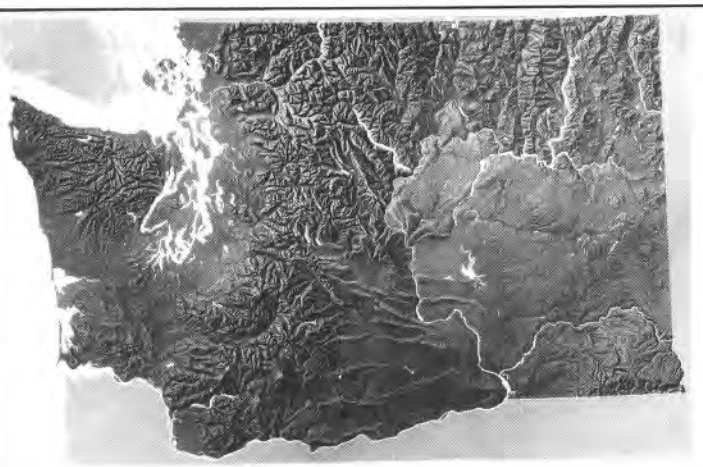

WASHINGTON GEOLOGIC NEWSLETTER

Volume 15 Number 3 July 1987

Washington State Department of Natural Resources

Division of Geology and Earth Resources

Part of building in Poulsbo on an ancient, deep-seated slide. Reactivation of the slide in 1974 severely damaged the building and adjacent streets and utilities. (see article, p. 3)

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WASHINGTON GEOLOGIC NEWSLETTER

The Washington Geologic Newsletter is published quarterly by the Division of Geology and Earth Resources, Department of Natural Resources. The newsletter is free upon request. The Division also publishes bulletins, information circulars, reports of investigations, and geologic maps. A list of these publications will be sent upon request.

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TIMBER, FISH AND WILDLIFE

by
Raymond Lasmanis, State Geologist

Leaders from the timber industry, environmental groups, Indian tribes, and the state Departments of Fisheries, Game, Ecology, and Natural Resources have been meeting since August 1986 to reach a mutually satisfactory agreement on forest practices regulations and forest management. A comprehensive package has been developed by this Timber, Fish and Wildlife group (TFW) that calls for significant changes in the manner in which forest practices are evaluated and regulated and natural resources are managed.

Of the the eleven key components of the new management system under the TFW program, forest practices on unstable slopes have been identified as a major issue because harvesting timber and working on such slopes can, in some instances, accelerate natural instability processes and impact fish, wildlife, water, cultural and archaeological resources, public capital improvements, and off-site property. Management decisions regarding the potential impacts of such timber harvests can be improved by (1) using more complete technical and scientific data and information; (2) having technical specialists on the ground to assess impacts and offer appropriate management alternatives; and (3) defining ways to measure the effectiveness of state-of-the-art management practices.

Resolution of the unstable slopes issue will require investment by state government, industry, and others in improving the

(continued on page 15)

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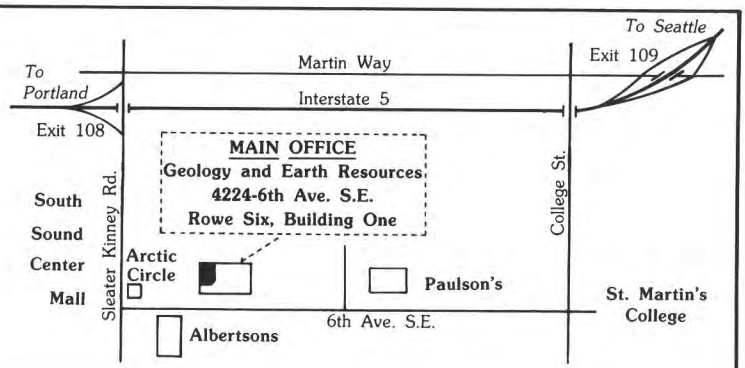


SOIL BLUFFS + RAIN = SLIDE HAZARDS

by
Gerald W. Thorsen

INTRODUCTION

"Landslide season" in the Puget Lowland normally occurs from November through April. During that period, familiar names commonly reappear in the press. The Alki, Queen Anne, and Magnolia districts of Seattle are mentioned in the news nearly every winter. This repetition is because natural landslides usually occur where they have occurred before. In spite of such warnings, there is a variety of reasons to crowd development against or even to occupy slide hazard areas. If these reasons are important enough, the risks and/or extra costs may be acceptable.

Probably the commonest reasons for individuals choosing to live with the slide hazards of Puget Lowland bluffs are the view from the top (Fig. 1) or, in the case of waterfront property, access to water from the bottom. Where industry is concerned, there can be even more compelling reasons to accept such hazards. For example, a railroad must have a relatively level, albeit narrow route. A beach can meet both criteria (Fig. 2). Unfortunately, in the Puget Lowland, beaches are commonly backed by unstable bluffs.

Such compromises of location and risk must also be made with other transportation systems. The Seattle freeway was built, at staggering cost, through a zone of unstable bluffs and dormant landslides. Because of the stability problems, the area had been relatively unoccupied. The political and economic decisions for selecting such a route were thus considered justifiable. Similarly, some of our most popular shoreline parks (such as Kopachuck, Camano, Sequim Bay, and Golden Gardens) probably exist largely because the areas were too unstable for other development.

This article is a discussion of Puget Lowland bluffs and the more common forms of landslides affecting them. Most examples are from coastal bluffs, as they are among the best exposed and most active. Stability problems associated with steep bluffs in unconsolidated sediments are, of course, not confined to either coastal areas or western Washington. Many miles of such bluffs in eastern Washington are now sliding, primarily as a result of reservoir drawdown and irrigation. Here, areas relatively dry for thousands of years are now being subjected to "artificial precipitation". The resulting increases in soil water locally have profound effects on bluff stability.

SETTING THE STAGE

Repeated continental glaciation punctuated by long periods of floodplain, delta, and lake deposition has left thick sections of unconsolidated materials over the bedrock of the Puget Lowland. These materials, "soil" to

Figure 1.--Demand for view property, such as this area overlooking the Strait of Juan de Fuca, continues to increase along with the Puget Sound area's population. Here, local collapse of somewhat cohesive sandy soil causes it to break up and flow to the beach. Winter storms remove the dry-flow deposits, re-exposing the toe of the bluff to wave erosion.

Figure 2.--A large landslide complex south of Edmonds. The activities of railroad track maintenance crews have replaced wave erosion as the means of removing mudflows at the toe of the slide.

Figure 3.--These homes are part of a development overlooking the floodplain of the Stillaguamish River near Interstate Highway 5. The till bluff is the scarp of a large landslide (Minard, 1985) probably triggered by the river undercutting the bluff.

the geologist or engineer, are hundreds or even thousands of feet thick in places. Following the sculpting and compaction by the last continental ice sheet to occupy the Lowland, wave, as well as modern and Pleistocene stream erosion (Figs. 3 and 4) have cut hundreds of miles of steep bluffs into these sediments. Many of these miles are in or near population centers. Thus, the pressure for residential development is great and is increasing.

Of these bluffs, probably those along the marine waters of the Puget Lowland have been the most systematically studied. The slope stability maps of the Coastal Zone Atlas (Washington Dept. of Ecology, 1978-80) show more than 660 miles of these bluffs as "unstable". Included in this category are approximately 71 miles of recently active landslides and 65 miles of old, apparently dormant slides. Both figures are, no doubt, understated. This is because recent slides narrower than about 200 feet were difficult to show at the map scale used and some old slides were probably not recognized. Marine bluffs may not be fully representative of the bluffs fringing floodplains or glacial meltwater channels, but they vividly display the

Figure 4.--Lake Kapowsin and ground fog mark this sinuous glacial meltwater channel. Remnants of soil bluffs fringing such long abandoned channels remain along the fronts of the Cascade foothills.

range of stability problems that exist throughout the Lowland.

