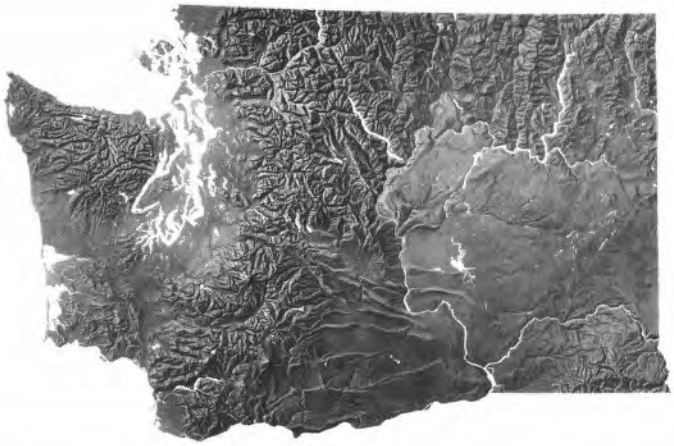

WASHINGTON GEOLOGY

Washington Department of Natural Resources, Division of Geology and Earth Resources Vol. 21, No. 3, November 1993

(Left) Eileen Strickland, a quality control technician at Columbia River Carbonates in Woodland, Washington, tests a sample of a ground calcium carbonate slurry, essentially liquid stone, that is ready to use for paper coating. (Right) This finished coating product can be transported to customers by tank truck. (See related article, page 3.)

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WASHINGTON GEOLOGY

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National Geologic Mapping Act Update

by Raymond Lasmanis

In fiscal year 1993, Congress appropriated $21,982,000 for the National Geologic Mapping Program. The funds for federal FY 93 were divided by program components as follows:

Program	Authorization	Funding
Federal mapping	$12,500,000	$10,852,000
Federal support	9,500,000	9,791,000
State mapping	15,000,000	1,339,000
Education support	500,000	0

Note that the U.S. Geological Survey (USGS) mapping program received 87 percent of authorization, USGS mapping support received 103 percent of authorization, education was not supported, and state mapping was supported at 9 percent of authorization.

Forty-four states submitted proposals to receive a portion of the $1,339,000. Our original request to the USGS was for field mapping and analytical support and for the cost of printing the 1:250,000-scale map of the southeast quadrant. This grant request for $51,000 was rejected.

On September 3, 1993, we submitted a modified request for $25,000. The scope of this proposal is to acquire geologic data in the Roche Harbor and Bellingham 1:100,000-scale quadrangles. Radiometric dating, geochemistry, and travel costs were included in the proposal, which was approved by the USGS on September 30.

The National Geologic Mapping Act authorization for state mapping support in FY 94 is $18,000,000. The American Association of State Geologists (AASG) continues to support full funding for the National Geologic Mapping Program. However, AASG believes it is imperative that the program receive an increase of at least $10 million over the President's budget for FY 94. Also, AASG has taken the position that the allocation of the budget be made among the four program elements in proportion to the authorization in the National Geologic Mapping Act of 1992.

The rationale for the proposed increase above the President's budget request for FY 94 is to maintain the federal mapping program elements at their FY 93 level, to increase support of the state mapping program element to a more reasonable level, and to begin funding the educational program.

If the increase is obtained and the allocation is made in proportion to authorization levels for FY 94, then the FY 94 program would be as follows:

Federal mapping	$11,112,000
Federal support	7,952,000
State mapping	14,306,000
Education support	612,000
Total	$33,982,000

The state of Washington would benefit from full funding of the act for FY 94, but we must recognize that the federal budget deficit will make it extremely difficult to achieve that goal.

The 'Geology' of Papermaking

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INTRODUCTION

You have probably come across old books and newspapers that have become brown and brittle with age and crumble when you turn the pages. This deterioration is due to the acidic nature of the most common commercial papermaking process. It has created major problems for libraries and archives that must keep these materials available for users—restoration and preservation are expensive activities. Changes in the chemistry of papermaking (and to some extent ink) over the last 30 years have improved the life span of today's papers by making it possible to produce acid-free paper at a much lower cost. This means that many of the books printed in 1993 will look just as good as they do now in the year 2093—in fact, for hundreds of years to come.

HOW PAPER IS MADE

Paper is a thin mat of cellulose derived from some kind of vegetable fiber, usually wood fiber. In the most common commercial papermaking process, wood is ground up and the fibers are then treated and bleached to produce paper "pulp". Wood fibers contain a high percentage of lignins and other impurities that, if left in the paper, eventually decay and produce acid that attacks the cellulose, turning the paper brown and brittle. Wood pulp requires extensive treatment before it's suitable for ordinary papermaking and even more treatment before it's pure enough for high quality permanent papers.

The pulp is used to make up the basic structure of a sheet of paper, which is simply a web of fibers that adhere to each other and form a seamless sheet similar in appearance to cloth fabric. Paper for printing also has to repel water and hold ink in crisp lines, an attribute known as "printability". Rosin and alum (aluminum sulfate) have commonly been added to "size" the paper. This process is done under acidic chemistry (pH<7), and relatively expensive fillers and coatings that do not dissolve in acid (commonly kaolin clay from Georgia and more fiber) must be used.

CALCIUM CARBONATE AND THE PAPERMAKING PROCESS

As manufacturers searched for economical methods of producing paper, they began to replace rosin and alum with AKD, an alternative chemical sizing agent. This shifts the process chemistry from acid to neutral or alkaline. Calcium carbonate ($CaCO_3$), which dissolves in acid, cannot be used in the acid papermaking process, but in the alkaline process it acts as a "buffer" to neutralize the small amounts of acid that may form within a paper (or be absorbed by it from the environment.) This greatly enhances paper longevity.

There are two distinct uses for $CaCO_3$ in making paper. The first use is as a "filler" in the paper sheet itself. The second use is as a coating applied to the surface of the sheet. Filler enhances such fundamental qualities of paper as whiteness and opacity, whereas coating gives smoothness and glossy sheen and provides a base for sharp, clear printed type and images in magazines and fine books.

To make paper at an affordable price, wood for fiber has to be available at a reasonable distance from the mill, and it has to be of a type suitable for pulping. Washington has an excellent, and until recently, a ready supply of fiber for pulp (particularly Douglas fir and hemlock trees, which produce strong, long fibers). However, as the domestic timber industry changes, minerals are proving to be an economical additive. When we consider that pulp prices range from $400 to $500 per ton compared to $120–$150 per ton of $CaCO_3$, we can see that even small increases in the amount of $CaCO_3$ used can make a difference in costs. When 1 percent of the fiber content is replaced by 1 percent of mineral filler, nearly $1 million can be saved annually at a mill that produces 600–700 tons of paper each day. In coated paper, the total amount of ground $CaCO_3$ added can be increased even further, thereby increasing the savings.

Over the years, the ratio of filler to fiber has increased, particularly in Europe, where pulp is far more expensive. In some European mills, the combined levels of $CaCO_3$ filler and coating now exceed 50 percent of the weight of a sheet of coated paper. Other mineral pigments, such as kaolin and titanium dioxide (TiO_2), are used in paper production for filler, coating, and their brightness-enhancing properties. Location of economically viable deposits of such minerals also impacts the cost of making paper. In Europe, both pulp and kaolin are being imported—some from the U.S. However, European papermakers make greater use of natural sources of $CaCO_3$, which are abundant. American papermakers do not yet use as much mineral filler, partly because the abundance of trees means that pulp costs less in this country. At least that has been the situation until recently.

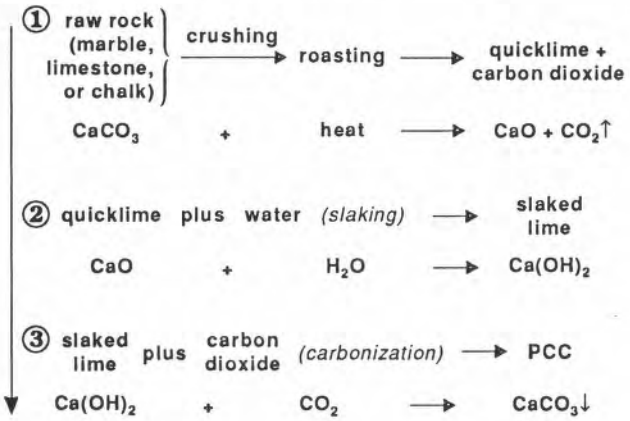
TYPES OF CALCIUM CARBONATE USED IN PAPERMAKING

Two types of $CaCO_3$ are used in the papermaking process—"natural" $CaCO_3$ (from limestone, marble, or chalk) and "synthetic" or precipitated $CaCO_3$. Natural $CaCO_3$ is mined from high-grade calcite deposits and then finely ground. It is referred to as ground calcium carbonate, or GCC, in the paper industry. Chemically precipitated $CaCO_3$ is also used on paper and is known as PCC. $CaCO_3$ used for filler is referred to as "filler grade", whereas $CaCO_3$ used for coating is termed "coating grade". The two grades differ in particle size, the ratio of water to solids in the $CaCO_3$ slurry, and other characteristics.

Papermakers have found there are significant advantages to using $CaCO_3$ in making paper for printing and writing. The mineral is not only an inexpensive whitening pigment for filler and coating, but in the case of GCC, the raw material is readily available worldwide, although deposits of limestone or marble that have suitable brightness and purity are limited. PCC, on the other hand, is produced by chemical processes (Fig. 1) and has some limitations, particularly in regard to how much can be added as filler.

In Europe today, ultra-fine ground calcium carbonate is the more widely used type of filler. Limestone or marble of high purity is ultra-fine ground by a sophisticated "wet-grinding" method until 90 percent of the particles are less than 2 microns (1 micron = 1 millionth of a meter) in diameter (Fig. 1). The particles are suspended in a slurry that consists of about 75 percent solids (cover photo). In the U.S., GCC

PRECIPITATED CALCIUM CARBONATE



GROUND CALCIUM CARBONATE

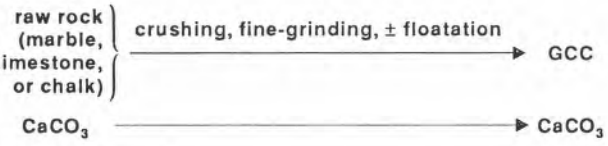


Figure 1. Comparison of the processes for producing precipitated calcium carbonate (PCC) and ground calcium carbonate (GCC). The PCC process consists of three separate chemical reactions, while GCC manufacture is basically a series of physical processes (which may include floatation for coating grade GCC) to remove impurities and grind the stone.

dominates the coating grade market, while PCC holds the lion's share of the carbonate filler applications.

PCC is commonly produced at satellite plants adjacent to paper mills. Paper mill flue gas (CO_2) is passed through a solution of burnt lime or quicklime [$Ca(OH)_2$] in water; the precipitate is PCC. The particles produced in this way range from 1.5 to 2.5 microns. These particles are dispersed in a slurry at about 20 percent solids.

There are other differences between the natural mineral $CaCO_3$ and the "synthetic" precipitated form. The shapes of the tiny particles in the GCC and PCC products are fundamentally different. GCC particles have a rhombohedral structure (the common crystal form of calcite), whereas PCC is scalenohedral (Fig. 2), sometimes referred to as a rosette structure because the tiny calcite spikes cluster and emanate from the particle core like petals in a rose. Such particles present a greater surface area than the GCC rhombohedrons, thereby enhancing their light-scattering quality, which in turn leads to paper having higher brightness and opacity. However, the rosette spikes tend to leave voids within and between particles, which adversely affects paper strength and fiber-to-fiber bonding.

Coating pigments must be applied to the paper at a very high ratio of $CaCO_3$ particles to water in order to produce a smooth, glossy finish. Although PCC manufacturers have been developing a rhombohedral PCC particle, its cost is not yet competitive, and GCC will most likely continue to dominate the coating market.

The total amount of PCC that can be used as filler is limited. Serious problems with holes and paper strength begin to develop as the amount is increased beyond threshold levels. These problems can be overcome to some extent by blending

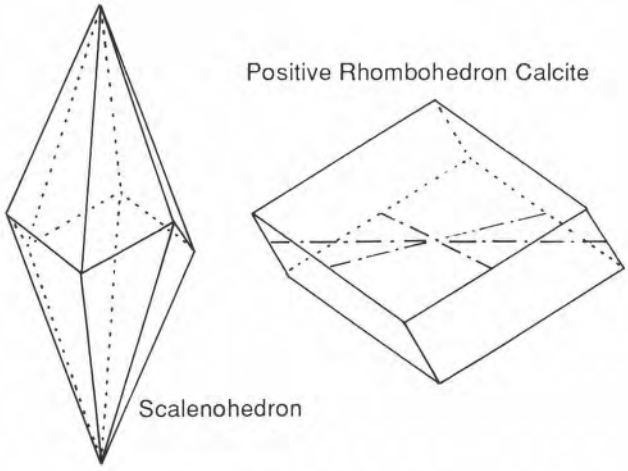


Figure 2. Scalenohedral crystal, typical of precipitated calcium carbonate, and a rhombohedral crystal, typical of natural calcium carbonate, or calcite.

GCC with the PCC filler. The combination enables the papermaker to achieve higher loading levels with fewer problems. However, most paper mills that use PCC satellite plants have made long-term agreements that limit or even exclude the opportunity to use GCC in their formulations.

Characteristics of PCC

As filler, PCC offers these advantages:

- If there is an on-site satellite plant, no dispersant chemicals are needed to keep the slurry from settling during transportation, thus reducing the cost of chemicals.
- Higher opacity, brightness, and bulk result from the scalenohedral morphology of PCC crystals.
- There is less abrasion during the production process; abrasion is detrimental to the expensive paper machine screens and parts.
- The electric kinetic surface charge (cationic zeta potential) is enhanced, which makes for better particle distribution on the sheet.

