WASHINGTON GEOLOGY

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Mount Baker volcano from the northeast. Bagley Lakes, in the foreground, are on a Pleistocene recessional moraine that is now the parking lot for Mount Baker Ski Area. Just below Sherman Peak, an erosional remnant on the left skyline, is Boulder Glacier. Park and Rainbow Glaciers share the area below the main summit (Grant Peak, 10,778 ft). Boulder, Park, and Rainbow Glaciers drain into Baker Lake, which is out of the photo on the left. Mazama Glacier forms under the ridge that extends to Hadley Peak on the right. (See related article, p. 3 and Fig. 2, p. 5.) Table Mountain, the flat area just above and to the right of center, is a truncated lava flow. Lincoln Peak is just visible over the right shoulder of Mount Baker. Photo taken in 1964.

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Revised State Surface Mining Act—1993

by Raymond Lasmanis

The 1993 regular session of the 53rd Legislature passed a major revision of the surface mine reclamation act as Engrossed Second Substitute Senate Bill No. 5502. The new law takes effect on July 1, 1993.

Both environmental groups and surface miners testified in favor of the act. Two sections relating to growth management, local government, and water control authorities were vetoed by Governor Mike Lowry.

The new surface mine reclamation act provides for the following:

- The Department of Natural Resources has the exclusive authority to regulate reclamation.
- This regulatory program is self-funded through raising the annual fee for each permit from $250/year to $650/year.
- Additional compliance personnel will be provided in the field to enhance the program.
- Permits issued after July 1, 1993, shall be known as Reclamation Permits; operating permits issued between 1971 and June 30, 1993, will be converted.
- Quality reclamation plans are required by the new law; substandard plans need to be upgraded to comply with specifications and approved before July 1, 1998.
- Segmental reclamation is required for any depleted portion of a mine greater than 7 acres or a depleted working face longer than 700 lineal feet.
- Stringent penalty provisions for non-compliance are specified.

During the next eight months, staff will be going through an implementing process. In conjunction with our client groups, procedural rules will be developed first, followed by substantive rules.

As a result of legislative action, the public can expect an improved surface mine reclamation program in Washington State. ■

Galster Wins Burwell Award

Richard W. Galster has been named recipient of the 1993 E. B. Burwell, Jr., Award for Bulletin 78, **Engineering geology in Washington**. The award is given by the Engineering Geology Division of the Geological Society of America (GSA).

Galster, a consulting engineering geologist, was chairman of the editorial committee for this two-volume collection of papers published to commemorate the 100th anniversary of Washington statehood (1889–1989).

The Burwell Award was established in 1968 to honor the memory of Edward B. Burwell, Jr., one of its founders and long the Chief Geologist, U.S. Army Corps of Engineers. The award is given annually to the author(s) of a published paper of distinction in engineering geology or the related fields of applied soil or rock mechanics. It will be presented at the GSA annual meeting in Boston on Oct. 27, 1993.

This is the second national award for Galster and Bulletin 78. In 1991, he received the Claire P. Holdredge Award from the Association of Engineering Geologists.

Bulletin 78 is available from the Division of Geology and Earth Resources for $27.75 + 2.25 tax (WA residents only) = $30.00. Please add $1.00 for postage and handling.

Current Behavior of Glaciers in the North Cascades and Effect on Regional Water Supplies

by Mauri S. Pelto
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The North Cascade Glacier Climate Project (NCGCP) was established in 1983 to monitor the response of North Cascade glaciers to changes in climate. NCGCP receives its funds from numerous sources, primarily the Foundation for Glacier and Environmental Research. Each summer, NCGCP hires several students from Pacific Northwest colleges as assistants. Between 1984 and 1990, NCGCP observed the behavior of 117 glaciers; 47 of these were selected for annual study (Fig. 1). NCGCP has collected detailed information (terminus behavior, geographic characteristics, and sensitivity to climate) on 107 glaciers in every part of the North Cascade region. Annual mass balance measurements have been made on twelve glaciers and annual runoff measurements on four. Because most glaciers are in wilderness areas, researchers used simple equipment that could be transported in backpacks. This ensured a "light tread", minimized expenses, and allowed us to monitor many glaciers in a short time. With a glacier monitoring network now firmly established, our emphasis has shifted to providing natural-resource managers with information on fluctuations in glacier runoff.