LANDSLIDES

Gulleying, dry ravel, and other forms of essentially particle-by-particle erosion are important bluff-modifying processes. Landslides, however, may remove as much material in minutes or hours as other forms of erosion do in hundreds of years. The bluffs of the Puget Lowland are particularly susceptible to landslides for a variety of reasons. Among these are their steepness, the abundant rainfall in the area, and the commonly striking contrasts in permeability of their materials. These permeability contrasts create local ground-water concentrations that commonly dictate where, how, and when a landslide will occur.

It is this "how", the type of slide failure and movement, that commonly determines the nature and extent of the slide hazard. Safe construction setback distances from both top and bottom of a bluff must consider such factors. The names of slide types are generally derived from how slides initially fail--for example, as falls, slides, or flows. However, many landslides fail in one manner but travel in another--that is, a slump or rotational failure may in part move as a flow (Figs. 5 and 6). Thus, pigeonhole names can be misleading. Slide types are discussed here only because the slide type often provides clues to the nature of the hazard.

Slumps

A common Puget Lowland slide form is the upper bluff slump. In most of the places where these occur, the lower bluff is usually very compact silt or "blue clay" that does not fail at all. Instead, the slumped upper bank material, once it is disturbed, turns into mud and flows down and over the steep but still intact lower bluff (Fig. 6). This mode of failure leaves a distinctive landform, the mid-bluff bench, along the top of the lower unfailed silt or clay.

The bluff below the bench is very steep, commonly exceeding 60°. The bench itself tends to have a hummocky surface, and the steepness of the slope above it increases upward, approaching vertical at the scarp of the slump. This bench may not be easily recognized if the last movement was not recent and if the vegetative cover is dense.

Some of the best examples of upper bluff slumping in the Seattle area are in the Alki area, Fort Lawton, and Golden Gardens. In the last instance, the park area itself has apparently not had a serious slope failure in many decades, but the telltale bench and abundant groundwater are obvious. A slump just north of the park damaged or destroyed almost a dozen homes in 1974. Other classic upper bluff slump areas are Scatchet Head on Whidbey Island (Fig. 5), north of Apple Cove Point on the Kitsap Peninsula (Fig. 6), and the Thorndyke Bay area of Jefferson County.

Debris Avalanches

Shallow debris avalanches are another common form of landslides along the bluffs of the Puget Lowland, especially where bluffs are made up of compact silt, clay, or silty sand. Characteristically, the landslides are only a few tens of feet wide, and the "mat" of material that moves is seldom deeper than the depth of penetration of tree roots--in such soils, 3 to 4 feet. The soil materials are made less compact or loosened by roots and by freeze-thaw cycles, but the underlying undisturbed material remains relatively impervious to infiltrating rainfall. The result is a zone of saturation at the base of the loosened soil/root mat during periods of heavy rain.

Figure 5.--Rain infiltrating the upland surface of southern Whidbey Island easily penetrates the underlying sand, but further downward movement of the water is impeded by the relatively impermeable silt layer. A zone of saturation at the top of the silt causes slumps in the overlying sand. The disturbed and now saturated sand oozes over the steep silt bluff as a series of mudflows.

When a patch of such material loses its grip on the hillside, its weight is suddenly transferred to adjacent material downslope. The rapid progressive slope failure results in a tangled pile of trees, brush, and soil at the base of the bluff (Fig. 7). The resulting lineal scar of bare, compact subsoil may take decades to fully revegetate. When it does, the scar is commonly covered by a telltale lineal strip of alder trees, all of about the same age and size.

Storm drainage, even that from a single lot, may trigger a debris avalanche. The common practice of disposing of trash, construction rubble, and land-clearing debris on soil bluffs also may set the stage for a debris avalanche. Because they involve only a thin layer of materials, debris avalanches are seldom a threat to homes or other structures at the top of a bluff. However, these avalanches are a serious hazard to those living below, in spite of their relatively small volume. This is because the avalanches attain a high rate of speed as they flow downslope. Even a small debris avalanche can easily smash through the wall of a frame house and/or drop uprooted trees through the roof.

SOIL FALL/FLOW

Soil fall is commonest in relatively dry cohesive sediments. Where such materials are excessively undercut by wave or stream action, the resulting steep bluffs may simply collapse. Where bluff materials are cohesive and contain abundant dessication cracks, the slide deposit will be made up of hard, angular clay and/or silt "boulders" (Fig. 8). Where bluff sediments are less cohesive, the initial collapse may cause the landslide mass to disintegrate and move as a dry flow. Such flows commonly form steep cone-like deposits at the bases of bluffs (Fig. 1).

Figure 6.--Falling trees caused much of the damage to this beach cabin near Kingston. The steep clay bank behind the cabin did not fail, but mud and trees from higher on the slope flowed over it.

Figure 7.--Shallow debris avalanches such as this one on Camano Island are common throughout the Puget Lowland. They occur as soil/vegetation-mat slides on clay or silt slopes too compact for root penetration or for rapid infiltration of precipitation. Dark streaks are muddy water.

Figure 8.--This Smith Island bluff is made up of easily erodable sand and is overlain by cohesive but intensely fractured glaciomarine sediments. Wave cutting causes soil fall, with bluff retreat averaging 27 inches per year (Ralph Keuler, written commun., 1986)

Extremely cohesive sediments such as till may not break up significantly when a bluff collapses. Instead, when undercut, such bluffs tend to "calve", as does the front of a floating glacier. This tendency is at least in part due to the existence of deep vertical cracks that parallel the bluff face (Fig. 9). Such cracks cause large slabs, on the order of 3 to 5 feet thick, to break away. In falling from considerable height, such slabs may break into large chunks and present hazards similar to those of a rock fall that contains large boulders. A slab that moves only a short distance may remain intact and lean against the base of the bluff like a giant tombstone for many years before it is obliterated by erosion.

FLOW

Few Puget Lowland landslides begin as flows, but most end up travelling as such, at least in part. This should be no surprise, as almost all Puget Lowland landslides are triggered by excessive groundwater. Such

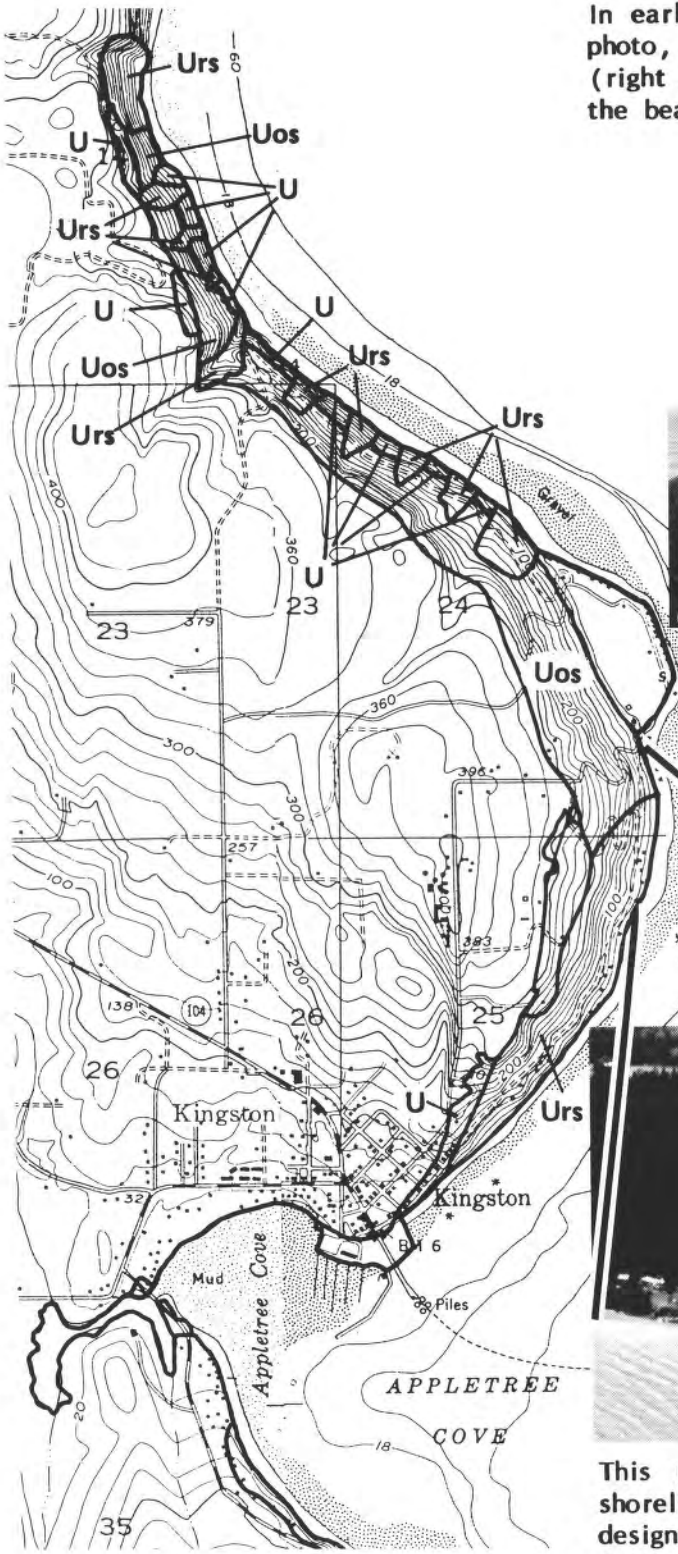
Figure 9.--Bluffs composed entirely of till, such as this one in Port Townsend, may stand vertically for decades. When they fail, it is usually as slabs breaking off at cracks parallel to the bluff face.