Disadvantages are:

- The large surface area of the particles decreases the efficiency of sizing.
- Small voids interfere with fiber to fiber bonding and consequently reduce the strength of the paper sheet.
- PCC retains more water than does GCC, which means that the speed of paper production is reduced; associated drainage problems affect the way paper behaves on a press (termed "runability").
- Production problems increase dramatically when the load of PCC passes 15–18 percent of the sheet weight.
- Unreacted sizing (AKD) that is attached to PCC particles remains as residue that is detrimental to paper production.
- Traces of quicklime that have not been neutralized in production adversely affect paper quality and runability.

Characteristics of GCC

Use of GCC offers these advantages:

- Substantially higher filler levels are possible, thereby maximizing savings (and profitability) for papermakers.

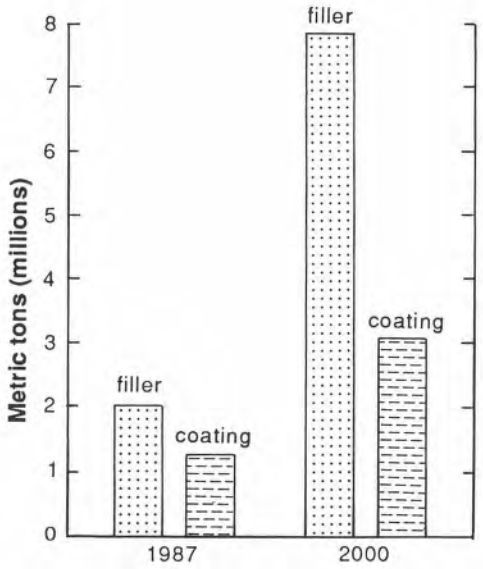


Figure 3. Worldwide demand for calcium carbonate as filler and coating. Data from P. Black and L. Haulkin, Technical Association for the Pulp and Paper Industry Journal, v. 73, no. 11, p. 93.

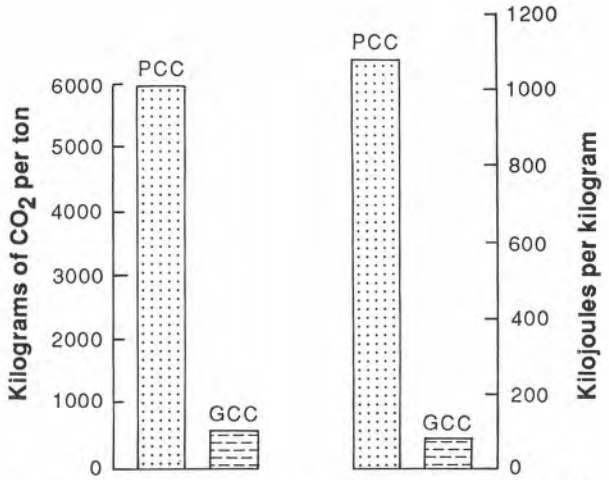


Figure 4. Comparison of carbon dioxide generation (left) and energy demand for precipitated calcium carbonate (PCC) and for ground calcium carbonate (GCC).

- Particle shape is conducive to better fiber bonding and stronger paper.
- Runability is better because the paper retains less water and drains better.
- Sizing efficiency is good.
- There are no residual deposits.

But GCC has these disadvantages:

- Brightness and opacity are slightly lower when compared with paper containing the same amount of PCC.
- GCC has to be kept in suspension during transport to customers; chemical dispersants that prevent particle settling add to costs.
- There is somewhat more abrasion during the papermaking process because of the hardness and shape of natural $CaCO_3$.

Combining PCC and GCC

At present, PCC as filler can make up only about 15–18 percent of the total paper weight. It now seems that GCC, when used in combination with PCC in filler formulation or if used alone, provides a superior filler result. This is because it is possible to make paper with more $CaCO_3$ and less wood fiber than when using PCC alone. When mills experimented with substituting a mix of 75 percent GCC and 25 percent PCC for 100 percent PCC, they found that the mix resulted in a tougher paper that would do well where paper is handled a lot, such as xerographic processes. Other characteristics differed little. When GCC made up more than 60 percent of the mix, it seemed to produce paper that was less porous and with fewer holes. GCC filler also produced less dust when it was used on offset presses.

Outlook for Future Use

Papermakers continually strive to create papers that work well for their customers but use higher and higher levels of inexpensive fillers. In the 1990s, the domestic paper industry faces economic and environmental challenges akin to those the European producers have dealt with for decades. Timber supplies will continue to drop dramatically as we deal with ecological challenges, and there will be a commensurate increase in fiber costs. Every year, the average American consumes paper and wood products equivalent to a 100-foot, 16-inch-diameter tree. The demand for higher quality printing paper and intensified competition stemming from increased production capacity worldwide will compel U.S. producers to make paper at lower costs. In this decade, U.S. filler levels, primarily calcium carbonate, will match those now commonplace in Europe. The current worldwide average for filler usage is about 20 percent. We can probably expect increases in the use of minerals for both fillers and coatings in the coming decade and beyond (Fig. 3).

ENVIRONMENTAL CONSIDERATIONS

Calcium carbonate is a mineral that has virtually no adverse impact on nature. Paper containing calcium carbonate is also superbly postured for recycling. Pulp fibers can be recycled as many as five times before they become too short to be used again (without addition of longer fibers). An alkaline-based manufacturing environment, one that is $CaCO_3$-rich, is less damaging to the fibers. Acid-based chemistry tends to weaken fiber more quickly, papers made this way cannot be recycled as many times before breaking down.

While there are clear advantages to having a $CaCO_3$ source on site, there is a caveat with respect to energy consumption. PCC plants in North America, of which 34 are operated by Mineral Technologies, Inc., typically purchase quicklime from "outside" lime manufacturers. Quicklime is produced by adding heat to $CaCO_3$, which produces CaO (quicklime) and CO_2. The CaO is hydrated to produce slaked lime. Making quicklime is energy-intensive because of the power required to heat (calcine) the $CaCO_3$ (limestone) and drive about 50 percent (by weight) of the limestone up the smokestack as CO_2. Despite the similar energy expenditure required to mine the raw limestone for the production of either GCC or PCC, it has been estimated that, pound for pound, it takes about 8 times more energy to produce PCC than to make GCC. Furthermore, and in spite of the fact that somewhat CO_2-enriched process gas from pulp mills can be captured in the carbonization process [$Ca(OH)_2$ slaked lime +

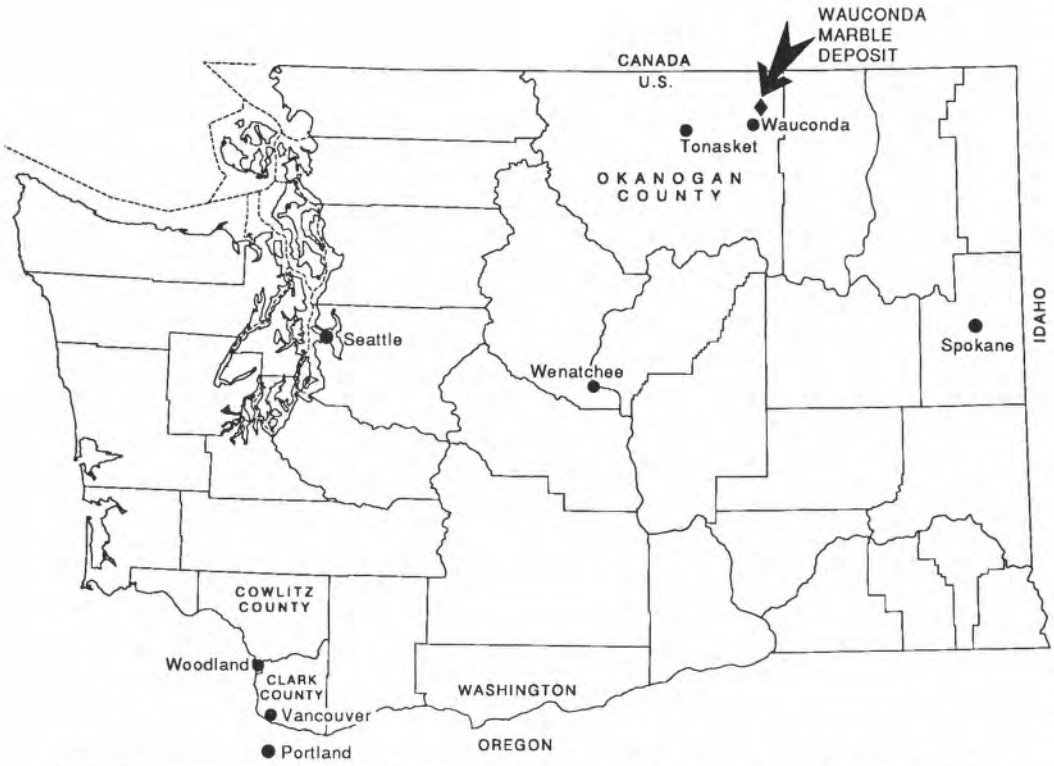


Figure 5. General location of the Wauconda marble deposit (4 miles northeast of the town of Wauconda) and the Columbia River Carbonates plant at Woodland, WA, which is centrally located to served the needs of the Pacific Northwest paper industry.

CO_2 gas → precipitated $CaCO_3$ crystals + H_2O], the total PCC process, including the energy required for quicklime production, releases nearly 13 times more CO_2 than making GCC (Fig. 4). As air-quality standards are tightened and energy taxes loom, paper manufacturers in the U.S. may find it economically advantageous to use more GCC.

SOURCES OF $CaCO_3$ FOR GCC

Chemical and brightness characteristics for the ideal GCC supply are easy to define. The calcium carbonate, whether limestone or its metamorphic equivalent, marble, should be as close to 100 percent pure $CaCO_3$ as possible—about 95 percent purity is considered minimum. The fraction of the raw rock that does not dissolve in dilute hydrochloric acid must be small, on the order of a few percent. Silica (SiO_2), typically as quartz or in its amorphous form, should not constitute more than 1 percent of the total composition. Percentages of both dolomite [$(Mg,Ca)CO_3$, in which magnesium substitutes for calcium] and silica have to be very low because both are abrasive and can damage the fine screens on which paper slurry is laid as the paper is formed.

Figure 6. The transformation of marble to magazines begins at this quarry near Wauconda in north-central Washington. Non-continuous "campaign" mining during fair-weather months produces tens of thousands of tons of raw rock that will become GCC within a year. The rock face (on the left) is drilled and blasted; the resultant blocks are then crushed, sorted by size and cleaned by passing them over vibrating metal grates, stockpiled, weighed, and trucked to a railroad siding (Fig. 7) for transport.

Brightness is defined on a scale of 0 to 100. Values from the mid-90s to 100, measured by either GE or Zeiss Elrepho testing equipment, are considered acceptable. High brightness normally means a very low concentration of iron in the raw rock.

And there are other considerations: the GCC source has to be close to the market so transportation costs will be low; there has to be enough tonnage to assure a long-term supply; and of course, there has to be a market for the product.

During the early and mid-1980s, as use of $CaCO_3$ in paper was beginning in the U.S., exploration for raw rock sources for GCC products was extensive. Major natural resource companies were racing to identify and develop exceptionally pure deposits of $CaCO_3$ for in-house consumption (Boise Cascade) or for outside GCC sales (Cominco American Resources). Just one good discovery could satisfy the projected GCC demand.

THE WAUCONDA DEPOSIT

Reconnaissance for suitable raw $CaCO_3$ resources culminated in the fall

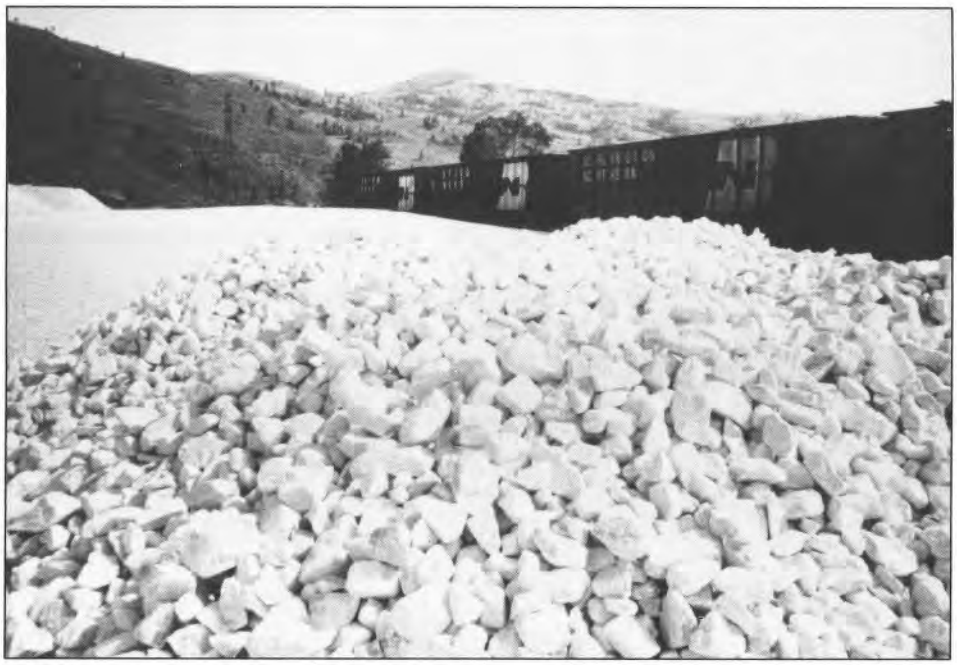


Figure 7. Six-inch-diameter pieces of high-purity and high-brightness marble are temporarily stockpiled at the Janis railroad siding south of Tonasket. The rock is transported in bottom-dumping railroad cars to the Columbia River Carbonates GCC plant at Woodland in southwest Washington.

