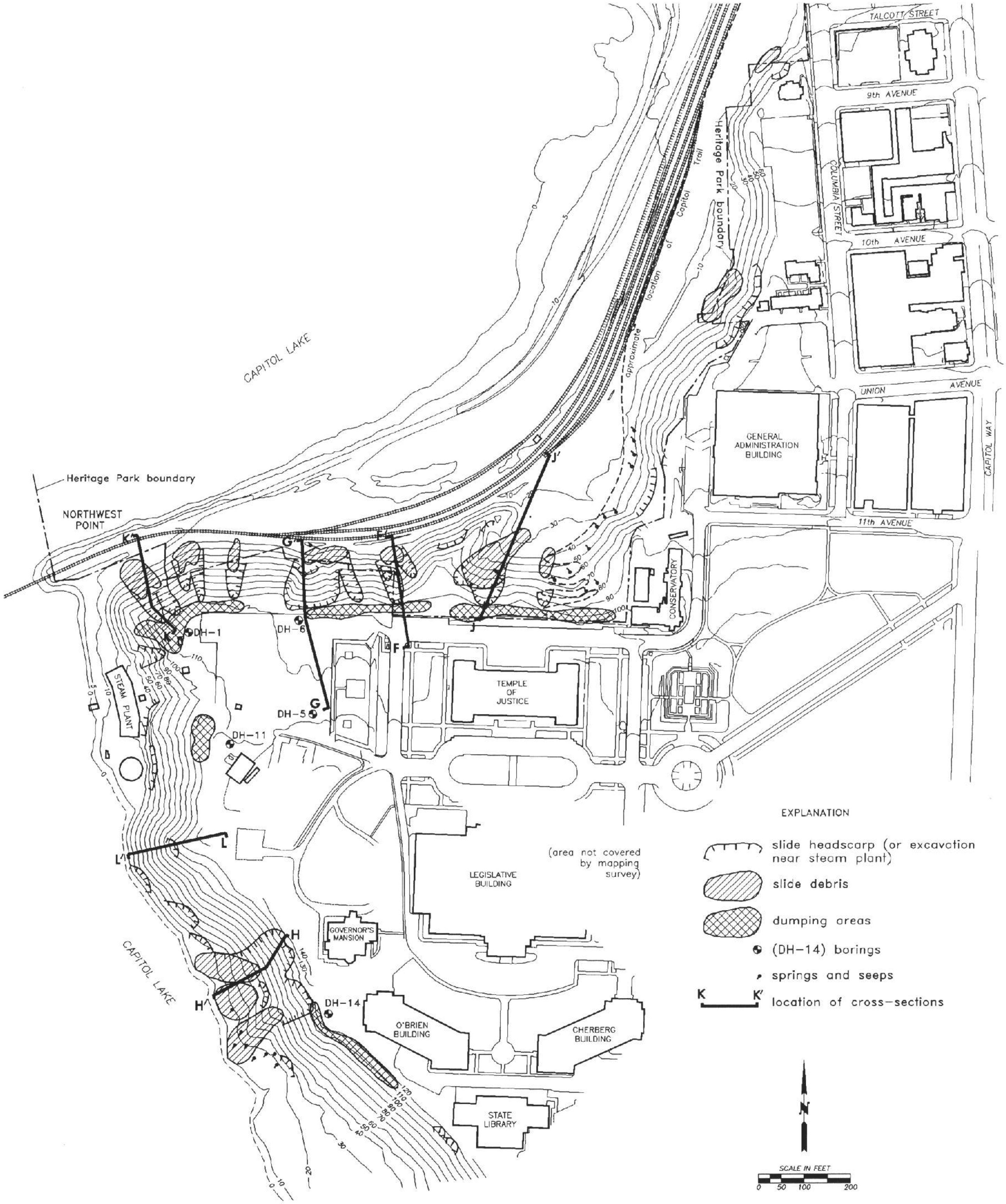
Thorson (1980) and Booth (1994) propose that during the later stages of Puget Lowland glaciation, subglacial meltwater streams cut channels into older glacial and nonglacial sediments, forming Budd Inlet and other local waterways, including the lower Deschutes River valley. Capitol Lake, formed by damming of the lower reach of the Deschutes River, is maintained at a constant pool elevation by a tide gate at its north end where it empties into Budd Inlet. The bluffs surrounding the campus, and along other parts of Capitol Lake and the shoreline of much of Budd Inlet, expose the sequence of glacial and nonglacial sediments that are prone to slumping, surface soil slips, and landsliding, even under normal winter conditions.

Since the retreat of the Puget ice lobe approximately 13,000 years ago, the slopes of the Capitol Campus bluffs have been modified by landsliding, stream erosion and surface runoff, and, more recently, artificial loading of the slopes with construction and organic waste. The west-facing slopes have also been undercut at the toe by the Deschutes River and, since the creation of Capitol Lake in 1959, by wave erosion. Development of the Capitol Campus facilities has modified surface and ground-water conditions (Ritchie and Cashman, 1959), affecting slope stability. Furthermore, a thick, dense silt unit at approximately 60 to 75 ft elevation perches water, saturating the overlying sediments and contributing to the instability.

In profile, the bluff slopes are typically concave in their upper portions and convex and hummocky in their lower portions. However, in contrast, the slopes immediately south of the power plant are markedly convex in profile from top to bottom, suggesting that this area has not yet experienced much large-scale landsliding. Most upper concave slope areas expose sediments or thin (2–4 ft) soil mantle. The lower slopes are mantled by about 4 to 10 ft of failed soil or slide debris. This soil mantle readily becomes saturated and remobilized downslope and is wet throughout much of the year.

Slope gradients along the campus range between 70 and 100 percent (35°–50°), but some exceed 170 percent (~65°). There is abundant evidence of repeated historic soil slips and small translational and rotational slope failures. Construction

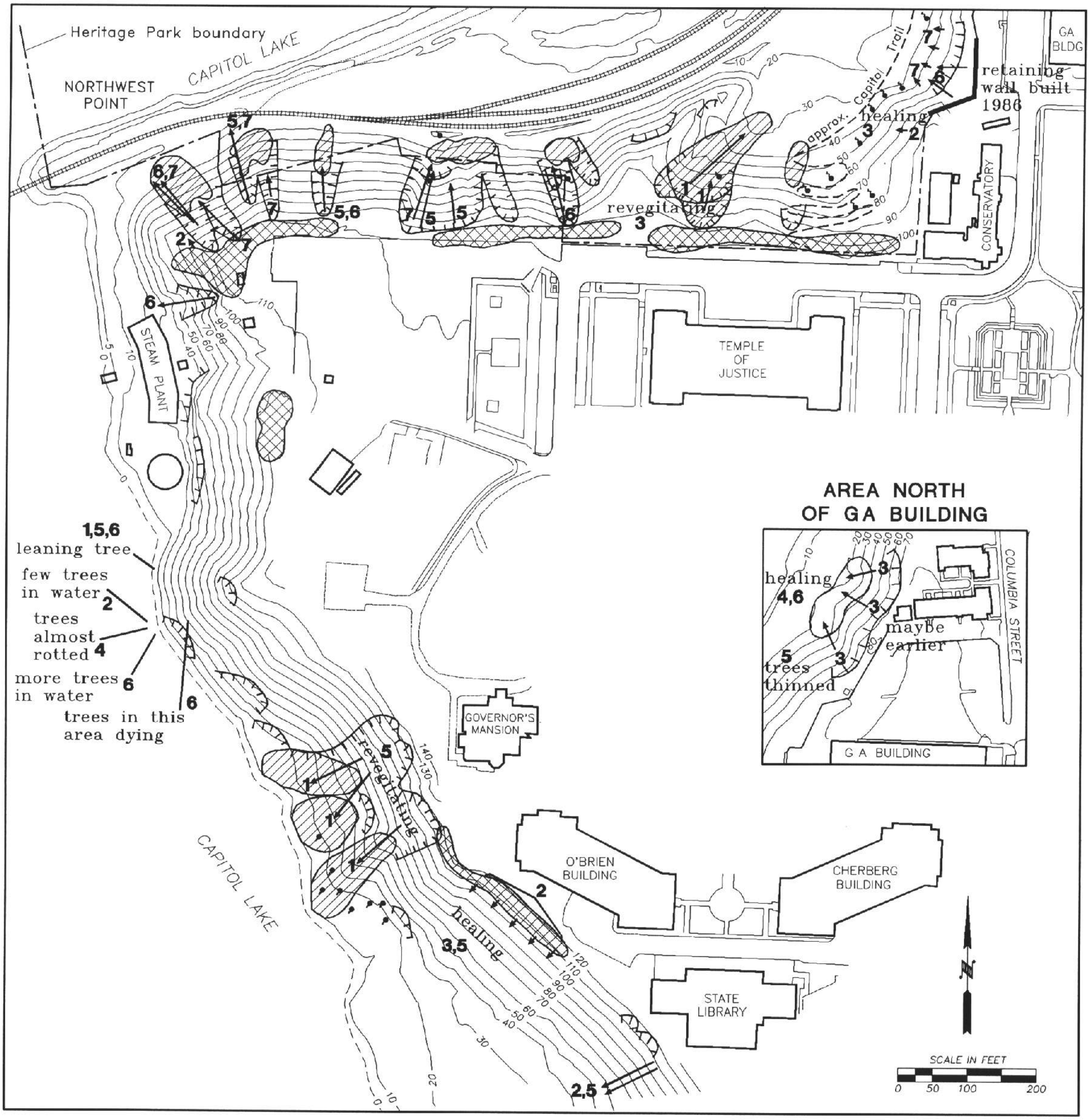
Figure 1. Location map of the Capitol Campus in Olympia, WA, showing landslide locations, landslide chronology, and cross-section locations.



Chronology of landslide activity visible in airphoto coverage

1 – 1965 photos – pre–1965; slump–earthflows west of Governor's Mansion
2 – 1972 photos – '65–'72; shallow debris slides, creep; about 4 slides per 1/2 mi of bluff
3 – 1978 photos – '72–'78; general period of recovery
4 – 1981 photos – '78–'81; no new activity
5 – 1985 photos – '81–'85; slides active east of the northwest point, about 1 slide per 100 ft localized
6 – 1989 photos – '85–'89; about 5 slide areas per 3/4 mi of bluff
7 – 1995 photos – '89–'95; activity around and east of northwest point

7 – Arrows indicate direction of failure; number coding corresponds to airphoto sequence



material and organic debris have been sidecast from the edges of the bluff, especially from the northwest point of the campus (Fig. 1), making these areas particularly unstable.

The large slump-earthflows on the slopes adjacent to the Governor's Mansion have steep headwalls with hummocky slide debris at the base. Over the years, these failures have formed debris fans that extend into Capitol Lake approximately 20 ft beyond the former shoreline (Fig. 1). Springs and seeps are visible in the headwall areas and at the base of the slope in the slide debris. Slope movement in this area has probably been sporadic, with different portions moving at different times. This makes it difficult to determine the age(s) of movement.

SITE HISTORY AND AIRPHOTO REVIEW

Historic airphotos show multiple slope failures along the bluffs over the past 30 years, allowing estimates of timing, frequency, and rates of revegetation. (A list of the seven sets of 1:12,400-scale photos for various times from 1965 to 1995 used in this study is given in Gerstel, 1996). Airphoto analyses, field observations from 1992 to 1995, interviews with long-time Capitol Campus employees, and a search of historical records identified numerous slope failures along the bluffs (Fig. 1). The two largest of these occurred just north of the Temple of Justice and west of the GA building. Both cut into native soils and may have been initiated by heavy rainfall and inadequate drainage systems, coupled with loading of the slopes by fill or sidecast construction debris and organic material. The failure near the GA building occurred in 1986 and was mitigated by a retaining wall (Fig. 2). The failure in front of the Temple of Justice occurred in the winter of 1958/59 and required modification of the adjacent parking area. A drainage system and buttress proposed and designed for the latter were never constructed.

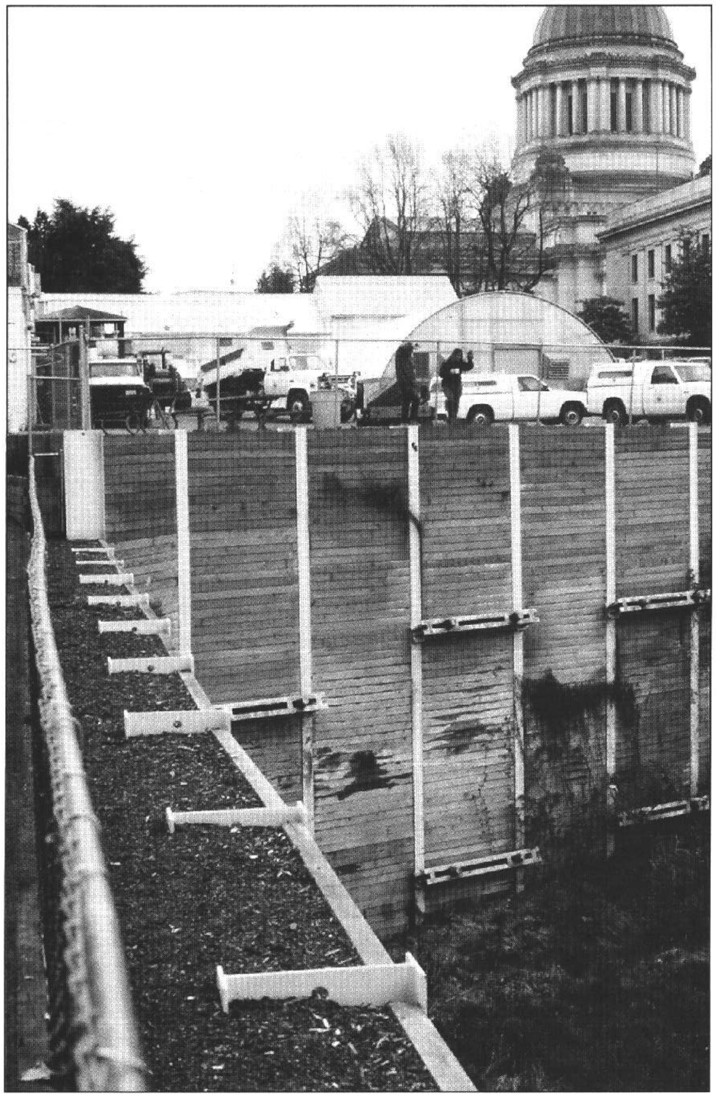


Figure 2. Retaining wall below the GA parking lot, with the State Capitol in the background. This retaining wall was built in 1988 to prevent continued headward landsliding of native bluff soils. An inclinometer at the base of the slope below the wall, however, shows some movement has occurred in the upper soil layer of the lower part of that slope. (View is to the southwest.)

Field observations and airphoto review show that localized soil slips, translational failures, and small rotational failures have occurred along the bluffs in an area north of the GA building and west of a private apartment building and from the area north of the Temple of Justice to the north side of the steam plant. In 1990, the north and west sides of the northwest point of the bluff failed as large debris slides. The slides buried the railroad and damaged the northeast corner of the steam plant. Both failures were almost certainly initiated by loading of the slope with construction waste, predominantly large blocks of concrete, poured concrete, and rebar (Allen, 1990).

From the steam plant southward for approximately 120 ft along the convex west-facing bluffs, there is little evidence of debris slides. There has, however, been persistent soil creep and small-scale slumping, especially along the lower part of the slope within about 25 ft of the lake (Fig. 3). Airphotos show stressed vegetation and toppled trees in the area of active slope movement, particularly since 1985. The upper part of the slope shows evidence of at least one small rotational slump (near sec. LL′ on Fig. 1). West of the Governor's Mansion is an area where larger rotational failures and debris slumps and slides occurred prior to the 1965 photos (Fig. 1), but it showed signs of continued periodic activity in subsequent airphotos.

South and west of the John L. O'Brien Building, the bluff slopes are now stable, but the gradient is unusually uniform and appears to have been modified at some time in the past.

Figure 3. View northeast from Capitol Lake to the convex slope south of the steam plant. Note leaning trees along the lower portion of slope; these indicate ongoing soil creep. This is the approximate location of section LL′ in Figure 1.

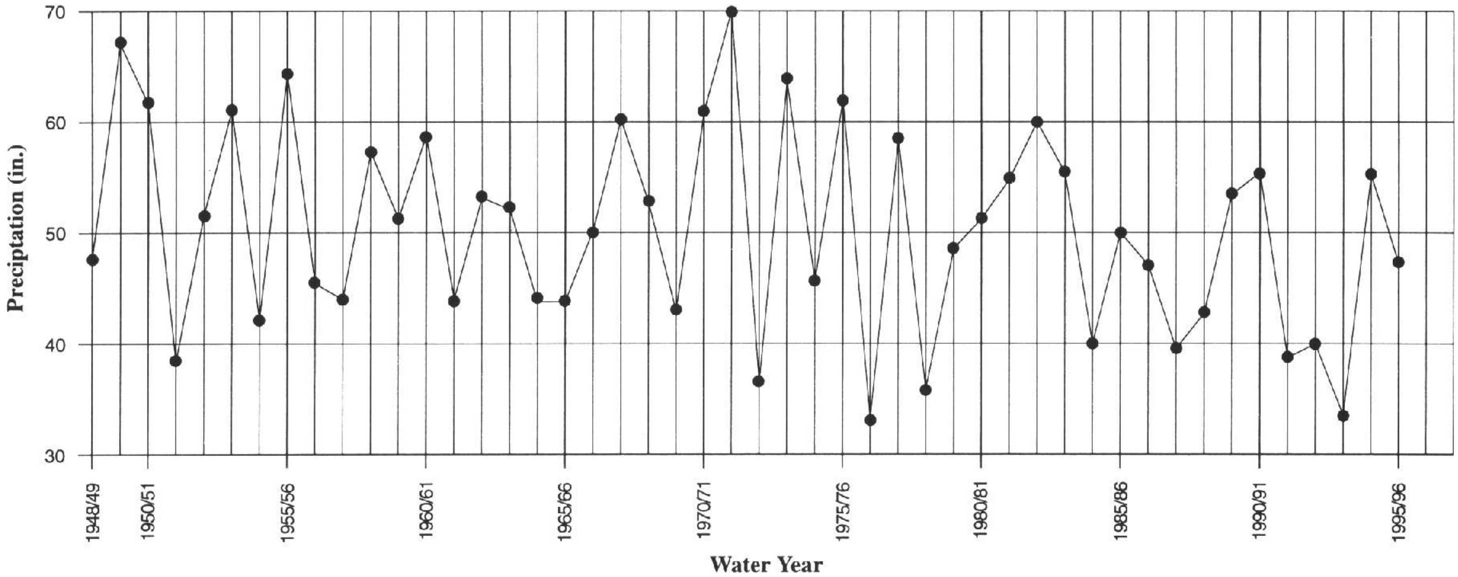


Figure 4. Precipitation record for the Olympia Airport plotted in water years (Oct. 1–Sept. 30).

The 'healing' designation in this area on Figure 1 denotes areas where vegetation had been disturbed, but it was unclear from the airphotos whether landsliding had actually occurred. Recent dumping of organic waste could eventually destabilize a portion of the slope. South of this area, west of the state library, are some additional small debris-slide scars that appear in airphotos to be relatively recent (<20 years) because of their young cover of vegetation.

Although mitigation measures were proposed for certain areas of the bluff (Ritchie and Cashman, 1959; Jordan/Avent and Associates, 1972?), the only reach of the bluff that received any constructed stabilization is the area west of the GA building where the retaining wall was built (Fig. 3).

Figure 4 shows precipitation records from the Olympia Airport for 1949 to 1993. Dates on Figure 1 show that periods of high landslide activity were concentrated from 1965 to 1972 and 1981 to 1995 (particularly 1981–1985), corresponding to the generally higher amounts of precipitation from 1968 to 1972 and from 1980 to 1984. Likewise, low landslide activity seems to correspond to the lower precipitation recorded between 1972 and 1980.

Correlating the slide activity of the late 1980s to the precipitation record is more difficult. In spite of generally lower-than-average precipitation recorded for these years (average ~50 in./yr), there is a general increase in the landslide activity. This lack of correlation may be due to some or all the following: increased surface runoff caused by paving, poor drainage from the campus, plugged storm drains, and sidecast organic and construction debris. The 1995 airphotos are most likely chronicling the landslides resulting from the severe storms of 1990. Most of these landslides were centered around the northwest point.

SITE GEOLOGY AND RESULTS OF THE DRILLING INVESTIGATION

The glaciofluvial and glaciolacustrine sediments exposed in the slopes adjacent to the Capitol Campus range from coarse sandy gravels and cobbles to fine sands and silts. The complex history of erosion and deposition of the glacial deposits, in particular the Vashon recessional fluvial and lacustrine deposits, is evident in the complex stratigraphy penetrated by the borings along the bluffs and elsewhere on the Capitol Campus (Fig. 5).

Correlation of the stratigraphy among the five holes drilled to investigate the native soils of the bluff is difficult, even though no two are separated by more than 600 ft. The unit that can be correlated with the most confidence, although its thickness varies, is the medium-dense laminated silt in which blow counts range from 20 to 30 blows per foot. The top of the silt unit is at about 52 ft above sea level (a.s.l.) in boreholes DH-5 and DH-6 and at about 90 ft a.s.l. in borehole DH-14 (Fig. 1). The silt is exposed in several places along the bluffs (secs. FF′ and GG′). (Gerstel, 1996, contains information about all sections.) Correlation between the borings and the bluff exposures is tentative because the upper contact of the silt unit is exposed in the bluffs at approximately 65 to 70 ft a.s.l.

The silt unit was probably deposited in a proglacial lake associated with the onset of the Vashon glaciation or may have been deposited by slightly earlier nonglacial low-energy streams. The question remains whether the silts are inset deposits or extend laterally well east and south of the bluff edge. In most holes, underlying the laminated silts is a dense coarse gravelly unit.

Very little water was detected during the drilling. Open standpipe piezometers were installed in borings DH-1 and DH-5 (Fig. 1) to determine the regional ground-water table and locate perched water. DH-1 was completed with one piezometer extending to a depth of 103 ft. DH-5 was completed with two piezometers, one extending to 109 ft, the other to 80 ft. Water levels in DH-1 have read consistently at about 101 to 102 ft below the surface (or about 7 ft a.s.l.) from mid-1993 through 1995, probably reflecting the regional ground-water table controlled by Capitol Lake. The deeper piezometer in DH-5 is apparently also reading the regional ground-water table at about 100 ft below the surface (or about 10 ft a.s.l.).

Damp to wet samples were recovered from depths of 34 ft and 14 ft in DH-6 and DH-14, respectively. These correspond to zones of iron staining, suggesting a fluctuating localized, possibly perched, water table at these depths.

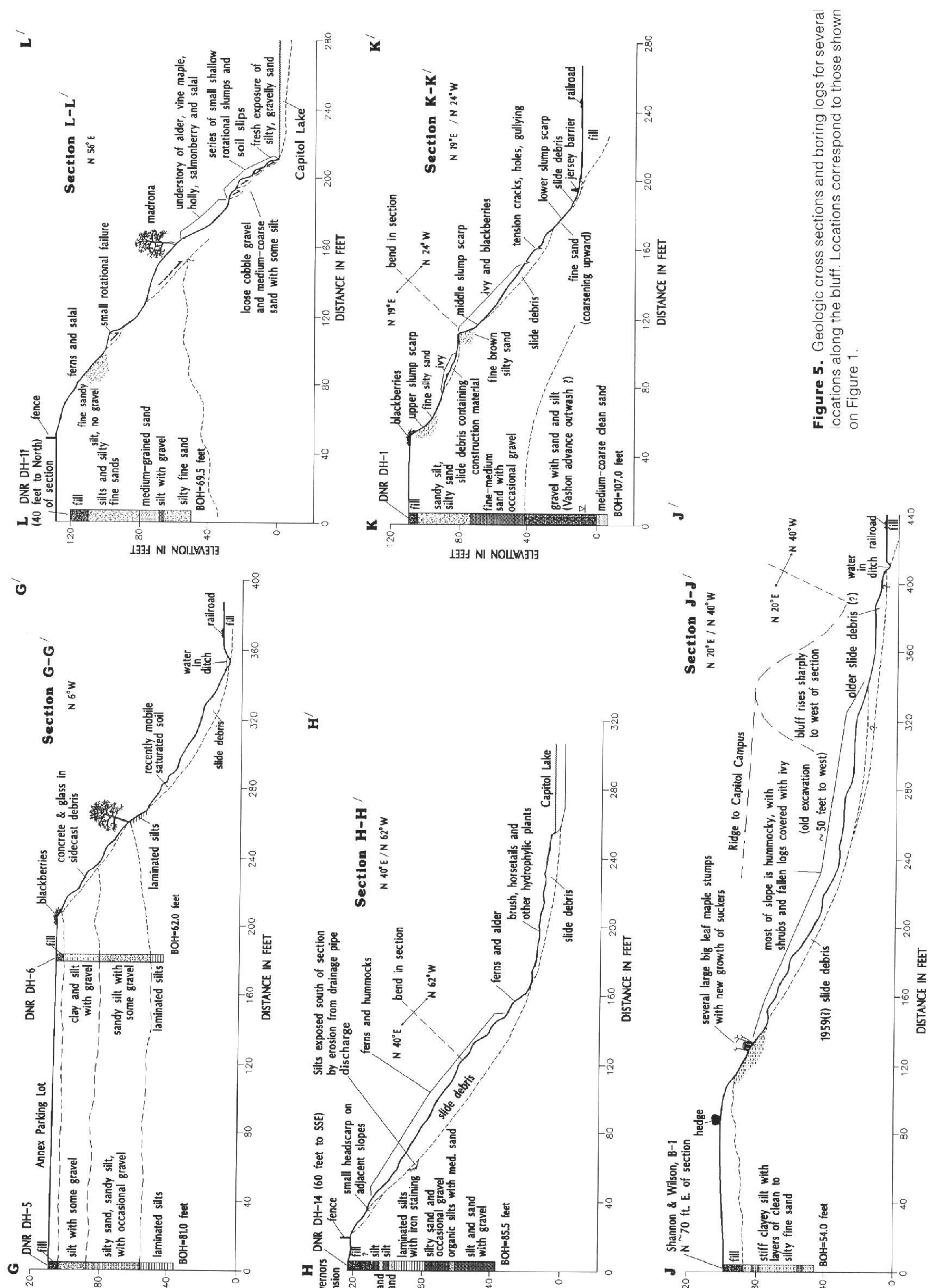


Figure 5. Geologic cross sections and boring logs for several locations along the bluff. Locations correspond to those shown on Figure 1.