groundwater, especially in combination with focused surface runoff, will commonly turn a slump, slide, or soil fall into a mudflow. The mudflow is capable of great destruction because its weight and viscosity enables it to move much bedload, logs, and even houses. The hazard of the mudflow's potential cargo may be greater than that of the mud itself (Fig. 6).

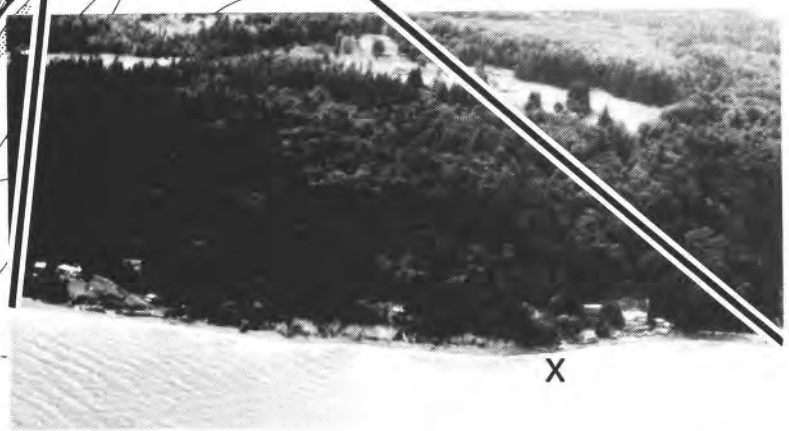
ANCIENT DORMANT SLIDES

While these are not technically a special type of slide, ancient dormant slides warrant separate discussion because of their large size and the fact that they are commonly difficult to recognize. Erosion has removed the smaller ones. The combination of their sheer size, erosion of diagnostic features, and commonly dense forest cover may fool a person examining a particular building site.

Recognition of an ancient slide may be made even more difficult where grading and development have removed or changed telltale features such as head or flank scarps. Recognition of a very large slide or landslide complex may come only with examination of aerial photographs or old records. Because



In early spring 1974 this ancient slump, at X in lower photo, reactivated, uplifting the slide toe at beach level (right side of photo) almost 8 feet above the rest of the beach.



This photo illustrates the section of Kitsap County shoreline bracketed by the leaders. Note that it was designated "Urs" (unstable-recent slide) in the county Coastal Zone Atlas. (Feature X shown in photo above.)

Figure 10.--Slope stability map for part of the coast near Kingston. U, unstable slopes; Uos, post-glacial but prehistoric slide; Urs, recent or historically active slide. (modified from Washington Dept. of Ecology, Coastal Zone Atlas, Kitsap County [v. 10], 1979.

some of our best examples of old dormant slides (Fig. 10) are deep-seated slumps, the toe area uplift or tilt characteristic of a slump may be one of the first signs of renewed movement (Fig. 10).

Fortunately, wholesale reactivation of such slides generally occurs slowly and may consist of only a few feet of movement in a particular episode. Unfortunately, even this amount of movement is enough to cause severe damage to structures and utilities, especially if they are founded on both stable and unstable ground (Cover Photo). Piecemeal reactivation of large slides is more common than reactivation of the entire mass. One 7,000-foot stretch of coastal bluff on Whidbey Island is an ancient slide complex that undergoes piecemeal adjustment every few years.

Ancient slides and slide complexes are areas not only of broken, disturbed, and weakened soil, but also of disrupted groundwater flow. The resulting erratic distribution of soil conditions make drainage or other stabilization techniques all the more difficult and expensive. Such difficulties are compounded by the slide's large size. Ownership of land parcels on such large slides is commonly divided, especially in high-value coastal residential areas. In such instances, some kind of group effort, such as formation of a "Natural Hazard Abatement District" (Kockelman, 1986) may be a solution to slide control. Piecemeal or lot-by-lot stabilization efforts are usually doomed from the start.

SLIDE RECOGNITION

Landslide recognition is an art based on training, experience, and careful attention to detail. Recognition is important because, as already mentioned, almost all natural slides and most construction- and drainage-related slides occur in areas where slides have previously occurred. Slide recognition should consider where the slide originated, as well as the slide deposit itself. One reason for this is that the slide mass, especially that of smaller slides, may have been completely removed by erosion.

With sufficient experience, one can become aware of subtle signs of a slide without at first even recognizing specific clues. The sense of the presence of a slide is especially useful on large ancient slides that have been modified by erosion and are covered with mature vegetation. In the case of slow-moving active slides, however, the process of recognition may begin with simply noticing something anomalous or out of place, such as a fir tree growing in a pond. Following are some characteristic features that may signal the presence of a slide:

Geomorphic characteristics:

- amphitheaters or scallops in an otherwise straight bluff line
- low bank areas in an area of bluffs (ancient slides)
- local reversals in slope direction (slumps) hummocky topography, especially with undrained depressions
- ground cracks (most slide forms) stair-step topography (multiple-slice slumps)
- slopes that steepen downward (very viscous flows)

Vegetation clues:

- distribution of water-loving plants on slopes, suggesting groundwater concentrations
- tilted or jackstrawed conifers (slumps, earthflows)
- patches of dead trees (suggesting sheared roots)
- linear groups of alder trees of the same age on a hillside (any active slide)
- bare soil patches, especially their slope and distribution (debris avalanches)
- buried logs and other vegetation (flows, debris avalanches)
- vegetation out of place (trees in ponds, etc.)
- split trees and/or stumps

Structural indications:

- buckled or crooked fence lines
- broken underground plumbing
- powerlines unusually taut or loose
- excessive foundation or driveway cracking
- new gaps between parts of structures (e.g., between deck and house)
- vertical elements out of plumb, tilted poles or walls
- sticking doors and windows

Other clues:

- aggregates of delicate fine-grained sediment in a high-energy environment (e.g., silt "pebbles" in a gravel)

- tilted sediments, such as lake bed silts that were deposited horizontally (slumps)
- muddy springs or muddy spring deposits
- water emerging or disappearing in a new area

Few, if any of these alone are certain indicators of landslides, but several in combination suggest that a landslide may be present.

WHAT TO DO

What can homeowners do if they notice some of these signs of slides? First, record and monitor them; keep photographic and written records. Make and record measurements from **permanent** reference points. (Repeated measurements of the width of a ground crack may not be meaningful if the walls of the crack are sloughing into it.) These records may help determine if the ground movement is merely settlement of poorly compacted fill, the result of tilting in a landscaping wall, or an actual landslide. If the ground movement appears to suggest landslide movement, the data collected can help experts determine the nature, extent, and rate of sliding.