The North Cascades of Washington extend from Interstate Highway 90 north to the Canadian Border. They are bounded on the west by the Puget Lowlands and on the east by the Columbia and the Chewuch (formerly Chewack) Rivers. This area supports 750 glaciers (Post and others, 1971) that store as much water as all of Washington's lakes, rivers, and reservoirs combined and provide approximately 230 billion gallons (87 million m^3) of water each summer (Meier, 1969). Nearly all this water is used for irrigation and power generation.

From 1944 to 1976, North Cascade glaciers were in good health: a majority of them advanced, and mean glacier runoff was high (Tangborn, 1980). Now, North Cascade glaciers are in retreat. This has been caused by a climate change, documented by records at eight North Cascade weather stations (Fig. 1). Mean winter precipitation for 1977 to 1992 has been 12 percent less than the long-term (1951–1980) mean for these stations. During the 1980s, NASA reported that the mean global temperature was 0.7°C (1.2°F) above the 1940–1978 mean. In the North Cascade region, most of the warming up to 1984 occurred during the winter (Trenberth, 1990). Mean summer temperature has been 1.0°C (1.8°F) above the long-term mean from 1985 to 1992.

HISTORIC TERMINUS BEHAVIOR

Since the end of the last ice age, three principal periods of alpine glacier advance have been identified in the North Cascades: Neoglacial (2,500–3,500 years ago), Little Ice Age (A.D. 1500–1800), and the recent advance (1944–1976) (Miller, 1969; Easterbrook and Burke, 1972; Hubley, 1956). The Neoglacial and Little Ice Age advances were of approximately the same magnitude; snowlines descended 100 to 150 m (330–490 ft) and all glaciers advanced substantially. The recent advance was much smaller, and only 50 to 60 percent of the North Cascade glaciers advanced (Hubley, 1956; Meier and Post, 1962).

During the Little Ice Age mean annual temperatures were 1.0 to 1.5°C (1.8–2.8°F) cooler than at present (Burbank, 1981; Porter, 1981). Depending on the glacier, the maximum advance occurred in the 16th, 18th, or 19th century, with little retreat prior to 1850 (Miller, 1969; Long, 1956). The temperature rise at the end of the Little Ice Age led to ubiquitous and rapid retreat from 1880 to 1944 (Hubley, 1956). The average retreat of Mount Baker glaciers from their Little Ice Age maximum to their present positions was 1,440 m (4,725 ft). In contrast, the average retreat of all North Cascade glaciers during this period was 550 m (1,800 ft); the range was from 1,600 m (5,250 ft) on Honeycomb Glacier to 100 m (325 ft) on Lower Curtis Glacier. The amount of recently deglaciated terrain in this area indicates that the climate change at the end of the Little Ice Age eliminated approximately 300 glaciers and approximately 30 percent of the total glacier area.

PRESENT TERMINUS BEHAVIOR

Advances and retreats are the best measures of long-term glacier health. With the exception of those on Mount Baker, few North Cascade glacier termini were observed prior to 1949. From 1951 to 1956, Richard Hubley of the University of Washington monitored terminus changes of North Cascade glaciers by taking aerial photographs of the glaciers each summer. This survey was continued by Austin Post of the U.S. Geological Survey (USGS) during the next decade. In the early 1970s, only glaciers on Mount Baker and Glacier Peak were observed by the USGS, and although some photographs were taken, since 1975 only the Klawatti and South Cascade Glacier termini have been analyzed (Tangborn and others, 1990). The only other terminus measurements since 1975 have been made by NCGCP.

For each glacier in the program, NCGCP crews determined terminus position change by measuring with a tape from fixed benchmarks at three locations beyond the glacier terminus—one at the center of the glacier and one each halfway from the center to the lateral margins of the terminus. Each measurement was made approximately perpendicular to the glacier front. The terminus change was the average of the three measurements.

Hubley (1956) demonstrated that North Cascade glaciers began to advance in the early 1950s, after 30 years of rapid retreat, in response to a sharp rise in winter precipitation and a decline in summer temperature beginning in 1944. Approximately half the North Cascade glaciers advanced during the 1944–1978 period of glacier growth (Hubley, 1956; Meier and Post, 1962; Muller, 1977). Advances of Mount Baker glaciers ranged from 120 to 800 m (395–2,625 ft) (Harper, 1992) and culminated in 1978 (Heikkinnen, 1984).

By 1984, all Mount Baker glaciers were retreating. In 1990, NCGCP measured the retreat of nine Mount Baker glaciers from their recent maximum positions. The average retreat was 50 m (165 ft) (Fig. 2, Table 1).