Borehole DH-1, drilled in 1992, was also completed as a slope inclinometer. Repeated monitoring of this inclinometer has not shown any movement to date. The lack of movement confirms field observations suggesting that slope instability is primarily a result of shallow, translational failures.

PRE-STORM SLOPE STABILITY MODELING

Field observations before February 1996, combined with the borehole data, suggested three likely mechanisms of slope failure along the bluffs of the Capitol Campus (Fig. 6A–6C). Figure 6A illustrates a simple, thin translational failure of an approximately 3- to 6-ft-thick mantle of sidecast material and (or) remobilized native soil, or colluvium. Figure 6B illustrates a small rotational slump in native soils, common on the upper slopes west of the Governor's Mansion and the mechanism of the 1959 Temple of Justice failure and the 1986 failure near the GA building. Locally these slumps transform into slump-earthflows as the soils attain residual strengths and develop excess porewater pressures. Such features are visible at the base of the slope west of the Governor's Mansion. Figure 6C illustrates a combination of these processes, in which failures are caused or enlarged by both addition of sidecast material and mobilization of native material by small rotational failures. I considered the latter to be the most likely model for the mechanism causing the instability along most of the north-facing campus bluff slopes.

To evaluate the stability of the bluffs, I used the field observations, borehole data, and soil test results in three slope stability modeling programs, applying them to the profile along section GG′. This section best represents general bluff slope conditions and shows the best correlation between bluff exposures and borehole data.

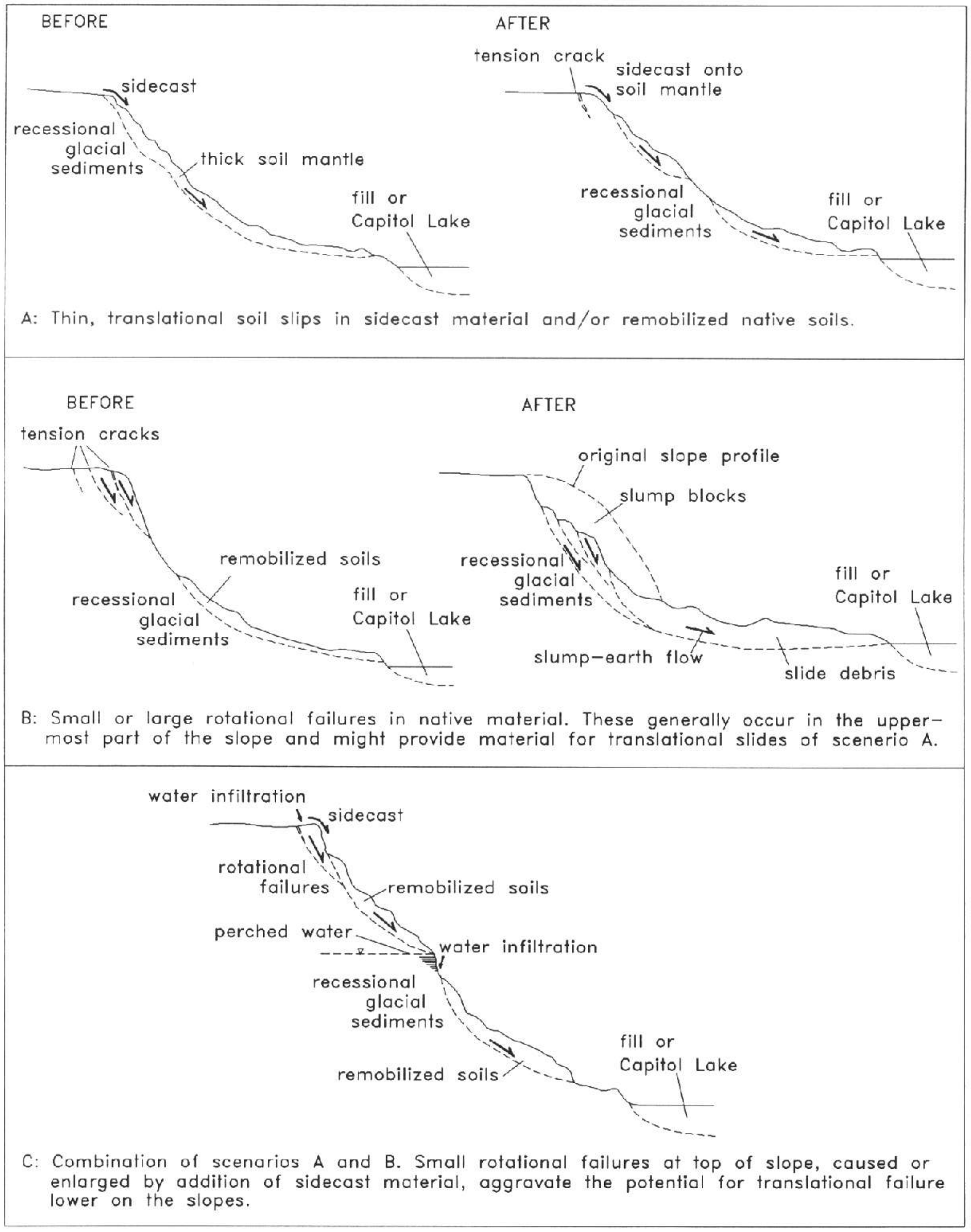


Figure 6. Schematic drawing of likely mechanisms of bluff landsliding.

Level I Stability Analysis (LISA)

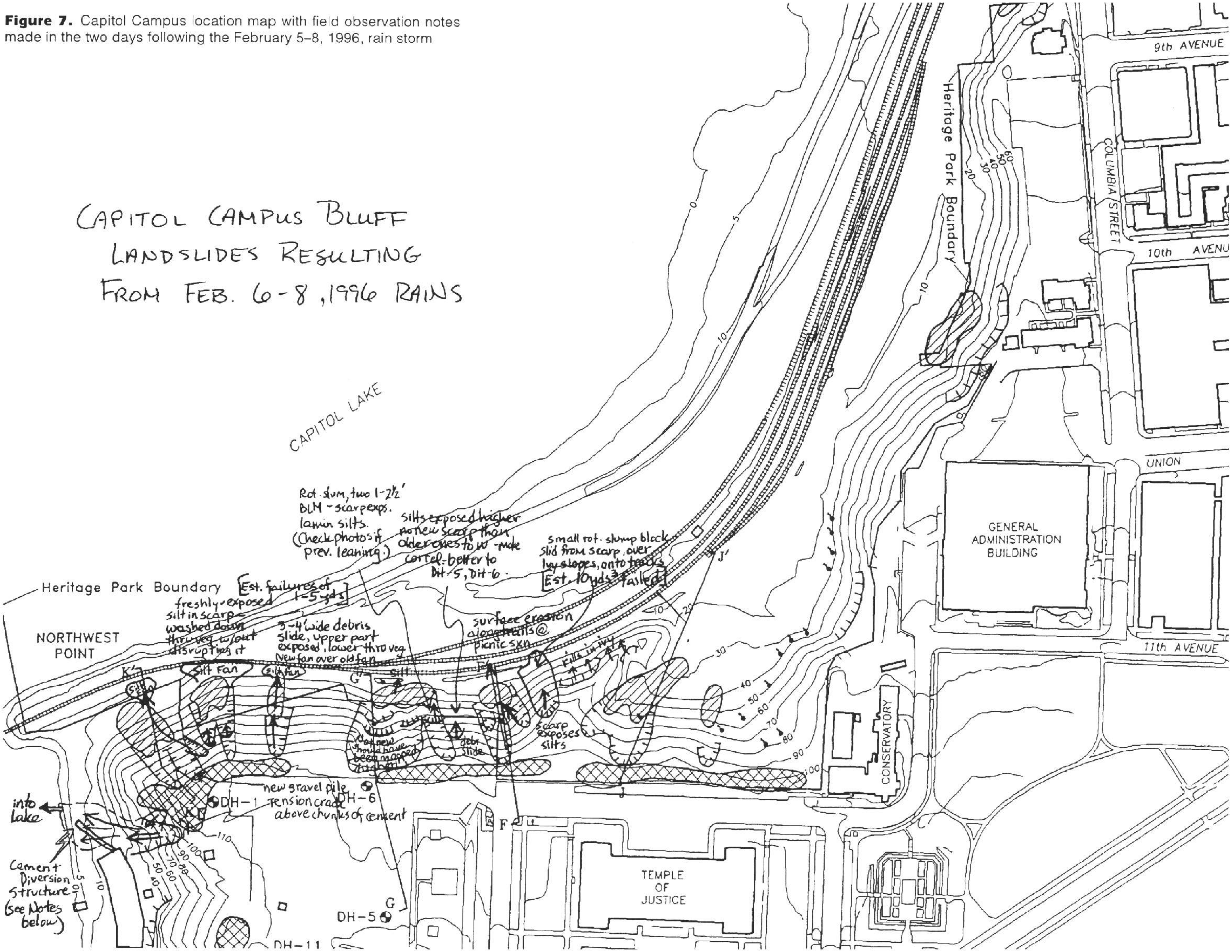
A reasonable distribution of *in-situ* shear strengths for the soils mantling the bluff slopes was back-calculated using the Deterministic Level I Stability Analysis (DLISA) software developed by the U.S. Forest Service Intermountain Research Station, Moscow, Idaho. DLISA calculates a factor of safety using the infinite slope model for a single set of input values. For these analyses, a factor of safety of 1.00 was assumed, and the failure surface was assigned to the soil mantle/in-place soil contact. The analyses looked at soil thicknesses ranging from 2 to 10 ft and ground-water depths of several inches to full saturation. A range of shear strengths with ϕ's of 20° to 27° was determined by back calculations. Shear strengths for the soil mantle in this model are considered to be residual and therefore more likely to fall within the lower end of that range. The LISA analysis does not consider the effects of stratigraphy or ground-water conditions in the slope underlying the soil mantle.

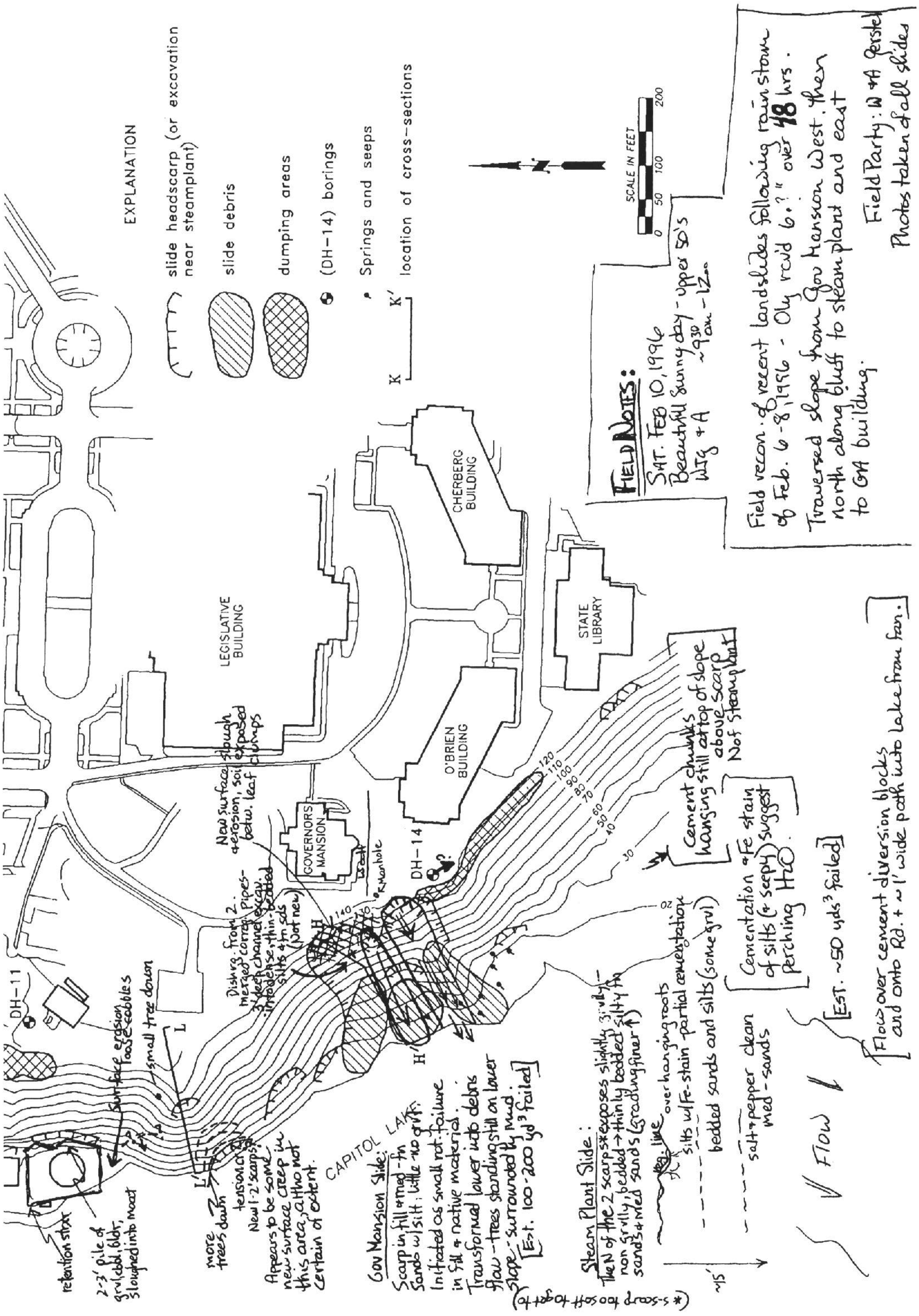
With the range of soil and slope parameters determined in the DLISA back-analysis, I used the program LISA, which uses a probabilistic Monte Carlo simulation, to model the slope for half saturation (ground-water ratio of 0.50) and full saturation (ground water ratio of 1.0). The results showed that for the factor of safety range corresponding to the determined range of soil and slope parameters, the modeled stability conditions can vary from very stable to very unstable, depending on the water content of the soil. As would be expected, the greater the degree of saturation, the higher the likelihood of slope failure.

XSTABL Analysis

To evaluate the stability of the in-place native soils or sediment, soil parameters from the LISA analyses and labora-

Figure 7. Capitol Campus location map with field observation notes made in the two days following the February 5–8, 1996, rain storm




EXPLANATION
slide headscarp (or excavation near steamplant)
slide debris
dumping areas
(DH-14) borings
Springs and seeps
location of cross-sections
K K'
SCALE IN FEET
0 50 100 200
LEGISLATIVE BUILDING
CHERBERG BUILDING
STATE LIBRARY
O'BRIEN BUILDING
GOVERNORS MANSION
CAPITOL LAKE
DH-11
DH-14
FIELD NOTES:
SAT. FEB 10, 1996
Beautiful sunny day - upper 50's
WJG + A
~930 am - 12
Field recon. of recent landslides following rainstorm of Feb. 6-8, 1996 - Oly rcv'd 6.?" over 48 hrs.
Traversed slope from Gov Mansion West, then north along bluff to steam plant and east to GA building.
Field Party: W + A Gerstel
Photos taken of all slides
retention struct
2-3' pile of grvl, cbbl, bldr, sloughed into moat
Surface erosion loose cobbles
small tree down
more trees down
New 1-2' scarps tension cracks
Appears to be some new surface creep in this area, altho not certain of extent.
Gov Mansion Slide:
Scarp in fill + med-fn sands w/ silt; little to no grvl.
Initiated as small rot. failure in fill + native material.
Transformed lower into debris flow - trees standing still on lower slope - surrounded by mud.
[Est. 100-200 yd³ failed]
Steam Plant Slide:
The N of the 2 scarps* exposes slightly grvlly, non grvlly, bedded → thinly bedded silty fn sand3 + med sands (grading finer ↑)
(* s-scarp too soft to get to)
~15'
seep line
overhanging roots
silts w/ Fe-stain partial cementation
bedded sands and silts (some grvl)
salt + pepper clean med-sands
Cementation + Fe stain of silts (+ seepy) suggest perching H_2O.
[Est. ~50 yds³ failed]
Flow over cement diversion blocks and onto Rd. + ~1' wide path into lake from fan.
FLOW
Dishrg. from 2 merged corrug. pipes - 3' deep channel excav. into dense, thin-bedded silts + fn sds (Not new)
New surface slough + erosion, soil exposed betw. leaf clumps
Cement chunks hanging still at top of slope above scarp
Not steamplant
Manhole
Seep
120 110 100 90 80 70 60 50 40 30 20
140 130

tory testing (Dames and Moore, 1965; Geolabs-Washington, Inc., 1988; WDOT, 1988; and this investigation) were applied to the modeling program XSTABL, developed by Sunil Sharma at the University of Idaho. XSTABL performs a two-dimensional limit equilibrium analysis to compute the factor of safety for a layered slope using the modified Bishop or Janbu methods. Residual strengths were used to model the soil mantling the slope, and peak strengths were used to model the in-place sediments described earlier in this report. Examples of XSTABL analyses appear in Appendix F of Gerstel (1996).

Models considered for the XSTABL analyses were set up to evaluate the factor of safety for the bluff slopes both at the soil mantle/native soil contact (Fig. 6A) and within the native soils (Fig. 6B). Five soil units were differentiated:

- soil mantle
- upper bluff unit, silt with gravel
- medium to dense to dense laminated silt unit
- basal bluff unit, gravel in sand
- fill from Capitol Lake dredgings

In the first round of analyses, XSTABL was directed to generate random searches for circular failure surfaces, looking at slightly variable strength parameters and ground-water conditions for the soil mantle. In the next round of analyses, the soil mantle was given higher (closer to peak) shear strengths, and a failure circle was specified that would force the analysis into the native soils. These runs were also evaluated under several ground-water conditions.

Results of Slope Modeling

The first round of computer modeling suggested that the bluffs are most likely to continue to fail by the processes depicted in Figure 6A or 6C. Applying residual shear strengths of $\phi = 20^o–23^o$ (or less) and low cohesion values to the soil mantle, the random-search XSTABL runs showed that failures are likely to occur most frequently at the soil mantle/native soil contact, particularly with a high water table in the soil mantle. Using shear strength values of $\phi = 24^o–27^o$ for the soil mantle, weighing the fact that some of it might demonstrate shear strengths closer to peak values, the generated critical failure surfaces commonly appeared within the native soils. In both scenarios, a factor of safety of less than 1.0 is achieved under hydrologic conditions estimated for average to high local winter precipitation. Furthermore, the stability analyses showed that only minimal increases in ground-water saturation are necessary to decrease the stability.

In the next round of computer modeling, a failure surface was specified below the soil mantle/native soil contact (within the native soils) to assess the stability of the native soils. Hydrologic conditions were modeled to represent each of the following:

- periods of low precipitation,
- surface runoff affecting only the soil mantle,
- an increase in the thickness of the perched water layer in the soil mantle (increase in groundwater concentration with controlled surface runoff), and
- heavy winter precipitation affecting ground-water concentrations in both the soil mantle and the perched water layer in the upper bluff unit of silt and gravel.

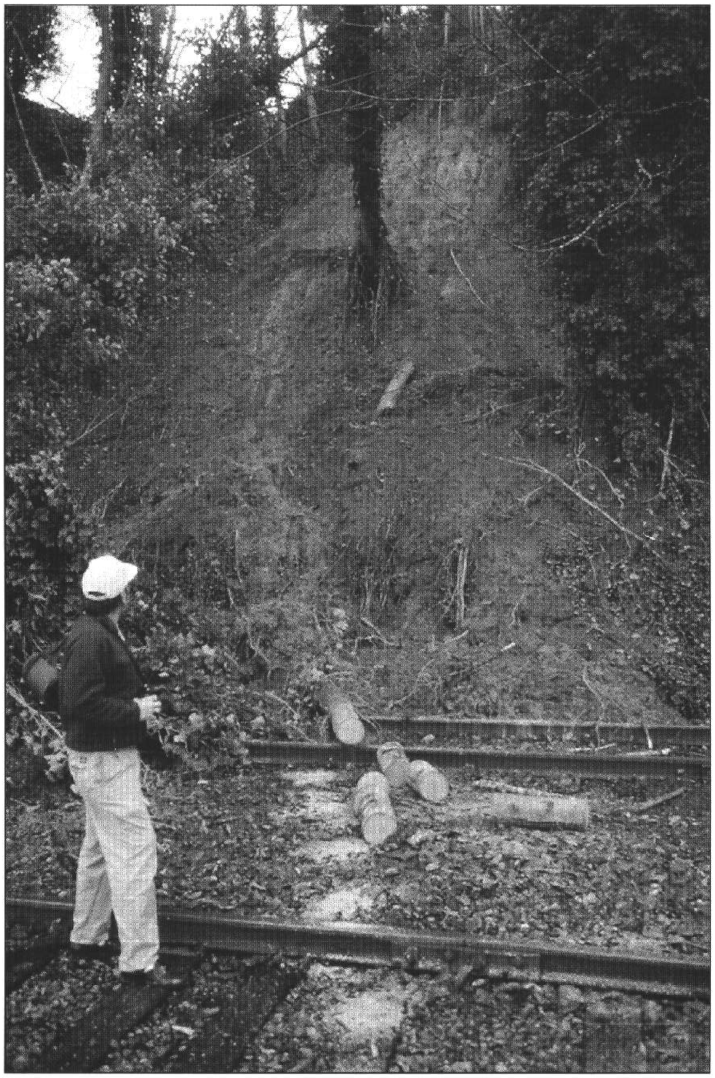


Figure 8. This debris slide is on the slope north of the west end of the Temple of Justice. It was thought to be the easternmost slide on the Capitol Campus bluffs resulting from the February 1996 storm. The slide incorporated fill and sandy sediment overlying the laminated silt unit (exposed in the upper part of the slide path), displaced a 1-ft-diameter tree, and overrode vegetation on the lower portions of the slope, finally coming to rest on the railroad tracks at the base of the slope.

These later runs illustrated conditions of low to moderate stability, with calculated factors of safety of 1.02. The last run (Gerstel, 1996) showed an unstable situation, with a calculated factor of safety of less than 1.0.

From these analyses, I concluded that under average winter hydrologic conditions the Capitol Campus bluff slopes are moderately stable to unstable. Failure of the soil mantle is more likely during times of high ground-water levels and (or) high precipitation. The slope modeling suggested that the infiltration of water into the soil mantle/sidecast, by means of surface runoff and seepage from perched water layers, is much more likely to result in slope instability than just an increase in the thickness of the perched water table(s) in the native soil material (that is, overlying the laminated silts). However, small rotational failures into the native soils, particularly in the upper portions of the slopes, would likely occur following heavy rains and (or) disturbance to the slopes such as by excavation and (or) vegetation removal.