If you notice the signs of a landslide on land you are considering purchasing, some of your options are:

- consulting available information, such as government maps or reports, and records of local regulatory agencies
- hiring an expert in slope stability and landslide analysis
- talking to residents in the area, especially those who have lived there for many years
- choosing an alternative site.

Clearly, the decision to purchase would be based partly on the intended land use. For example, the economic impact of a landslide on a tree farm might be considerably less than that on a residential structure, and the cost of preparing the site for the proposed activity might determine if the land is a reasonable investment.

Landslides are a normal erosional process, more common in some settings than in others. In places, they may even be desirable. For example, without the fine sediments "fed" to beaches by landslides, many sandy beaches would become fields of gravel and boulders. In general, the individual would do well to avoid slides. Structural controls are often extremely expensive and seldom justified for low- or even moderate-density residential areas.

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Tubbs, D. W., 1974, Landslides in Seattle: Washington Division of Geology and Earth Resources Information Circular 52, 15 p. [Discusses 1972 landslides, their geologic setting, and the distribution in time of rainfall. Includes a map showing slide location and the "hazardous zone"]

Washington Department of Ecology, 1978-1980, Coastal zone atlas of Washington: Washington Department of Ecology, 12 v. [Each county volume includes a colored coastal strip map showing landslides and relative slope stability. Brief text includes some details of geology and slope stability]

Correction:

On page 11 of Volume 15, no. 1, of this newsletter: the age of the rhyodacite at the Cannon mine is 43.2 $\pm$ 0.4 m.y.

OIL AND GAS EXPLORATION IN WASHINGTON AT ITS HIGHEST LEVEL IN RECENT YEARS

by

William Lingley

Petroleum exploration in Washington State is presently at its highest level since the early eighties despite the lingering recession in the oil industry. Five wells are presently testing in the state, two are suspended, and two other locations have been permitted. In many parts of the state, bidding for mineral-rights lease acquisition is highly competitive (David Faley, Walt Mays and Associates, oral commun., 1987). Furthermore, the presence of six Vibroseis reflection seismograph crews, which have been acquiring data for Shell, Exxon, Chevron, Amoco, Arco, and other companies during 1987, suggests that the present level will persist or increase during 1988.

This increase in activity results primarily from two factors:

(1) Improvements in seismic data quality. These improved data are allowing geophysicists to locate heretofore obscured anticlinal culminations having potential to trap petroleum, and

(2) A marked decrease in unexplored sedimentary basins where explorationists can seek large and therefore economically significant petroleum accumulations. Large oil or gas fields generally cover large areas. However, most sedimentary basins have been intensively drilled, and, as a consequence, Washington contains some of the few remaining unexplored areas within the United States.

Exploratory activity has been concentrated in the Columbia Basin where this month Shell Western Exploration and Production, Inc., staked a location for a 15,000-foot-deep wildcat, the Darcell-Western Exploration-1. Additionally, Shell continues to acquire approximately 60 miles of reflection seismic data per month, mainly in Grant County. Exxon is also actively acquiring seismic data in Adams and Franklin Counties.

The Shell Darcell-Western Exploration-1, located in sec. 10, T. 10 N., R. 33 E., Walla Walla County, will be one of the most significant wells drilled in the United States this year. This wildcat has potential to open a new petroleum province. It is the first test of prospective sedimentary rock underlying the Columbia River basalt to be drilled in the entire eastern half of the Columbia Basin (Fig. 1). The Development Associates, Inc., Basalt Explorer No. 1 drilled in Lincoln County recovered red shale and siltstone barren of fossils and granitic rocks from a core taken at total depth.

Furthermore, the Darcell-Western Exploration-1 will be the first wildcat in the Columbia Basin drilled solely on the basis of geophysical interpretations. In the past, interpretation of subsurface geologic conditions favorable for petroleum entrapment was not possible because data from geophysical tools such as seismographs, gravimeters, magnetotellurometers, and magnetometers used to "see" into the subsurface lacked resolution and/or record quality requisite to identify prospects. Explorationists were obliged to choose wildcat locations by extrapolating geological observations from the outcrop into the subsurface. A prospect such as the Darcell-Western Exploration structure could not have been located because structure cropping out at this location is not conducive to petroleum entrapment. That Shell chose to locate this well on a southwest-dipping homocline on the east flank of the Pasco subbasin suggests that data quality in the Columbia Basin is no longer an insurmountable problem.

The well will spud in the Frenchman Springs Member of the Wanapum Basalt and penetrate approximately 700 feet of older Wanapum Basalt and 6,300 feet of Grande Ronde Basalt (S. P. Reidel, oral commun., 1987). It is predicted that these basalts unconformably overlie Eocene siliciclastic strata equivalent to the Swauk/Roslyn sections subcropping in the western part of the Columbia Basin; these rocks were the primary exploratory objectives of wells drilled heretofore. Extrapolation of regional stratigraphy suggests that Oligocene to lowermost

Figure 1.--Index map showing the location of the proposed Shell Western Exploration and Production Inc., Darcell-Western Exploration-1 wildcat and other significant Columbia Basin wildcats. RSH, Rattlesnake Hills; BN, Burlington Northern.

Miocene volcanogenic rocks penetrated by wells drilled in the western parts of the basin are missing at the Darcell-Western Exploration-1 location owing to non-deposition. Geologists speculate that the well may penetrate older basalts of the Columbia River Basalt Group, Ice Harbor basalt feeder dikes, and/or Mesozoic strata. The last would have particular significance for tectonic reconstruction of the Pacific Northwest as it

could constrain the northern extent of Blue Mountains accretionary terranes (Pessagno and Blome, 1986). It is also significant for future petroleum exploration because oil-prone source rocks have been observed in Mesozoic strata cropping out in northeastern Oregon (Fisk, 1987).

Elsewhere in Washington, exploration activity is also intense. The Carbon River Partnership has installed four pump-jacks on their coalbed methane wildcats, which are located a few miles south of Carbonado in Pierce County. These are the first pumps to have been installed in Washington wildcat wells since 1954.

Twin Rivers Petroleum, Inc., continues to test their State No. 1-30 near Joyce in Clallam County. The operator has flared some gas from lower Miocene conglomerates but has not yet announced the open-hole flow potential.

Arco has recently completed a reconnaissance seismic survey of leases in Wahkiakum County near Skamokawa. The objective of this study is to locate geologic conditions analogous to those at the Mist gas field in northwestern Oregon. Many operators have been discouraged by the results of drilling in adjacent areas: one of the nearby wells spudded in basalt of the Columbia River Basalt Group, drilled through a section of Goble Volcanics, and reached total depth in basalts that may be part of the Crescent Formation. However, investigation of the area undertaken by the Division of Geology and Earth Resources as part of the revision of the state geological map (Walsh, 1987) indicates that Cowlitz Formation sandstones may be present in the area Arco is surveying.

A Vibroseis survey is presently under way in the Ferndale area of Whatcom County near the depleted Bellingham gas field. Whatcom County, like most of western Washington, has geologic conditions which have resulted in poor seismic records. However, the potential for natural gas accumulations in coalbed or sandstone reservoirs is apparently encouraging explorationists. Sandstones of both the Huntingdon and Chuckanut Formations have relatively favorable characteristics for gas reservoirs.

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MINING DIRECTORY AVAILABLE

The Division of Geology and Earth Resources has released in its open file report series a directory of active underground mines, surface hardrock mines, and sand and gravel pits in Washington. This information was compiled by the U.S. Department of Labor, Mine Safety and Health Administration. A list of active coal mines is appended.

The list of underground mines and sand and gravel pits is current as of February 13, 1987; the list of surface hardrock mine and coal mine operators is current as of April 30 of this year.