Figure 8. The Columbia River Carbonates building in which the marble is processed.

Figure 9. Raw material is stockpiled at the Woodland plant. On the right are tanks that store the finished slurry.

of 1984 when members of a joint venture team, Columbia River Carbonates and Genstar Stone Products, identified a previously unrecognized, large-tonnage deposit of fairly pure white marble in Okanogan County (Fig. 5). The deposit (Fig. 6), located 4 miles northeast of the town of Wauconda, is an elliptical podiform body that was delineated by the study of outcrops and drill cores. The marble is nested in a group of hornfels, amphibolites, and calc-silicate rocks of the Permian Spectacle Formation that lies east of the Okanogan metamorphic core complex and just west of the Toroda Creek graben. Geologists theorize that the marble and associated rocks in the Wauconda district are parts of Paleozoic exotic terranes that were formed elsewhere and accreted to the edge of North America as the Pacific oceanic plate passed under the continental plate. The complex geologic history and setting of the Wauconda district marbles account for some of the impurities.

Columbia River Carbonates keeps the purity and brightness of the Wauconda marble at acceptable levels through several processes that are broadly termed "beneficiation". Small dolomitic zones and dikes or sills of lamprophyre and altered porphyritic rocks are removed during quarrying through selective mining and hand sorting. After trucking to a facility at the Janis railroad siding (Fig. 7), south of Tonasket, six-inch fragments of quarry-run marble are passed across a vibrating screen that shakes off the fines (clay and dirt) before being loaded into railroad cars for shipment to the Columbia River Carbonates mill at Woodland. The fine particles, such as oxidized clay, adhere to and discolor the stone and reduce brightness. This screening is enough to meet standards for filler grade and dry ground products, which have less stringent criteria than coatings.

At the mill (Figs. 8 and 9), the part of the marble that will become coating is refined by flotation. Flotation removes minor amounts of pyrite, quartz, and graphite and results in a product that has a brightness of 95 to 96. Columbia River Carbonates is the only manufacturer west of the Mississippi that produces coating grades (Fig. 9). They are marketed throughout the Pacific Northwest (Fig. 10) from the centrally located Woodlands plant.

Figure 10. In addition to truck transport (cover photo), slurry is shipped by rail to paper mill customers.

Wauconda was one of many districts in the Northwest and Canada that were studied in the search for marble of whiting (pigment) potential. Other sources of suitable rock were found but are not plentiful. Considerations of purity and brightness, transportation, and the small market for GCC that developed while the use of PCC was rapidly increasing hampered development of other high-quality carbonate deposits in Washington, Alaska, and Canada. Small parts of the vast high-calcium limestone resources on Texada Island, British Columbia, have high brightness, but this stone is now largely used for making portland cement. Former marble-producing districts in Washington, such as Northport and others in the western part of the state, generally contain too much dolomite or quartz (1%) or are simply too dark for use in fine white papermaking. ■

Major Metals Used in the Chevrolet Lumina APV Minivans And Their Common Mineral Sources

Metal	Common ore minerals	Use
Aluminum	Bauxite (a rock, largely gibbsite and diaspore)	Air conditioning, transmissions, trim parts, radiators, engine parts, molds for manufacturing
Chromium	Chromite	Chrome plating, steel alloy
Copper	Chalcocite, bornite, chalcopyrite	Wiring, motor windings, radiators, bushings, instruments, electronic parts
Gold	Native gold	Electronics, special wiring connectors for such things as air bags
Iron	Goethite, hematite, magnetite	Castings for engines, pumps, axles, brakes; steel parts for gears, shafts; sheet metal; rust-proofing
Lead	Galena	Batteries, electronics, solder, manufacturing processes
Molybdenum	Molybdenite	Special steels, lubricants
Nickel	Pentlandite	Steel shafts, electric parts, magnets, plating
Platinum	Native platinum	Ignition parts, catalytic converter, electronics
Silicon	Quartz	Glass, glass fiber, engine and transmission cast parts, ceramic parts for ignition, electronics and emission systems
Silver	Native silver, argentite	Plating for electronic parts in radios, connectors, on-board computers
Tin	Cassiterite	Batteries, solder, plating, lubricants, bushings, tires, electronics
Tungsten	Wolframite, scheelite	Lamp filaments, radio and electronic parts
Zinc	Sphalerite	Solder, plating, batteries, electronic parts, tires, zinc-coating of body parts for rust prevention

(From *Rocks & Minerals*)

Landslide Inventory and Analysis of the Tilton Creek–Mineral River Area, Lewis County, Washington

Part 1: Terrain and Geologic Factors

by Joe D. Dragovich, Matthew J. Brunengo, and Wendy J. Gerstel

INTRODUCTION

Because much of Washington's commercial forest land is in mountainous terrain, it is susceptible to slope instability of various forms and rates. Some forest practices (notably those associated with roads and timber harvest) can increase mass wasting on slopes of marginal stability. Since implementation of the Timber/Fish/Wildlife Agreement in 1987, the Cooperative Monitoring, Evaluation, and Research committee, the Sediment, Hydrology, and Mass Wasting technical steering committee, and the Department of Natural Resources (DNR) have been engaged in cooperative interdisciplinary efforts to study mass erosion on forest lands, improve methods by which it is addressed, and generally reduce the adverse effects of forest practices on slope stability and downstream resources.

As one means of addressing these goals, a Slope-Stability Hazard Zonation Pilot Project was designed and completed using the resources and personnel of both the Forest Practices Division and the Division of Geology and Earth Resources (DGER) of DNR. The project's broad purposes were to (1) complete a landslide inventory of a selected pilot area, (2) collect topographic, geologic, soils, climatic, and vegetation data relevant to the landslides, and (3) compare the inventory with the state soil survey slope hazard ratings (and other hazard zonation strategies) to assess their utility. We present an overview of our results in this and the next issue of *Washington Geology*. In this issue, we present information pertaining to the relations among terrain features (landslide elevation and aspect), geologic materials and landforms, slope gradient, and incidence of landsliding.

Pilot Study Area

The pilot study area, 199 mi^2, lies at the intersection of the southern part of the Cascade Range in Washington and a prominent westward branching sub-range, generally termed the Northcraft mountains. Rugged terrain and a variety of geomorphic features result from factors that include glacial erosion and deposition, high yearly precipitation (60–100 in.), and mass wasting of folded and faulted Tertiary volcanic and sedimentary bedrock. The variation in land use, ownership, topography, geologic and soils characteristics, climate, landforms, and mass-movement features in the study area allows the results to be applied to many other forested areas that have similar characteristics.

For the pilot project, we divided the general (whole) study area into a focus area, which we examined in detail using aerial photos and field verification of landslides, and a perimeter area, which was investigated using aerial photos and only field reconnaissance (Fig. 1). The focus study area of 61,061 acres (95.4 mi^2) contains 1,021 mapped landslides, of which 667 were field-verified. The perimeter area is 60,949 acres (95.2 mi^2) and contains 651 mapped landslides, 31 of them field-verified.

Methods

We used a modification of the landslide classification scheme of Varnes (1978), which is in turn an outgrowth of previous work by Varnes (1958) and Sharpe (1938). We combined the Varnes landslide classes into three groups: deep-seated, shallow, and cliff (rock-slope) failure types; and we defined road-related failures as a separate type of shallow failure (Table 1). Shallow landslides such as debris slides, avalanches, and torrents (including debris flows and hyperconcentrated floods) typically start as rapid translational failures of the soil mantle (Figs. 2 and 3). Shallow slides also include road-related landslides that emanate from road fill, sidecasts, cutbanks, or landings (Figs. 4 and 5). Deep-seated rotational landslides such as debris slumps, rock slumps and slump-earthflows are generally much larger features (Fig. 6). For completeness, we also inventoried prominent cliffs where rock fall, rock topple, and rock sliding are the primary processes of mass wasting.

We used two sets of aerial photos to map landslides in the general study area prior to field verification in the summer of 1991. These are a black and white 1:14,000-scale set (1988) and a color 1:24,000-scale set (1978). Lewis County soil map orthophotographs (1976) supplemented our aerial-photo interpretations. The landslides were traced on mylar overlays of the aerial photos; polygons were transferred to U.S. Geological Survey 7.5-minute topographic maps and digitized using AutoCAD®. We repeated our aerial-photo mapping after the field season to calibrate our field observations and photo interpretations.

For each landslide, we recorded data on a spreadsheet for documentation and analysis. The features recorded include elevation of the landslide crown, azimuthal direction (aspect) of movement, stream type affected, geologic and soil unit(s) underlying the disturbed area (that is, beneath the landslide rupture surface), geologic structure orientations, movement direction (dip-slope, scarp-slope, and cross-slope failure modes), and geomorphic characteristics (for example, hummocky topography).

We also measured hillslope gradients adjacent to the failures from topographic maps and in the field. Using the aerial-photo scale or field measurements, we measured the rupture surface width, length, and depth to derive a landslide area and volume.

We classified each landslide by activity level (active, recent, dormant, or ancient) and by our certainty (definite, highly probable, probable, or questionable) that it is a landslide. Assignment of activity or certainty was based on the clarity and number of observed landslide features (such as head scarp, flanks, toes), as well as their morphologic freshness. These and other data and observations were documented on field forms, which we filed with a photograph of the landslide.

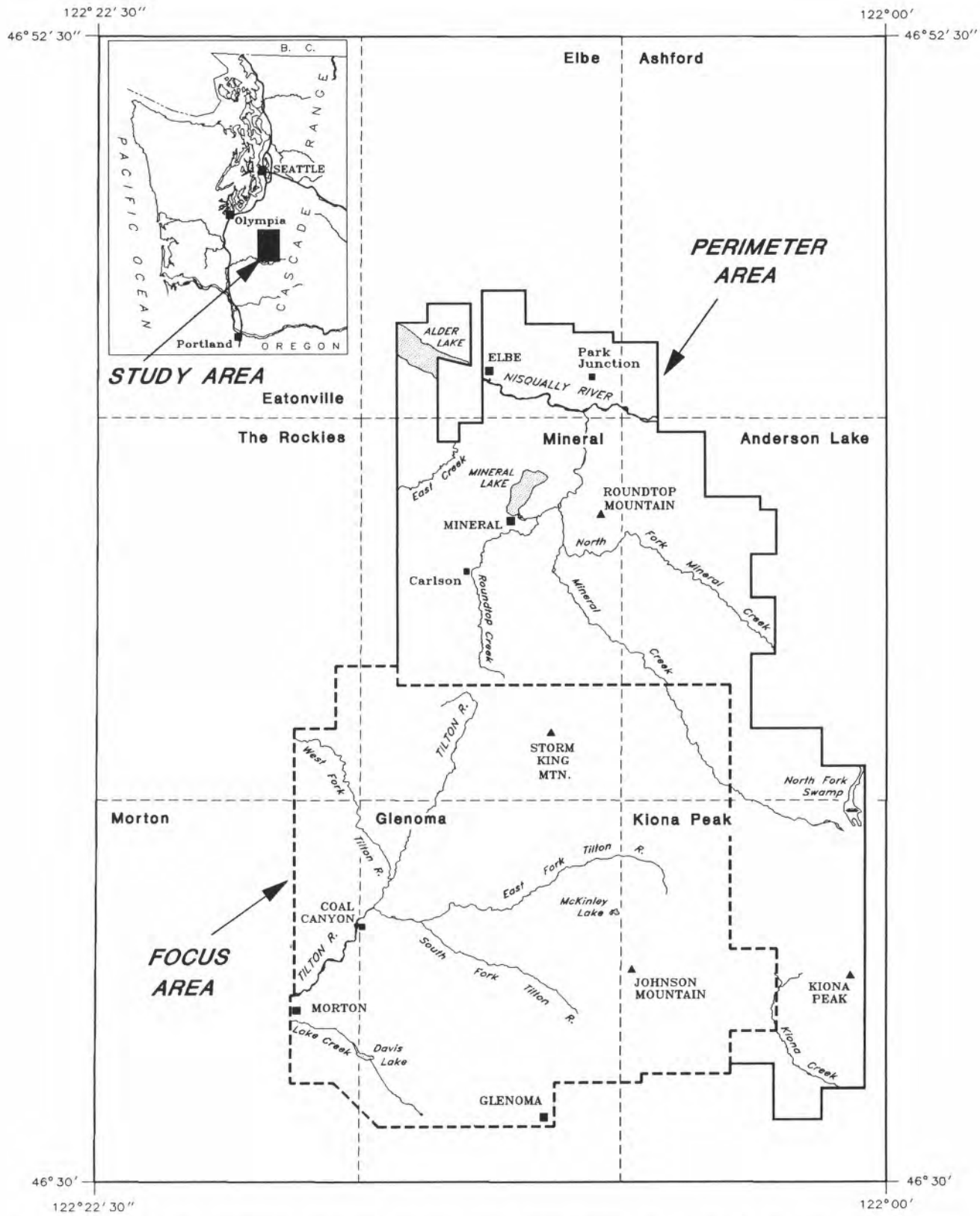


Figure 1. Location of the pilot-project study area. This area contains diverse geomorphologic features, land uses, Tertiary volcanic rocks, Eocene sedimentary rocks, and Pleistocene glacial deposits. The study area was chosen because its varied terrain resembles so many different parts of the Olympic and Cascade mountains of Washington. The lighter dashed lines are boundaries of U.S. Geological Survey 7.5-minute quadrangles; quadrangle names are prominently featured, usually in an upper corner.