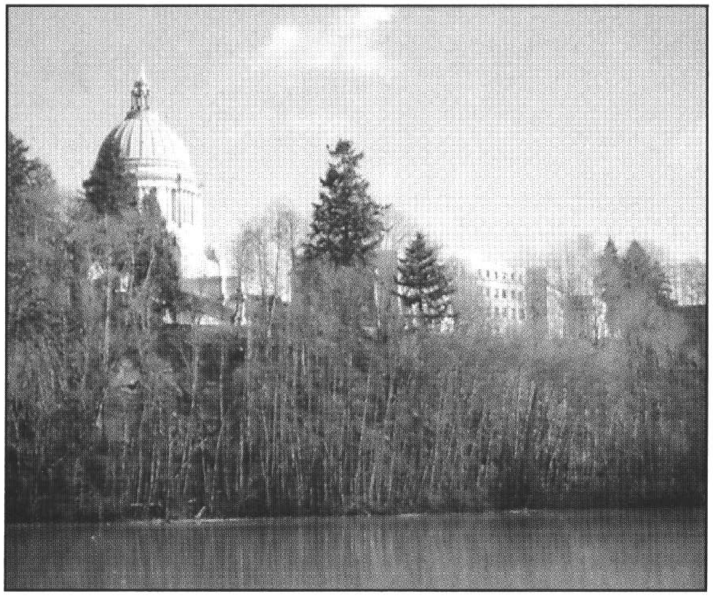


Figure 9a. View across Capitol Lake from Deschutes Parkway to the landslides that occurred behind the O'Brien building, south of the Governor's Mansion. (Photo by Matt Brunengo).

Figure 9b. View down the larger slide path from just south of the retaining wall behind the Governor's Mansion. The headscarp of the smaller slide lies to the north (right), just out of view; however, the deposition area of both slides is visible in the center of the photo. Slide material was deposited into Capitol Lake (at the top, background of the photo). These slides initiated in the unconsolidated sandy material overlying the dense laminated silt unit.

THE STORM OF FEBRUARY 5–8, 1996

The storm that hit Washington, Oregon, and Idaho during that four-day period dropped more than 8 in. of rain in Olympia. On February 8 alone, 2.75 in. was recorded at the Olympia Airport.

Field reconnaissance along the Capitol Campus bluffs on February 9 and 10 revealed several new landslides and debris flows ranging from approximately 2 to 5 yd^3 to as much as 150 to 200 yd^3 of displaced material. Figure 7 shows the locations of these landslides along with other notes about disturbances that resulted from the storm.

Some slides contained organic material mobilized with the slide debris from the upper slopes. In one or two places along the north-facing slopes, the slide overrode the ground vegetation on the lower portion of the slopes, leaving it dirty but intact. One slide (Fig. 8) initiated in the sediments overlying the laminated silt and deposited approximately 10 to 12 yd^3 of material (including a 1-ft-diameter tree) across railroad tracks at the base of the slope. The dewatering slide debris typically spread out once it reached the level ground at the base of the slope, depositing a fan of fine silt.

The largest slide occurred just to the southwest of the Governor's Mansion, where two debris flow paths were separated by about 20 ft of undisturbed slope (Fig. 9). The larger path is approximately 50 ft across and started at the top of the slope. The smaller one, to the north, is about 30 ft across and initiated about 10 ft below the top of the bluff. Both slides reached Capitol Lake and deposited sediment and large organic debris in the water. Sewer pipes and a manhole were exposed at the top of the slope between the two slide scarps. Continued headward erosion of the scarps will put these utilities at risk.

A slide of approximately 50 yd^3 occurred on the slope behind the north end of the steam plant (Fig. 10a). Here, a debris flow destroyed a fence and overtopped a 3-ft concrete diversion structure near the northeast corner of the building. At the base of the slope the debris fanned out across the access road, finally reaching Capitol Lake. The two headscarps from which the slide initiated are now critically oversteepened, and tree roots overhang the fresh slide scarps (Fig. 10b). Blocks of concrete construction waste rest precariously on the slopes above and between the scarps. Recommendations have been submitted to GA to recontour the slide head scarp to a slope gradient of 1.5:1 and buttress the slope and side scarps with quarry spall. Construction was scheduled for August 1996.

A slide of about 5 yd^3 occurred on the north-facing slope of the northwest point (Fig. 11). At the edge of the annex parking lot is a portion of a recently dumped pile of gravel. The remainder of the gravel and several large wooden wire spools rest on the slope below. The jersey barriers at the base of the slope kept the slide debris from flowing onto the access road and railroad tracks.

Reactivation of the landslide on the slopes north of the Temple of Justice probably also resulted from the February rain storm (Fig. 12 and cover photo). This reactivated slide was first noted in April 1996 during brushing for the Capitol Trail. A dense cover of ivy and slash may have hidden the early stages of this latest slope movement. This movement forced relocation of the trail to the (surprisingly) more stable ravine fill to the east.

GEOLOGIC INSIGHT PROVIDED BY THE FEBRUARY LANDSLIDES

The slope failures resulting from the February 5–8 storm show that mapping previously unstable slopes can indicate areas of future instability. Prior to February 1996, I had concluded from field observations, borehole data, and computer-assisted slope stability modeling that small failures were likely to continue occurring along the steepest portions of the bluffs. The modeling showed that these failures would be most common where a 3-to-10-ft-thick soil mantles the slope, typical along the north-facing bluff slopes. The soil mantle is easily saturated and subsequently remobilized by surface runoff and storm-water drainage discharging onto or into the bluff slopes and by recharge from seeps and springs.

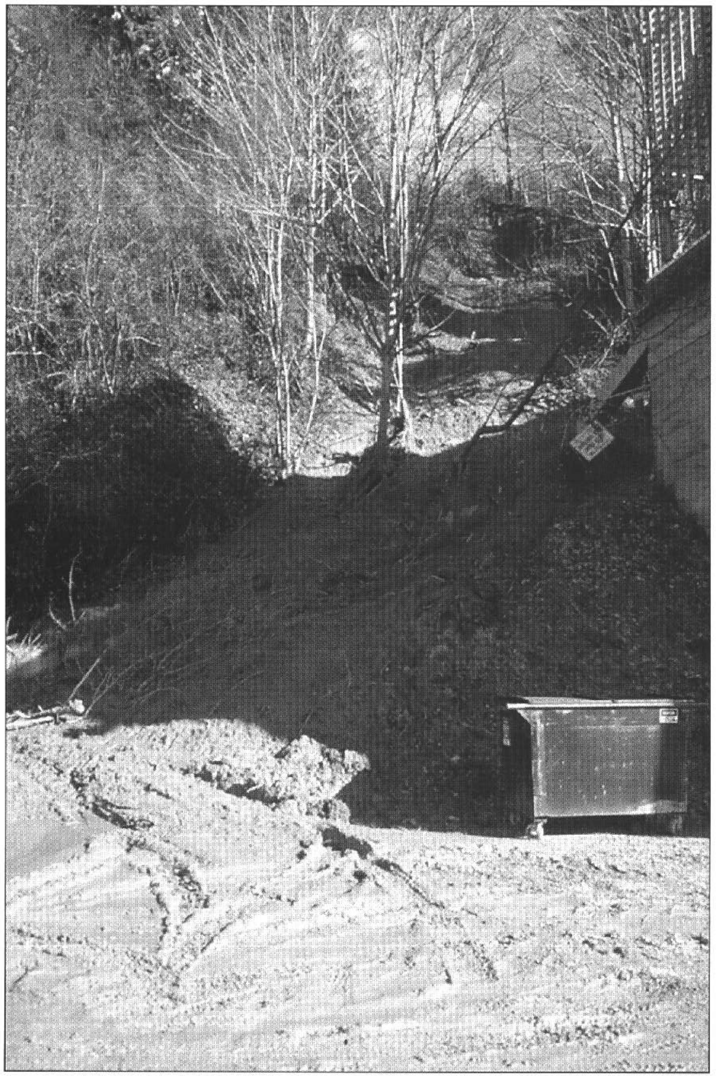


Figure 10a. This landslide at the north end of the steam plant resulted from the combined effects of soil saturation by the February 1996 storm and previous loading of the slope with sidecast concrete construction debris. It initiated from two headwall areas (top center of photo and to left of center behind trees) in interbedded sand and silt overlying less permeable silts. Slide debris was deposited on the steam plant access road, and sediment from the slide runout reached Capitol Lake.

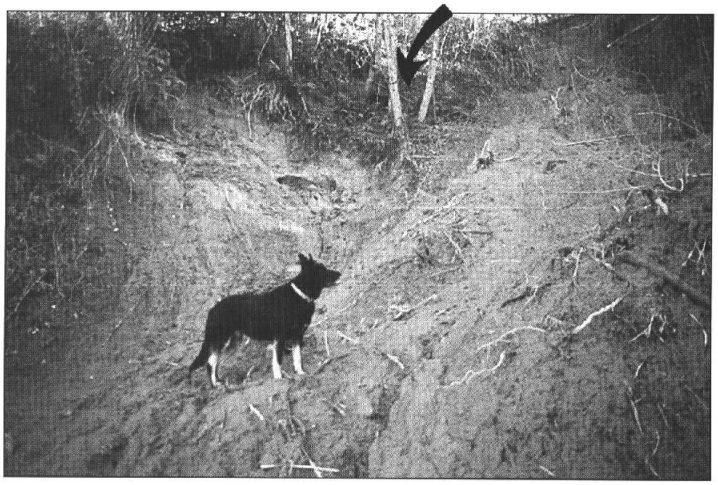


Figure 10b. View upslope (east) to the two headwall areas. The dog (about 2.5 ft high at the shoulder) stands about midway on the slope in the slide path. The arrow points to an area of sidecast concrete blocks mantling the slope; other blocks are incorporated in the slide debris.

Computer modeling further suggested that small rotational failures into the native, undisturbed soils were likely to occur less frequently. However, such failures could occur during periods of extreme precipitation and associated high water tables and runoff. As fresh material is exposed, it also becomes susceptible to erosion and saturation, eventually adding to the material in the soil mantle.

The February 1996 landslides have provided valuable information about the mechanisms of bluff failure and have substantiated the stability analysis in the report submitted to GA. These relatively small failures, initiating on the upper slopes in the soil mantle and (or) partially into the native sediments, transformed into debris flows downslope. For a period of several days to a few weeks after the storm, the slide debris remained fully saturated, suggesting that it primarily incorporated the soil mantle that was saturated at the time of failure.

Exposures in the fresh landslide scarps suggest that most of the slides initiated in the sediments overlying the laminated silt unit or some comparable (facies-related) impermeable sediments in the bluff. With these exposures, this silt unit can now be more confidently traced along most of the bluff. Its upper contact is approximately 20 ft (along the north-facing bluff) to 30 ft (along the west-facing bluff) below the top of the bluff.

The disposal of organic material and construction waste over the edge of the bluff, particularly near the northwest point, has exacerbated already unstable conditions. Even so, sidecast pull-back should be assessed on a site-by-site basis. In places, the sidecast material has become imbedded in the slope and acts somewhat like armor. In other places, its removal could disturb well-established vegetation. Where tension cracks in the sidecast are visible at the bluff edge and no vegetation has established itself, or where large cement blocks are likely to further destabilize the slope and potentially cause injury or damage during a landslide, pull-back and (or) removal of this material might be appropriate.

In my original report to GA (Gerstel, 1996), I concluded that episodic slope movement is still likely where there is evidence of historic rotational slumping (commonly transitional to slump-earthflows), such as adjacent to the Governor's Mansion and north of the Temple of Justice parking lot. These soils are poorly drained, and upper slopes are oversteepened. At least a few water pipes/storm drainages discharge onto or into the slopes, and springs are numerous, many flowing year-round. Both of these areas failed during the February storm.

In keeping with the 1911 Capitol Campus development plans prepared by the architectural firm of Wilder and White, the slopes below the Temple of Justice were selected as the site for the Capitol Trail. The report to GA, however, concluded that the proposed excavation for Heritage Park facilities north of the Temple of Justice would likely increase the potential for instability. A team of engineers, geologists, and landscape planners from GA, Department of Natural Resources (Engineering Division and DGER), and Cedar Creek Work Station staff and inmates designed the trail to take into account the potential instability of the slopes by planning minimal excavation (Fig. 13) and sufficient drainage. Compliance with the

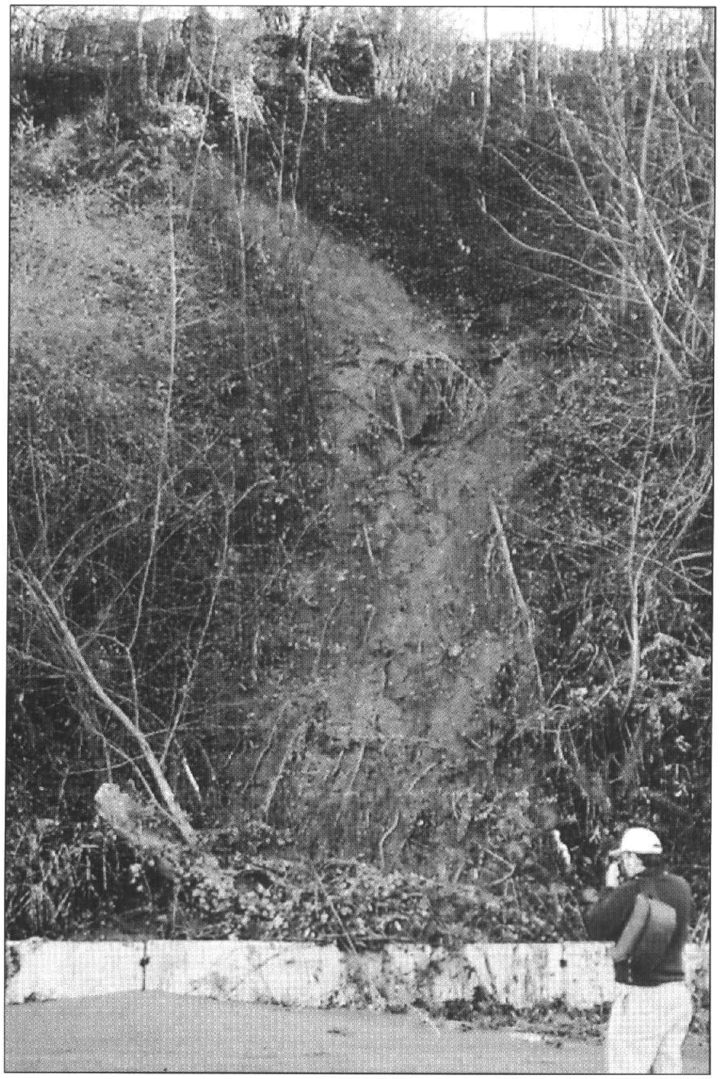


Figure 11. This landslide occurred on the north side of the northwest point also as a result of the combined effects of soil saturation by the February 1996 storm and previous loading of the slope with sidecast construction waste. The slide initiated in sediment overlying the laminated silt unit and incorporated construction waste and vegetation. The jersey barrier at the base of the slope trapped the larger material, while the sediment flowed onto the access road through a gap between barrier segments, forming a fan that remained saturated for several days.

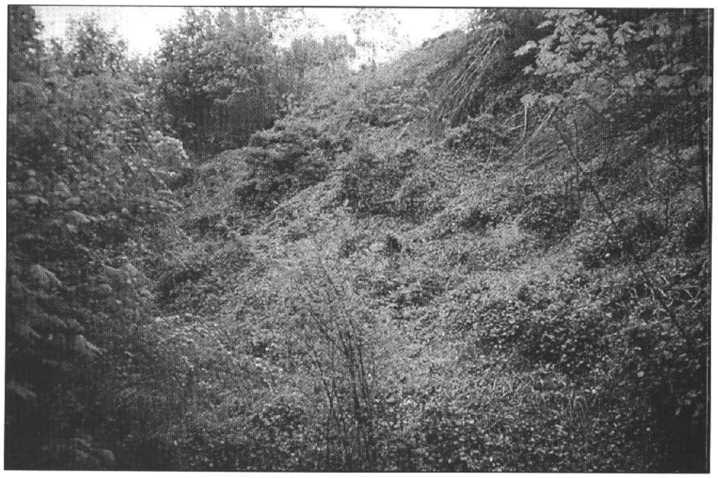


Figure 12. The initial brushed line for the trail on the slope below the Temple of Justice (shown here) uncovered a newly formed headscarp. The cover photo shows a lower slope failure where a rotted stump gave way on oversteepened sediment overlying the impermeable silt unit.

Figure 13. Materials and techniques used in construction of the Capitol Trail were chosen to accommodate the sensitive stability conditions of the slope. Light-weight fill and lack of cutslopes were specific design features used to minimize impact on the slopes.

Americans with Disabilities Act required that the trail wind its way along the slopes at a 4 to 6 percent grade.

After clearing brush for the trail and discovering the reactivated landslide, the team relocated the trail to the slopes west of and adjacent to the greenhouse/conservatory. A large volume of unengineered fill from construction of the Capitol Campus (early 1900s) underlies this location. This fill presents stability conditions different from those of the natural bluff slopes. A stability analysis of the fill, recently completed by DGER, concludes that the fill is stable under present hydrologic conditions.

On the basis of combined results of the bluff and fill analyses, the trail was designed using low-cost materials and methods unique to this site in anticipation of continued slope movement and ongoing maintenance. Retaining walls anchored to the hillside form the downslope wall of the trail. The wall and ground surface are then lined with permeable fabric overlying perforated pipes that collect and direct natural surface water along the slope. The fill behind the retaining wall consists of light-weight bark and wood chips, all overlain by a 3- to 4-in. layer of bound gravel.

CONCLUSIONS

The geology and glacial history of the Puget Lowland results in coastal bluffs being a common feature of the local morphology. Land-use planning, specifically urban development, must carefully consider the risks and hazards associated with development in these areas (Thorsen, 1987). Continued bluff retreat is to be expected and can be accommodated by limiting construction, avoiding overdesign and potential costly repairs, preserving vegetation, and maintaining natural ground-water flow conditions.

REFERENCES CITED

Allen, Tony, January 9, 1990, [Field notes and observations with recommendations submitted to Peter Waugh]: Washington Department of General Administration, Division of Engineering and Architecture, 2 p.

Booth, D. B., 1994, Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation: Geology, v. 22, p. 695-698.

Dames & Moore, 1965, Report of soils investigation, proposed garage site, State Capitol grounds, Olympia, Washington: Dames & Moore [under contract to] Washington Department of General Administration, 1 v.

GeoEngineers, 1988, Letter to Washington Department of General Administration *in* Emergency hillside stabilization, Capitol Campus, Olympia, Washington, project no. 88-112, plans and specifications: GeoEngineers [under contract to] Washington Department of General Administration, 1988, 1 v.

Geolabs-Washington, Inc., 1973, Subsurface investigation, canyon fill, Capitol Campus, Olympia, Washington: Geolabs-Washington, Inc. [under contract to] Washington Department of General Administration, 17 p.

Gerstel, W. J., 1996, Slope stability analysis of the bluffs along the Washington State Capitol Campus, Olympia, Washington: Washington Division of Geology and Earth Resources Open File Report 96-3, 1 v.

Jordan/Avent and Associates, 1972(?), Embankment dewatering system, Capitol Campus, Olympia, Washington: Jordan/Avent and Associates [under contract to] Washington Department of General Administration, 6 pl.

Ritchie, A. M.; Cashman, J. B., January 15, 1959, [Letter to Earnest Dore, Olympia, Washington]: Ritchie and Cashman, 4 p.

Thorsen, G. W., 1987, Soil bluffs + rain = slide hazards: Washington Geologic Newsletter, v. 15, no. 3, p. 3-11.

Thorson, R. M., 1980, Ice-sheet glaciation of the Puget Lowland, Washington, during the Vashon Stade (late Pleistocene): Quaternary Research, v. 13, p. 303-321.

Washington Department of Transportation, 1988, General Administration building slide correction geotechnical report; June 24, 1988: Washington Department of Transportation [under contract to] Washington Department of General Administration, 1 v.

The Portico Group & The SWA Group, 1992, Heritage Park—A celebration of Washington State heritage, Washington State Capitol Olympia, Washington; Draft predesign study: The Portico Group [under contract to] Washington Department of General Administration, 1 v.

Shannon & Wilson, Inc., 1986, Geotechnical studies, seismic rehabilitation Temple of Justice building, Olympia, Washington: Shannon & Wilson, Inc. [under contract to] ECI/Stafford, 1 v. ■

Geologic Exhibits at Tacoma's Washington State History Museum

The grand opening of the new Washington State History Museum in Tacoma took place on August 10. On display in a half-acre of space are both permanent and traveling exhibits, complete with videos and recorded sounds. A three-screen theater will be the site of special events.

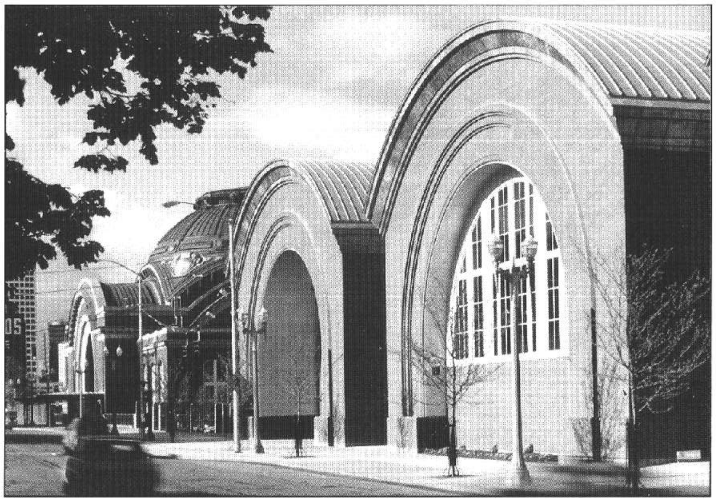
To the right of the main entrance is a part of the museum titled 'Natural Setting'. Here there is a 'Slice of Washington', a three-dimensional topographic-geologic section that passes across the state from northwest to southeast, from the Olympic Peninsula to the Blue Mountains.

State Geologist Raymond Lasmanis, with assistance from geologist David Norman, made major contributions to the geologic exhibits. The cross section is based on information developed and sketched by Lasmanis.

Lasmanis and Norman also donated numerous rock and mineral specimens from their personal collections to the museum. These specimens are in five large drawers in the exhibit area. Each drawer provides information about topics like volcanoes, fossils, fluorescent rocks, ores, and mineral pigments. Each drawer also has a state location map, short explanatory texts, and objects that are associated with the rock and mineral samples. For example, a lead fishing sinker is placed next to a specimen of galena, a lead ore mineral from the Pend Oreille mine in Metaline Falls.

A table-top map features a computer-animated evolution of the state's geology illustrating changes in the topography. Visitors can 'watch' the Missoula or Bretz floods and the development of the Cascades.

Other exhibits in this new facility focus on the state's Native American heritage (including a display of 11,000-year-old Clovis artifacts), early encounters with European and American explorers, frontier times, and railroading. Other parts of the exhibit floor are devoted to a glimpse of life during the Depression and World War II and to a look forward.



The new Washington State History Museum on Pacific Avenue in Tacoma. (Photo courtesy of The Washington State Historical Society, Joel Polsky Photography.)

The Washington State Historical Society owns this new museum. The society's first historical museum was built in 1911 on a site northwest of the city center. The new museum is located at 1911 Pacific Avenue in Tacoma on land donated by the city, just south of the Union Station building, which also opened in 1911.

Museum hours are Tuesday–Saturday, 10:00 am–5:00 pm; Thursday, 10:00 am–8:00 pm; Sunday, 11:00 am–5:00 pm; and closed Monday. Tours can be arranged with Ann Cook at (206) 798-5898. For more information about the museum, memberships, or activities, call toll free 1-888-238-4373. ■

Marine Vertebrate Paleontology on the Olympic Peninsula

Lawrence G. Barnes, Curator of Vertebrate Paleontology
Natural History Museum of Los Angeles County
900 Exposition Boulevard, Los Angeles, CA 90007
and
Curatorial Affiliate
Thomas Burke Memorial Washington State Museum
University of Washington, Seattle, WA 98195

James L. Goedert
15207 84th Avenue Court NW
Gig Harbor, WA 98329
and
Museum Associate
Section of Vertebrate Paleontology
Natural History Museum of Los Angeles County

INTRODUCTION

Washington's Olympic Peninsula is important from a paleontological standpoint because of its nearly continuous sequence of lower Eocene through middle Miocene marine sediments that are well exposed along its northern shoreline facing the Strait of Juan de Fuca (Fig. 1). These strata contain a rich record of vertebrate, invertebrate, and plant fossils spanning approximately 25 million years of Earth's history. For many years, the Olympic Peninsula's various formations have received considerable attention from invertebrate paleontologists. Accordingly, the associated mega-invertebrates and Foraminifera have provided a good biostratigraphic framework for the vertebrate fossils in these deposits.

Now some important fossil vertebrates found here are generating wide interest as well. Examples of these fossils are strange flightless diving birds called plotopterids that evolved penguin-like anatomy and swimming methods; the world's oldest desmostylian, a stocky quadrupedal, intertidal herbivore called *Behemotops proteus*; some of the world's earliest and most primitive ancestors of the living sea lions, called enaliarctine pinnipeds; the earliest whales in the North Pacific Ocean, including various primitive baleen whales, the aetiocetids, that still had teeth; and the mollusk-grinding 'beach bear' named *Kolponomos clallamensis*.