The report is titled "Directory of Washington Mining Operations" and is available from the Division's Olympia office, whose address is given on page 2 of this newsletter. Please request Open File Report 87-7. The price of the report is $1; please add $1 to each order for shipping and handling.

TIMBER, FISH AND WILDLIFE

(continued from page 2)

geologic, landslide, hydrologic, and other related data bases, as well as in making more technically skilled personnel available to deal with unstable areas on site. Utilizing the Department of Natural Resources' GEOMAPS system, the information to be included in site analyses will be:

- distribution of soils types
- distribution of surficial and bedrock geologic units
- location of areas of known landslide potential
- identification of critical rain-on-snow areas
- amount and timing of annual rainfall
- topographic information
- ground- and surface-water information
- hazard zonation maps
- related information from regional DNR offices and private timber companies

An inventory of geological hazards through data review and generation of geological maps for areas not now adequately mapped will require project geologists as members of the TFW interdisciplinary team. The Departmentof Natural Resources' funding request of February 23, 1987, under Baseline Information--Geologic instability, estimated that staffing for TFW work through 1995 would consist of two geologists at the Geologist 2 level.

The legislatively approved TFW budget is requiring the department to adjust the scope of the program. Historically, geological instability has had the most pronounced negative effects in Whatcom and Skagit Counties. Therefore, application of geologic hazard data under TFW will begin in the Northwest Region.

MEETINGS

Pacific Northwest American Geophysical Union
September 2-3, 1987
The Evergreen State College, Olympia, WA
Abstract deadline: August 3
Information: Timothy Walsh or William Phillips, Washington Division of Geology and Earth Resources, PY-12, Olympia, WA 98504; (206) 459-6372

Northwest Mining Association
93rd annual meeting, Dec. 3-5, 1987
Sheraton Hotel, Spokane, WA
Theme: A World of Opportunity
Information: (509) 624-1158

Pacific Northwest Metals and Minerals Conference (AIME-ASM)
May 3-6, 1988
Sheraton Hotel, Spokane, WA
Theme: Gold Quest '88
Information: (509) 624-1150

STAFF NOTES

Nancy Joseph gave a talk to the American Institute of Mining Engineers in April on Washington's mineral industry in 1986. She also presented three in-service workshops for 81 elementary school teachers in the Spokane District; she discussed formation and identification of rocks and minerals.

During April, **Josh Logan** participated as an instructor in a DNR-wide forest practices training session, coordinated by the Division of Forest Regulation and Conservation (FRAC). The purpose of the training was to inform DNR personnel of prudent forest practices. Josh discussed the influence of geologic conditions on forest slope stability. He gave a short course on geologic terminology and reading geologic maps, using as examples maps, slides of geologic features, and case histories. Instructors from seven area offices and FRAC presented related information. A similar session is planned for fall 1987.

William Lingley was recently elected to the Board of Directors of the Northwest Petroleum Association.

STATE GEOLOGIC MAP OPEN FILE REPORTS NOW AVAILABLE

Geologic maps of the southwest quadrant of Washington are now available as a series of open file 1:100,000-scale quadrangle maps. These maps were compiled by staff geologists of the Division as the first stage of compilation leading to publication of a map of the southwest quadrant of Washington at a scale of 1:250,000. As reported in this Newsletter in October 1983, we decided to compile the geology of the state at 1:100,000 scale because (1) modern base maps at 1:100,000 scale exist for the entire state, (2) geologic map compilations at this scale will be useful to resource managers and explorationists, and (3) the 1:100,000 scale allows our geologic staff to preserve most of the detail of the original source maps.

The open file maps available are listed below. Maps for the south half of the Snoqualmie Pass and southwest quarter of the Wenatchee 1:100,000 quadrangles are not included in the series because modern geologic maps for these quadrangles are available from the U.S. Geological Survey. The price for each map is given with its description. Please include $1 with each order to cover the cost of postage and handling. Mail your order to: Department of Natural Resources, Div. of Geology and Earth Resources, Mail Stop PY-12, Olympia, WA 98504.

Open File Report 86-3
Walsh, T. J., 1986, Geologic map of the west half of the Toppenish quadrangle, Washington: 7 p., 1 plate, scale 1:100,000
Price, $0.93; tax, $0.07; total, $1.00.

Open File Report 86-4
Walsh, T. J., 1986, Geologic map of the west half of the Yakima quadrangle, Washington: 9 p., 1 plate, scale 1:100,000
Price, $0.93; tax, $0.07; total, $1.00.

Open File Report 87-2
Walsh, T. J., 1987, Geologic map of the Astoria and Ilwaco quadrangles, Washington and Oregon: 28 p., 1 plate, scale 1:100,000
Price, $1.39; tax, $0.11; total, $1.50.

Open File Report 87-3
Walsh, T. J., 1987, Geologic map of the south half of the Tacoma quadrangle, Washington: 10 p., 1 plate, scale 1:100,000
Price, $0.93; tax, $0.07; total, $1.00.

Open File Report 87-4
Phillips, W. M., 1987, Geologic map of the Mount St. Helens quadrangle, Washington and Oregon: 59 p., 1 plate, scale 1:100,000
Price, $2.32; tax, $0.18; total, $2.50.

Open File Report 87-5
Korosec, M. A., 1987, Geologic map of the Mount Adams quadrangle, Washington: 39 p., 1 plate, scale 1:100,000
Price, $1.86; tax, $0.14; total, $2.00.

Open File Report 87-6
Korosec, M. A., 1987, Geologic map of the Hood River quadrangle, Washington and Oregon: 40 p., 1 plate, scale 1:100,000
Price, $1.86; tax, $0.14; total, $2.00

Open File Report 87-8
Logan, R. L., 1987, Geologic map of the Chehalis River and Westport quadrangles, Washington: 16 p., 1 plate, scale 1:100,000
Price, $0.93; tax, $0.07; total, $1.00

Open File Report 87-9
Logan, R. L., 1987, Geologic map of the south half of the Shelton and the south half of the Copalis Beach quadrangles, Washington: 15 p., 1 plate, scale 1:100,000
Price, $0.93; tax, $0.07; total, $1.00

Open File Report 87-10
Phillips, W. M., 1987, Geologic Map of the Vancouver quadrangle, Washington and Oregon: 27 p., 1 plate, scale 1:100,000
Price, $1.39; tax, $0.11; total, $1.50.

Open File Report 87-11

Schasse, H. W., 1987, Geologic map of the Centralia quadrangle, Washington: 28 p., 1 plate, scale 1:100,000

Price, $1.39; tax, $0.11; total, $1.50.

Open File Report 87-13

Phillips, W. M., Walsh, T. J., 1987, Geologic map of the northwest part of the Goldendale quadrangle, Washington: 7 p., 1 plate, scale 1:100,000

Price, $0.93; tax, $0.07; total, $1.00.

Open File Report 87-16

Schasse, H. W., 1987, Geologic map of the Mount Rainier quadrangle, Washington: 46 p., 1 plate, scale 1:100,000

Price, $1.86; tax, $0.14; total, $2.00.

SELECTED REPORTS ADDED TO THE LIBRARY, WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES,

MAY AND JUNE, 1987

THESES

Gage, D. R., 1981, Basic and applied projects in analytical chemistry--I. The development of a sulfur specific detector for gas chromatography based on SO_2 fluorescence; II. The application of laser Raman spectrometry for the determination of quartz and cristobalite in Mount St. Helens volcanic ash: University of Idaho Doctor of Philosophy thesis, 125 p.

Harris, Elaine, 1984, The effect of ashfall from the May 18, 1980 eruption of Mount St. Helens on cryptogams: Washington State University Master of Science thesis, 50 p.

Hayward, James L., Jr., 1982, Effects of nest habitat, behavior, and volcanic ash on reproductive success in ring-billed and California gulls: Washington State University Doctor of Philosphy thesis, 58 p.

Hornig, C. E., 1984, Effects of Mt. St. Helens ashfall on aquatic insects: University of Idaho Master of Science thesis, 74 p.