[1] In this article, the first unit of measurement given is the reporting unit, and the conversion is of approximately equal precision.

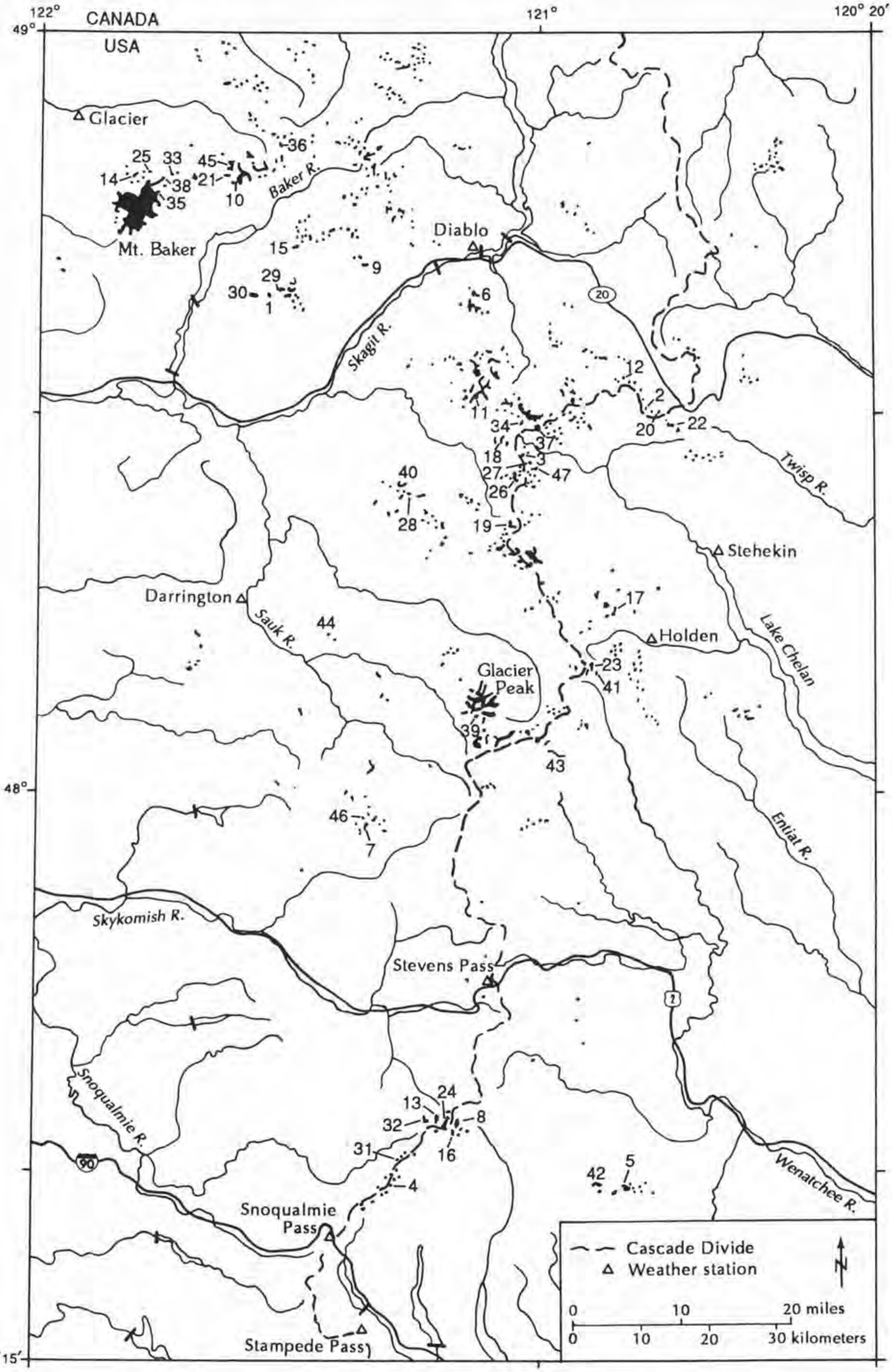

Figure 1. Locations of the 47 North Cascades glaciers studied by the NCGCP. Area weather stations also shown.