This article includes a summary of the rock units that have yielded important vertebrate fossils and notes on some of the significant and, in some cases, peculiar, vertebrate groups whose fossils have been found in them.

GEOLOGIC AND PALEONTOLOGIC BACKGROUND ON THE OLYMPIC PENINSULA

The stratigraphically superimposed marine sedimentary rocks of the late Eocene to Oligocene Makah Formation, the early Oligocene to early Miocene Pysht Formation, and the early Miocene Clallam Formation (Fig. 2) have all yielded vertebrate fossils of one kind or another. These rocks are exposed for more than 70 miles along the south shore of the Strait of Juan de Fuca in wave-cut cliffs and terraces and in excavations (such as quarries). The stratigraphy and invertebrate paleontology of this thick sedimentary sequence are relatively well known (for example, Addicott, 1976a, 1976b; Moore and Addicott, 1987; Rau, 1964; Snavely and others, 1980; Tabor and Cady, 1978), but only a very few of the contained fossil vertebrates have been recorded (Stirton, 1960, and Tedford and others, 1994 [*Kolponomos*]; Olson, 1980 [plotopterid bird]; Domning and others, 1986, and Ray and others, 1994 [*Behemotops*]; Barnes, 1987, 1989b, and Barnes and others, 1995 [aetiocetid whales]; Muizon, 1991 [eurhinodelphid dolphin]).

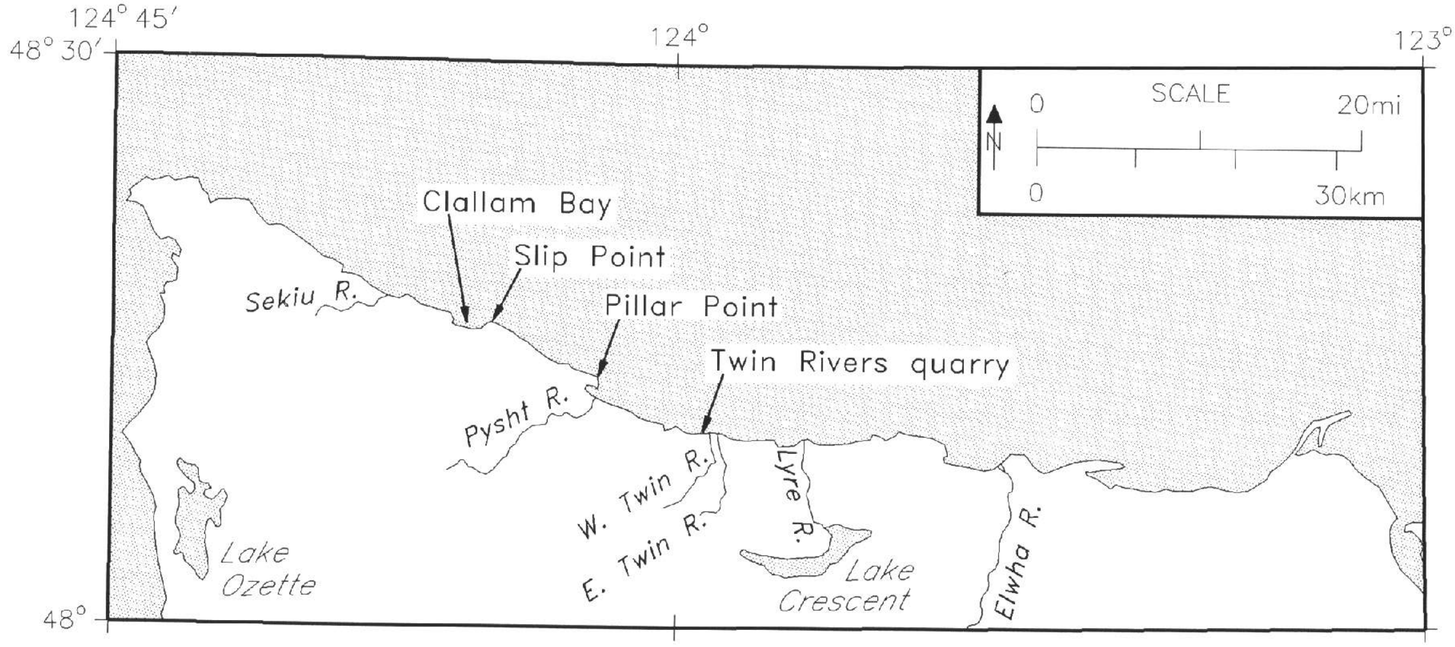


Figure 1. The northern part of the Olympic Peninsula. Features named here serve to locate outcrop areas of important marine sedimentary rocks that have yielded fossil vertebrates.

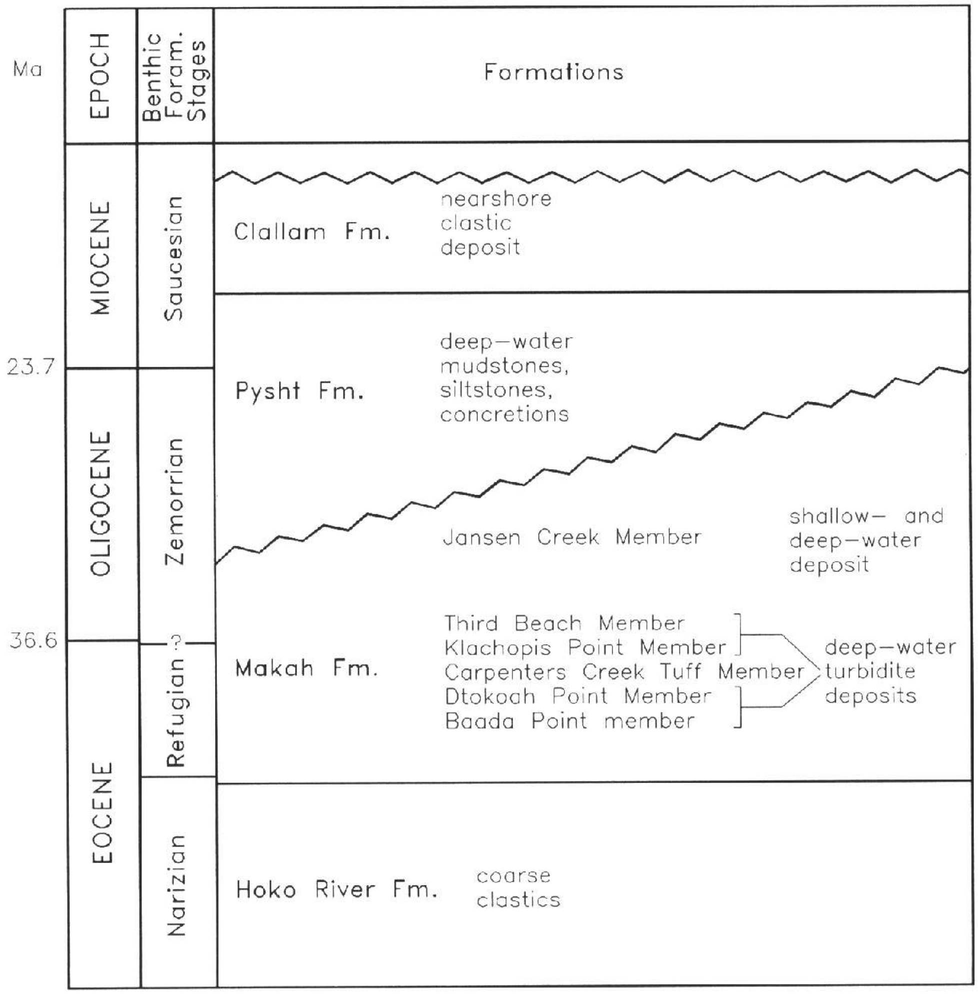


Figure 2. Correlation of the sequence of Tertiary fossil vertebrate-bearing stratigraphic units on the Olympic Peninsula, Washington.

The Eocene and Oligocene rocks are predominantly deep-water sediments, and the Miocene rocks represent progressively shallower marine environments. These rock units accumulated in a basin adjacent to the ancestral Vancouver Island.

Makah Formation

The Makah Formation was deposited in a deep-water, submarine-fan setting and ranges in age from late Eocene to late Oligocene (Snavely and others, 1980). It contains six named members, four of which are thick turbidite sandstones. A fifth, the Jansen Creek Member, is as much as 200 m thick and consists of shallow- and deep-water sediments that slumped or slid off the Vancouver Island shelf/slope into a deep marginal basin (Snavely and others, 1980; Niem and others, 1989). A sixth unit is a thin tuff deposit. Thin-bedded sandstones and siltstones separating each member represent basin-plain and outer fan-fringe deposits (Snavely and others, 1980).

The oldest cetaceans that have been discovered on the Olympic Peninsula, or from anywhere in the North Pacific realm for that matter, have been found in the Jansen Creek Member (Kaler, 1988). These fossils include nearly complete skulls and some partial skeletons. None of these specimens has yet been prepared, but from what we can see protruding from the rocks, four or five different species appear to be represented.

The Jansen Creek Member has also yielded at least five different kinds of birds, three of which are flightless pelecaniform plotopterids (Fig. 3). Most of the plotopterid specimens from the Makah Formation are extremely difficult to prepare because the concretions in which they are found do not respond well to acid etching and many of the concretions are harder than the enclosed bones.

Siltstone of the upper part of the Makah Formation exposed between Shipwreck Point and the mouth of the Sekiu River (Fig. 1) has yielded several unidentified agorophiid odontocetes (toothed whales) and primitive mysticetes (baleen whales) (Squires and others, 1991; Goedert and others, 1995).

Pysht Formation

The Pysht Formation, which unconformably overlies the Makah Formation, is composed mostly of concretion-bearing mudstones and siltstones of early Oligocene through earliest Miocene age and was deposited in a neritic (subtidal to about 200 m) to mid-bathyal (ca. 1,000 m) environment. It is best exposed along the Olympic Peninsula shoreline between the mouths of the Lyre and Pysht Rivers and in the Twin Rivers quarry. It conformably underlies the late early Miocene Clallam Formation. Coastal outcrops of the Pysht Formation yield abundant concretions that locally contain relatively abundant organic remains.

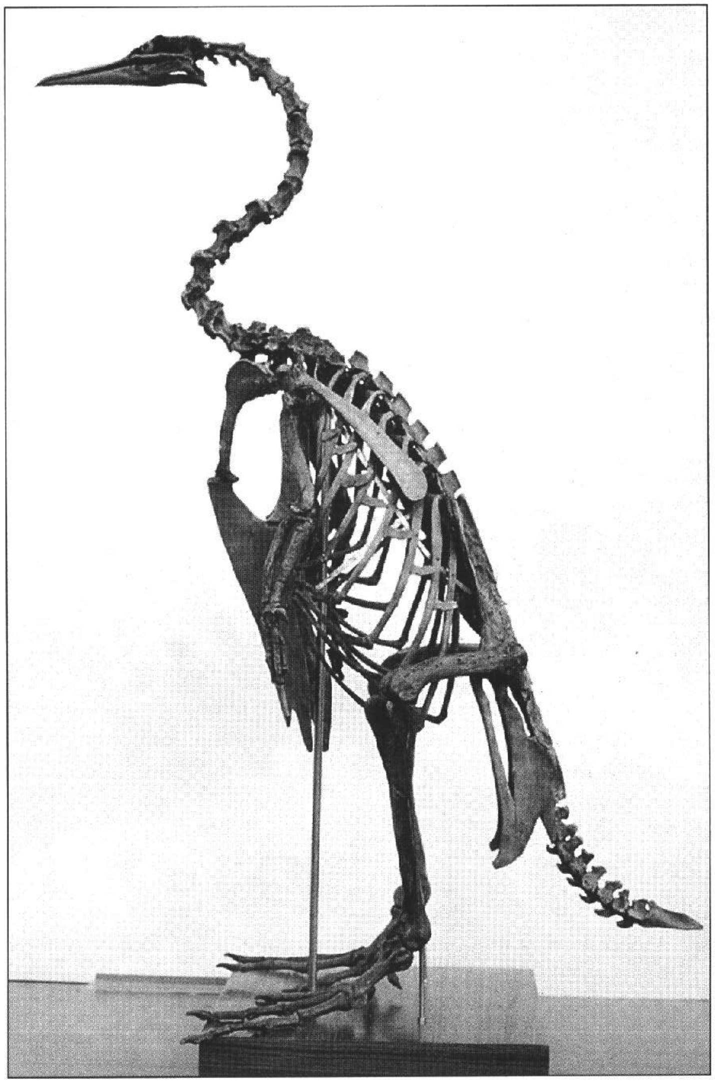
The holotype of the flightless plotopterid bird, *Tonsala howardae* Olson, 1980, was found in this formation, and additional specimens of this species and another larger species of plotopterid have subsequently been found.

The holotype and a referred specimen of the large and primitive early desmostylian, *Behemotops proteus* (Fig. 4), were also found in the Pysht Formation (Domning and others, 1986; Ray and others, 1994).

Cetaceans are by far the most abundant vertebrates in the Pysht Formation, represented by approximately ten as-yet unidentified small to medium-size species of primitive toothed whales of an 'agorophiid grade' of evolution (explained later in this article). The mysticetes are less abundant and include at least two species of baleen-bearing mysticetes, ranging from small to moderate size. Excavation of a moderate-size mysticete skull was reported by Kaler (1989), and another mysticete skeleton is currently being prepared for exhibit at the Thomas Burke Memorial Washington State Museum in Seattle (Crowley and Barnes, 1996).

Among the most unusual cetaceans from the Pysht Formation are the very primitive toothed aetiocetid mysticetes. These small whales are morphologically somewhat intermediate between the ancestral archaeocete whales and the baleen-bearing mysticetes, and in the Pysht Formation they are repre-

Figure 3. A reconstructed skeleton of a Late Oligocene penguin-like plotopterid bird from Kyushu, Japan. This is in the postulated terrestrial posture; the bones are very similar to those of penguins, and it is thought that they were flightless yet were powerful swimmers. Similar specimens have been collected from the Pysht Formation on the Olympic Peninsula, including the plotopterid, *Tonsala howardae*.



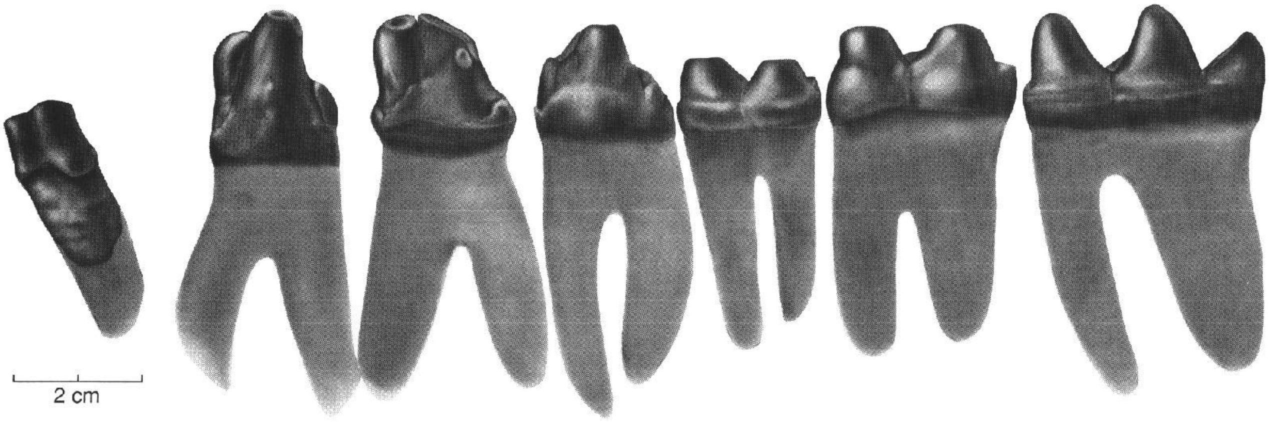
sented by *Chonecetus goedertorum* Barnes and Furusawa, 1995 (*in* Barnes and others, 1995) and possibly a few other as-yet undescribed species.

The world's oldest pinnipeds, related to the ancestors of modern sea lions and walruses, have been found in the upper part of the Pysht Formation. They are represented by an as-yet unstudied skull of a relatively large, long-headed enaliarctine otariid (eared seal) and a bizarre, small, broad-headed, unnamed enaliarctine (preliminarily reported by Hunt and Barnes, 1994).

A potentially very important skull of an artiodactyl (land mammal, those with two-hoofed feet, as in deer) has also been found in this formation by Goedert, and upon analysis it promises to help with a correlation to the terrestrial mammalian chronology. Fossils of land mammals and other terrestrial vertebrates have been found in most marine deposits; perhaps they are the remains of animals swept into the sea by rivers. The rocks representing the Cenozoic Era on the North American continent are divided into North American Land Mammal Ages based on characteristic assemblages of fossil mammals. Discoveries of land mammals in marine deposits provide opportunities to correlate sequences of marine and terrestrial deposits.

Clallam Formation

The Clallam Formation conformably overlies the Pysht Formation and is a lower Miocene nearshore coarse clastic unit. It



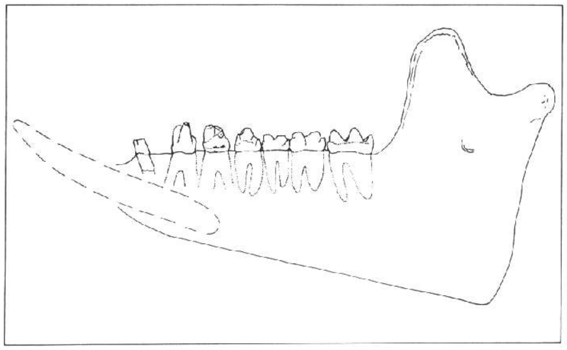
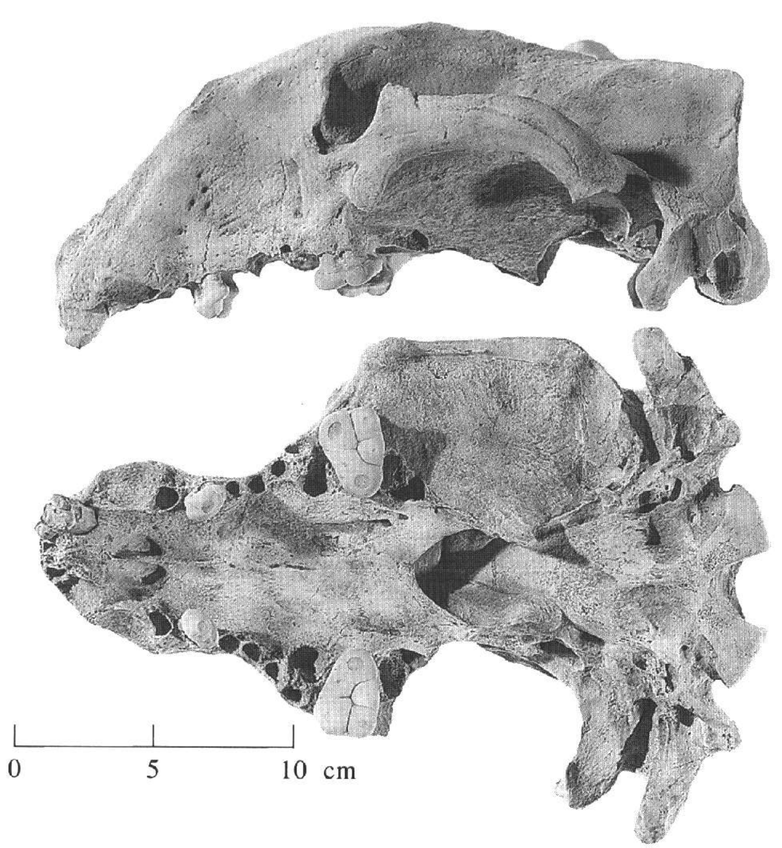


Figure 4. The right lower teeth (at about life size) and a line drawing of the reconstructed right lower jaw (as seen from the inside of the jaw) of the archaic desmostylian, *Behemotops proteus* Domning, Ray and McKenna, 1986, a quadrupedal, intertidal herbivore found in the upper Oligocene Pysht Formation near Twin River by William R. Buchanan. The teeth were found associated in one rock, but the jaw had mostly decomposed prior to fossilization. The outline of the lower jaw, with the large canine tusk indicated by dashed lines, is based on other specimens from the Olympic Peninsula and the coast of Oregon. (Natural History Museum of Los Angeles County catalog no. 124106; illustration modified from Ray and others, 1994, fig. 13.)

Figure 5. The best known skull of the rare beach-dwelling bear, *Kolponomos clallamensis* Stirton, 1960 (in left lateral and ventral views), found in the early Miocene Clallam Formation at Clallam Bay by Albin Zukofsky II. In both views the nose is pointing toward the left. A diet of hard-shelled, rock-dwelling intertidal invertebrates is suggested by the forward-directed eyes that would have allowed stereoscopic vision, the protruding snout with elongate incisors and canines that could have acted like pliers, the large mastoid and paroccipital processes at the back of the skull for attachment of strong neck muscles, and the broad, flat cheek teeth forming an efficient grinding mechanism. (Natural History Museum of Los Angeles County catalog no. 131148.)



is well exposed in the sea cliffs between Clallam Bay and Pillar Point and contains cobbles, plant remains, locally abundant mollusks, and rare vertebrate fossils. Several different types of 'dolphins' have been found: extinct, long-snouted eurhinodelphids, long-snouted platanistoids, and extinct kentriodontids. Most specimens remain unprepared and unstudied, but one, *Squaloziphius emlongi* Muizon, 1991, is a large dolphin, belonging in the family Eurhinodelphidae. Surprisingly, pinnipeds and desmostylians are rare and, to date, sirenians, sperm whales, and mysticetes have not been found in this formation.

The most 'famous' vertebrate fossil from the Clallam Formation (and possibly from all of the Olympic Peninsula) is *Kolponomos clallamensis* Stirton, 1960, long an enigmatic marine carnivore that was based only on the holotype snout. A recently collected, nearly complete skull (Fig. 5) found near Slip Point has at last revealed that the animal was a highly evolved, invertebrate-crushing 'beach bear' (Tedford and others, 1994). It had long toes, so was not a swimming carnivore like a seal or sea lion, and was probably not even so well adapted to an aquatic existence as the sea otters. It had forward-directed eyes and long front teeth that suggest that it could pry rock-dwelling invertebrates off rocks. Its heavily worn cheek teeth were wide and flat, even more so than those of sea otters, and these would have been suitable for crushing shelled organisms.

PLOTOPTERID BIRDS

Members of the extinct family Plotopteridae are mostly large, flightless, pelecaniform birds that evolved in the North Pacific convergently with penguins. Their bodies were torpedo shaped, their necks and beaks were long, and their wings were short and modified into paddles in a manner like the penguins. Presumably, like penguins, plotopterids could 'fly' underwater while hunting for food (Olson and Hasegawa, 1979) and stood erect while walking on land.

The first plotopterid discovered was a small bird named *Plotopterum joaquinensis*, and it was named solely on the basis of a single bone (a coracoid, located in the chest) from earliest Miocene rocks near Bakersfield, California. No additional bones of this species have ever been discovered. Subsequently, a fair diversity of other plotopterids has been discovered both in North America and Japan, all geologically older and most larger.

The holotype of the large (goose-size) plotopterid, *Tonsala howardae* Olson, 1980, was found in the Pysht Formation on the Olympic Peninsula. Other large plotopterids have also been found in upper Oligocene rocks in Japan on the islands of Hokkaido and Kyushu. The specimens from Hokkaido are from deposits that contain aetiocetid whales that are similar to those from the Pysht Formation. Several plotopterid specimens have been found in upper Oligocene deposits on Kyushu, and the Kitakyushu Museum has on exhibit some composite skeletons of these birds mounted in both swimming posture and as if they were moving on land (Fig. 3).

PINNIPEDS

Pinniped fossils include two separate lineages that have different places of origin. The true seals of the Family Phocidae apparently originated in the Atlantic realm and did not reach the North Pacific until late Pliocene time. A few scattered phocid fossils (extinct harbor seals and elephant seals) have been found in late Pliocene and Pleistocene deposits in California, Oregon, and Japan, but none have been reported in Washington.

The other group of pinnipeds (family Otariidae) includes the sea lions, fur seals, walruses, and their extinct relatives (Barnes, 1989a) and apparently originated in the North Pacific. The group is very diverse and includes several extinct lineages that proliferated in Miocene and Pliocene time. The modern sea lions, fur seals, and walruses are but a vestige of the former diversity of this group.

The otariid subfamily Enaliarctinae is the most primitive group of sea lion-like animals, and the oldest members of this subfamily are represented by the fossils from the Pysht Formation. These fossils have yet to be studied in detail. Other enaliarctines from Oregon and California include the ancestry of various later otariid lineages (Barnes, 1979, 1989a, 1992).