Kendra, W. R., 1983, Effects of volcanic ash on the composition, abundance, and vertical distribution of benthic macroinvertebrates in Chatcolet Lake, Idaho: University of Idaho Master of Science thesis, 40 p.

Peterson, D. A., 1982, Effects of fine volcanic ash on surface irrigation in central Washington: Washington State University Master of Science thesis, 111 p.

Pottmeyer, Judith Ann, 1984, The effect of Mt. St. Helens tephra on the water relations and growth of Verbascum thapsus L.: Washington State University Doctor of Philosophy thesis, 187 p.

Thorndycraft, R. B., 1974, An investigation of silicate ores--Beneficiation and X-ray analytical procedures: University of Washington Master of Science thesis, 101 p.

Waldron, Richard L., 1986, Hydrothermal alteration of the Gamma Ridge rocks on Glacier Peak, and their relation to hot spring activity: Western Washington University Master of Science thesis, 57 p.

PUBLICATIONS OF FEDERAL AGENCIES

U.S. Geological Survey

Abrams, G. A., 1987, Principal facts for gravity stations in the vicinity of Mount St. Helens, Skamania County, Washington: U.S. Geological Survey Open-File Report 87-271, 12 p.

Bortleson, G. C.; Cox S. E., 1986, Occurrence of dissolved sodium in ground waters in basalts underlying the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 85-4005, 24 p., 5 plates.

Dinwiddie, G. A.; Trask, N. J., 1986, U.S. Geological Survey research in radioactive waste disposal--Fiscal years 1983, 1984, and 1985: U.S. Geological Survey Water Resources Investigations Report 87-4009, 109 p.

Drost, B. W.; Whiteman, K. J., 1986, Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington: U.S. Geological Survey Water Resources Investigations Report 84-4326, 11 sheets, scale 1:500,000.

Gerin, Marybeth; Stevenson, A. J., compilers, 1979, Equal-area base map of the north Pacific Ocean, northeast section; Albers equal-area projection: U.S. Geological Survey Open-File Report 79-856, 1 sheet, scale 1:2,500,000.

Gerin, Marybeth; Stevenson, A. J., compilers, 1979, Equal-area base map of the northeast Pacific Ocean; Albers equal-area projection: U.S. Geological Survey Open-File Report 79-857, 1 sheet, scale 1:5,000,000.

Lum, W. E., 1986, Reconnaissance of the water resources of the Hoh Indian Reservation and the Hoh River Basin, Washington; with a section on fluvial sediment transport in the Hoh River, by L. M. Nelson: U.S. Geological Survey Water-Resources Investigations Report 85-4018, 56 p.

Rowley, P. D.; Miller, D. M.; Miller, F. K., compilers, 1986, An overview of geologic mapping needs in the United States: U.S. Geological Survey Open-File Report 86-573, 82 p.

Turney, G. L.; Dion, N. P.; Sumioka, S. S., 1986, Water quality of selected lakes in Mount Rainier National Park, Washington, with respect to lake acidification: U.S. Geological Survey Water-Resources Investigations Report 85-4254, 45 p.

Vallier, T. L.; Brooks, H. C., editors, 1986, Geology of the Blue Mountains region of Oregon, Idaho, and Washington--Geologic implications of Paleozoic and Mesozoic paleontology and biostratigraphy, Blue Mountains province, Oregon and Idaho: U.S. Geological Survey Professional Paper 1435, 93 p.

Whiteman, K. J., 1986, Ground-water levels in three basalt hydrologic units underlying the Columbia Plateau in Washington and Oregon, spring, 1984: U.S. Geological Survey Water-Resources Investigations Report 86-4046, 4 sheets.

Other Federal Agencies

La Liberte, Patrice; Harris, W. M., compilers, 1987, Federal offshore statistics--1985; Leasing, exploration, production, and revenues, with Tables 5, 9, and 11 abridged: U.S. Minerals Management Service MMS-87-0008, 75 p.

Lavelle, J. W.; Davis, W. R., 1987, Measurements of benthic sediment erodibility in Puget Sound, Washington: U.S. National Oceanic and Atmospheric Administration Technical Memorandum ERL PMEL-61, 43 p.

U.S. Bureau of Land Management, 1987, Spokane resource management plan, record of decision, Rangeland Program Summary (RPS): U.S. Bureau of Land Management [Spokane, Wash.], 62 p.

Zak, J. A., 1978, Geology of Fort Lewis and Yakima firing center: U.S. Army, Fort Lewis Environmental and Energy Control Office, 21 p.

PUBLICATIONS OF STATE AND LOCAL AGENCIES

Mount St. Helens and other volcanoes

Eichelberger, John; Keady, C. J.; Wright, Donald, 1975, Mt. Baker, 11 April to 1 July, 1975: EG&G Los Alamos Operations, 31 p.

Keller, S. A. C., editor, 1986, Mount St. Helens--Five years later: Eastern Washington University Press, 441 p.

Sneva, F. A.; Britton, C. M.; Mayland, H. F.; and others, 1982, Mt. St. Helens ash--Considerations of its fallout on rangelands: Oregon State University Agricultural Experiment Station Special Report 650, 27 p.

Sorensen, J. H., 1981, Emergency response to Mount St. Helens' eruption--March 20 to April 10, 1980: University of Colorado Natural Hazards Research and Applications Information Center, Working Paper 43, 63 p.

Marine and Coastal Geology

Phillabaum, S. D., 1973, A geomorphic inventory of Whatcom County marine shoreline with considerations for its management: Western Washington State College Institute for Freshwater Studies Technical Report 20, 176 p.

Sutton, G. H.; Lewis, B. T. R.; Ewing, J.; Duennebier, F. K.; Iwatake, B.; Tuthill, J. D., 1980, Lopez Island ocean bottom seismometer intercomparison experiment; final report: Hawaii Institute of Geophysics Report HIG-80-4, 1 v.

Soil Surveys

Beieler, V. E., 1975, Soil survey of Chelan area, Washington, parts of Chelan and Kittitas Counties: U.S. Soil Conservation Service, 104 p., 50 plates.

Halloin, L. J., 1987, Soil survey of Clallam County area, Washington: U.S. Soil Conservation Service, 213 p., 67 plates.

Harrison, E. T.; McCreary, F. R.; Nelson, F. L., 1973, Soil survey of Columbia County area, Washington: U.S. Soil Conservation Service, 88 p., 50 plates.

Lenfesty, C. D.; Reedy, T. E., 1985, Soil survey of Yakima County area, Washington: U.S. Soil Conservation Service, 345 p., 87 plates.

Pringle, R. F., 1986, Soil survey of Grays Harbor County area, Pacific County, and Wahkiakum County, Washington: U.S. Soil Conservation Service, 296 p., 165 plates.

Rasmussen, J. J., 1976, Soil survey of Yakima Indian Reservation irrigated area, Washington, part of Yakima County: U.S. Soil Conservation Service, 51 p., 36 plates.

Raver, M. L., 1974, Soil survey of Garfield County area, Washington: U.S. Soil Conservation Service, 71 p., 50 plates.

Zulauf, A. S.; Starr, W. A., 1979, Soil survey of north Ferry area, Washington, parts of Ferry and Stevens Counties: U.S. Soil Conservation Service, 118 p., 73 plates.

Coal Mine Hazards

McLucas and Associates, Inc., 1987, Evaluation of coal mine hazards associated with the underground workings of the Green River coal mine as they pertain to property contained in Lots 10 and 11 owned by Cascade Security Bank of Enumclaw situated within the Remolif addition, section 36, T. 21 N., R. 6 E., W.M., King County, Washington: McLucas and Associates, Inc., 1 v., 1 plate.

Other Reports

Engineering Geology and Soils Engineering Symposium, 23rd, 1987, Proceedings, 1 v.

Hill, M. L., editor, 1987, Cordilleran section of the Geological Society of America: Geological Society of America DNAG Centennial Field Guide 1, 490 p.