The number of landslides of any given analyzed factor (for example, number of landslides per slope gradient class) was normalized into a ratio of the number of landslides per unit area, or landslide density, in order to remove the variations in area from our statistics and to facilitate comparisons. The unit of area chosen was 160 acres, or one-quarter of a square-mile section. A geographical information system (GIS) and digital elevation model (DEM) data were used to determine the distribution by area of slope-gradient, elevation, and aspect classes. Areas of geologic map units were calculated in the GIS from a digitized version of the Centralia quadrangle 1:100,000-scale geologic map (Schasse, 1987).

In our analyses, we compared the density of landslide types with various terrain characteristics (aspect, slope gradient, bedrock landforms) and geologic units. We used all certainty and activity classes (Fig. 7) in our analyses (that is, we did not eliminate questionable landslides). The assumption is that our screening process, field verification procedures, and knowledge of local geologic conditions have satisfactorily removed the majority of misidentified landslides. Also, the main advantage of a large database is that the small proportion of misidentified landslides is within the error limits of the large data set and will not significantly skew the data.

STUDY FINDINGS

Landslide Types

Most landslides can be accurately identified by detailed examination and interpretation of aerial photos. In the field, only 2.3 percent of presumed landslides detected on aerial photos were observed to be other geomorphic features—for example, a probable glacial cirque mistaken for a deep-seated land-

Table 1. Varnes' (1978) slope movement types. Abbreviations correspond to the column and row symbols on the Varnes (1978) classification chart. Road landslides are shallow landslides originating from road fills, sidecast, landings and cutbanks

Varnes (1978) Landslide types	Abbreviations	General landslide types used in this study
Debris slump	IIIAh	Deep-seated
Rock slump	IIIAg	Deep-seated
Slump-earthflow	VIs5	Deep-seated
Debris slide	IIIBk	Shallow[1]
Debris avalanche	VBq3	Shallow[1]
Debris torrent	VBq(t)	Shallow[1]
Debris flow[2]	VBq(f)	Shallow[1]
Rock fall, rock topple	Ia-IId2[3]	Cliff

[1]Road landslides are shallow slides originating from road landings, cutbanks, sidecasts, fill slopes, or running surfaces

[2]Debris flows and hyperconcentrated floods are included with debris torrents in the inventory

[3]Category includes Varnes' rock slide and rock block slide

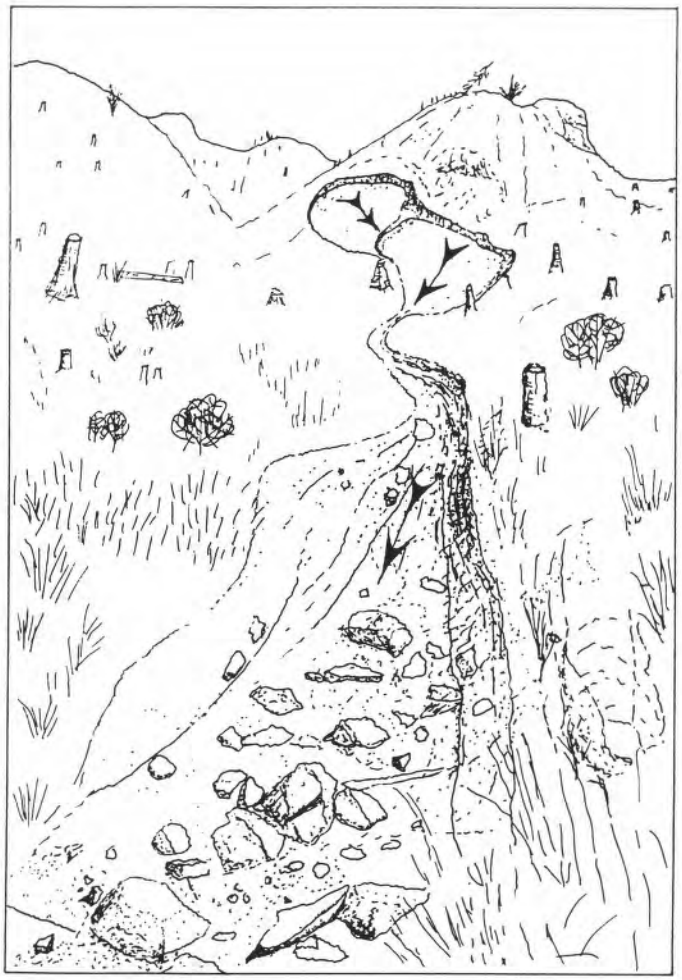


Figure 2. A debris torrent on a ridge on Storm King Mountain east of the main stem of the Tilton River. The landslide originates in colluvium below a rock outcrop and adjacent to a hollow. The soil along the fresh scarp is not thick. We observed many shallow failures in thin rocky soils. This landslide probably was initiated during the winter storms of 1990–1991, after the 1988 aerial-photo set and recent enough to have minimal revegetation.

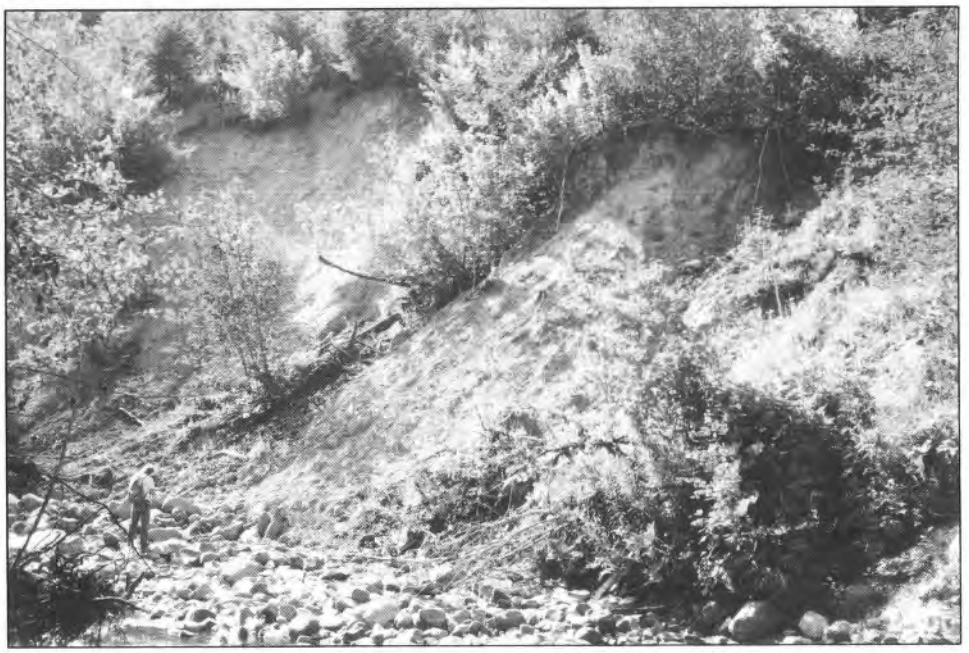
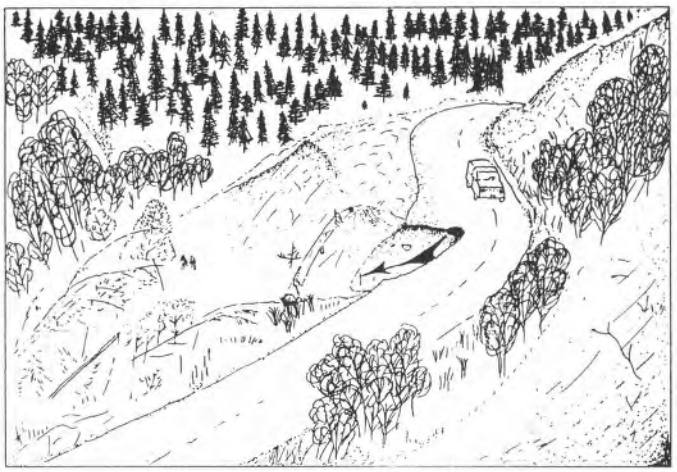


Figure 3. Shallow landslide along the East Fork Tilton River. This debris slide occurs on the toe of a debris slump, similar to that in Figure 6. Mechanically disrupted or sheared materials along toes of deep-seated landslides have lowered strength and cohesion and are subject to stream undercutting. Debris slides in this type of setting are detrimental to stream quality. Note the person (lower left) for scale.

slide. We deleted these non-landslide features from the inventory. The overall similarity of the final numbers and distribution of landslide types in the focus area (largely field-verified) and the perimeter area (chiefly mapped from aerial photos) supports our confidence in our aerial-photo interpretations.

Two methods of communicating the rates of landslide incidence in an area are by landslide numbers or by planimetric area of rupture. Our data show that old, slow-moving, deep-seated landslides, most of which are hundreds to thousands of years old, are numerically the second most common landslide type in our general study area (Fig. 7, Table 2). However, the surface of rupture (failed area) of deep-seated failures covers about 10 percent of the focus area and is the primary mass-wasting feature. The rupture area of all other failure types sum to less than 1 percent of the focus area. More important, 44 percent of the shallow landslides from roads and slopes occur *on* deep-seated landslides that cover only approximately 20 percent of the focus study area (10 percent total surface of rupture area and an estimated 10 percent total deposit area below the rupture area). These shallow landslides typically originate on scarps, flank, or toe of deep-seated failures; fewer were found on the main slide bodies.



We conclude that the increased incidence of shallow landsliding *on* large deep-seated failures results from:

(1) over-steepened soil or rocks on the scarps, flanks, and toes (Fig. 2);

(2) discontinuous macropores, disrupted drainages, closed depressions, or perched ground water which may cause positive pore-water pressure;

(3) sheared rock and soil that have lower residual strength and cohesion; and

Figure 4. Debris slide in sidecast along a tributary to Mineral Creek, probably the result of stream undercutting and seepage pressures through the road prism during the storms of 1990–1991. This failure was assigned certainty and activity categories of definite and recent, respectively, and was probably accompanied by significant surficial erosion. This type of landslide degrades stream water quality.

Figure 5. Road failure along the West Fork Tilton River caused by a blocked culvert. The blockage and resultant seepage through the road prism elevated pore pressures that led to failure of the road, probably as a debris flow with significant surficial erosion.

(4) projection of deep-seated landslide toes into streams and resultant undercutting and shallow failure of stream-side slopes.

Other factors remaining constant, the incidence of shallow *on* deep landslides should be greater as the activity of a deep-seated slide increases. However, old deep slides also contain a higher number of superimposed shallow slides, which implies that even though deep-seated failures are probably not directly triggered by forest practices, they are affected by the results of such activities (i.e., decay of root strength and (or) reduced evapotranspiration after tree harvest). The documented higher incidence of shallow failure on these landforms, combined with the sensitivity of shallow failure to tree removal, warrant caution and appropriate hazard evaluation on these common landforms.

We observed that undercutting of slopes is an important failure mechanism in the area, particularly in narrow inner gorges where streamflow is constrained by hillslopes that impinge directly on the streams (Figs. 3, 5, and 6). Removal of slope buttresses and resultant landsliding by undercutting contributed to 37 percent of the deep-seated landslides, 18 percent of the shallow landslides, and 12 percent of the road-related landslides in the focus area.

Shallow landslides from hillslopes are numerically the most common form of landslides in the study area (Fig. 7, Table 2). Shallow slides usually result from the build-up of pore-water pressure in soil mantles on steep slopes, and are thus common in hollows where ground-water convergence results in buoyant uplift on the soil particles and loss of shear strength. Soil-mantle failures in these hollows are masked by sloughing and revegetation in about 30 to 60 years. Generally, shallow hillslope and road failures that we were able to identify tend to be young (active or recent) and thus easy to identify, whereas

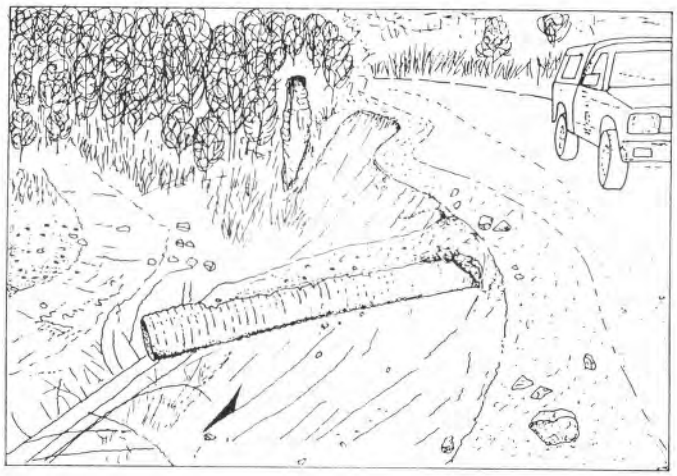


Figure 6. Deep-seated landslide (center of photo) along the East Fork Tilton River. The stream has cut into the valley-bottom till deposit and, by removing the base of the slope, has caused debris slumps along this part of the river. Notice the arcuate scarp (shadow) and well-defined gently sloped landslide head below the scarp. The scarp of this landslide is 910 ft wide, and we calculated that 1,736,000 yd^3 of material moved downslope at this site.