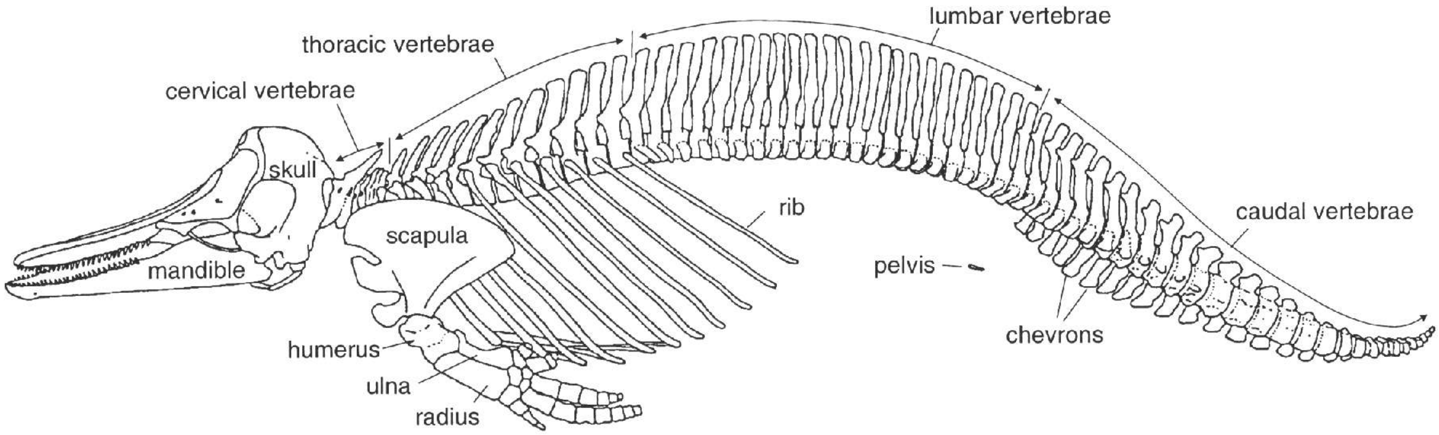


Figure 6. Skeleton of the living dusky dolphin *Lagenorhynchus obscurus*, showing the position of bones within the body. This can be helpful when identifying fossils of extinct cetaceans. Drawing reproduced by permission, from the Annual Review of Earth and Planetary Sciences, v. 22, ©1994.

DESMOSTYLIANS

Desmostylians are an extinct order of mammals that lived only around the margins of the North Pacific Basin from late Oligocene through late Miocene time. They were an offshoot of a primitive group of hoofed mammals (ungulates) that remained herbivorous and inhabited shallow, nearshore, marine waters. Their skeletal structure indicates that they were heavy-bodied and could swim perhaps as well as a hippopotamus. Presumably they ate sea grasses and (or) kelp; their incisors and canines were large, forward-protruding scoops, and their cheek teeth had broad grinding surfaces.

They are generally rare as fossils. The first specimens found were thought to represent some aberrant type of sirenian (sea cows, manatees), but subsequently discovered skeletons clearly revealed their unique anatomy.

Specimens of the earliest and most primitive desmostylian, *Behemotops proteus,* (Fig. 4) were found in the lower Oligocene part of the Pysht Formation (Domning and others, 1986; Ray and others, 1994). Fossils of a similar species have been found on Hokkaido, Japan. The Clallam Formation might be expected to yield specimens of the typical middle Miocene desmostylian, *Desmostylus*, but identifiable specimens have not been found to date. The approximately correlative Astoria Formation on the Oregon coast has yielded some very important specimens of *Desmostylus*.

EARLY WHALES

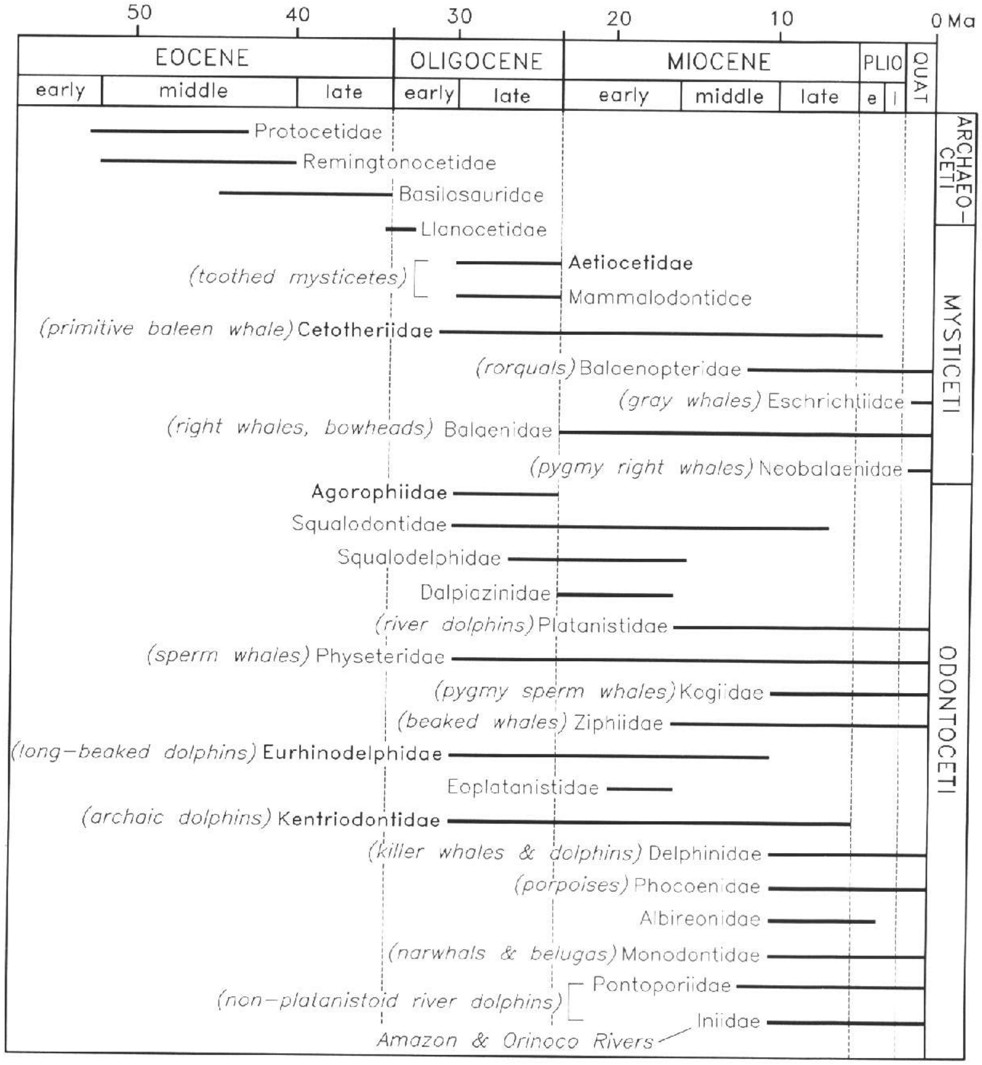
Fossil, anatomical, genetic, and biochemical evidence indicates that whales and dolphins (cetaceans) descended from primitive ungulate land mammals called mesonychians that are related to such modern land mammals as artiodactyls, the group that includes cows, pigs, camels, and deer. The cetacean body has become streamlined for efficient swimming and is well insulated by blubber. Cetaceans have only a few hairs remaining on the face, the nose (blowhole) is located on the top of the skull, and external ears are lacking, but underwater hearing is well developed, and the toothed whales can echo-locate by using high-frequency sounds. The cetacean skull is distinctive by having an elongate snout (rostrum) made of the bones that in other mammals lie in front of the nasal openings and comprise the front of the upper jaw (Fig. 6). The lower jaw is elongated commensurate with the rostrum. The front legs are relatively short and expanded as flippers, with many finger bones called phalanges, and the elbow joint is rigid. The back legs disappeared early in whale evolution, but some early whales had external hind limbs and most modern species still retain small vestigial hind limb bones buried in their bodies. Most cetaceans have a dorsal fin, and all have a typical horizontal tail fluke that provides propulsion. (See reviews by Barnes, 1984, and Fordyce and Barnes, 1994.)

Cetaceans were already adapted to marine life by middle Eocene time. The early whales had teeth of different functions as in generalized mammals: incisors, canines, and multiple-rooted premolars and molars, termed heterodont dentition. One early whale from Pakistan, *Pakicetus inachus*, had such heterodont dentition, may have been amphibious, and had a skull about 35 cm long.

It appears that cetaceans in the past, as do the modern species, lived both near shore and in the open ocean. When they die, some whales now tend to strand on beaches, but this high-energy, constantly changing environment is not conducive to fossilization. The early Tertiary, or Paleogene, marine rocks of the Olympic Peninsula were deposited offshore in deeper water, and in such environments there were increased possibilities for undisturbed fossilization. Most fossil whale specimens that we have found on the Olympic Peninsula are articulated skeletons or composed of closely associated bones of one individual, indicating that the skeletons were not dispersed by currents or predators prior to burial. Most fossil whale skeletons are found in a belly-up position. When a whale dies in the open ocean, it floats at the surface for a considerable period of time. Gasses of decomposition are trapped in the abdomen and the large throat pouch. When the body finally decomposes, it apparently is more likely to land on the sea floor upside down, in the same position in which it had floated at the ocean's surface.

Late Eocene to earliest Miocene time, well represented in the rock record on the Olympic Peninsula, was a pivotal period in whale evolution (Fordyce and Barnes, 1994). During this time various lineages appeared (Fig. 7), diversified, and spread throughout the world's oceans, and the odontocetes and mysticetes evolved (Barnes, 1976, 1984; Barnes and Mitchell, 1978; Barnes and others, 1985; Fordyce, 1992; Fordyce and Barnes, 1994; Fordyce and others, 1992; Whitmore and Sanders, 1976). There have been scattered reports and descriptions

Figure 7. Distribution of the various cetacean families through time. Solid lines represent reported or probable age ranges; bold type indicates presence in Olympic Peninsula strata (Modified from Fordyce and Barnes, 1994, fig. 1.)



of important and fascinating early whales of this age, but no consistent pattern of Paleogene whale evolution or systematics has appeared (Whitmore and Sanders, 1976). Therefore, rocks on the Olympic Peninsula have the potential for revealing critical information about the early evolution of whales, especially the primitive members of the modern groups.

The most abundant cetaceans in both the Makah Formation and the lower part of the Pysht Formation are 'agorophiids'. Agorophiids are archaic, heterodont odontocetes; however, the Agorophiidae had come to be used as a grade of evolution, creating an artificial classification. 'Agorophiids' have been found on both the Atlantic and Pacific sides of North America (Whitmore and Sanders, 1977; Fordyce and Barnes, 1994; Cruz-Marin and Barnes, 1996). When fully studied, fossils of 'agorophiids' from the Olympic Peninsula and elsewhere will undoubtedly be classified in several new families.

Among the most interesting whales from the Olympic Peninsula are the *toothed* aetiocetid mysticetes. Whales in the primitive, extinct family Aetiocetidae are small (about 3 to 6 m long), primitive, toothed mysticetes that persisted into late Oligocene time (Barnes, 1987, 1989b; Kimura and others, 1992; Barnes and others, 1995), long after more highly evolved, baleen-bearing mysticetes had appeared (Barnes and Sanders, 1990; Sanders and Barnes, 1989, 1991). Although no known aetiocetid could be ancestral to baleen-bearing mysticetes, their morphological characters are in many ways 'intermediate', demonstrating the types of transitional steps undoubtedly passed through in the early evolution of baleen-bearing mysticetes from archaeocete ancestors. Late Oligocene aetiocetids have been found on both sides of the north Pacific Ocean: on Vancouver Island, Canada; in Oregon and Washington, U.S.A.; in Baja California Sur, Mexico; and on the islands of Kyushu and Hokkaido, Japan (Kimura and others, 1992; Barnes and others, 1995). These fossils now indicate considerable diversity in the family, with several different contemporaneous lineages in late Oligocene time.

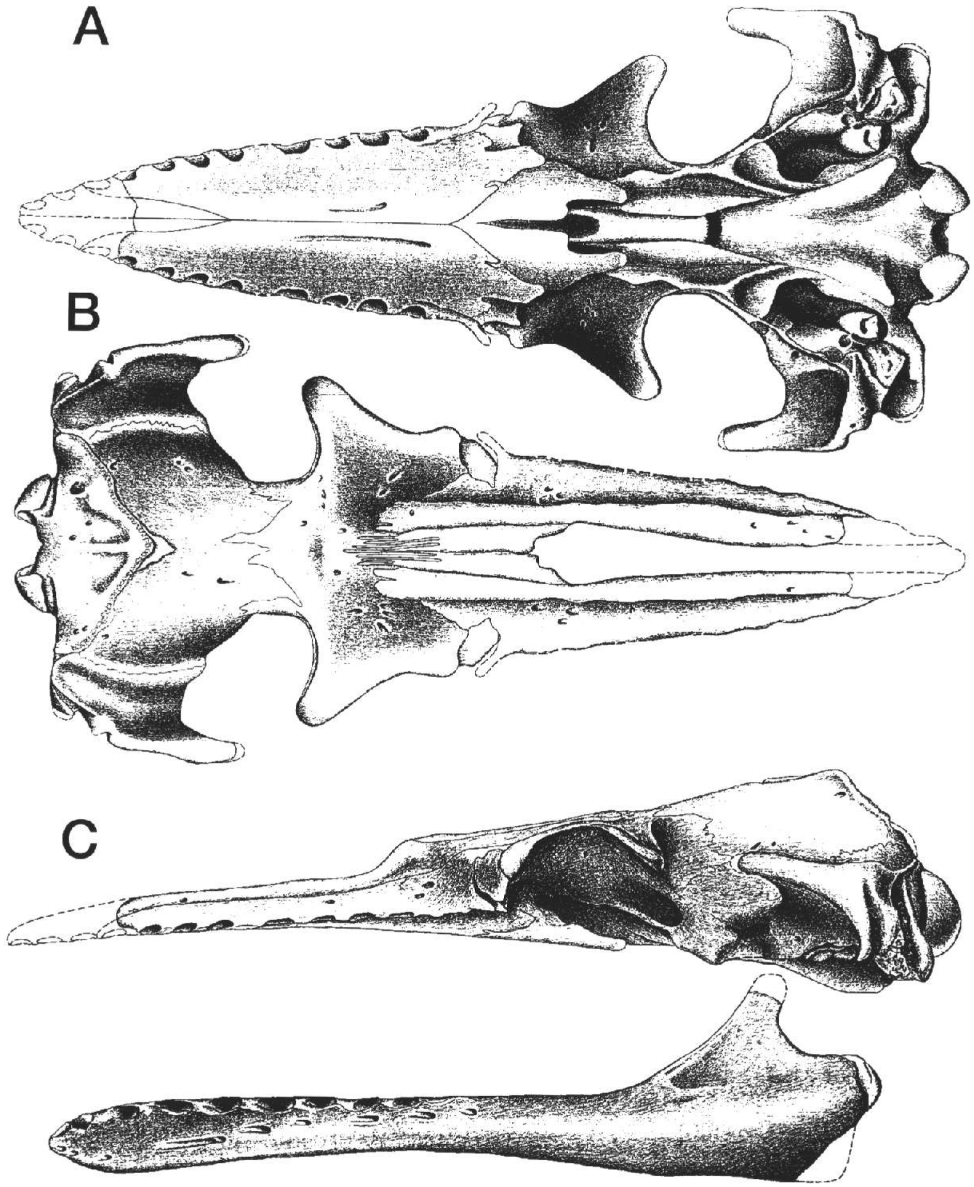
The primitive aetiocetid *Chonecetus sookensis* Russell, 1968, is from the upper Oligocene Hesquiat Formation on Vancouver Island. The more derived *Chonecetus goedertorum* Barnes and Furusawa, 1995 (*in* Barnes and others, 1995), from the upper Oligocene Pysht Formation (Fig. 8) has the primitive placental mammalian dental count of 11 teeth on each side of each jaw, upper and lower. The type genus of the family is *Aetiocetus* Emlong; its type species, *A. cotylalveus* Emlong, 1966, known only from the late Oligocene Yaquina Formation on the coast of Oregon, also has 11 upper teeth on each side of the rostrum.

GENERAL OBSERVATIONS

In general, primitive odontocetes, especially 'agorophiids', and small toothed aetiocetid mysticetes dominate the Paleogene cetacean assemblages of the Olympic Peninsula. These assemblages are similar to those from the upper Oligocene deposits of coastal Oregon and on Hokkaido, Japan. This is in contrast to the assemblages of similar age in New Zealand that are dominated by toothless, baleen-bearing mysticetes, and those in South Carolina (Barnes and Sanders, 1990; Sanders and Barnes, 1989, 1991) and the Caucasus Mountains (Mchedlidze, 1976, 1984, 1988; Barnes, 1985) that are dominated by advanced odontocetes and baleen-bearing mysticetes and lack toothed aetiocetid mysticetes. The taxonomic composition of the cetacean assemblages of Washington may reflect the fact that most of the deposits represent deeper waters than those in New Zealand and South Carolina.

Oddly enough, reptiles have not been found in the marine rocks of the Olympic Peninsula, and sharks and bony fishes

Figure 8. Restoration of the holotype specimen of the primitive tooth-bearing mysticete whale, *Chonecetus goedertorum* Barnes and Furusawa, 1995, collected from the upper Oligocene Pysht Formation in the Twin Rivers quarry by James L. and Gail H. Goedert. **A**, the skull in ventral view; **B**, the skull in dorsal view; **C**, the skull with left lower jaw in lateral view. (Natural History Museum of Los Angeles County catalog no. 131146; skull length as preserved is 46 cm.)



are relatively uncommon. Mammals and marine birds dominate all the vertebrate assemblages.

A rather profound faunal change is recorded in lower Miocene rocks on the Olympic Peninsula. Mysticetes, which are relatively common in the Pysht Formation, are unknown in the overlying Clallam Formation, and the cetaceans in the Clallam Formation are limited to small 'dolphins'. This probably is because waters became progressively shallower throughout the deposition of the Clallam Formation. Pinnipeds are rare in the Clallam Formation but relatively abundant in correlative rocks in Oregon, California, and Japan. Desmostylians appear to become extinct locally at about this time, although they are common in correlative rocks of Vancouver Island, Oregon, California, and Japan. Plotopterid birds appear to become extinct locally at this time also, but they survived longer in California and Japan. The large pelagic cephalopod, *Aturia*, common in parts of the Makah and Pysht Formations, is also quite rare in the Clallam Formation, again probably because of the shallowing marine environment.

COLLECTING METHODS

Collecting in rock units like the Makah Formation, which represents mid- to lower bathyal, basin-plain and outer fan-fringe environments, requires much patience. Fossils of any kind are relatively rare in these rocks. Collecting the fossil-bearing nodules and concretions is sometimes like 'working blind'—learning what they contain may be a long, tedious process.

Once they are located, excavation of the fossil-bearing nodules is difficult because the strata dip steeply into the beach and because excavations quickly fill with water, mud, and piling worms. During the winter, some collecting has to be done at night (by lantern) to take advantage of favorable tides.

These concretions, by virtue of their dense nature, serve to protect the enclosed fossils so that plaster jackets are usually not necessary. The rocks containing the fossils can be carried off the beach using either backpacks or slings.

Almost everything we are learning from the fossils found on the Olympic Peninsula started with discoveries made by amateurs. Just as important as the discovery, however, is proper excavation, examination, and documentation of these fossils. A few misplaced blows to a fossil from a pick or hammer can destroy an immense amount of data.

You can help. If you think you have discovered some fossil bones, teeth, or a skull, please contact someone who can show you how to properly remove the fossils or who can make arrangements to excavate them. Suggested contacts are: Dr. John Rensberger, Thomas Burke Memorial Washington State Museum, Seattle, (206) 543-6776, or the authors, Dr. Lawrence Barnes, (213) 744-3329, or James Goedert, (206) 857-3045.

ACKNOWLEDGMENTS

National Geographic Society Grant No. 4439-90 to Barnes and Goedert supported collecting and research on fossil whales from the Olympic Peninsula. The following people contributed to field work and (or) donated specimens: Ross and Marion Berglund, William R. Buchanan, Ernie Coventon, Gail H. Goedert, Ruth-Ann Toney, and Albin Zukofsky II. We are particularly grateful to the Holnam-Ideal Corporation for allowing us to salvage important fossils from their Twin Rivers quarry. Dr. Yoshihiko Okazaki of the Kitakyushu Museum and Institute of Natural History, Kitakyushu, Japan, provided the photograph of the mounted plotopterid skeleton in his museum. Robert L. Clark, former Senior Museum Technician at the Natural History Museum of Los Angeles County (LACM), prepared the skulls of *Chonecetus goedertorum* and *Kolponomos clallamensis*. The *Behemotops* illustrations in Figure 4 were prepared by Mary Parrish of the U.S. National Museum of Natural History, and copies were provided by David Bohaska, Department of Paleobiology, U.S. National Museum of Natural History. The *Chonecetus* illustrations in Figure 8 were prepared by Wendy Smith-Griswold, former scientific illustrator at LACM; and photos of the *Kolponomos* skull were prepared by Donald Meyer, former staff photographer at LACM.

SELECTED REFERENCES

Addicott, W. O., 1976a, Neogene molluscan stages of Oregon and Washington. *In* Fritsche, A. E.; Ter Best, H., Jr.; Wornardt, W. W., editors, The Neogene Symposium: Society of Economic Paleontologists and Mineralogists, p. 95-115.

Addicott, W. O., 1976b, New molluscan assemblages from the upper member of the Twin River Formation, western Washington—Significance in Neogene chronostratigraphy: U.S. Geological Survey Journal of Research, v. 4, no. 4, p. 437-447.

Anonymous, [L. G. Barnes], 1992, Paleontology excavations in Washington State and Mexico: Natural History Museum of Los Angeles County, Terra, v. 30, no. 4, p. 46-47.

Barnes, L. G., 1976, Outline of eastern North Pacific fossil cetacean assemblages: Systematic Zoology, v. 25, no. 4, p. 321-343.

Barnes, L. G., 1979, Fossil enaliarctine pinnipeds (Mammalia: Otariidae) from Pyramid Hill, Kern County, California: Natural History Museum Los Angeles County Contributions in Science 318, p. 1-41.

Barnes, L. G., 1984, Whales, dolphins and porpoises—Origin and evolution of the Cetacea. *In* Gingerich, P. D.; Badgley, C. E., convenors; Broadhead, T. W., editor, Mammals—Notes for a short course: University of Tennessee, Department of Geological Sciences, Studies in Geology, v. 8, p. 139-154.

Barnes, L. G., 1985, Review—G. A. Mchedlidze, General features of the paleobiological evolution of Cetacea, 1984 [English translation]: Marine Mammal Science, v. 1, no. 1, p. 90-93.

Barnes, L. G., 1987, *Aetiocetus* and *Chonecetus,* primitive Oligocene toothed mysticetes and the origin of baleen whales: Journal of Vertebrate Paleontology, v. 7 (supplement to no. 3, abstracts), p. 10A.

Barnes, L. G., 1989a, A new enaliarctine pinniped from the Astoria Formation, Oregon, and a classification of the Otariidae (Mammalia: Carnivora): Natural History Museum of Los Angeles County Contributions in Science 403, p. 1-26.

Barnes, L. G., 1989b, *Aetiocetus* and *Chonecetus* (Mammalia: Cetacea)—Primitive Oligocene toothed mysticetes and the origin of baleen whales [abstract]: Fifth International Theriological Congress, Abstracts of Papers and Posters, Rome, Italy, 22–29 August 1989, v. 1, p. 479.

Barnes, L. G., 1992, A new genus and species of middle Miocene enaliarctine pinniped (Mammalia, Carnivora, Otariidae) from the Astoria Formation in coastal Oregon: Natural History Museum of Los Angeles County Contributions in Science 431, p. 1-27.

Barnes, L. G.; Domning, D. P.; Ray, C. E., 1985, Status of studies on fossil marine mammals: Marine Mammal Science, v. 1, no. 1, p. 15-53.

Barnes, L. G.; Kimura, M.; Furusawa, H.; Sawamura, H., 1995, Classification and distribution of Oligocene Aetiocetidae (Mammalia; Cetacea; Mysticeti) from western North America and Japan. *In* Barnes, L. G.; Hasegawa, Y.; Inuzuka, N., editors, The Island Arc [Thematic issue—Evolution and biogeography of fossil marine vertebrates in the Pacific realm]: Proceedings of the 29th International Geological Congress, Kyoto, Japan, v. 3, no. 4, p. 392-431.

Barnes, L. G.; Mitchell, E. D., 1978, Cetacea. Chapter 29 *in* Maglio, V. J.; Cooke, H. B. S., editors, Evolution of African mammals: Harvard University Press, p. 582-602.

Barnes, L. G.; Sanders, A. E., 1990, An archaic Oligocene mysticete from South Carolina [abstract]: Journal of Vertebrate Paleontology, v. 10 (supplement to no. 3), p. 14A.