FACULTY AND STUDENT GEOLOGIC RESEARCH PROJECTS, WASHINGTON COLLEGES AND UNIVERSITIES 1987

University of Washington

Department of Geological Sciences

Faculty Projects

Kinematic history of the Pasayten fault in Washington and southern British Columbia--Darrel Cowan

Kinematics of the Late Cretaceous Rosario thrust zone, San Juan Island--Darrel Cowan

Petrology of the Chiwaukum Schist and related rocks, central Washington--Bernard W. Evans

Student Projects

Paleomagnetism of Upper Jurassic clastic rocks, San Juan Island, Washington--Scott Bogue and John Carver (with Darrel Cowan)

A theoretical model for bedload transport of sand grains by wind--Susan R. Calder

Depositional environments, basin evolution, and tectonic significance of the Eocene Chumstick Formation, Cascade Range--James E. Evans

Stratigraphy, depositional setting and tectonic significance of the clastic cover to the Fidalgo ophiolite, San Juan Islands--John T. Garver

Geochronology and geochemistry of Archaean basement rocks, Kangerdlugssuaq region, East Greenland--Sarah E. Hoffman

Progressive deformation of the Orca Group and its bearing on the Paleogene accretionary history of southern Alaska--Kevin J. Kveton

Epithermal Au-Ag mineralization, Wenatchee Heights, Washington--Jacob Margolis

Multicomponent diffusion in silicate liquids--William Minarik and Mark Ghiorso

Chemical variation in isofacial blueschists and greenschists from the Shuksan suite, Washington; evidence for primary magmatic differentiation trends and subsequent alteration--Claudia Owen

Petrology of mafic stocks in the Chilliwack Composite Batholith, North Cascades, Washington--Jeffrey H. Tepper

The kinetics of water-rock interaction in mid-ocean ridge hydrothermal systems--James T. Wells

Geophysics Program

Faculty Projects

[Abbreviated titles; student collaborators in parentheses]

Hanford network--Stephen D. Malone and Anthony Qamar

Debris flows--J. Dungan Smith (Guy Gelfenbaum)

Geothermal seismicity--Stephen D. Malone and Anthony Qamar (Peggy Brown, Robert Leet)

Earthquakes in the Pacific Northwest--Robert S. Crosson (Jonathon Lees, Li Ma)

Earthquake hazards--Robert S. Crosson

Columbia Glacier--Robert S. Crosson and Anthony Qamar

Glacier structures--Charles F. Raymond (Tad Pfeffer)

Glacier comparison--Charles F. Raymond

Hydrogen in metals--J. Michael Brown

Domain structure--Ronald T. Merrill

DAC geophysics--Yosiko S. Sorenson

Marine sediment transport--J. Dungan Smith

Agassiz Ice Cap survey--Edwin D. Waddington

Earthquake education--Linda L. Noson

Seismic structure--Robert S. Crosson (David Lapp, Steve Wyneken)

Washington Mining and Mineral Resources Research Institute

(Selected geologic projects)

A process for utilization of natural deposits of limestone for lime refractories--Richard C. Bradt (Univ. of Washington)

In-situ infra-red studies of coal char reactivity; effects of mineral composition--Barbara Krieger-Brockett (Dept. of Chemical Engineering, Univ. of Washington)

Fractal geometry and the quantification of surface changes during sintering of iron oxides--K. C. Lindell (Dept. of Chemical Engineering, Washington State Univ.)

The electrokinetic dewatering of mines, slurries, and tailings--E. J. Davis (Dept. of Chemical Engineering, Univ. of Washington)

The Witwatersrand Basin, depositional or preservational; The justification for exploring for new Au/U districts--Eric S. Cheney (Univ. of Washington)

Gold in skarn deposits--L. D. Meinert (Washington State Univ.)

Distribution of immobile trace elements in hydrothermally altered rocks associated with various types of gold deposits--Mohammed Ikramuddin (Eastern Washington Univ.)

Ladle desulfurization with alkali carbonate/lime mixtures--Y. K. Rao (Dept. of Materials Science and Engineering, Univ. of Washington)

Central Washington University

Faculty Projects

Stratigraphy and geology of the Columbia River basalts in the western Columbia Plateau (Filey Road-Priest Rapids, Whiskey Dick, Yakima Canyon areas, Black Rock quadrangle)--Robert D. Bentley and John E. Powell

Deep crustal transect, 117th meridian, Oregon and Washington (in cooperation with

International Lithosphere Program and Institute for the Study of Continents, Cornell University)--Steven E. Farkas and Don Ringe

Study of (1) methods to transfer geologic map information to a Geographic Information System with public-domain software, and (2) computer-assisted petrography for real-time color image analysis--James Hinthorne

Student Projects

Geology of the proposed Grant County Waste Management Facility--James Peterson

Sediment transport directions in the Vantage and Squaw Creek Members of the Ellensburg Formation in the vicinity of Yakima Canyon and Hog Ranch anticline--Suzanne Skvarek

Geologic history of Kittitas County (poster for display at County Fair)--Geology Club members

Western Washington University

Faculty Projects

[Names of collaborators in parentheses]

Geochemistry of the central and northern Cascades--R. S. Babcock

Geochemistry of Tertiary igneous rocks of the Olympic Peninsula--R. S. Babcock

Paleomagnetism of the Midnight Peak Formation, Methow Valley, Washington; northward transport or mid-folding remagnetization?--M. E. Beck, Jr., and R. F. Burmester (D. R. Bazard)

Petrology and structure in the northwestern Cascades, Washington and British Columbia--E. H. Brown

Possible terrane trajectories for mid-Cretaceous plutons of the north Cascades, Washington and British Columbia--D. C. Engebretson (J. A. Carey, J. D. Dragovich)

Sediment transport, sediment storage, and sediment budget studies in the Deer Creek basin (tributary to the North Fork Stillaguamish) with special reference to the DeForest Creek landslide--H. M. Kelsey (J. N. Thompson, J. A. Maloy)

Study of groundwater flow in the unconfined aquifer at two 10-mi^2 study sites north of Lynden, Washington, on the Sumas outwash plain--H. M. Kelsey (K. Creahan)

Coastal geomorphology of Baltic Finland and Estonia--M. L. Schwartz

Accurate dating of Quaternary sediments by thermoluminescence methods--G. W. Berger and D. J. Easterbrook

Dating marine terrace deformation north of the Mendocino triple junction--G. W. Berger and D. J. Easterbrook

Dating and correlation of early Pleistocene tephra and paleomagnetism of early Pleistocene sediments in the Puget Lowland--D. J. Easterbrook (with John Westgate, Nancy Naeser, John Roland, and Bob Carson)

Student Projects

The petrology, stratigraphy, and basin history of the Montesano Formation, southwestern Washington and southern Olympic Peninsula--P. K. Bigelow

Structure and petrology of the Lookout Mountain-Little Devil Peak area, north Cascades, Washington--J. A. Cary

Shore stabilization in Singapore--A. Dold

The structural and metamorphic history of the Sibley Creek area, north Cascades--J. D. Dragovich

Petrography and tectonic significance of the Blue Mountain unit, Olympic Peninsula, Washington--J. M. Einarsen

Paleomagnetism and tectonic interpretation of the Crescent and Blakely Formations on Kitsap Peninsula, Washington--J. W. Purdy

Mid-Tertiary volcanic rocks of the Timberwolf Mountain area, south-central Cascades, Washington--J. M. Schultz

The sedimentation and tectonics of the breccia at Cape Flattery, the Lyre Formation, northwest Olympic Peninsula, Washington--A. B. Shilhanek

Sediment transport at the intersection of the foreshore and the water table--R. J. Turner

Quantification of the net shore-drift rates in Puget Sound and the Strait of Juan de Fuca--R. S. Wallace

Eastern Washington University

Faculty Projects

Mineralogy of the Golden Horn batholith, North Cascades, Washington--Russell C. Boggs