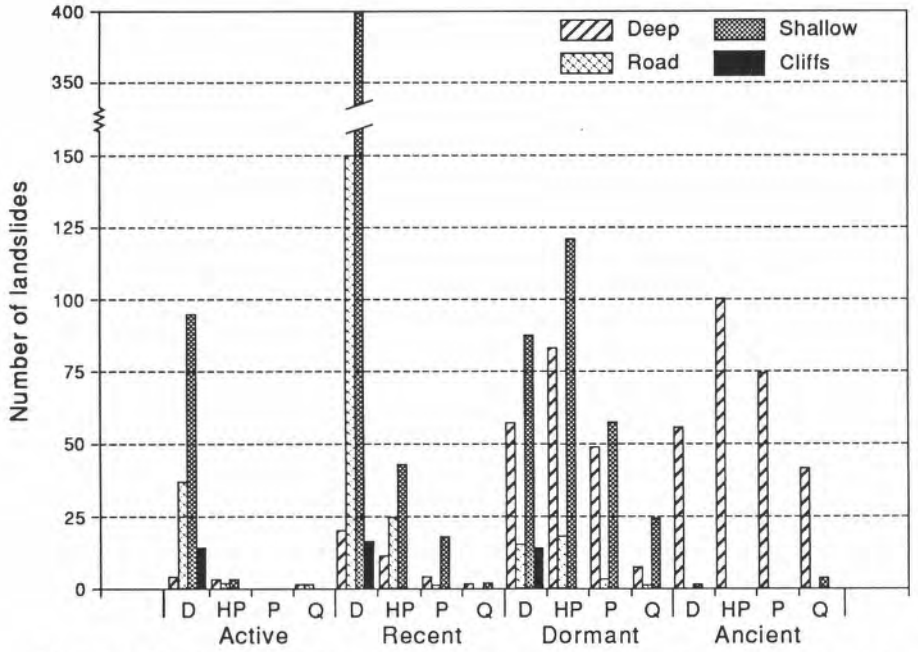


Figure 7. Numbers of landslides classified by certainty of identification and activity for the general study area. Degrees of certainty are D, definite; HP, highly probable; P, probable; and Q, questionable. The *broad* landslide categories (deep, road, shallow, and cliff) are summed from the specific landslide types (Table 1). Deep-seated landslides include rock slump, debris slump, and slump-earthflow sub-types and are summed as deep. Shallow landslides include debris slide, debris avalanche, and debris torrent sub-types, all of which are shallow soil–mantle failures typified by translational motion. Road landslides are shallow failures originating at logging or other roads. Cliff failures include rockfalls, topples, and slides from bedrock escarpments. Deep-seated landslides are dominated by the geomorphically subdued, dormant or ancient activity classes and, owing to their antiquity and erosional modification, commonly are classed as probable or questionable. Conversely, shallow landslides, owing to the short duration of recognizability, commonly are identified with higher levels of certainty (definite or highly probable).

the geomorphically persistent deep-seated failures tend to be much older (thousands of years in some cases) and less active (Fig. 7).

Most road-related landslides originated in sidecast, primarily as debris avalanches and secondarily as debris slides. Overloading and artificial steepening of slopes with sidecast and fill materials are the most significant causes of road-related landslides in the study area. Road fill, sidecast, and landing failures constituted 82 percent of the road landslides in the focus area. These may be more detrimental to water quality than cut-slope failures (18 percent of road failures) because they may more easily exit the road area, enter tributaries, become water-laden, and affect major streams.

Table 2. Landslide statistics in the focus area

Attributes	Deep	Shallow	Road	Cliff
Number of landslides	315	533	147	32
Total area (acres)	5894	130	19	43
Proportion of study area (%)	10	0.2	0.03	0.07
Total area (ft^2)	256,750,000	5,680,000	827,300	1,877,000
Minimum area (ft^2)	705	95	80	1260
Maximum area (ft^2)	25,000,000	320,500	69,160	219,000
Average area (ft^2)	815,100	10,660	5,630	58,660
Area standard deviation (ft^2)	1,623,000	32,400	10,400	57,100
Number of landslides/160 acres	0.83	1.4	0.39	0.08

Landslides and Terrain Features

Variations in microclimate due to elevation or exposure to sunlight and moisture-bearing winds can cause significant differences in geomorphic processes. We collected elevation and aspect data for each landslide in order to test the relation of these factors to landsliding. In our analyses, we grouped both elevation and aspect into convenient ranges—500 feet and 30°, respectively.

A slightly greater density of shallow failures between elevations of 1,500 and 3,000 feet is partly related to (1) the effectiveness of stream-undercutting along valley bottoms common in this elevation interval and (2) the regional rain-on-snow zone in this elevation range, which can result in increased soil pore pressures, and thus more frequent soil-mantle failure. The more uniform distribution of road-related failures with elevation suggests this failure mode is not controlled by elevation and that management history (such as road maintenance, compaction, culvert spacing) is probably of greater importance.

The aspect, or azimuth of the initial failure direction, was also ascertained for each landslide. Figure 9 shows that, except for cliffs, landslides have a higher density on slopes facing east-southeast (91–120°) and south (151–210°). Also, in the general study area and for hillslope and road-related shallow landslides combined, we observed 2.1 landslides/160 acres on south-facing slopes (91–270°) versus only 1.4 landslides/160 acres on north-facing slopes (271–90°). North-facing slopes are exposed to fewer days of freeze-thaw, retain moisture longer, and commonly have a better vegetative cover than slopes that face in other directions. These aspect-related situations can result in less active erosion. Furthermore, increased failure of southerly slopes may be related to the dominant storm direction in the Pacific Northwest. Most major rainstorms in the region approach from the south or southwest. This preferentially brings warm winds and heavier rains, which can accelerate snow-pack melt, to southwest-facing slopes and so increases pore-water pressures during rain-on-snow events.

Slope gradient is a dominant factor controlling the location of landslides. Reasonable estimates of pre-failure slope gradients can be determined by measuring slopes adjacent to landslides. Using hand-held clinometers, we measured slopes directly above landslide scarps or along landslide flanks. We also measured gradients by using the scale and rise along scarps or flanks on USGS 7.5-minute topographic maps. Seventy-six percent of slope measurements generated from topographic maps were less steep than those measured in the field (averages in Table 3) because the contour intervals used to calculate gradients on topographic maps average out the important steep slope

segments that control the location of slide initiation.

We observed that deep-seated failures generally are initiated on gentler gradients than shallow failures. Notice the lower slope ranges, averages, and modes for the deep-seated landslides in Figure 10 and Table 3. This finding agrees with those of several other studies. For example, Sidle and others (1985) generalized that slower processes, such as slumps and slump-earthflows, generally begin on gentler slopes than other failure types. In the literature, the gradients for initiation range as low as 7° for rotational slumps and 4° for earthflows. We measured deep-seated failures on slopes as gentle as 6°. However, most field-measured slopes of large, deep landslides were in the 21–45° range.

Gradients we measured adjacent to shallow and road failures support the findings of many investigators that shallow landslides are commonly initiated on slopes greater than 25° and can generally be expected on slopes greater than 35° (Table 3 and Fig. 10), especially if the soil has poor cohesion or is poorly bound to the underlying parent material. Most slopes steeper than 35° are susceptible to rapid soil movement if soil is present. The major failure peak at 36–40° for both slope and road-related slides matches observations by other workers that many slopes steeper than 35° are inherently unstable, given long spans of time. For example, the longer a steep slope is exposed to storms, the more likely it is to fail.

Landslides and Geologic Materials

Using previous map compilations and our field observations, we identified the parent material (Table 4) along the rupture surface for each landslide. The composition of the parent material (rock and unconsolidated sediments such as glacial deposits) strongly influences mechanical strength and permeability, and thus slope stability. It indirectly controls soil properties such as mineral composition, texture, particle angularity and sphericity, and permeability. For example, we document a very high incidence of landsliding on the Hayden Creek till (Fig. 11; unit Qdh*). This may be the result of several factors, including (1) the impermeability of this unit imparted by its compactness and lack of penetrative joints; (2) its valley-bottom position and resultant susceptibility to stream undercutting; (3) minimal penetration of roots into the dense till; and (4) a smooth glide surface along the soil–till interface.

Another example of the interactions of parent material and landsliding can be found in the shallow intrusive rocks of the area. Medium-grained andesitic and (particularly) rhyolitic parent materials have

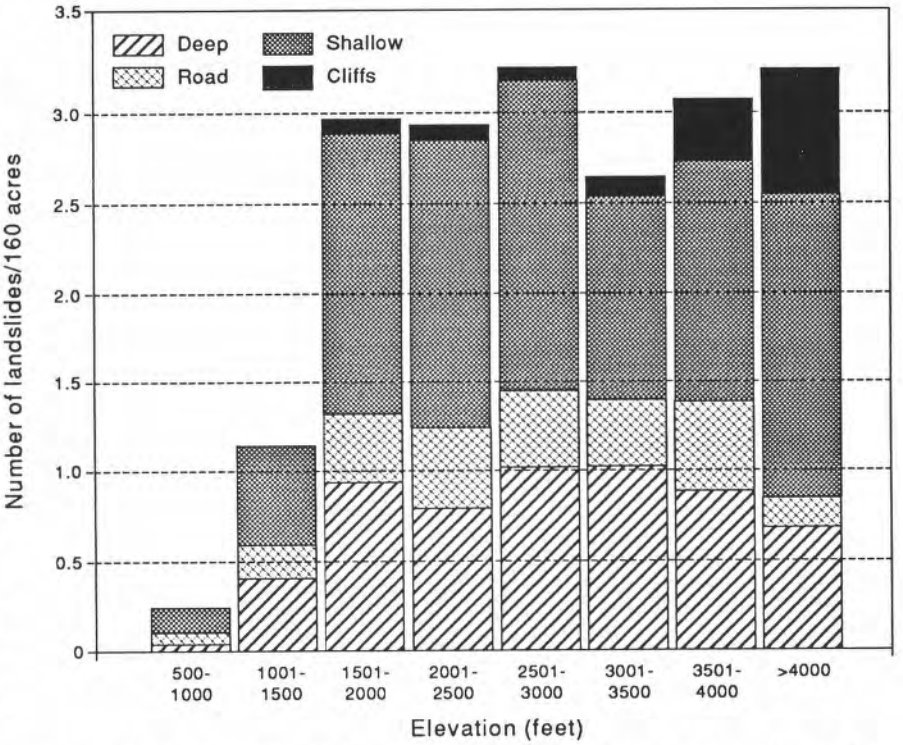


Figure 8. Numbers of landslides/160 acres by elevation. The data were normalized to landslides/160 acres using GIS. Note the overall increase in shallow hillslope and road-related landslide densities at elevations between 1,501 and 3,000 feet. These failures are triggered by brief, intense precipitation events and may be related to rain-on-snow water inputs common in this elevation range across the region. Our data show that deep-seated and cliff failures, which are largely controlled by seasonal groundwater fluctuations and freeze-thaw, respectively, are proportionally less common in the rain-on-snow zone.

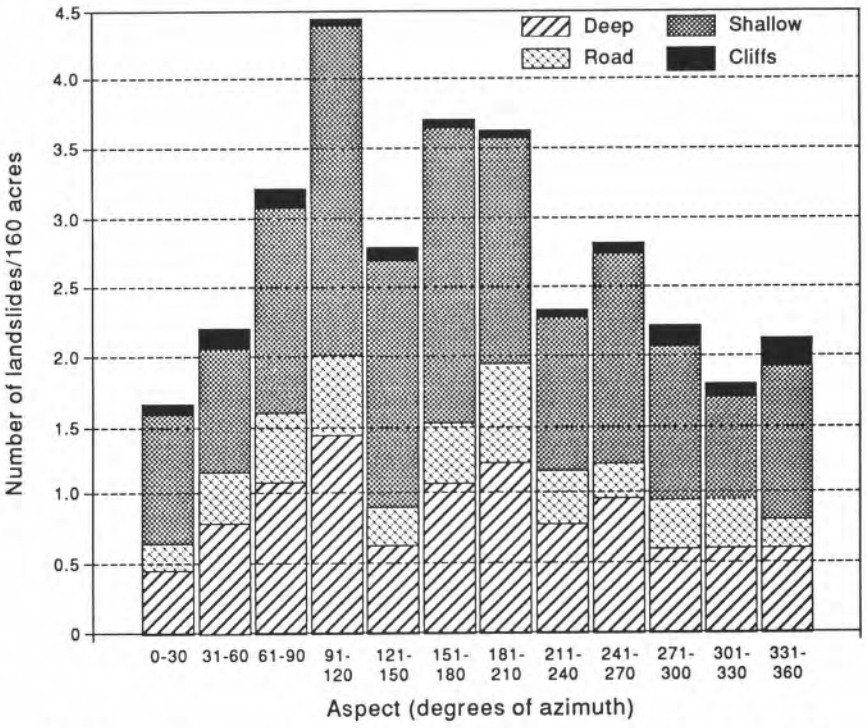


Figure 9. Numbers of landslides/160 acres by aspect. The data were normalized to landslides/160 acres using GIS. The X axis is in 30° azimuth intervals. The density of landslides on the slopes that face south (90–270°) suggests climatic control; this is the dominant direction of storm approach in the Cascades. This orientation could result in an increase in shallow landslides (shallow and road categories), which are sensitive to short-term inputs of water into the soil mantle.

fairly high quartz and low ferromagnesian mineral (biotite and hornblende) contents and a high to very high incidence of landsliding (Fig. 11; unit Ti*). Without biotite and hornblende, which weather to clay, siliceous rocks produce coarse, clay-poor soils. Such materials have low cohesion and are susceptible to shallow soil mantle failures on oversteepened (in this case glacially scoured) slopes.