Crowley, B. E.; Barnes, L. G., 1996, A new late Oligocene mysticete from Washington State [abstract]: The Paleontological Society Special Publication 8, p. 90.

Cruz-Marin, A.; Barnes, L. G., 1996, A new agorophiid from San Juan de la Costa, Baja California Sur—The oldest odontocete from Mexico [abstract]: The Paleontological Society Special Publication 8, p. 91.

Domning, D. P.; Ray, C. E.; McKenna, M. C., 1986, Two new Oligocene desmostylians and a discussion of tethytherian systematics: Smithsonian Contributions to Paleobiology, v. 59, p. 1-56.

Emlong, D. R., 1966, A new archaic cetacean from the Oligocene of northwest Oregon: Bulletin of the Museum of Natural History, University of Oregon, v. 3, p. 1-51.

Fordyce, R. E., 1992, Cetacean evolution and Eocene/Oligocene environments. *In* Prothero, D.; Berggren, W., editors, Eocene–Oligocene climatic and biotic evolution: Princeton University Press, p. 368-381.

Fordyce, R. E.; Barnes, L. G., 1994, Evolutionary history of whales. *In* Wetherill, G. W., editor, 1994 annual review of earth and planetary sciences: Annual Reviews, Inc., [Palo Alto, Calif.], v. 22, p. 419-455.

Fordyce, R. E.; Barnes, L. G.; Okazaki, Y.; Kimura, K.; Hasegawa, Y.; McLeod, S. A.; Horikawa, H.; Goedert, J. L.; Miyazaki, S., 1992, Summary of taxa and geologic and geographic distributions of fossil Cetacea in the Pacific realm [abstract]: 29th International Geological Congress, Kyoto, Japan, August, 1992, Abstracts, v. 2, p. 349.

Fordyce, R. E.; Barnes, L. G.; Miyazaki, N., 1995, General aspects of the evolutionary history of whales and dolphins. *In* Barnes, L. G.; Hasegawa, Y.; Inuzuka, N., editors, The island arc [thematic issue—Evolution and biogeography of fossil marine vertebrates in the Pacific realm: Proceedings of the 29th International Geological Congress, Kyoto, Japan, v. 3, no. 4, p. 373-391.

Goedert, J. L.; Barnes, L. G., 1996, The earliest known odontocete—A cetacean with agorophiid affinities from latest Eocene to earliest Oligocene rocks in Wash. State [abstract]: The Paleontological Society Special Publication 8, p. 148.

Goedert, J. L.; Squires, R. L.; Barnes, L. G., 1995, Paleoecology of whale-fall habitats from deep-water Oligocene rocks, Olympic Peninsula, Washington State: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 118, p. 151-158.

Hunt, R. M., Jr.; Barnes, L. G., 1994, Basicranial evidence for ursid affinity of the oldest pinnipeds: Proceedings of the San Diego Society of Natural History, v. 29, p. 57-67.

Kaler, K. L., 1988, Whale hunting on the Olympic Peninsula: Washington Geologic Newsletter, v. 16, no. 3, p. 16-17.

Kaler, K. L., 1989, Another cetacean (whale) fossil from the Olympic Peninsula: Washington Geologic Newsletter, v. 17, no. 2, p. 16-17.

Kimura, M.; Barnes, L. G.; Furusawa, H., 1992, Classification and distribution of Oligocene Aetiocetidae (Mammalia, Mysticeti) from western North America and Japan [abstract]: 29th International Geological Congress, Kyoto, Japan, August, 1992, Abstracts, v. 2, p. 348.

Mchedlidze, G. A., 1976, Osnovnyye cherty paleobiologicheskoy istorii Kitoobraznykh [Basic features of the paleobiological history of the Cetacea]: Akademia Nauk Gruzinskoi SSR, Institut Paleobiologii, "Metsniereba" Press, 136 p. [In Russian]

Mchedlidze, G. A., 1984, General features of the paleobiological evolution of Cetacea: Amerind Publishing Co. Pvt. Ltd., New Delhi [for the Smithsonian Institution Libraries and National Science Foundation], 136 p.

Mchedlidze, G. A., 1988, Fossil Cetacea of the Caucasus: Amerind Publishing Co. Pvt. Ltd., New Delhi [for the Smithsonian Institution Libraries and National Science Foundation], 150 p.

Moore, E. J.; Addicott, W. O., 1987, The Miocene Pillarian and Newportian (Molluscan) stages of Washington and Oregon and their usefulness in correlations from Alaska to California: U.S. Geological Survey Bulletin 1664, p. A1-A13, pl. 1-4.

Muizon, C. de, 1990 (1991), A new Ziphiidae (Cetacea) from the early Miocene of Washington State (USA) and phylogenetic analysis of the major groups of odontocetes: Bulletin du Museum National d'Histoire Naturelle, Paris, series 4, v. 12, p. 279-326.

Niem, A. R.; Snavely, P. D., Jr.; Chen, Ying; Niem, W. A., 1989, Jansen Creek Member of the Makah Formation—A major Oligocene submarine landslide or slump deposit from the Vancouver shelf in the Juan de Fuca deep margin basin, NW Olympic Peninsula, Washington [abstract]: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 123.

Olson, S. L., 1980, A new genus of penguin-like pelecaniform bird from the Oligocene of Washington (Pelecaniformes; Plotopteridae). *In* Campbell, K. E., Jr., editor, Papers in avian paleontology honoring Hildegard Howard: Natural History Museum of Los Angeles County Contributions in Science 330, p. 51-57.

Olson, S. L.; Hasegawa, Y., 1979, Fossil counterparts of giant penguins from the North Pacific: Science, v. 206, p. 688-689.

Rau, W. W., 1964, Foraminifera from the northern Olympic Peninsula, Washington: U.S. Geological Survey Professional Paper 374-G, p. 1-33.

Ray, C. E.; Domning, D. P.; McKenna, M. C., 1994, A new specimen of *Behemotops proteus* (Order Desmostylia) from the marine Oligocene of Washington: Proceedings of the San Diego Society of Natural History, v. 29, p. 205-222.

Russell, L. S., 1968, A new cetacean from the Oligocene Sooke Formation of Vancouver Island, British Columbia: Canadian Journal of Earth Sciences, v. 5, p. 929-933.

Sanders, A. E.; Barnes, L. G., 1989, An archaic Oligocene mysticete from South Carolina, U.S.A. [abstract]: Eighth Biennial Conference on the Biology of Marine Mammals, Pacific Grove, California, December 1989, Abstracts, p. 58.

Sanders, A. E.; Barnes, L. G., 1991, Late Oligocene *Cetotheriopsis*-like mysticetes (Mammalia, Cetacea) from near Charleston, South Carolina: Journal of Vertebrate Paleontology 11 (supplement to no. 3, abstracts), p. 54A.

Snavely, P. D., Jr.: Niem, A. R.; MacLeod, N. S.; Pearl, J. E.; Rau, W. W., 1980, Makah Formation—A deep-marginal-basin sequence of late Eocene and Oligocene age in the northwestern Olympic Peninsula, Washington: U.S. Geological Survey Professional Paper 1162-B, p. 1-28.

Squires, R. L.; Goedert, J. L.; Barnes, L. G., 1991, Whale carcasses: Nature, v. 349, no. 6310, p. 574.

Stirton, R. A., 1960, A marine carnivore from the Clallam Miocene Formation, Washington—Its correlation with nonmarine faunas: University of California Publications in Geological Sciences, v. 36, no. 7, p. 345-368.

Tabor, R. W.; Cady, W. M., 1978, Geologic map of the Olympic Peninsula, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-994, 2 sheets, scale 1:125,000.

Tedford, R. H.; Barnes, L. G.; Ray, C. E., 1994, The early Miocene littoral ursid carnivoran, *Kolponomos*—Systematics and mode of life: Proceedings of the San Diego Society of Natural History, v. 29, p. 11-32.

Whitmore, F. C., Jr.; Sanders, A. E., 1976 (1977), Review of the Oligocene Cetacea: Systematic Zoology, v. 25, p. 304-320. ■

New Whales From Washington

James Goedert and Lawrence Barnes, authors of the preceding article, have found a partial skull, partial mandible, and some teeth of the world's earliest toothed whale (Goedert and Barnes, 1996, above) in the lower part of the Lincoln Creek Formation in Mason County. The formation straddles the Eocene–Oligocene boundary. The characteristics of the skull indicate that the suborder Odontoceti must have had its origin at about that time or earlier. The cranial features resemble those of the Agorophiidae, and the whale has the typical mammalian dental pattern of 11 teeth on each side of the upper and lower jaws. The specimen is the oldest of this family to be found in the eastern North Pacific.

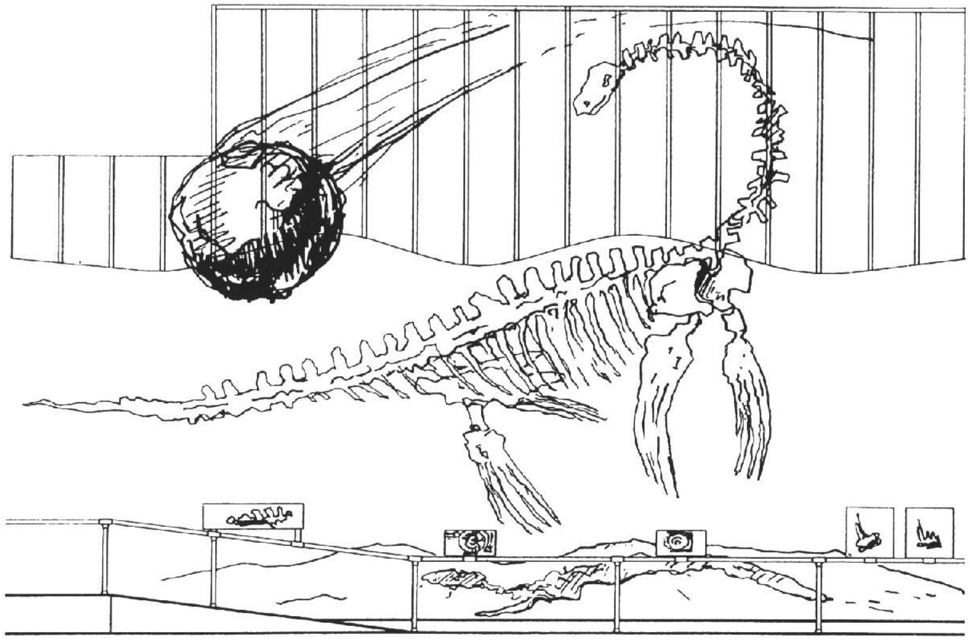
Bruce Crowley of the Burke Museum in Seattle and Lawrence Barnes have described (Crowley and Barnes, 1996, above) a new whale from the Pysht Formation (late Oligocene). The fossil cetacean consists of a skull with an incomplete rostrum, all the cervical vertebrae, partial scapulae, some thoracic and lumbar vertebrae, long bones of the front limbs, and some broken ribs. The specimen is very primitive and fairly large. The authors believe it would likely be classified as a primitive member of the Cetotheriidae, affiliated with the genus *Mauicetus*. Crowley assembled the partial skeleton in the Burke's 'fossil workshop'.

Both discoveries were reported at a symposium 'Origin and Early Evolution of Whales' organized and chaired by Lawrence Barnes for the Sixth North American Paleontological Convention held at the Smithsonian Institution in Washington, DC, in June of this year. Scientists from all over the world gave 23 presentations about whale evolution. The Natural History Museum of Los Angeles County has agreed to publish a book incorporating the research of all contributors to the symposium, and Barnes will be the editor. It is very significant that important new fossils found in Washington State elucidating the early development of both toothed and baleen whales will be included, and this work stems from collaboration by staff of the Burke Museum and the Natural History Museum of Los Angeles County and dedicated amateurs and volunteers of both institutions.

Burke Museum Plans New Exhibit

"Life and Times of Washington" is the title of a 5,000-ft^2 permanent display planned to open in October 1997. The history of the geologic construction of the state and development of the landscape are the theme.

The Burke is currently acquiring new vertebrate fossils or remounting some already in the collection. The Mesozoic display will feature the *Allosaurus* in a new pose, attacking a stegosaur. Also on exhibit will be some dinosaur eggs and a marine reptile, the 30-ft-long "Puntledge elasmosaur" from Courtenay, British Columbia. This section of the display will end under an asteroid (shown in the accompanying sketch), where there will be information about the massive extinction event at the end of the Cretaceous.



The Tertiary portion of the exhibit will include a new cast of the Blue Lake rhino (described in *Washington Geology*, v. 16, no. 4, 1988).

Representing the Pleistocene will be a cast of a 14-ft-tall mastodon donated by Fox's Gem Shop of Seattle and a large saber-toothed cat, among other fossils.

For more information, contact the Burke at (206) 543-5590. Museum members will be following progress in the Burke's newsletter. ■

Smithsonian Research Fellowships and Internships

Applications for 1997 pre- and postdoctoral fellowships in geological sciences are due January 15. Possible disciplines are meteorics, mineralogy, paleobiology, petrology, planetary geology, sedimentology, and volcanology. Minority internships for 10 weeks in summer, fall, or spring are offered for undergraduate and graduate students.

Information is available from: Smithsonian Institution; Office of Fellowships and Grants; 955 L'Enfant Plaza, Suite 7000; Washington, DC 20560; *e-mail:* siofg@sivm.si.edu.

Remediation Course Offered

Wright State University announced a new 12-week distance learning course titled 'Site Remediation' to start in January. The course is designed for environmental professionals who are involved with cleanup of contaminated sites.

For more information, contact: The Center for Ground Water Management; Wright State University; 3640 Col. Glenn Hw, 056 Library; Dayton, OH 45435-001; *phone:* (513) 873-3648; *fax:* (513) 873-3649; *e-mail:* IRIS@desire.wright.edu; *Internet:* http://biology.wright.edu/cgwm/cgwm_home.html.

New Database Added to Library

The Mining Environment Database, version 2.0, is now available for searching at the Division of Geology and Earth Resources Library in Olympia.

The Mining Environment Database, developed and maintained by the J. N. Desmarais Library at Laurentian University, contains over 13,000 citations on abandoned mines, land reclamation, acid mine drainage, and related topics. A separate entry is created for each journal article, conference paper, or chapter in an edited monograph, with author, title, and source information; most records have a brief abstract. Coverage is international in scope. The Library has a hard copy of most citations.

Several enhancements have been added to the 1996 edition. Users have the option of limiting their search to the two identified subsets of the database, acid drainage or land reclamation, or of searching the complete file. An option has been added to limit keyword searches by date of publication.

Desmarais Library is seeking donations of appropriate articles or conference papers, as well as copies of mining and environmental legislation and regulations from other jurisdictions. It is especially interested in acquiring, with permission, copies of both environmental impact studies and research for decommissioned mine sites, as well as the internal reports of mining companies.

The Mining Environment Database is available on CD-ROM for $200 Canadian; upgrades are $100 Canadian. Orders should be sent to: CIMMER, Room FA380; Laurentian University; Sudbury, Ontario, CANADA P3E 2C6. *Phone:* (705) 673-6572; *fax:* 705-673-6508; *e-mail:* cmosher@admin. laurentian.ca.

Cascadia Region Earthquake Workgroup (CREW)

Since the early 1980s, scientists have accumulated geological and geophysical evidence for great Cascadia subduction zone (CSZ) earthquakes affecting the area from northern California to British Columbia. Scientists soon started to share their research results not only at scientific conferences but also with the public at a series of workshops sponsored by the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the Washington Department of Natural Resources (DNR), and the Oregon Department of Geology and Mineral Industries.

The emerging consensus in the scientific community of the potential for a great earthquake (summarized in Atwater and others, 1995) has led to increased attention to subduction events. Recent earthquakes in Washington, Oregon, and northern California and definition of the Seattle fault serve as reminders that the Pacific Northwest contains several earthquake sources; the Northridge and Kobe earthquakes demonstrate the enormity of the destruction that can be generated in urban areas.

Concern that such impacts could be spread over much of the Pacific Northwest prompted 40 geoscientists and emergency managers representing all levels of government along the CSZ to convene a workshop in 1992. The participants agreed upon the need for a regional partnership to address Pacific Northwest earthquake issues, and they delegated a core group to continue planning for a regional earthquake mitigation strategy, with representatives from the DNR, Oregon Division of Emergency Management, California Office of Emergency Services, British Columbia Provisional Emergency Program, Emergency Preparedness Canada, FEMA, USGS, and the National Oceanic and Atmospheric Administration. A post-workshop questionnaire gathered information about needs and resources from 20 agencies. In 1993, the core group attempted to formulate a regional earthquake mitigation strategy and a list of priorities, but it became apparent that it was necessary to have input from business, industry, and lifeline organizations that provide the critical services and economic components on which the Cascadia region depends. In May 1994, the core group began planning a workshop called *Finding the Weak Links* to involve high-level participants from lifelines, government, and industry representing all areas of the Cascadia region. The workshop was also intended to define how the region might be fragmented by a subduction zone event and to develop a vision to deal with regionwide priority issues.

Participants in the *Finding the Weak Links* workshop proposed the creation of a project-oriented group to address regionwide earthquake mitigation. The core group was replaced by a steering committee that represented the private sector as well as the governmental agencies of the original group. The steering committee was charged with developing a mission, goals, and an organizational framework for coordinating the players, resources, and mitigation activities regionwide.

The outgrowth of this planning effort is CREW, a private–public coalition working to reduce the risk of Cascadia region earthquake hazards by linking regional mitigation resources and encouraging regional mitigation projects. CREW consists of Northwest-based entities that share an interest in regionwide hazard reduction. Government, corporate, medical, financial, manufacturing, utility, and transportation groups all contribute to CREW. CREW is committed to creating a Cascadia regional risk-reduction and preparedness effort.

The goals of CREW are to:

- Promote efforts to reduce the loss of life and property
- Develop mitigation initiatives to sustain a viable post-disaster economy
- Target education efforts to motivate key decision makers to undertake mitigation actions
- Foster linkages among key utility and transportation providers and supported business and industry.

For more information about CREW, visit the web page at:

http://www.geophys.washington.edu/CREW/index.html

Reference Cited

Atwater, B. F.; Nelson, A. R.; Clague, J. J.; Carver, G. A.; Yamaguchi, D. K.; Bobrowsky, P. T.; Bourgeois, Joanne; Darienzo, M. E.; Grant, W. C.; Hemphill-Haley, Eileen; Kelsey, H. M.; Jacoby, G. C.; Nishenko, S. P.; Palmer, S. P.; Peterson, C. D.; Reinhart, M. A., 1995, Summary of coastal geologic evidence for past great earthquakes at the Cascadia subduction zone: Earthquake Spectra, v. 11, no. 1, p. 1-18. ■

Mars and the Channeled Scabland

In September 1995, Matt Golombek, Ken Edgett, and Jim Rice of Arizona State University led a group of K–12 teachers through Washington's scabland to help them envision the task of the robotic vehicle that will be placed in the Ares Vallis area of Mars during the Pathfinder mission. As part of the week's activities, the teachers and scientists put on an open house at Chase Middle School and a workshop at Salk Middle School, both in Spokane.

The Pathfinder mission is scheduled for December 1996, and thanks to the collaboration of the university, the Jet Propulsion Laboratory, the Lunar and Planetary Institute, and NASA, a lot of children will know more about the scabland and the future of exploration on Mars. The workshop was written up in the March/April issue of *The Planetary Report* and in a report prepared by the Lunar and Planetary Institute, LPI Technical Report 95-1, parts 1 and 2.

To get more information about this innovative linking of geology and space exploration, contact Ken Edgett, director of the Arizona Mars K–12 Education Program, Arizona State University, Tempe, AZ 85287-0112. The Division library has a copy of the report (see p. 31).

Book Review: Geology of the Pacific Northwest

Elizabeth S. Norman
South Puget Sound Community College
Olympia, WA 98512

Geology of the Pacific Northwest
by Elizabeth L. Orr and William N. Orr
McGraw-Hill (1996). 409 p. Softcover.

Compiling information about the geology of the Pacific Northwest is a monumental undertaking—the Orrs are to be commended. In addition to the geologic and tectonic history of each province, they cover the physiography and historical metal mining and touch on modern hazards. Their geologic information is up to date, drawing on the work of experts in each area. Even their geologic time scale is updated with a more recent age for the beginning of the Paleozoic: 550 million years ago.

I have been looking for a textbook to use in an introductory regional geology class, so it was with anticipation of using this book that I began reading it. However, the first chapter swamps the reader with a compressed version of the tectonic interpretation of geologic events in the Northwest. This chapter would be difficult for a beginning student to absorb. The introductory chapter made more sense to me when I read it again, after I had worked through the rest of the book.

The introduction summarizes the regional tectonic events chronologically, but I still flipped between chapters trying to relate events in one region to another. This would have been easier if there were chapter subheadings by age and if the table of contents included subheadings. From my standpoint as a teacher, I would like to see an expanded chronological discussion and illustrations that tie events in the physiographic provinces to each other as well as to the bigger picture (North American and worldwide paleogeography). For example, the authors might note the similarities between the fauna of the famous Cambrian Burgess Shale deposits and faunas of Cambrian shales in China.

The body of the book is well written but technical. For the general (but educated) public and lower division college students, a few introductory chapters similar to those in *Cascadia* (McKee, 1972) and environmental and historical geology textbooks would be helpful. Some concepts are introduced at random. For example, a discussion of batholiths appears halfway through the book, although it would have been beneficial near the beginning where the Coast Range batholith of British Columbia was discussed. The book does contain a glossary with simple diagrams, which will aid the novice geologist.

Most chapters can be read out of sequence—they are self-contained. The Cascades chapter, however, relies on the chapters covering British Columbia to clarify the tectonic picture.

Because I would like to fill gaps in my knowledge of local geology, I would have appreciated some literature citations in the text, in addition to the further reading suggested at the end of each chapter. The Orrs reference the sources of their figures, and that is helpful. However, their figures are not numbered or keyed to the text; I found this confusing and frustrating in many places. I would have liked to see more geologic maps and more geographic information on maps, such as roads. While *Roadside Geology of Washington* (Alt and Hyndman, 1984) lacks detail, it can be used in conjunction with the Orrs' book on a road trip.

Many of the block diagrams help readers visualize the tectonic events. The diagram on page 220 illustrating three stages of Snake River geology was worth paragraphs of text description. Other text descriptions would benefit from a map or diagram. Some of the photos (all in black and white) could be jettisoned to make room for these. One concept that would benefit from a diagram is the idea that slower convergence leads to a steeper subducting plate. It was not obvious from the text that the authors were referring to young, warm, buoyant oceanic crust that needs more time to sink. (I kept thinking faster convergence means steeper angles, which is true for old dense oceanic crust like that at the Mariana trench.)

The Orrs dismiss western Washington coal production without mentioning the Centralia Coal Mine, which produces about 4.7 million short tons a year, or about 1 percent of U.S. domestic coal production. They do mention the Roslyn coal fields, which produced about 63 million tons between 1882 and 1963, when the mines closed down.

Some minor corrections are needed—for example, photo references to the Washington Department of Geology and Earth Resources should be to the Washington Division of Geology and Earth Resources. (The preface has it right.) In one photo caption, you should see eastern Washington, not British Columbia, if you look east from Mount St. Helens and Mount Adams.

Although the cost of this book (about $44) is similar to that of full-color geologic texts, the print quality is poor. In the copy I reviewed, the text was in shades of gray, while numerous photos seemed out of focus, leaving me wondering what I was looking at.

With *Cascadia* out of print and out of date tectonically, this book at least partly fills the need for a regional geology text on the Pacific Northwest. I was impressed by the technical discussions of the geology. This book would be useful for 300-level courses (and above) or to geologists interested in learning more about regional Northwest geology. A few corrections, some reorganization, and additions might broaden the audience to which the book would appeal. The Orrs' book will definitely be part of my personal library and accompany me on road trips.

References Cited

Alt, D. D.; Hyndman, D. W., 1984, Roadside geology of Washington: Mountain Press Publishing Co., 282 p.