Mineralogy of the Sawtooth batholith, Idaho--Russell C. Boggs

Mineralogy of the Wind Mountain laccolith--Russell C. Boggs

Mathematical modeling of small drainage basin behavior--John P. Buchanan

Sedimentation in sand-bed braided rivers--John P. Buchanan

Sedimentology of the Cretaceous-age coarse-clastic deposits in Washington and Nevada--John P. Buchanan

Hydrologic study of Chamokane Creek, northeastern Washington--John P. Buchanan

Permian bryozoans of the carbonate units of the Mission Argillite, northeastern Washington--Ernest H. Gilmour

Bryozoans and paleoecology of the Otter Formation, Little Belt Mountains, Montana--Ernest H. Gilmour

Biostratigraphic studies of Pennsylvanian and Permian bryozoans in North American and Pakistan--Ernest H. Gilmour

Carbonate petrology of the Antler Peak Limestone, northeastern Nevada--Ernest H. Gilmour

Rare earth elements geochemistry of gold deposits--Mohammed Ikramuddin

Distribution of immobile trace elements in hydrothermally altered rocks associated with various types of gold deposits--Mohammed Ikramuddin

Thallium--a potential guide to mineral deposits--Mohammed Ikramuddin

Geochemistry of sediment-hosted precious metals deposits--Mohammed Ikramuddin

Development of new analytical methods by inductively coupled argon plasma and electro-thermal atomic absorption--Mohammed Ikramuddin

Chemical composition of sediments from archaeological sites in central Washington--Mohammed Ikramuddin

Geochemistry of granitic rocks of northeastern Washington--Mohammed Ikramuddin

Hydrogeochemical methods of exploration for gold and silver--Mohammed Ikramuddin

Geochemistry of platinum group elements--Mohammed Ikramuddin

Geochemistry of volcanic rocks and its relationship to gold-silver mineralization--Mohammed Ikramuddin

Geochemistry of gallium--Mohammed Ikramuddin

Glacial and catastrophic flood history of eastern Washington--Eugene P. Kiver

Geology of the national parks--Eugene P. Kiver

Quaternary map of northeastern Washington east of the Okanogan River--Eugene P. Kiver

Structure and stratigraphy of the Middle Paleozoic Antler orogen in northwestern Nevada--Linda B. McCollum

Stratigraphy, sedimentology, and paleontology of the Cambrian System of the Great Basin--Linda B. McCollum

Paleozoic paleoecology and the Lower to Middle Cambrian extinctional event--Linda B. McCollum

Paleozoic continental margin sedimentation in western U.S.--Linda B. McCollum

Mesozoic transcurrent faulting and suspect terranes in the Great Basin--Linda B. McCollum

Alkaline igneous rocks and related precious metal deposits--Felix E. Mutschler

Epithermal precious metal deposits--Felix E. Mutschler

Compilation of computer data base of whole-rock chemical analyses of igneous rocks--Felix E. Mutschler

Major and trace element chemistry of "porphyry" molybdenum, tin-tungsten, and copper systems--Felix E. Mutschler

Laramide and younger tectonics and magmatism in the eastern Rocky Mountains--Felix E. Mutschler

Stylolites in ore deposits--James R. Snook

Thrust faulting in northeastern Washington--James R. Snook

Petrology of the Quartz Hill molybdenum deposit, Alaska--James R. Snook

Paleomagnetic investigation of glacial Lake Missoula flood deposits--William K. Steele

Use of remanent magnetization direction to correlate air-fall ash deposits from Cascade volcanoes--William K. Steele

Mechanism of acquisition of remanent magnetization by air-fall ash--William K. Steele

Student Projects

Gold deposits in the alkaline rock igneous centers of Colorado--Daniel W. Fears

Geology of the southwest quarter of the Aeneas Valley 15' quadrangle, Okanogan County, Washington--Charles W. Gulick

Geochemical characteristics of tin-bearing granites--Fred T. Langston

Gold deposits associated with alkaline plutons and volcanics; selected trace element geochemistry--Robbin W. Finch

Vertical geochemical variations in granodiorite associated with the molybdenum-copper porphyry deposit at Mount Tolman, Ferry County, Washington--Danelle D. Elder

Reconnaissance trace element geochemistry of the Loon Lake batholith, northeastern Washington--Adolphus A. Afemari

Granite molybdenite systems--North American Cordillera--Curtis A. Hughes

Petrography of carboniferous dolomites, Springdale area, Washington--Mehemed S. Gheddida

Economic geology and production cost analysis of the Golden Sceptre Mine, Boundary County, Idaho--T. Michael Sweeney

Sedimentology of the Winthrop Sandstone, north-central Washington--Robert L. Rau

Geology of the Gold Hill-Mica Mountain area, Latah County, Idaho--Gary D. Walker

Paleomagnetism of Lake Missoula flood deposits in the Sanpoil River valley of northeastern Washington--Russell G. Mitchell

Biogeochemical methods of exploration for gold deposits--Richard B. Lestina

The geochemistry of precious metal mineralization in post-emplacement ophiolitic terrains, Ingalls Ophiolite Complex, Washington--Phillip C. Nisbet

Pegmatites in northeastern Washington--John W. Aiken

Paleoecology of the Ferdelferd fossil beds, Diamond Peak Formation (Mississippian), Elko County, Nevada--W. Gregory Goodwin

Geologic map of the Boulder Mountain 7-1/2' quadrangle, northeastern Utah--Andrew R. Mork

Depositional processes in the magnetization of air-fall ash--James E. Garman

Clay formation of rocks under humid tropical climatic condition in east Jiwo Hills, Java--Aryono S. Salehdanu

Depositional model of catastrophic flood bars in the Pine Creek Channel, eastern Washington--Robert A. Pinotti

The geochemical characterization of a part of the Stillwater Complex, Montana, with particular reference to the platinum-group elements--Michael W. Knoper

Geology of the McCollough Creek area, Douglas County, Oregon--Allen V. Ambrose

Bryozoan biostratigraphy of the Phosphoria Formation, southeastern Idaho--Robert C. Walker

Induced polarization-direct current resistivity methods in the exploration for paleodrainage channels--John S. McBeth

Petrology and mineralization of the William Henry Bay zinc prospect--Stanley A. Ellison

Economic geology of the Sherman molybdenum prospect, Okanogan County, Washington--Grant R. Newport

Geochemistry of alaskite and quartz monzonite of Mount Spokane, northeastern Washington, and its relation to uranium mineralization--Roy Bongiovanni

Biostratigraphy and lithostratigraphy of the late Devonian-early Mississippian Pilot Shale of eastern Nevada and western Utah--Mark E. Jones

Geochemistry and petrography of veins and wall rocks associated with gold-silver mineralization in the Republic District, Ferry County, Washington--Walter M. Martin

Sedimentation and mineralogical composition of the Latah Formation (Miocene), eastern Washington--John D. Robinson

Geology and mineral deposits of the Lightning Mountain-Rattle Creek area, eastern Bonner County, Idaho--John E. Etienne

FERROS--A computerized data base for Precambrian auriferous banded iron-formations and related rocks--Glen R. Carter

Giant lode gold camps of North America--Mark J. Mihalasky

Halogens as pathfinder elements for petroleum exploration--Tony L. Gordon

Geochemistry of igneous rocks from Newport and adjacent areas, northeastern Washington--L. Christine Russell

Upper Cambrian carboniferous section in the Toano Range near Wendover, Nevada--Joseph Drumheller

Surficial geology and basin stability of the Lightning Creek drainage basin, Clark Fork County, Idaho--Charles C. Cacek

Washington State University

Faculty Project

Studies of the Columbia River Basalt Group--Peter R. Hooper

Student Projects

Southern limits of the Colville batholith-Grace and Wade Holder

Volcanic rocks of the Republic graben--Grace and Wade Holder

Intrusive rocks northeast of Republic, Washington--Charles Knaack

Grays Harbor College

Faculty Project

Seismic stratigraphy and Holocene changes in sea level, Grays Harbor estuary--James B. Phipps

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