"Weaker" rock interlayers exist in otherwise mostly stable geologic units. For example, overall, the continental sedimentary rocks of the Puget Group (Table 4) have a moderate landslide density (Fig. 11). However, the mechanically weak and relatively impermeable shale beds in this unit exhibit a very high landslide density. The same condition is observed for volcanic breccia or volcaniclastic lithologies within the volcanic rock units. Knowing where the weaker lithologies are improves the reliability of stability analyses. Detailed geologic mapping (approximately 1:50,000 or larger scale) is commonly required in site-specific slope-stability assessments. Using mapping that was both incomplete and at a range of scales in western Washington, Fiksdal and Brunengo (1980, 1981) observed only fair (and locally poor) correlation between landslide incidence and geologic units. DGER's open-file geologic map compilations at 1:100,000 currently provide the most complete coverage.

Landslides and Geologic Structures

Landslides are controlled by geologic structures (such as joints and bedding) as well as by materials. Rock layers have various compositions, permeabilities, and degrees of alteration. Bed contacts, as well as joints, serve as boundaries to subsurface water movement or restrict penetration and development of root systems. They are typically discontinuities in strength, therefore potential failure surfaces.

Folding of rocks creates dip and scarp slopes. The control that these slopes have over location of landsliding is indicated by the fact that a little more than half of shallow failures in the focus study area occur on dip slopes and scarp slopes. Master joint sets in folded rocks commonly parallel fold axes. Joints influence landsliding in the same way as bedding—by serving as physical discontinuities. We also found a high incidence of landslides along mapped faults.

For each landslide, we differentiated dip-slope, scarp-slope and cross-slope failure types (Fig. 12). Dip slopes are parallel to bedding and can allow soil or rock layers to slide down-slope along bedding planes. Scarp slopes are roughly perpendicular to dip slopes; bedding dips into the slope, and failures cut across bedding, typically along joints. Cross slopes are defined as those slopes that are oblique to both dip slopes and scarp slopes.

The planimetric areas of dip, scarp, and cross slopes were not measured, so the numbers for these landforms could not be normalized into landslide densities. However, as the more general case, cross slopes may represent a higher proportion of the area. We found that cross-slope failures are indeed the more common failure type for all rock and landslide types (Figs. 12 and 13). Cross-slope failures are probably controlled more by joints than by bedding planes, emphasizing the importance of joints to slope stability.

Table 3. Landslide slope measurement statistics. MG, map-generated slope measurements; FG, field-generated slope measurements. Dominant range is the interval containing the majority of measurements in Figure 7. Mode is the most common slope range (not a single value)

Landslide type/ data type	Slope (degrees)					
	Avg.	Mode	Dominant range	Std. dev.	Max.	Min.
Deep/MG	28.3	26–30	16–45	8.6	75	8.0
Deep/FG	33.0	36–40	11–55	8.6	52	15.0
Shallow/MG	34.2	36–40	21–50	10.3	67	6.0
Shallow/FG	44.4	41–45	26–55	7.3	70	20.0
Road/MG	35.0	36–40	21–45	9.2	58	12.0
Road/FG	40.9	36–40	31–50	5.0	57	30.0

The significant role of bedding permeability and strength anisotropy along dip slopes is implied by (1) the number of dip-slope failures (Fig. 13), (2) the likelihood that the total area of dip slopes is relatively small and thus landslide density is probably high on these landforms, and (3) the multitude and importance of slope factors that are unrelated to slope type or bedding orientation. These factors taken together indicate that the incidence of dip-slope failures is significant in the study area, and that dip slopes are inherently less stable under many circumstances. Comparison of rock type to slope type

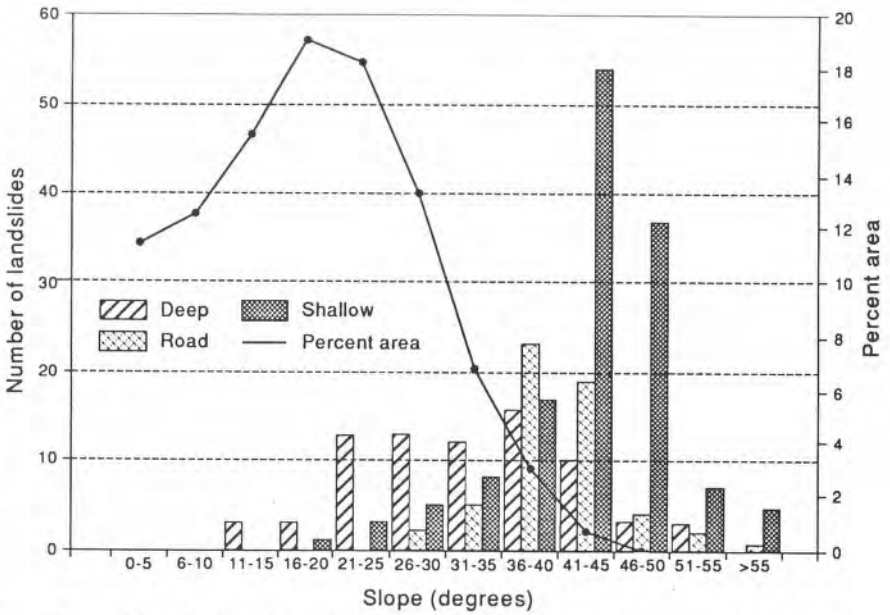


Figure 10. Number of landslides by type per category of field measured slope (in 5° classes) compared with percent of the study area for each slope category. The number of landslides can be approximately normalized by noting the percent area (black line) obtained by GIS for each slope class in the general study area. (Note the axis on the right.) The GIS-generated slope ranges show that areas of slope classes decrease significantly on slopes steeper than 25°. Hillslope and road-related shallow landslides are typically initiated at slopes steeper than 26° (50 percent grade) and are very common on slopes greater than 35°. The reduced area of slopes greater than 25° demonstrates that steep slopes have higher landslide densities because of the increasing incidence of landsliding. Deep-seated landslides are observed on slopes as gentle as 11° and are generally initiated on gentler slopes than are shallow failures. The lack of slope class percent area (black line) for slopes steeper than 50° is a side effect of the way GIS measures slopes, i.e., the areas occupied by these steep slopes is so small that they are not accurately recorded by GIS at this scale.

Table 4. Rock units in the pilot study area. Units whose symbols begin with Q are of Quaternary age (1.6 million years old or younger); those beginning with T are of Tertiary age (1.6 to 67 million years old)

Unit	Lithologic description	Unit	Lithologic description
Qal	Alluvium	Toh	Ohanapecosh Formation: andesitic to basaltic breccias, conglomerates, (volcaniclastic) sandstones, and lava flows (including rare dacitic to rhyolitic compositions), locally interbedded with shale
Qls	Landslides, including the scarp, main body and deposit (as compiled by Schasse, 1987), on the geologic map of the Centralia 1:100,000 quadrangle)	Tva	Basaltic andesite and andesite flows, with lesser dacite flows, flow breccia, and thin, rare interbeds of shale, tuff, volcanic sandstone, and conglomerate
Qoe	Evans Creek outwash deposits	Tvc	Volcaniclastic lapilli and ash-pumice lithic tuff, volcanic sandstone and conglomerate, or breccia, interbedded locally with unit Tva basaltic andesite and andesite flows
Qdh	Hayden Creek drift, undivided	Tno	Northcraft Formation: basaltic andesite, andesite, basalt, with sills and interbedded flow breccia
Qdht	Hayden Creek till	Tva_0	Andesite and basalt flows, with minor interbedded volcanic breccia
Qdw	Wingate Hill drift, undifferentiated	Tpg	Puget Group: continental feldspathic sandstone interbedded with siltstone, shale, claystone, and coal; locally interbedded with lava flows, tuffs, volcaniclastic breccias, pebble conglomerates, and brackish-water deposits
Tva_3	Andesite flows, with subordinate breccia		
Tvb_3	Basalt flows, locally with tuff, lahars, and minor sedimentary rocks		
Tir	Rhyolite dike (Kiona Creek area)		
Tidi	Diorite dikes, sills, or plugs		
Tid	Dacite dikes, sills, or plugs		
Tia	Andesite dikes, sills, or plugs; andesite grades locally into andesite porphyry and diorite		
Tva_2	Andesite flows, with minor interbedded volcaniclastic breccia and conglomerate (Kiona Creek area)		

shows a slightly higher incidence of landsliding along bedding planes in the strongly bedded rock types, such as the Puget Group.

Part 2 of this article will appear in the next issue. It will discuss soils and timber-harvest history and their effect on slope stability in the study area. We will also summarize the study's conclusions.

ACKNOWLEDGMENTS

We thank field assistants Bryn Thoms and Kim Farley, cartographers Carl Harris, Jeanne Carlton, Nancy Eberle, Stu Smith, Liz Thompson, Dale Roberts, and Keith Ikerd, and geologists Tim Walsh, Josh Logan, Hank Schasse, Pat Pringle, Bill Lingley, Eric Schuster, and Dave Norman for their help with this project.

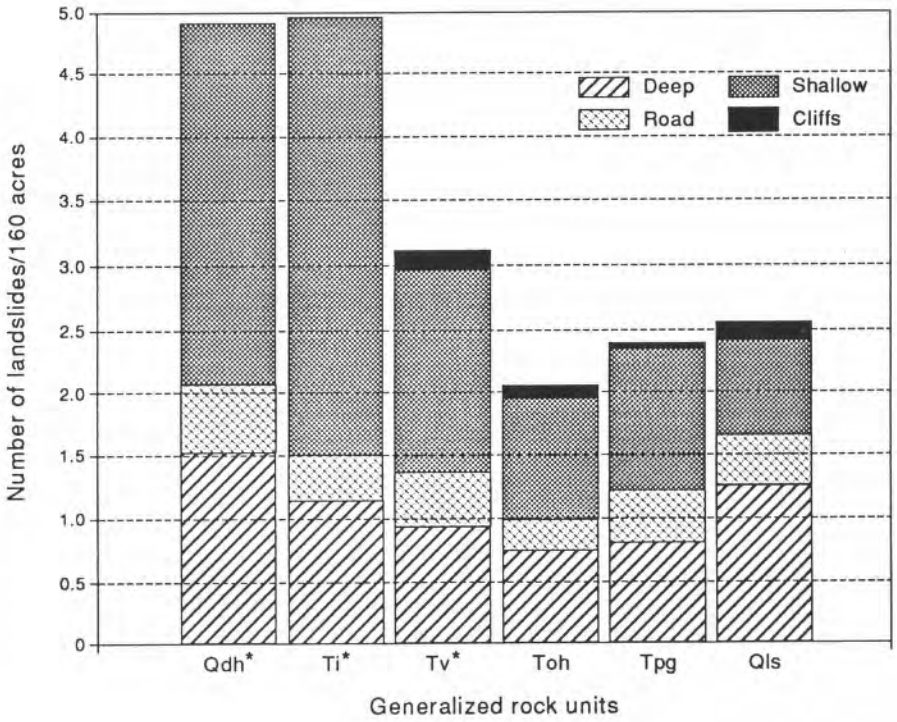


Figure 11. Number of landslides/160 acres for generalized rock units in the focus study area. Generalized rock units are groupings based on lithologies of the units given in Table 4. In this figure, Qdh* represents units Qdht and Qdh; Ti* represents units Tir, Tidi, Tia, and Tid; Tv* represents Tva, Tva_0, Tva_2, Tva_3, Tvc, and Tvb_3. Toh, Tpg, and Qls represent these single units. Qoe, Qdw, and Tno are not shown here because either there are no landslides recorded on these units or they represent a very small part of the study area. We observed a background value of about 2.5 landslides/160 acres for most units. Units most susceptible to landsliding are Hayden Creek till (unit Qdht) and Tertiary intrusive rhyolite (unit Tir). The lack of jointing, low permeability, and susceptibility to stream undercutting cause Qdht to readily perch water and to fail by shallow landsliding. The high quartz and low ferromagnesian mineral content in Tir (and to a lesser extent in unit Tia) result in coarse clay-poor soils. These soil have low cohesion and are more susceptible to shallow failure.

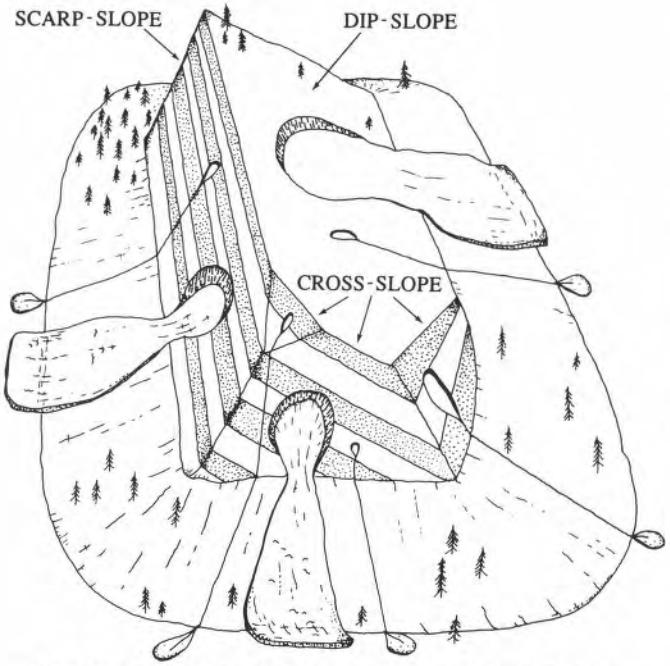


Figure 12. Diagram showing slope types relative to bedding orientation.