McKee, Bates, 1972, Cascadia; The geologic evolution of the Pacific Northwest: McGraw-Hill Book Company, 394 p. ■

Historical Mining Claim Tracings Commercially Available

The Kroll Map Company, Inc., in Seattle owns turn-of-the-century mine claim maps that were produced by the O. P. Anderson Map and Blue Print Co., Washington Map and Blue Print Co., and others. The map inventory provided to us by Kroll Map Company includes:

- Methow Group owned by Hidden Treasure
- Methow (Okanogan County), Hidden Treasure group
- Squaw Creek (Okanogan County), Hidden Treasure mine
- Squaw Creek Mining District (Okanogan County)
- Kennedy's map of Silverton Mining District
- Stillaguamish District (Snohomish County), Gordon Creek Gold & Copper Mining Co.
- Stillaguamish District (Snohomish County), Deer Creek Gold & Copper Mining Co.
- Stillaguamish Mining District (Snohomish County)
- Index and its vicinity (Snohomish County)
- Money Creek District (King County), Gold Mountain Mining Company
- Sucia Island Stone mine (San Juan County), claim of Simon P. Randolph
- Fair Haven Mining District, Candle Creek
- Osoyoos District, claims held by S. Field, F. G. Vernon, D. McIntyre, L. W. Riske
- Leavenworth District (Okanogan County)
- Leavenworth District (Okanogan County), Monterey Gold Mining & Milling Co.
- Leavenworth Mining District, Negro and Peshastin Creeks camps
- Leavenworth District (Okanogan County), Northland Mining Co.
- Peshastin and Negro Creek Mining Districts (Kittitas County)
- Colville Reservation and Trail Creek Mining Districts, Seattle Gold and Copper Mining and Milling Co.
- Colville Reservation and Trail Creek Mining District, Bald Eagle Gold Mining Co. and Syndicate Gold Mining Co.
- Money Creek, Miller River, and Buena Vista Mining Districts (King County)
- Granite Mountain and Buena Vista Districts
- Monte Cristo and Silver Creek Mining District (Snohomish County)
- Mount Baker or Nooksack Mining District (Whatcom County)
- Cascade portion of Skagit, Whatcom, and Okanogan Counties
- Hamilton Mining District (Skagit County)

For more information about these maps, contact:

The Kroll Map Company
2700 Third Avenue
Seattle, WA 98121
phone: (206) 448-6277
fax: (206) 448-6270

Electronic Green Journal

The University of Idaho Library announces a new issue of the *Electronic Green Journal* (v. 3, issue 1; ISSN: 1076-7975), a professional refereed publication devoted to information on international environmental topics. The journal serves as an educational environmental resource and includes both practical and scholarly articles, bibliographies, reviews, editorial comments, and announcements. The journal is academically sponsored; however, its focus is the educated generalist as well as the specialist.

Original contributions from authors are welcome. Guidelines for authors are available on the World Wide Web as indicated below or from the editors. Reviewers for books are also needed; books available for review are listed on the journal's web site. Advertisements are accepted. Text or images can be accommodated, and links to home pages of publishers and other advertisers can also be arranged.

Send contributions, advertisements, requests for guidelines, or requests for any other information about the journal to:

Maria Jankowska, General Editor, majanko@uidaho.edu
Mike Pollastro, Managing Editor, mikep@uidaho.edu

Preferred access to the journal is on the World Wide Web. Point your browser to:

http://www.lib.uidaho.edu:70/docs/egj.html

The journal is also available by ftp: anonymous ftp: www.lib.uidaho.edu (directory: /pub/egj). *Please note:* gif files (graphics) must be ftp-ed in binary mode.

Subscriptions are also available by e-mail. ASCII text versions of the contents of the journal will be e-mailed to subscribers. To subscribe, e-mail to:

MAJORDOMO@UIDAHO.EDU with the following in the body of the message:

subscribe egj *your_email_address* (substitute your preferred e-mail address here) ■

WANT TO GET OFF OUR MAILING LIST?

The Division pays for printing and postage for *Washington Geology* from an always-tight budget. Help us use our resources well by letting us know if you no longer wish to receive this 'journal'. We will take your name off the list immediately.

Selected Additions to the Library of the Division of Geology and Earth Resources

May 1996 through July 1996

THESES

Anderson, S. W., 1990, Topics in extrusive silicic volcanism: Arizona State University Doctor of Philosophy thesis, 181 p.

Baines, C. A., 1992, Determination of sustained yield for the shallow basalt aquifer in the Moscow area, Idaho: University of Idaho Master of Science thesis, 60 p.

Balocki, J. B., 1990, A preliminary examination of relationships between catchment characteristics and volumes of infrequent large floods: University of Washington Master of Science thesis, 124 p.

Bardoux, Marc, 1993, The Okanagan Valley normal fault from Penticton to Enderby, south-central British Columbia: Carleton University Doctor of Philosophy thesis, 292 p.

Cooley, S. W., 1996, Timing and emplacement of clastic dikes in the Touchet Beds of south-central Washington: Whitman College Bachelor of Arts thesis, 37 p.

Cushman, E. H., 1923, A study of the equipment and operation of the Tacoma smelter: University of Washington Bachelor of Science thesis, 67 p.

Fabritius, R. A., 1995, Shear-wave anisotropy across the Cascadia subduction zone from a linear seismograph array: Oregon State University Master of Science thesis, 126 p.

Farooqui, M. A., 1994, Petrology and provenance of the Middle Proterozoic Bonner Formation and its correlatives, Belt Supergroup, Montana, Idaho and Washington: University of Montana Doctor of Philosophy thesis, 262 p.

Frehner, H. K., 1957, Development of soil and vegetation on the Kautz Creek flood deposit in Mount Rainier National Park: University of Washington Master of Science thesis, 83 p.

Gabriel, A. O., 1988, An evaluation of coastal hazard management programs in the Puget Sound lowland: Western Washington University Master of Science thesis, 168 p.

Ginn, Shannon, 1996, The impact of land use practices and hydrology on a slump-earthflow landslide, Olympic Peninsula, Washington: Carleton College Senior Integrative Exercise [thesis], 48 p.

Horath, F. L., 1989, Permeability evolution in the Cascadia accretionary prism—Examples from the Oregon prism and Olympic Peninsula melanges: University of California, Santa Cruz, Master of Science thesis, 104 p.

McConkey, B. G., 1993, Modeling cold region agricultural hillslope hydrology: Washington State University Doctor of Philosophy thesis, 160 p.

Montgomery, J. A., 1993, Measurement and prediction of long-term soil–landscape change in the Palouse region induced by tillage and water erosion: Washington State University Doctor of Philosophy thesis, 253 p.

Rot, B. W., 1995, The interaction of valley constraint, riparian landform, and riparian plant community size and age upon channel configuration of small streams of the western Cascade mountains, Washington: University of Washington Master of Science thesis, 67 p.

Seal, Rebecca, 1994, Mechanisms of downstream fining in gravel bed rivers: University of Minnesota Doctor of Philosophy thesis, 226 p.

Includes:

Seal, Rebecca; Paola, Christopher, Observations of downstream fining on the North Fork Toutle River, Mt. St. Helens, Washington. p. 1-45.

Seal, Rebecca; Parker, Gary; Paola, Christopher, The effect of local patchiness of gravel grain size distributions on bed load transport in braided rivers. p. 46-65.

U.S. GEOLOGICAL SURVEY

Published reports

Booth, D. B., 1995, Surficial geologic map of the Maple Valley quadrangle, King County, Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF- 2297, 1 sheet, scale 1:24,000.

Mullineaux, D. R., 1996, Pre-1980 tephra-fall deposits erupted from Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1563, 99 p.

Southwest Washington Erosion Workshop, 1996, Pre-workshop abstracts: U.S. Geological Survey; Washington Department of Ecology, 1 v.

U.S. Geological Survey, 1996, Washington: U.S. Geological Survey Mineral Industry Surveys, 6 p.

Wilshire, H. G.; Howard, K. A.; Wentworth, C. M.; Gibbons, Helen, 1996, Geologic processes at the land surface: U.S. Geological Survey Bulletin 2149, 41 p.

Open-File and Water-Resources Investigations Reports

Ebbert, J. C.; Cox, S. E.; Drost, B. W.; Schurr, K. M., 1995, Distribution and sources of nitrate, and presence of fluoride and pesticides, in parts of the Pasco Basin, Washington, 1986–88: U.S. Geological Survey Water-Resources Investigations Report 93-4197, 173 p., 3 pl.

OTHER REPORTS ON WASHINGTON GEOLOGY

Anderson, James; Marcus, Kim; Wilson, Jerry, 1990, California, Oregon, and Washington archaeological resource study; Volume II—Geology: U.S. Minerals Management Service OCS Study 90-0088, 90 p.

Bausch, Doug, compiler, 1996, WSSPC '95—Annual report and sixteenth meeting of the Western States Seismic Policy Council: Arizona Division of Emergency Management, 1 v.

Includes:

Bausch, Doug; Boerner, Matthias, compilers, Synopsis of seismic threats in the western United States—Impacts to the national transportation infrastructure. 59 p.

Walsh, T. J.; Palmer, S. P., The 1995 Robinson Point earthquake, Puget Sound, Washington—A small event with potentially large consequences. p. 125.

Canning, D. J., 1991, Sea level rise in Washington State—State-of-the-knowledge, impacts, and potential policy issues; Version 2.1: Washington Department of Ecology, 57 p.

Deobald, W. B.; Buchanan, J. P., 1995, Hydrogeology of the West Plains area of Spokane County, Washington: Spokane County Water Quality Management Program, 111 p.

Economic and Engineering Services, Inc., 1989, Island County ground water management plan; Part A, Technical memorandum—Hydrogeologic characterization and background data collection relating to groundwater protection and management: Economic and Engineering Services, Inc., 1 v.

Friends of the Pleistocene, 1996, Quaternary glaciation and tectonism on the western Olympic Peninsula, Washington—A field guide for the Friends of the Pleistocene 3rd annual Pacific Northwest Cell field conference: Friends of the Pleistocene, 1 v., 2 pl.

Includes:

Ginn, Shannon, A guide to the Bogachiel River landslide for the FOP trip to the Olympic Peninsula, Washington. 4 p.

Pazzaglia, F. J.; Brandon, M. T., Tectonic implications of fluvial terraces along the Clearwater River, Olympic Mountains, Washington. 50 p.

Thackray, G. D., Glaciation and coastal neotectonic deformation on the western Olympic Peninsula, Washington. 23 p.

Golombek, M. P.; Edgett, K. S.; Rice, J. W., Jr., editors, 1995, Mars Pathfinder Landing Site Workshop II—Characteristics of the Ares Vallis region and field trips in the Channeled Scabland, Washington: Lunar and Planetary Institute Technical Report 95-01, 2 v.

Includes:

Edgett, K. S.; Rice, J. W., Jr., editors, Summary of education and public outreach. Part 2, p. 17-29.

Edgett, K. S.; Rice, J. W., Jr., Summary of field work in the Channeled Scabland. Part 2, p. 9-16.

Edgett, K. S.; Rice, J. W., Jr.; Baker, V. R., editors, Field trips accompanying the Mars Pathfinder Landing Site II Workshop—Channeled Scabland and Lake Missoula break-out areas in Washington and Idaho. Part 1, p. 31-63.

Jacobin, Louis, 1917, repr. 1996?, Old king coal—The Pierce County mining district in late 1917: Heritage Quest Press [Orting, Wash.], 52 p.

Meitzler, S. K., compiler and editor, 1994, Mining tragedies in Carbon River coal county, 1890–1930: Heritage Quest Press [Orting, Wash.], 68 p.

Niem, A. R.; Snavely, P. D., Jr., 1994, Tertiary stratigraphy of the Juan de Fuca basin, northern Olympic Peninsula, with a side excursion toward Hurricane Ridge, by William S. Lingley, Jr.: Northwest Petroleum Association Field Trip Guidebook, 33 p.

Null, Barbara, editor, 1992, Shoreline management—Symposium proceedings, Everett, Washington, December 13–14, 1991: Washington Sea Grant Program; Washington Department of Ecology, 154 p.

Includes:

Boule, Marc, Wetlands and shoreline management—Where have we been? Where are we going? p. 131-132.

Boyle, B. J., Shoreline management and the public trust. p. 123-126.

Carr, Paul, The Port Angeles harbor resource management plan—How it came to be. p. 65-67.

Cheney, Daniel; Oestman, Richard; Volkhardt, Greg; Getz, Jenna, Creation of rocky intertidal and shallow subtidal reefs to mitigate for the construction of Elliott Bay Marina, Puget Sound, Washington. p. 29-36.

Collins, Brad, Future of Port Angeles shoreline master program, harbor plan and comprehensive plan. p. 69-70.

Gregoire, Christine, Celebrating 20 years of Washington's Shoreline Management Act. p. 3-6.

Hess, M. B., Spokane shoreline master program 1974–1991. p. 89-90.

House, David, Wenatchee riverfront plan. p. 97-98.

Hulsizer, Elsie, Lake Union shoreline amendments, Seattle's Lake Union. p. 107-110.

Koenig, David, City of Everett waterfront planning. p. 73-75.

Lattin, Stan, Grays Harbor estuary management plan—A balance between economic development and resource protection. p. 17-18.

Malin, R. S., Port of Olympia. p. 119-120.

Malone, T. W., The Lake Union–Ship Canal industrial corridor. p. 101-106.

McKay, Nancy, Shoreline management and the Puget Sound plan. p. 129-130.

Owen, John; Cooper, Robert; Gregoire, Dennis; Koenig, David, Shoreline planning on Everett's harborfront—Public access planning as a comprehensive planning tool in a rapidly changing development environment. p. 77-86.

Stevens, T. C., Padilla Bay National Estuarine Research Reserve. p. 23-26.

Sweeney, K. W., Port Angeles harbor resource management plan. p. 61-63.

Swensson, Pete, Shoreline planning in Olympia's harbor. p. 113-118.

Thomas, J. K., Shoreline management—The first twenty years. p. 9-14.

O'Brien, Rachel; Keller, C. K., 1993, Estimation of groundwater recharge in the Palouse loess using environmental tritium: Washington Water Research Center A-172-WASH, 87 p.

Orr, E. L.; Orr, W. N., 1996, Geology of the Pacific Northwest: McGraw-Hill Companies, Inc., 409 p.

Pacific Science Center, 1990, N.E.W.T. (Northwest Earthquake Workshop for Teachers)—Instructor's manual: Pacific Science Center, 1 v.

Schmidt, K. M., 1994, Mountain scale strength properties, deep-seated landsliding, and relief limits: Timber, Fish & Wildlife Program TFW-SH10-95-001, 166 p.

Sebring, Al, compiler, 1902, repr. 1983, Sebring's Skagit County illustrated—Historical and pictorial publication of Skagit County, Wash.: Meico Associates, Inc. [South Prairie, Wash.], 36 p.

Severson, K. J.; Johnstone, D. L.; Keller, C. K., 1990, Hydrogeochemical parameters affecting vadose-zone microbial distributions at two sites: Washington Water Research Center A-162-WASH, 90 p.

Stewart, B. M.; Williams, B. C.; Lambeth, R. H., 1995, Investigation of acid production, leaching, and transport of dissolved metals at an abandoned sulfide tailings impoundment—Monitoring and physical properties: U.S. Bureau of Mines Report of Investigations 9577, 82 p.

Stinson, Margaret; Norton, Dale, 1987, Metals concentrations in ASARCO discharges and receiving waters following plant closure: Washington Department of Ecology, 23 p.

Strong, J. M.; Schuettke, V. E.; Loftfield, M. K.; Wohlford, E. M.; Peltier, M. L.; Knutsen, D. E.; Owens, Wendy; Miller, K. A.; King, J. K., 1993, Nisqually delta study, June 15–August 27, 1993: South Puget Sound Community College, Saint Martin's College, University of Puget Sound, 1 v.

Thurston Regional Planning Council, 1993, Inventory and characterization of shoreline armoring, Thurston County, Washington, 1977–1993: Thurston Regional Planning Council, 90 p., 6 foldout pl.

Tooley, John; Erickson, Denis, 1996, Nooksack watershed surficial aquifer characterization: Washington Department of Ecology Report 96-311, 1 v., 1 plate.

University of Washington Geophysics Program, 1996, Quarterly network report 96-A on seismicity of Washington and Oregon, January 1 through March 31, 1996: University of Washington Geophysics Program, 28 p.

Washington Department of Ecology, 1994, Inventory of dams in the State of Washington; rev. ed.: Washington Department of Ecology Publication 94-16, 150 p.

Washington Water Research Center, 1985, Proceedings from the conference; Protection and management of aquifers with emphasis on the Spokane–Rathdrum aquifer: Washington Water Research Center Report 62, 118 p.

Includes:

Ashlock, Dennis; Burns, W. J.; Hartz, K. E.; Luther, M. Q.; Kennedy, Michael, What can communities do to preserve and protect their aquifers? A panel discussion. p. 95-105.

Collins, Bruce, The development of a detailed data base for informed decision making. p. 35-38.

Esvelt, L. A., Water quality of the Rathdrum Prairie–Spokane Valley aquifer system. p. 7-22.

Miller, S. A., The impact of stormwater runoff on groundwater quality and potential mitigation. p. 55-76.

Moos, D. W., The state viewpoint. p. 49-54.

Ravan, J. E., Keynote address. p. 1-6.

Rawlings, Grace, Community efforts—Origin and development of the Spokane–Rathdrum aquifer management plans (Washington). p. 27-30.

Robison, C. D., Jr., Landfill and solid waste management for the City of Spokane. p. 89-94.

Scott, D. M.; Dobratz, William; Maxwell, J. M., Wastewater treatment—A sewer plan. p. 39-46.

Taam, Damon, Landfill and solid waste management for Spokane County. p. 83-88.

Woodhouse, Philip R., editor and compiler; Jacobson, Daryl; Petersen, Bill; Pisoni, Victor, 1996, Hard rock mines of the west central Cascades: Northwest Underground Explorations [Seattle, Wash.], 233 p.

PAPERS ON WASHINGTON GEOLOGY

Adams, John, 1996, Paleoseismology in Canada—A dozen years of progress: Journal of Geophysical Research, v. 101, no. B3, p. 6193-6207.

Agapito, J. F. T., 1991, Economic benefits gained by rock mechanics—Three case studies: Mining Engineering, v. 43, no. 2, p. 215-219.

Alidibirov, M. A., 1995, A model for the mechanism of the May 18, 1980 Mount St. Helens blast: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 217-225.

Alsina, D.; Woodward, R. L.; Snieder, R. K., 1996, Shear wave velocity structure in North America from large-scale waveform inversions of surface waves: Journal of Geophysical Research, v. 101, no. B7, p. 15,969-15,986.

Anderson, S. W.; Fink, J. H.; Rose, W. I., 1995, Mount St. Helens and Santiaguito lava domes—The effect of short-term eruption rate on surface texture and degassing processes: Journal of Volcanology and Geothermal Research, v. 69, no. 1-2, p. 105-116.

Arattano, M.; Savage, W. Z., 1994, Modelling debris flows as kinematic waves: International Association of Engineering Geology Bulletin, no. 49, p. 3-13.

Axtmann, E. V.; Stallard, R. F., 1995, Chemical weathering in the South Cascade Glacier basin, comparison of subglacial and extraglacial weathering. *In* Tonnessen, K. A.; Williams, M. W.; Tranter, Martyn, editors, Biogeochemistry of seasonally snow-covered catchments: International Association of Hydrological Sciences Publication 228, p. 431-439.

Baker, E. T., 1996, Geological indexes of hydrothermal venting: Journal of Geophysical Research, v. 101, no. B6, p. 13,741-13,753.

Benosky, C. P.; Merry, C. J., 1995, Automatic extraction of watershed characteristics using spatial analysis techniques with application to groundwater mapping: Journal of Hydrology, v. 173, no. 1-4, p. 145-163.

Berger, G. W., 1991, The use of glass for dating volcanic ash by thermoluminescence: Journal of Geophysical Research, v. 96, no. B12, p. 19,705-19,720.

Bjornstad, B. N.; McKinley, J. P.; Stevens, T. O.; Rawson, S. A.; Fredrickson, J. K.; Long, P. E., 1994, Generation of hydrogen gas as a result of drilling within the saturated zone: Ground Water Monitoring & Remediation, v. 14, no. 4, p. 140-147.

Brandon, A. D.; Creaser, R. A.; Shirey, S. B.; Carlson, R. W., 1996, Osmium recycling in subduction zones: Science, v. 272, no. 5263, p. 861-864.

Brechtel, C. E.; Hardy, M. P., 1993, Design of pillars with backfill interaction—A case study. *In* Fairhurst, Charles, editor, Comprehensive rock engineering—Principles, practice and projects; Vol. 2—Analysis and design methods: Pergamon Press, p. 711-732.

Bruner, J. C., 1991, Comments on the genus *Amyzon* (family Catostomidae): Journal of Paleontology, v. 65, no. 4, p. 678-686.

Burnham, R. J., 1994, Plant deposition in modern volcanic environments: Royal Society of Edinburgh Transactions—Earth Sciences, v. 84, parts 3 and 4, p. 275-281.

Carapella, Ruth, 1996, Flood damage assessment in the Pacific Northwest: Earth Observation Magazine, v. 5, no. 5, p. 17-20.

Carey, S. N.; Gardner, J. E.; Sigurdsson, Haraldur, 1995, The intensity and magnitude of Holocene plinian eruptions from Mount St. Helens volcano: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 185-202.

Carrara, P. E.; Kiver, E. P.; Stradling, D. F., 1996, The southern limit of Cordilleran ice in the Colville and Pend Oreille valleys of northeastern Washington during the Late Wisconsin glaciation: Canadian Journal of Earth Sciences, v. 33, no. 5, p. 769-778.

Carson, Bobb; Holmes, M. L.; Umstattd, Kea; Strasser, J. C.; Johnson, H. P., 1991, Fluid expulsion from the Cascadia accretionary prism—Evidence from porosity distribution, direct measurements, and GLORIA imagery. *In* Tarney, J.; Pickering, K. T.; Knipe, R. J.; Dewey, J. F., editors, The behaviour and influence of fluids in subduction zones: Royal Society of London Philosophical Transactions, Series A, no. 335, p. 331-340.

Clark, P. U.; Clague, J. J.; Curry, B. B.; Dreimanis, A.; Hicock, S. R.; Miller, G. H.; Berger, G. W.; Eyles, Nicholas; Lamothe, M.; and others, 1993, Initiation and development of the Laurentide and Cordilleran ice sheets following the last interglaciation: Quaternary Science Reviews, v. 12, no. 2, p. 79-114.

Cooke, G. D.; Welch, E. B.; Martin, A. B.; Fulmer, D. G.; Hyde, J. B.; Schrieve, G. D., 1993, Effectiveness of Al, Ca, and Fe salts for control of internal phosphorus loading in shallow and deep lakes: Hydrobiologica, v. 253, no. 1-3, p. 323-335.

Dake, H. C., 1935, Fluorescent minerals of Oregon and Washington: Mineralogist, v. 3, no. 1, p. 20.

Damon, P. E.; Cain, W. J.; Donahue, D. J.; Burr, George, 1991, Anomalous 11-year delta ^{14}C cycle at high latitudes: Radiocarbon, v. 33, no. 2, p. 190.

Day, R. W., 1995, Potential for seepage erosion of landslide dam—Discussion: Journal of Geotechnical Engineering, v. 121, no. 9, p. 673-674.

DeGraff, J. M.; Aydin, Atilla, 1993, Effect of thermal regime on growth increment and spacing of contraction joints in basaltic lava: Journal of Geophysical Research, v. 98, no. B4, p. 6411-6430.

De la Colina, Jaime; Eberhard, M. O.; Ryter, S. W.; Wood, S. L., 1996, Sensitivity of seismic assessment of a double-deck, reinforced concrete bridge: Earthquake Spectra, v. 12, no. 2, p. 217-244.

Derkey, R. E., 1996, Washington: Mining Engineering, v. 48, no. 5, p. 80-81.

Edgett, K. S.; Rice, J. W., Jr.; Golombek, M. P., 1996, Scientists, educators prepare for Mars Pathfinder mission: Eos (American Geophysical Union Transactions), v. 77, no. 2, p. 9-10.

Ertan, I. E.; Leeman, W. P., 1996, Metasomatism of Cascades subarc mantle—Evidence from a rare phlogopite orthopyroxenite xenolith: Geology, v. 24, no. 5, p. 451-454.

Ettl, G. J.; Peterson, D. L., 1995, Extreme climate and variation in tree growth—Individualistic response in subalpine fir (*Abies lasiocarpa*): Global Change Biology, v. 1, no. 3, p. 231-241.

Ettl, G. J.; Peterson, D. L., 1995, Growth response of subalpine fir (*Abies lasiocarpa*) to climate in the Olympic Mountains, Washington, USA: Global Change Biology, v. 1, no. 3, p. 213-230.

Fairchild, L. H., 1987, The importance of lahar initiation processes. *In* Costa, J. E.; Wieczorek, G. F., editors, Debris flows/avalanches—Process, recognition, and mitigation: Geological Society of America Reviews in Engineering Geology, v. VII, p. 51-61.

Findley, D. P.; Deardorff, G. B., 1990, 17 miles to Mount St. Helens—Operational aspects of the geotechnical investigation: Highway Geology Symposium, 41st, Proceedings, p. 1-19.

Folger, Tim, 1993, A gentle subduction: Discover, v. 14, no. 9, p. 30.

Fountain, A. G.; Vaughn, B. H., 1995, Changing drainage patterns within South Cascade Glacier, Washington, USA, 1964–1992. *In* Tonnessen, K. A.; Williams, M. W.; Tranter, Martyn, editors, Biogeochemistry of seasonally snow-covered catchments: International Association of Hydrological Sciences Publication 228, p. 379-386.