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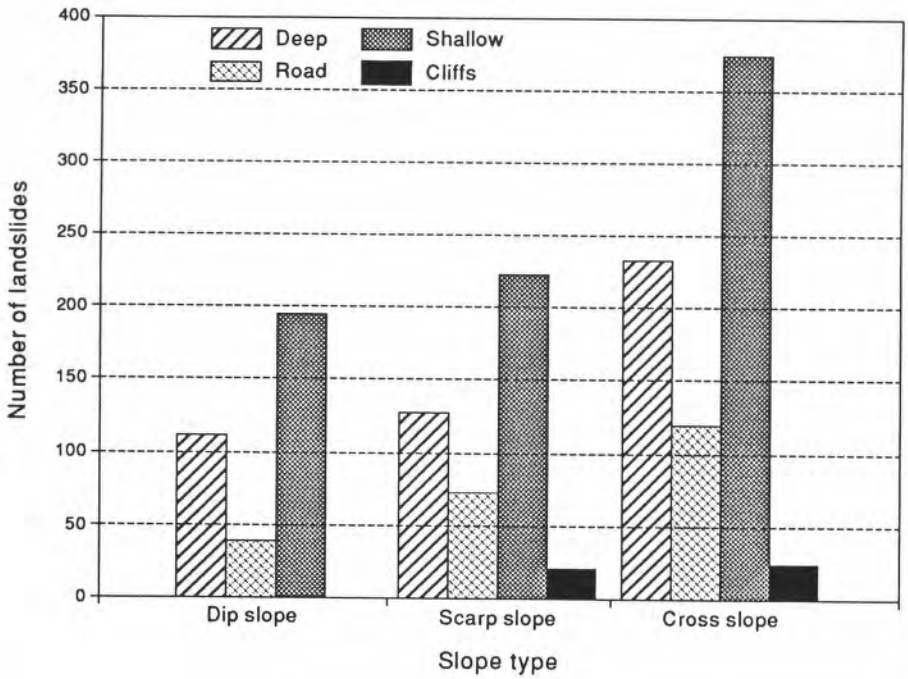

Figure 13. Numbers of landslides versus slope types for the general study area. Dip-slope failures are commonly attributed to mechanical or hydrologic inhomogeneities in strongly bedded or foliated rocks. Scarp slopes generally parallel a master joint set that is systematically related to fold axes. The specific slip-plane geometry of dip-slope landslides contrasts with the many slip planes possible in scarp- and cross-slope landslides. Dip slopes are less common than the more general scarp and cross slopes, but the density of landslides on these slopes is relatively greater. Rock units in which bedding is moderately to well developed fail on dip slopes more commonly than do massive to poorly bedded intrusive or volcanic rock units. Shallow landslides are slightly more sensitive to bedrock structures (such as bedding and joints) than are road-related or deep-seated landslides; note the slightly lower proportion of cross-slope shallow landslides. We infer that road failures are least sensitive to bedding orientation inhomogeneities because there is a high proportion (51.7%) of road cross-slope failures and low proportion of dip-slope failures in the general area. Road failures are more directly related to road material and construction techniques.

Seismology Resources for Teachers

Help for science teachers (K–12) whose curriculum includes earthquakes, earthquake preparedness, and related earth science topics is available from the Seismological Society of America. Resources listed include reference information (books, pamphlets, scientific papers), videotapes, computer hardware and software, and databases. For a copy of "Seismology: Resources for Teachers", send a self-addressed, stamped envelope to SSA, 201 Plaza Professional Building, El Cerrito, CA 94530-4003.

Foreign Minerals

The United States depends on foreign sources for 50 percent or more of 23 strategic and critical minerals. We import all of our arsenic, bauxite and alumina, columbium, graphite, manganese, mica, strontium, and thallium. In addition, 90 percent or more of gemstones, asbestos, platinum-group metals, and industrial diamonds come from other countries. Reduced production in the U.S. of vital minerals increases dependence on off-shore sources.

From U.S. Bureau of Mines

Tri-State Agreement on Mining

by David K. Norman

Officials of Washington, Idaho, and Oregon signed an agreement in 1993 to share technical information about mine regulation and training opportunities. The Washington Department of Natural Resources, Division of Geology and Earth Resources received a 2-year, $70,000 grant from the U.S. Environmental Protection Agency to fund this agreement; Idaho and Oregon received similar amounts. Ultimately this agreement will lead to wiser resource development and protection.

Mine regulators in these three states now face more complex issues than in the past, and in order to be effective, they must keep abreast of the latest technology. Earlier this year, a team of regulators, represented mainly by Allen Throop (Oregon), Bruce Schuld and Jerry West (Idaho), and David Norman (Washington), visited several mines in Washington, British Columbia, and Idaho. The emphasis of their investigation was on water quality, chemical mining methods, and reclamation techniques at recently reclaimed and operating mines. A short summary of visits follows.

Asamera Minerals Inc.'s Cannon Mine

During their visits in Washington, the team observed underground operations, tailings impoundments, and surface reclamation at the Cannon gold mine in Wenatchee. The mine, operated by Asamera Minerals Inc., uses a flotation method to concentrate gold. Concentrated ore is shipped to Japan for smelting. Asamera is nearing completion of mining and has finished earth work on some of the upper roads (Fig. 1), drainages, and pits (Fig 2).

Underground stopes are backfilled with concrete made with locally mined sand and gravel, and ore is then removed from the adjacent stope. This method allows for more recovery of ore and eliminates subsidence.

The tailings are too finely ground to be used as backfill, so they must be handled in an impoundment that was constructed across the valley. The impoundment has no synthetic geotextile liner placed below the tailings impoundment, but natural clays below the dam act as a liner and have very low permeability. Four wells in the valley below the impoundment are used for water quality monitoring. The well that is being used to determine the background quality of water entering the tailings impoundment is upstream of the facility, and the elevation of the well bottom is higher than the final maximum elevation of tailings.

Battle Mountain Gold's Crown Jewel Project

Battle Mountain Gold (BMG) proposes to develop an open-pit gold mine on Buckhorn Mountain near Chesaw in north-central Washington. BMG plans to treat the ore with a vat cyanide leach process that uses a carbon recovery system and an International Nickel Company (INCO) patented sulfur dioxide (SO_2) cyanide destruction process. The BMG's proposal calls for a tailings impoundment lined with clays compacted to a at very low permeability (10^{-6} cm/sec or less) and synthetic geomembrane liners. Nine ground-water monitoring wells and 17 surface-water monitoring sites and water from four adits are being used to gather baseline data for the environmental impact statement that is being prepared.

Homestake Mining Co.'s Nickel Plate Mine

The tri-state group visited the Nickel Plate mine in southern British Columbia because it is geologically similar to the proposed Crown Jewel Project. It uses ore processing techniques like those proposed for the Crown Jewel, as well as the INCO SO_2 cyanide destruction method. However, due to the nature of the ore deposit at Nickel Plate, several open pits have been mined rather than one large pit as proposed for the Crown Jewel Project. Homestake backfills mined-out pits with waste rock, which necessitates leaving the last pit as a series of benches and highwalls. In contrast, requirements in the state of Washington call for benches and highwalls to be selectively blasted to form scree slopes and a natural appearance.

Waste-rock dump slopes at the Nickel Plate mine are generally 3 feet horizontal for each 1 foot vertical (or 3:1); there is a maximum height of 80 feet between terraces or breaks in slope on the dumps. Topsoil is placed on waste-rock slopes that are gentler than 3:1 to speed revegetation. Clays and silts salvaged from nearby glacial till supplement these soils. Crested wheat, rye, and clovers are the first ground cover plantings used here to stabilize the soils on dump slopes. The mine reclamationist plans to plant more native species as revegetation proceeds.

The tailings impoundment is dammed but unlined, and leakage through the underlying glacial till has been a problem. Homestake installed collection trenches and a buried collection piping system about 3 ft below the level of the adjacent Canty Creek and between the creek and the tailings impoundment. The system appears to be effectively retrieving cyanide, which is then pumped back to the tailings impoundment.

Figure 1. Road reclamation in progress at the Cannon mine. These slopes have been reshaped to match the local natural slopes. Seeding is done at first planting season after reshaping to minimize erosion.

Kinross Gold Inc.'s DeLamar mine

On May 26, the tri-state group visited the DeLamar gold and silver mine in southern Idaho. This mine, which consists of several pits, uses an agitated cyanide leach process to recover gold and silver. Historically, the high cyanide content in the tailings impoundment presented a danger to water quality and wildlife. The DeLamar mine recently built the first AVR (Acidification-Volatilization-Reneutralization) system in the U.S. to address their cyanide problem. This method recovers 183 lb/hr or 90+ percent of the excess cyanide, which is recycled for use rather than destroyed.

Figure 2. Reclaimed segments in the foreground have abundant new grass growth. DNR reclamation inspector Jack Powell (SE Region) talks to Reese Hastings of Asamera Minerals Inc. about reclamation of the upper pit, in the distance. Earth work on this pit is nearly complete, and revegetation will follow.

Acid water draining from old waste rock in Sullivan Gulch (a quarter mile southwest) of the DeLamar mine is currently being pumped back to the tailings impoundment as a short-term measure to control water-quality problems. Proposed long-term solutions include capping the waste to prevent infiltration of water or re-mining the waste rock.

The previous operating company, NERCO/DeLamar, improved water quality from one old adit, known as the 16 level adit, from which acidic water with high metal content was draining. The low pH and metals were degrading the water quality of Jordan Creek. Discharge from the adit is now being pumped to the tailings pond; this is a short-term solution to this problem. The effect on the tailings impoundment itself is being studied. Possible long-term solutions include blocking the adit and thereby preventing oxygen from reaching the system or trying to eliminate water from the underground workings.

To reduce handling costs and to improve reclamation, waste rock is being used to backfill some mined-out areas. Other reclamation at the site includes converting a clay borrow pit and numerous storm-water control ponds to wetlands.

Coeur d'Alene Mining Co.'s Thunder Mountain, Hecla Mining Co.'s Yellow Pine, and MinVen's Stibnite mines

On August 11–13, the team visited central Idaho to look at operating and reclaimed gravel and metal mines.

Because it is on patented claim land, the Coeur d'Alene Thunder Mountain gold mine, at an elevation of about 8,000 ft, was excluded from the surrounding "Frank Church River of No Return Wilderness Area". The site was mined in the mid-1980s. The earth-moving phase of reclamation was completed by 1991. Coeur d'Alene reshaped most of the open pits, the cyanide heap leach processing area, and the waste dumps. Revegetation is slowly becoming established. Lodgepole pines are doing well despite 2 years of drought, and grasses were doing fairly well, although disturbed areas are not yet fully covered.

This site shows the classic contrast between angle-of-repose waste dumps (approximately 1.5:1) and dumps whose slopes are at 3:1 or flatter. No vegetation was growing on the steep waste-rock dump slopes, which were failing, while gentler slopes appeared stable and sustained sparse vegetation.

Detoxified spent ore was removed from the cyanide heap leach pad and used to backfill pits. Upon completion of mining, all buildings were removed and aesthetically acceptable landforms were created (Fig. 3) and covered with growth media. Some coarse rock and logs were spread for habitat diversity and microclimate enhancement.

Thirteen monitoring wells were drilled around the processing area, three up-drainage and ten down-drainage. Numerous surface-water sites are being monitored. No cyanide has been detected in the ground water. Although one surface-

Figure 3. Reclaimed pit at Coeur d'Alene Mining Co.'s Thunder Mountain mine. Pit walls have been worked into sinuous contours and rolling topography. Newly planted vegetation has endured 2 years of drought. Lodgepole, which were severely stressed, show excellent recovery and growth after heavy winter snows and a wet summer. Grasses, still sparse, continue to provide seeds and spread.

water test detected cyanide, a re-test failed to repeat the find and the source was not determined.

Successes at this site include the ponds created by shaping the topography to trap snow drifts and the notable lack of highwalls in reclaimed open pits. Elk and deer are already grazing on this site.

Other mines visited in Idaho were MinVen's Stibnite mine and Hecla Mining Co.'s Yellow Pine mine. Hecla has completed mining and begun reclamation. The cyanide heap leach pad, stream, and ponds remain to be reclaimed. Hecla has sloped the waste rock dumps to about 3:1 to 4:1. Vegetation is doing well, and slopes appeared to be stable. The open pit has been partially reclaimed, but because the neighboring MinVen mine is still operating, Hecla can do no further reclamation.

Hecla applied state-of-the-art bioneutralization techniques to destroy cyanide and nitrate in their heap leach pad. This process involves the cultivation and introduction of microorganisms that actually thrive on free cyanide and most of the cyanide compounds found in the heap leach chemical environment.

The DeLamar, Thunder Mountain, and Yellow Pine mines all won awards for their outstanding reclamation efforts, which were above and beyond Idaho requirements. The awards were presented last summer by the Idaho Mining Advisory Committee and Idaho Governor Cecil Andrus at a luncheon held in honor of progressive mining companies.

Future work

Rebecca Christie and David Norman are preparing a bibliography of literature about reclamation of metal mines. A rough draft has been sent to interested parties for review. Bruce Schuld of Idaho's Department of Environmental Quality is developing a rapid bio-assay test to speed up water-quality testing and evaluate impacts. Future investigations will focus on mines in the Republic and Holden areas in Washington. ■

Information Available for Regulated Activities

Governor Mike Lowry recently issued Executive Order #93-06 on Improving State Regulatory Activities. The Division of Geology and Earth Resources regulates surface-mine reclamation, oil and gas exploration, geothermal exploration, and underground gas storage in Washington. To assist state and local governments, businesses, and private citizens in understanding the regulations and in fulfilling their regulatory obligations, the Division provides a wealth of articles and handouts.

Since passage of the amendments to the Surface Mining Act, the Division has prepared new forms and guidelines, which we hope will be easier to understand, to assist applicants for reclamation permits in preparing the detailed reclamation plans that are required by law.

Information on regulated activities that is available from the Olympia office is given below:

Articles in *Washington Geology*

- Building and decorative stone production in Washington, by Charles W. Gulick. 1992, v. 20, no. 2, p. 3-11.
- Industrial minerals in Washington—Production and potential, by Nancy L. Joseph. 1990, v. 18, no. 4, p. 8-16.
- Reclamation of quarries, by David K. Norman. 1992, v. 20, no. 4, p. 3-9.
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- Sand and gravel, quarried rock, and industrial minerals, by Charles W. Gulick and William S. Lingley, Jr. 1993, v. 21, no. 1, p. 25-30.
- Surface mining and surface mining law in Washington, by William S. Lingley, Jr., and David K. Norman. 1991, v. 19, no. 4, p. 38-48.
- Washington's mineral industry—1992, by Robert E. Derkey, Charles W. Gulick, and William S. Lingley, Jr. 1993, v. 21, no. 1, p. 3-4.

Information Circulars

- Directory of Washington mining operations, 1992, by William S. Lingley, Jr. and Connie J. Manson. 1992, IC 87, 76 p. $2.30 + .20 = $2.50.
- Oil and gas exploration in Washington, 1900–1982, by C. R. McFarland. 1983, IC 75, 43 oil and gas test well maps, 119 p. $2.30 + .20 = $2.50.

Open File Reports

- Surface mining in Washington—Some regulatory responsibilities of various federal, state and local government agencies, 1992, by David K. Norman, compiler. OFR 92-5, 22 p.

County Bibliographies

Bibliographies of the geology and mineral resources of selected counties (listed below) have been prepared in support of the Growth Management Act and updated through 1992. These are available free as paper copies or on disk. To order disk copies, please note the number of kilobytes in the files desired (indicated below) and send us the appropriate number of formatted 3.5-in. or 5.25-in. disks. Specify whether you want the file in WordPerfect 5.0 or 5.1 or ASCII. ASCII file users may wish to order a paper copy of each file; these copies will show text formatting lost in the conversion to ASCII. We will copy the requested files and return the disks to you.

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Walla Walla County (40K)
Whatcom County (202K)
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Continued on Page 27

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June 1 through September 30, 1993

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Russian Geologists to Speak at Northwest Mining Convention

For decades, world leaders and people in the mining industry have speculated about the purported endless supply of minerals that lay hidden in the former Soviet Union. Some of the mystery surrounding Russian mineral resources will be lifted this December in Spokane, WA, at the 99th annual meeting of the Northwest Mining Association.

A half-dozen experts from throughout Russia will share their knowledge of Russian geology and related mineral sciences at the NWMA short course "Global Business Opportunities—Examining the Differences" from Nov. 28–30 and the NWMA convention "International Mining—Pros and Cons" from Nov. 30–Dec. 3.

The Russian experts include Dr. Anatoly Siderov and Dr. Leonid Parfenov of the Russian Academy of Sciences who will discuss opportunities and problems for joint mining ventures in the Russian northeast and northern Siberia.

Parfenov, who is chief for the Laboratory on Regional Geology and Tectonics at Yakutsk in northern Siberia, will also open the convention as the luncheon speaker on December 1. His address will be "The Life of a Russian Geologist in Siberia". Before his appointment to Siberia about 10 years ago, he was chief of a similar laboratory at the Institute of Tectonics and Geophysics at Khabarovsk in the central Russian Far East.

Other Russian scientists will discuss the geology and minerals of their country on December 2 and 3. ■

Northwest Mining Association

CONVENTION, SHORT COURSES, AND TRADE SHOW

Spokane, November 28–December 3, 1993

Convention (Nov. 30–Dec. 3)

The theme of the convention is "International Mining—Pros and Cons". Development, discoveries, and opportunities in the Americas and the former Soviet Union will be examined.

Trade Show (Dec. 1–3)

The trade show will again have 300 or more displays of products and services available to the minerals industry.

Short Courses (Nov. 28–30)

- **Global Business Opportunities—Examining the Differences.** Regions to be emphasized are Russia, the Pacific Rim, Latin America, and Asia. Topics will include an overview of mineral districts and their relative importance on the world scene, financing, legal considerations, environmental protection requirements and attitudes, and awareness of how local customs and culture affect business practices.
- **Applied Biogeochemical Prospecting in Forested Terrain.** Course will cover basic principles of biochemical prospecting and lead participants through to "state-of-the-art" knowledge, leaning heavily on the instructors' experience in the Pacific Northwest, British Columbia, and the boreal forests of Canada.

For More Information

Contact the Northwest Mining Association, 10 N. Post, Suite 414, Spokane, WA 99201-0772. Phone: 509/624-1158; Fax: 509/623-1241

Prospectors & Developers Association of Canada

INTERNATIONAL CONVENTION AND TRADE SHOW

Toronto, March 5–9, 1994

PDAC Convention 94 will offer the latest information and news on investment, business, and technological aspects of worldwide mineral exploration and development. Three days of technical sessions, a one-day short course, a special session for adjudicated papers, a trade show with over 200 exhibitors, and social events will provide an excellent opportunity for delegates to learn, inform, and update their knowledge on the mineral industry in Canada and abroad.

Technical Program

The technical program is under development and areas already defined include papers, presented by leading experts, on:

- Alternative methods of financing exploration projects
- The global search for diamonds and the economics of diamond mining
- Gold projects in developing countries
- International discoveries and developments

There will be a strong focus on international exploration and development in special sessions where government or industry representatives will be able to discuss investment opportunities and the state of the mineral industry in their home county.

Short Course

A full-day short course on Saturday, March 5, entitled "Prospecting in Tropical Terrains", will take a close look at the unique geological, technical, and social aspects to be considered in any exploration program undertaken in tropical and subtropical countries.

Call for Papers

The Open Forum is a special session of adjudicated papers that runs parallel to the main technical program. Typically, the forum covers a wide variety of exploration- and development-related topics, including financing, geophysical and geochemical techniques, deposit descriptions, case histories, application of new technologies, geological potential of various countries, and software applications. Please send an abstract of no more than 200 words by January 7, 1994, to Mrs. Saley Lawton in the PDAC office.

Mine Tours

There are tentative plans to offer delegates the opportunity to visit world-class mining operations located in the Canadian Archean Shield, including:

- Hemlo gold camp
- Sudbury nickel and copper mines
- Timmins base metal and gold operations
- Base and precious metal mines in the Quebec Abitibi area
- Industrial mineral, dimension stone, and aggregate operations

For More Information

Contact PDAC, Suite 1002, 74 Victoria Street, Toronto, ON, Canada, M5C 2A5. Phone: 416/362-1969; Fax: 416/362-0101.

REGULATORY INFORMATION

Continued from page 21

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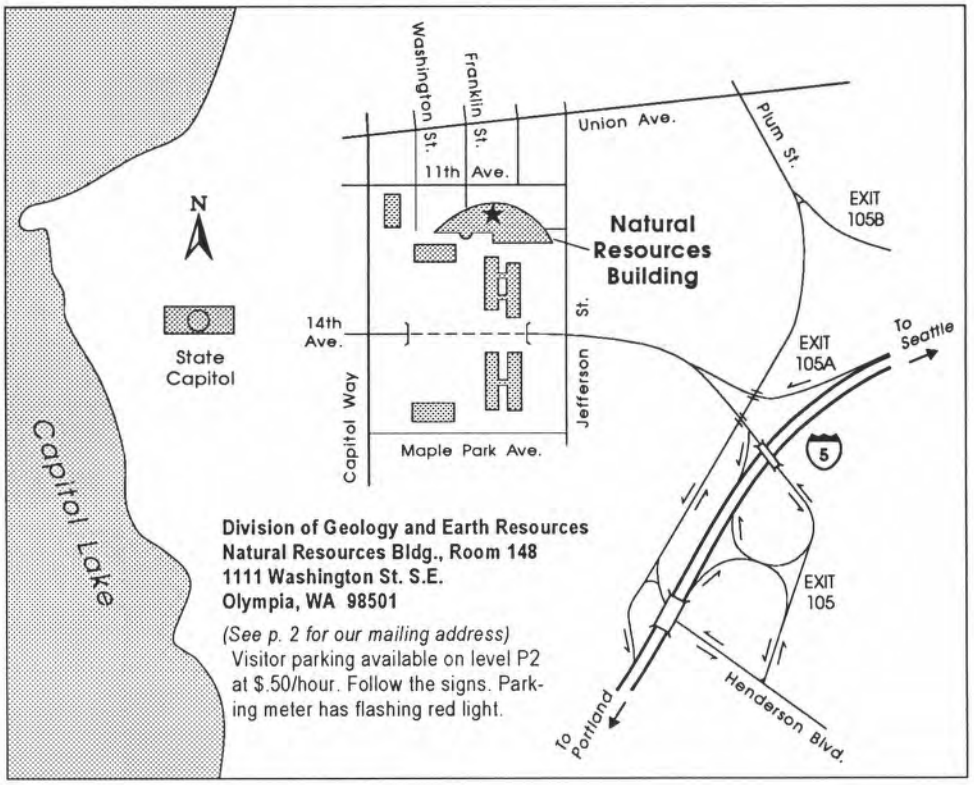

Winners Named in SME "Outstanding Student Paper Contest"

The North Pacific Section of the Society of Mining Engineers distributed awards to winners of the section's Outstanding Student Paper Contest at its monthly meeting in May. Lynne Holland, Western Washington University, won first place in the Graduate Division for her paper titled "Fourier transform infrared spectroscopy quantitative analysis of leached cappings over porphyry copper deposits"; she received a $400 scholarship. Richard Chaney, also of Western Washington University, won second place in the Graduate Division for his paper, "A study of gold mineralization at the Boundary Red Mountain mine, Whatcom County, Washington" and received a $300 scholarship.

First place winner in the Undergraduate Division was Michelle Robinson, University of British Columbia; her paper is titled "Genesis of the Blende carbonate-hosted Zn-Pb-Ag deposit, north-central Yukon Territory—Geologic, fluid inclusion, and isotopic constraints". She won a $400 scholarship.

Sponsors of the contest were Golder Associates, Inc., of Redmond, WA; Ingersoll Rand, Hart-Crowser, and CH2M Hill, all of Seattle, WA; Bondar Clegg of Vancouver, BC; Robbins Company of Kent, WA; ASARCO of Tacoma, WA; and Corkey Smith, Jr., of Bellingham, WA.

DGER Staff Changes

STAFF TRANSFERS

Venice Goetz (Geologist 2) has transferred to the Division of Forest Practices and has been promoted to Natural Resource Scientist 2. She will be doing watershed analysis and slope stability assessment for timber harvest.

Rex Hapala (Research Technician) has transferred to the Southwest Region, based in Castle Rock, and has been promoted to Geologist 2. He will be working as a surface mine reclamation inspector.

Naomi "Nonie" Hall (Clerk Typist 3) has transferred to the Division of Forest Land Management.

Shelley Reisher (Clerk Typist 2) is now a Fiscal Technician for the Division of Aquatic Lands.

Joan Castaneda (Clerk Typist 2) has also transferred to the Division of Aquatic Lands.

NEW STAFF

Angela Stanton (Clerk Typist 3) is a transfer from the Northwest Region in Sedro-Woolley, where she worked for six years with the surface mining, service forestry, and forest practices programs. Before that she was at the Southeast Region in Ellensburg for four years—two in Lands and two in the Radio Room. Angela plans to continue working toward a degree in business administration.

Karin Lang (Clerk Typist 2) is another new addition to our staff. Her early work experience is as a photographer. For the last three years, since her arrival in Olympia, she has spent the summers as a PBX Operator with the Division of Fire Control and the winters as a staff photographer for the State Legislature. She is also a published poet. Karin plans to continue working toward a degree at Puget Sound Community College.

Division Publications

Geologic maps of part of the Yakima Fold Belt, northeastern Yakima County, Washington, Open File Report 93-3, by Robert D. Bentley, Newell P. Campbell, and John E. Powell. Contains maps of the Yakima East, Harrah, Toppenish, and Granger 15-minute quadrangles, scale 1:31,680, and a set of associated cross sections. 5 folded sheets and a 13-page pamphlet that includes a table of major element analyses of basalts in the area. $8.33 + .67 tax (WA residents only) = $9.00

Roadside geology of Mount St. Helens National Volcanic Monument and vicinity, Information Circular 88, by Patrick T. Pringle has gone into its second printing! This 120-page book explains the geologic history of the Mount St. Helens area and provides mile-by-mile geologic road guides for seven routes of approach to the mountain. A geologic primer and glossary are included. (It is also available at Mount St. Helens National Volcanic Monument visitor centers.) $3.24 + .26 tax (WA residents only) = $3.50.

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DGER Spokane Field Office Has Moved

The Division of Geology and Earth Resources Spokane Field Office has moved to the old Post Office Building in downtown Spokane. Bob Derkey and Chuck Gulick are now in Room 209 on the same floor as the USGS geologists.

The new address is:

Department of Natural Resources
Division of Geology and Earth Resources
904 W. Riverside, Room 209
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Publications of the Association of American State Geologists

The State Geological Surveys, A History, Arthur Socolow, editor. Published in 1988, this compendium of historical records, anecdotes, and photographs for each state survey costs $20.

The State Geologists Journal disseminates information about the organization, facilities, activities, accomplishments, and publications of state surveys and mining bureaus. The price is $10 for the single issue per year.

The AASG Fact Book, updated annually, offers information about the programs of each of the state surveys and lists program managers and telephone numbers. It's available for $10.

Orders may be sent to Dr. Thomas M. Berg, Ohio Geological Survey, Dept. of Natural Resources, 4383 Fountain Square Drive, Bldg. B, Columbus, OH 43224-1362.

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