Francisco, M. D.; Clark, R. C., Jr., 1994, The Elliott Bay/Duwamish restoration program—A status report: Coastal Management, v. 22, no. 3, p. 309-317.

Friedman, R. M.; Armstrong, Richard L., 1995, Jurassic and Cretaceous geochronology of the southern Coast Belt, British Columbia, 49 degrees to 51 degrees N. *In* Miller, D. M.; Busby, Cathy, editors, Jurassic magmatism and tectonics of the North American Cordillera: Geological Society of America Special Paper 299, p. 95-139.

Glenn, B. P., 1991, Groundwater recharge for effective water management. *In* Colorado Water Engineering and Management Conference—Conference proceedings: Colorado Water Resources Research Institute, p. 393-404.

Goebel, Lorna, 1996, Stilpnomelane in Skagit County, Washington: Micro Probe, v. 8, no. 3, p. 2-5.

Golus, R. J.; Glenn, B. P., 1991, Artificial recharge to help Seattle's water supply. *In* Peters, H. J., editor, Ground water in the Pacific Rim countries: American Society of Civil Engineers, p. 120-126.

Grootes, P. M.; Farwell, G. W.; Schmidt, F. H.; Leach, D. D.; Stuiver, Minze, 1989, Importance of biospheric CO_2 in a subcanopy atmosphere deduced from ^{14}C AMS measurements: Radiocarbon, v. 31, no. 3, p. 475-480.

Guilbault, J.-P.; Clague, J. J.; Lapointe, Martine, 1995, Amount of subsidence during a late Holocene earthquake—Evidence from fossil tidal marsh foraminifera at Vancouver Island, west coast of Canada: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 118, no. 1-2, p. 49-71.

Hagerty, M. T.; Schwartz, S. Y., 1996, The 1992 Cape Mendocino earthquake—Broadband determination of source parameters: Journal of Geophysical Research, v. 101, no. B7, p. 16,043-16,058.

Hansen, E. J.; Johnstone, D. L.; Fredrickson, J. K.; Brouns, T. M., 1994, Transformation of tetrachloromethane under denitrifying conditions by a subsurface bacterial consortium and its isolates. *In* Hinchee, R. E.; Leeson, Andrea; Semprini, Lewis; Ong, S. K., editors, Bioremediation of chlorinated and polycyclic aromatic hydrocarbon compounds: Lewis Publishers, p. 293-297.

Harker, R. I., 1996, Curved tree trunks—Indicators of soil creep and other phenomena: Journal of Geology, v. 104, no. 3, p. 351-358.

Hearn, T. M., 1996, Anisotropic Pn tomography in the western United States: Journal of Geophysical Research, v. 101, no. B4, p. 8403-8414.

Hedges, J. I.; Keil, R. G., 1995, Sedimentary organic matter preservation—An assessment and speculative synthesis: Marine Chemistry, v. 49, no. 2-3, p. 81- 115.

Heliker, C. C., 1995, Inclusions in Mount St. Helens dacite erupted from 1980 through 1983: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 115-135.

Henderson, W. A., Jr.; Weber, M. H., 1993, Microminerals: Mineralogical Record, v. 24, no. 4, p. 311-314.

Herendeen, P. S.; Dilcher, D. L., 1991, *Caesalpinia* subgenus *Mezoneuron* (Leguminosae, *caesalpinioideae*) from the Tertiary of North America: American Journal of Botany, v. 78, no. 1, p. 1-12.

Hooker, B. S.; Skeen, R. S.; Petersen, J. N., 1994, Application of a structured kinetic model to the bioremediation of Hanford groundwater. *In* Hinchee, R. E.; Leeson, Andrea; Semprini, Lewis; Ong, S. K., editors, Bioremediation of chlorinated and polycyclic aromatic hydrocarbon compounds: Lewis Publishers, p. 387-391.

Ingraham, N. L.; Shadel, Craig, 1992, A comparison of the toluene distillation and vacuum/heat methods for extracting soil water for stable isotopic analysis: Journal of Hydrology, v. 140, no. 1-4, p. 371-387.

Jackson, C. R.; Cundy, T. W., 1992, A model of transient, topographically driven, saturated subsurface flow: Water Resources Research, v. 28, no. 5, p. 1417-1427.

Johnson, H. P.; Van Patten, Darcy; Sager, W. W., 1996, Age-dependent variation in the magnetization of seamounts: Journal of Geophysical Research, v. 101, no. B6, p. 13,701-13,714.

Johnson, M. C.; Anderson, A. T., Jr.; Rutherford, M. J., 1994, Pre-eruptive volatile contents of magmas. *In* Carroll, M. R.; Holloway, J. R., editors, Volatiles in magmas: Mineralogical Society of America Reviews in Mineralogy, v. 30, p. 281-330.

Jones, C. A.; Welch, E. B., 1990, Internal phosphorous loading related to mixing and dilution in a dendritic, shallow prairie lake: Water Pollution Control Federation Research Journal, v. 62, no. 7, p. 847-852.

Karlin, R. E.; Abella, S. E. B., 1996, A history of Pacific Northwest earthquakes recorded in Holocene sediments from Lake Washington: Journal of Geophysical Research, v. 101, no. B3, p. 6137-6150.

Khaleel, Raziuddin; Relyea, J. F.; Conca, J. L., 1995, Evaluation of van Genuchten-Mualem relationships to estimate unsaturated hydraulic conductivity at low water contents: Water Resources Research, v. 31, no. 11, p. 2659-2668.

Kilburn, J. E.; Sutley, S. J.; Whitney, G. C., 1995, Geochemistry and mineralogy of acid mine drainage at the Holden mine, Chelan County, Washington: Explore, no. 87, p. 10-14.

Kim, Kunsoo, 1993, Design, execution and analysis of a large-scale *in situ* thermomechanical test for siting high-level nuclear waste repository. *In* Hudson, J. A., editor, Comprehensive rock engineering—Principles, practice and projects; Vol. 3—Rock testing and site characterization: Pergamon Press, p. 881-913.

Krakauer, Jon, 1996, Geologists worry about dangers of living 'under the volcano': Smithsonian, v. 27, no. 4, p. 32-41.

Lentell, R. L.; Byrne, John, 1993, Geotechnical instrumentation for repository shafts. *In* Hossain, Q. A., editor, Dynamic analysis and design considerations for high-level nuclear waste repositories; Proceedings of the symposium: American Society of Civil Engineers, p. 401-413.

Lesser, J. A., 1994, Estimating the economic impacts of geothermal resource development: Geothermics, v. 23, no. 1, p. 43-59.

Lewis, B. T. R., 1991, Changes in P and S velocities caused by subduction related sediment accretion off Washington/Oregon. *In* Hovem, J. M.; Richardson, M. D.; Stoll, R. D., editors, Shear waves in marine environments: Kluwer Academic Publishers, p. 379-386.

Lisle, T. E., 1995, Effects of coarse wood debris and its removal on a channel affected by the 1980 eruption of Mount St. Helens, Washington: Water Resources Research, v. 31, no. 7, p. 1797-1808.

Luckman, B. H.; Kearney, M. S.; King, R. H.; Beaudoin, A. B., 1986, Revised ^{14}C age for St. Helens Y tephra at Tonquin Pass, British Columbia: Canadian Journal of Earth Sciences, v. 23, no. 5, p. 734-736.

Magee, Kari, 1996, From the scabland to Mars—Preparing for the Pathfinder mission: Planetary Report, v. 26, no. 2, p. 10-14.

Mock, C. J., 1995, Climatology of the seasonal precipitation maximum in the western United States. *In* Isaacs, C. M.; Tharp, V. L., editors, Proceedings of the eleventh annual Pacific Climate (PACLIM) Workshop: Interagency Ecological Program for the Sacramento–San Joaquin Estuary Technical Report 40, p. 161-170.

Monger, J. W. H.; Price, R. A., 1996, Comment on "Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow—Evidence for 3000 km of northward displacement of the eastern Coast Belt, British Columbia" by P. J. Wynne et al., and on "Paleomagnetism of the Spences Bridge Group and northward displacement of the Intermontane Belt, British Columbia—A second look," by E. Irving and others: Journal of Geophysical Research, v. 101, no. B6, p. 13,793-13,799.

Montgomery, D. R.; Abbe, T. B.; Buffington, J. M.; Peterson, N. P.; Schmidt, K. M.; Stock, J. D., 1996, Distribution of bedrock and alluvial channels in forested mountain drainage basins: Nature, v. 381, no. 6583, p. 587-589.

Nakai, Shun'ichi; Halliday, A. N.; Rea, D. K., 1993, Provenance of dust in the Pacific Ocean: Earth and Planetary Science Letters, v. 119, no. 1-2, p. 143-157.

Nelson, A. R.; Shennan, Ian; Long, A. J., 1996, Identifying coseismic subsidence in tidal-wetland stratigraphic sequences at the Cascadia subduction zone of western North America: Journal of Geophysical Research, v. 101, no. B3, p. 6115- 6135.

Newhall, C. G.; Fink, J. H.; Decker, R. W.; de la Cruz, Servando; Wagner, J.-J.; and others, 1994, Research at decade volcanoes aimed at disaster prevention: Eos (American Geophysical Union Transactions), v. 75, no. 30, p. 340, 350.

O'Brien, Jennifer, 1986, Jurassic stratigraphy of the Methow trough, southwestern British Columbia: Geological Survey of Canada Paper 86-1B, p. 749- 756.

Ofjord, G. D.; Puhakka, J. A.; Ferguson, J. F., 1994, Reductive dechlorination of Aroclor 1254 by marine sediment cultures: Environmental Science and Technology, v. 28, no. 13, p. 2286-2294.

Pelto, M. S., 1996, Annual net balance of north Cascade glaciers, 1984–94: Journal of Glaciology, v. 42, no. 140, p. 3-9.

Peterson, C. D.; Phipps, J. B., 1992, Holocene sedimentary framework of Grays Harbor basin, Washington, USA. *In* Fletcher, C. H., III; Wehmiller, J. F., editors, Quaternary coasts of the United States—Marine and lacustrine systems: SEPM (Society for Sedimentary Geology) Special Publication 48, p. 273-285.

Ralph, S. C.; Poole, G. C.; Conquest, L. L.; Naiman, R. J., 1994, Stream channel morphology and woody debris in logged and unlogged basins of western Washington: Canadian Journal of Fisheries and Aquatic Sciences, v. 51, no. 1, p. 37-51.

Rea, D. K.; Ruff, L. J., 1996, Composition and mass flux of sediment entering the world's subduction zones—Implications for global sediment budgets, great earthquakes, and volcanism: Earth and Planetary Science Letters, v. 140, no. 1- 4, p. 1-12.

Reinelt, L. E.; Horner, R. R., 1995, Pollutant removal from stormwater runoff by palustrine wetlands based on comprehensive budgets: Ecological Engineering, v. 4, no. 2, p. 77-97.

Rhoads, D. C.; Germano, J. D., 1990, The use of REMOTS(R) imaging technology for disposal site selection and monitoring. *In* Demars, K. R.; Chaney, R. C., editors, Geotechnical engineering of ocean waste disposal: American Society for Testing and Materials Special Technical Publication 1087, p. 50-64.

Rosgen, D. L., 1994, A classification of natural rivers: Catena, v. 22, no. 3, p. 169-199.

Sadowiak, P.; Wever, T., 1990, Reflection-diffraction seismic pattern at crustal suture zones: Tectonics, v. 9, no. 6, p. 1495-1513.

Schmierer, Kurt; Waddell, Richard, Jr., 1990, Determination of ultimate compliance at an NPL pump-and-treat site. *In* SUPERFUND '90—Proceedings of the 11th national conference: Hazardous Materials Control Research Institute, p. 668-672.

Schultz, R. A.; Watters, T. R., 1995, Elastic buckling of fractured basalt on the Columbia plateau, Washington State. *In* Daemen, J. J. K.; Schultz, R. A., editors, Rock mechanics—Proceedings of the 35th U.S. symposium: A. A. Balkema, p. 855-860.

Schuster, R. L.; Meyer, William, 1995, Potential for seepage erosion of landslide dam—Closure: Journal of Geotechnical Engineering, v. 121, no. 9, p. 674-675.

Scott, W. E., 1990, Patterns of volcanism in the Cascade arc during the past 15,000 years: Geoscience Canada, v. 17, no. 3, p. 179-183.

Shevenell, Lisa; Goff, F. E., 1995, Evolution of hydrothermal waters at Mount St. Helens, Washington, USA: Journal of Volcanology and Geothermal Research, v. 69, no. 1-2, p. 73-94.

Simon, Andrew; Hardison, J. H., III, 1994, Critical and supercritical flows in two unstable, mountain rivers, Toutle River system, Washington. *In* Cotroneo, G. V.; Rumer, R. R., editors, Hydraulic engineering '94; Proceedings of the 1994 conference: American Society of Civil Engineers, v. 2, p. 742-746.

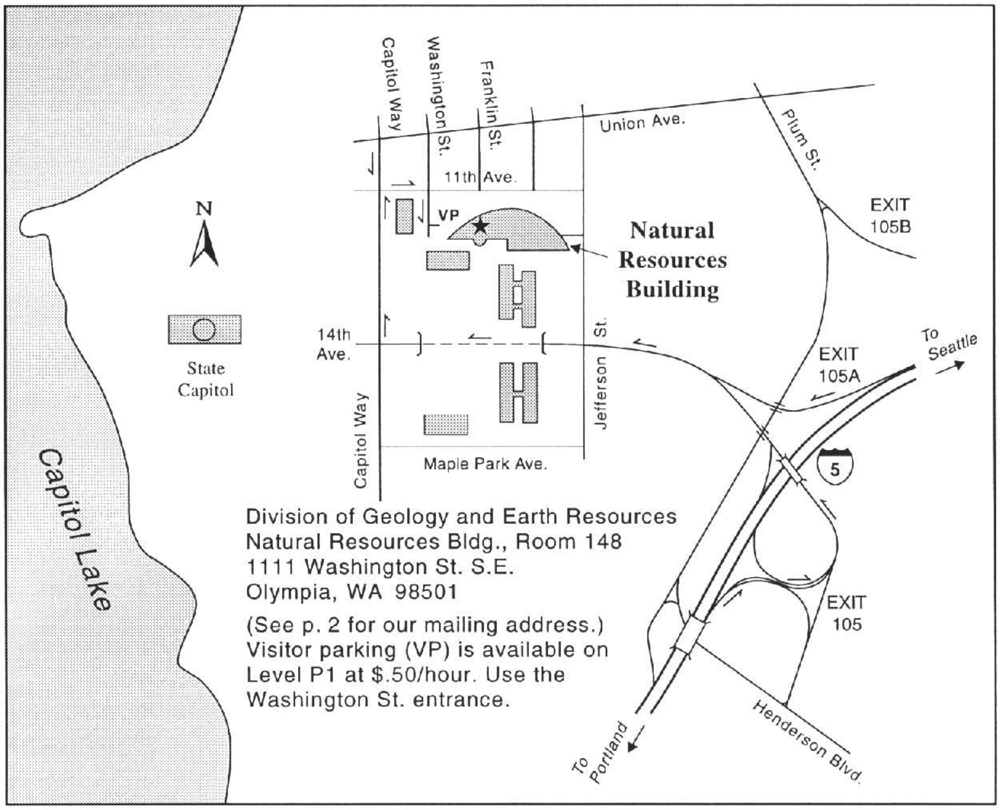
Sisson, T. W., 1995, Blast ashfall deposit of May 18, 1980 at Mount St. Helens, Washington: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 203-216.

Sousa, James; Voight, Barry, 1991, Continuum simulation of flow failures: Geotechnique, v. 41, no. 4, p. 515-538.

Sousa, James; Voight, Barry, 1995, Multiple-pulsed debris avalanche emplacement at Mount St. Helens in 1980—Evidence from numerical continuum flow simulations: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 227-250.

Squires, R. L., 1989, A new pseudolivine gastropod genus from the lower Tertiary of North America: Journal of Paleontology, v. 63, no. 1, p. 38-47.

HOW TO FIND OUR MAIN OFFICE



Squires, R. L.; Goedert, J. L.; Benham, S. R.; Groves, L. T., 1996, Protoconch of the rare ovulid gastropod *Cypraeogemmula warnerae* Effinger, 1938, from the Eocene of western Washington: The Veliger, v. 39, no. 2, p. 136-141.

Stetler, L. D.; Saxton, K. E., 1996, Wind erosion and PM10 emissions from agricultural fields on the Columbia plateau: Earth Surfaces Processes and Landforms, v. 21, no. 7, p. 673-685.

Symonds, R. B.; Rose, W. I.; Bluth, G. J. S.; Gerlach, T. M., 1994, Volcanic-gas studies—Methods, results, and applications. *In* Carroll, M. R.; Holloway, J. R., editors, Volatiles in magmas: Mineralogical Society of America Reviews in Mineralogy, v. 30, p. 1-66.

Symonds, R. B.; Rose, W. I.; Reed, M. H., 1988, Contribution of Cl- and F-bearing gases to the atmosphere by volcanoes: Nature, v. 334, no. 6181, p. 415- 418.

Synolakis, C. E., 1995, Tsunami prediction [letter]: Science, v. 270, no. 5233, p. 15-16.

Truex, M. J.; Skeen, R. S.; Caley, S. M.; Workman, D. J., 1994, Comparative efficiency of microbial systems for destroying carbon tetrachloride contamination in Hanford groundwater. *In* Hinchee, R. E.; Leeson, Andrea; Semprini, Lewis; Ong, S. K., editors, Bioremediation of chlorinated and polycyclic aromatic hydrocarbon compounds: Lewis Publishers, p. 80-85.

Tschernich, R. W., 1996, Zeolites from Kalama, Cowlitz County, Washington: Micro Probe, v. 8, no. 3, p. 15-19.

Ugolini, F. C.; Sletten, R. S., 1991, The role of proton donors in pedogenesis as revealed by soil solution studies: Soil Science, v. 151, no. 1, p. 59-75.

Umhoefer, P. J.; Miller, R. B., 1996, Mid-Cretaceous thrusting in the southern Coast belt, British Columbia and Washington, after strike-slip fault reconstruction: Tectonics, v. 15, no. 2, p. 545-565.

Walker, G. P. L.; Hayashi, J. N.; Self, Stephen, 1995, Travel of pyroclastic flows as transient waves—Implications for the energy line concept and particle-concentration assessment: Journal of Volcanology and Geothermal Research, v. 66, no. 1-4, p. 265-282.

Waltham, Tony, 1995, Excursion guide 11—Mount St Helens: Geology Today, v. 11, no. 6, p. 228-233.

Wang, Kelin; Davis, E. E., 1996, Theory for the propagation of tidally induced pore pressure variations in layered subseafloor formations: Journal of Geophysical Research, v. 101, no. B5, p. 11,483-11,495.

Ward, P. L., 1995, Subduction cycles under western North America during the Mesozoic and Cenozoic eras. *In* Miller, D. M.; Busby, Cathy, editors, Jurassic magmatism and tectonics of the North American Cordillera: Geological Society of America Special Paper 299, p. 1-45.

Whiting, Keith, 1991, Van Stone deposit, Stevens County, Washington. *In* Hollister, V. F., editor, Porphyry copper, molybdenum, and gold deposits, volcanogenic deposits (massive sulfides), and deposits in layered rock: Society for Mining, Metallurgy, and Exploration, Inc. Case Histories of Mineral Discoveries, v. 3, p. 215-217.

Wiles, G. C.; D'Arrigo, R. D.; Jacoby, G. C., 1995, Modeling North Pacific temperature and pressure changes from coastal tree-ring chronologies. *In* Isaacs, C. M.; Tharp, V. L., editors, Proceedings of the eleventh annual Pacific Climate (PACLIM) Workshop: Interagency Ecological Program for the Sacramento–San Joaquin Estuary Technical Report 40, p. 67-78.

Williams, Bob, 1988, Gaining more access is focus on west coast: Oil and Gas Journal, v. 86, no. 11, p. 46-48.

Wu, Weimin; Sidle, R. C., 1995, A distributed slope stability model for steep forested basins: Water Resources Research, v. 31, no. 8, p. 2097-2110.

Yanggen, D. A.; Born, S. M., 1991, Protecting groundwater quality by managing local land use: Groundwater & Public Policy, no. 6, p. 1-6.

Yuan, T.; Hyndman, R. D.; Spence, G. D.; Desmons, B., 1996, Seismic velocity increase and deep-sea gas hydrate concentration above a bottom-simulating reflector on the northern Cascadia continental slope: Journal of Geophysical Research, v. 101, no. B6, p. 13,655-13,671.

Zelt, B. C.; Ellis, R. M.; Clowes, R. M.; Hole, J. A., 1996, Inversion of three-dimensional wide-angle seismic data from the southwestern Canadian Cordillera: Journal of Geophysical Research, v. 101, no. B4, p. 8503-8529.

Zorpette, Glenn, 1996, Hanford's nuclear wasteland: Scientific American, v. 274, no. 5, p. 88-97.

OTHER REPORTS OF INTEREST

Costa, J. E.; Miller, A. J.; Potter, K. W.; Wilcock, P. R., editors, 1995, Natural and anthropogenic influences in fluvial geomorphology: American Geophysical Union Geophysical Monograph 89, 239 p.
Includes:

Costa, J. E.; O'Connor, J. E., Geomorphically effective floods. p. 45-56.

Grant, G. E.; Swanson, F. J., Morphology and processes of valley floors in mountain streams, western Cascades, Oregon. p. 83-101.

Deloitte & Touche LLP, 1996, Economic analysis: Deloitte & Touche LLP [under contract to] Washington Department of Natural Resources, 1 v.

Dunbar, P. K.; Lockridge, P. A.; Whiteside, L. S., 1992, Catalog of significant earthquakes, 2150 B.C.–1991 A.D., including quantitative casualities and damage: U.S. National Geophysical Data Center World Data Center A for Solid Earth Geophysics Report SE-49, 320 p.

Hollub, V. A.; Schafer, P. S., 1992, A guide to coalbed methane operations: Gas Research Institute, 1 v.

National Energy Foundation, 1995, Out of the rock—Integrated learning activities for studies: National Energy Foundation [Salt Lake City], 1 v.

Priest, G. R.; Qi, Ming; Baptista, A. M.; Peterson, C. D.; Darienzo, M. E., 1995, Tsunami hazard map of the Siletz Bay area, Lincoln County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-99, 1 sheet, scale 1:24,000.

Turner, A. K.; Schuster, R. L., editors, 1996, Landslides—Investigation and mitigation: National Academy Press, 673 p.

Wold, R. L., Jr.; Jochim, C. L., 1989, Landslides loss reduction—A guide for state and local government planning: U.S. Federal Emergency Management Agency Earthquake Hazards Reduction Series 52, 50 p.

DIVISION PUBLICATIONS

The Division's publications list has been updated. Please request a (free) copy to be sure you have up-to-date information about what is available and current prices. Please remember to send us $1 for postage and handling. This fee applies to all orders; we cannot mail out your order until we have correct payment.

The half-price sale of selected items is now over. The prices in the 1996 version of the publications list apply.

Now in preparation: Preliminary Bibliography and Index of the Geology and Mineral Resources of Washington, 1991–1995, Open File Report 96-6.

STAFF NOTES

Connie Manson, senior librarian of the Division of Geology and Earth Resources, has been elected Vice President/ President Elect of the Geoscience Information Society (GIS). Established in 1965, GIS is the primary professional society for geology librarians in North America. While it has only 237 members internationally, it is influential: it is an affiliated member of the Geological Society of America and the American Geological Institute and has representatives on various national boards.

As Vice President, Manson will organize the GIS annual meeting, to be held in Salt Lake City in 1997. She will then serve as President in 1998 and Past President in 1999.

Thuy Le has been working in Division of Geology and Earth Resources as a part-time Clerk Typist 2 since June. She is a full-time student at South Puget Sound Community College majoring in Business Administration. She came from Da Nang, Vietnam, in 1992 and hopes to become a naturalized citizen of the United States next year.

Summer Interns: We thank Community Youth Services for hiring Viet Tran (library page) and Marco Gonzalez (clerical aide) and allowing them to work in our office this summer. They are learning library and office skills on the job and have started and completed many tasks that would have otherwise had to wait to be completed. They are efficient, good natured, and intelligent and quickly complete each task. Thank you, Viet and Marco, for doing such a super job.

Errata

In the previous issue, page 30, the abbreviation for Alberta should be AB.

In v. 24, no. 1, p. 15, the second and third equations should read:

$$3MgO + 3Fe_{0.25}Si_{0.75} \rightarrow 3Mg + SiO + SiO_2 + Fe_{0.75}Si_{0.25}$$

$$6MgO + 4Al \rightarrow 6Mg + 2Al_2O_3.$$

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

BULK RATE
U.S. POSTAGE PAID
Washington State
Department of Printing

Department of Natural Resources
Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98504-7007

ADDRESS CORRECTION REQUESTED