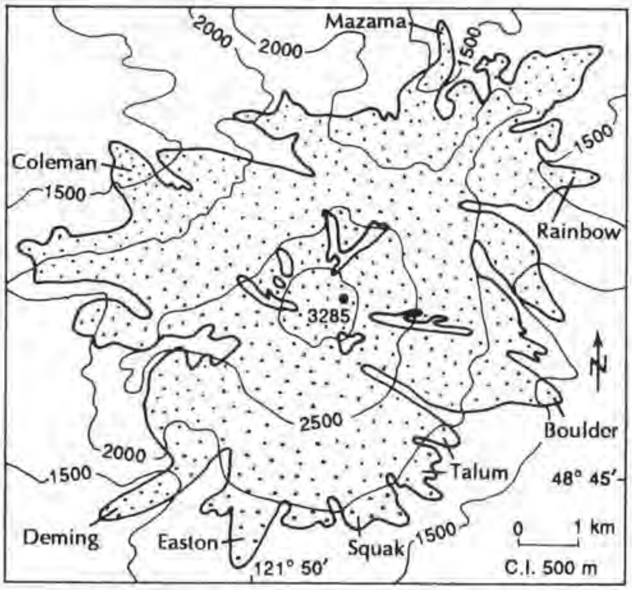

Figure 2. Glaciers on Mount Baker that have been part of the NCGCP study. See data in Table 1.

From 1984–1988, 91 of the 107 glaciers observed by NCGCP retreated significantly, 3 advanced, and 13 were in equilibrium. Of the 49 glaciers observed in 1992, 47 were retreating, and only LeConte Glacier on Sentinel Peak and Walrus Glacier on Clark Mountain were in equilibrium. Table 2 summarizes the terminus behavior of North Cascade glaciers from 1955 to 1992, and Table 3 lists the overall change in terminus position of 47 glaciers between 1984 and 1991 or 1992.

The recent retreat is due largely to a decrease in winter precipitation that began in 1977 (Fig. 3). At that time, the mean winter position of the Aleutian Low shifted southeast, resulting in more precipitation in Alaska and less precipitation in the Cascades (Trenberth, 1990; Pelto, 1990). The trend of North Cascade glacier retreat is typical of alpine glaciers around the world during the 1980s. In 1980, more than 50 percent of all small alpine glacier around the world were advancing (Haeberli, 1985), but in 1990 only 18 percent were advancing (Pelto, 1991).

One can also determine the current health of a glacier terminus by simply observing its profile and the number of crevasses (Meier and Post, 1962), as illustrated in Figure 4.

MASS BALANCE

For a glacier to survive, snow accumulation must equal or exceed snowmelt. Annual mass balance for a glacier is the difference between the amount of snow and ice accumulated and the amount of snow and ice melted during a hydrologic year (October–September). If there is more accumulation than melt, a positive balance results, and if net accumulation continues for several years, the glacier will advance. Where melting exceeds accumulation, a negative mass balance leads to glacier retreat.

For this discussion, estimates of mass balance are made from comparisons of annual snowline positions. The snowline, defined as a line above which the past winter's snow still covers older firn and ice, rises throughout the summer. Its position at the end of the hydrologic year (September 30) is the annual snowline position. The percentage of a glacier's total area that is above the snowline is a good indication of its mass balance (Meier and Post, 1962; Armstrong, 1989). The snowline can occur as a line at a specific altitude as it does at Mazama Glacier on Mount Baker, or it can be a patchwork of bare areas as at Eldorado Glacier near Cascade Pass.

Table 1. Minimum estimated advance of Mount Baker glaciers between 1949 and 1978 (Long, 1953, 1956; Muller, 1977) and the observed retreat of these glaciers from their 1979 maximum to 1990

Glacier	Advance (m) 1949-78	Retreat (m) 1979-90
Boulder	575	55
Coleman	610	73
Deming	510	53
Easton	440	8
Mazama	450	38
Rainbow	215	60
Squak	275	35
Talum	305	78

Factors Affecting Mass Balance

North Cascade glaciers are sensitive to four climatic variables: summer temperature, summer cloud cover, winter precipitation, and freezing levels during May and October precipitation events (Porter, 1977; Tangborn, 1980; Pelto, 1988). Glacier behavior is also influenced by geographic characteristics that affect how much snow accumulates and melts: orientation (the direction the glacier faces), glacier altitude, accumulation sources, radiational shading, and location with respect to the Cascade Crest. For example, a southern orientation and few surrounding peaks lead to increased sun exposure and more summer melting. A westward orientation results in reduced wind drift accumulation compared to an eastern orientation because most storms come from the southwest. Glacier altitude is the mean altitude of the glacier with respect to the mean local annual glacier snowline. Radiational shading is a combination of glacier orientation and the shading provided by the surrounding peaks. All these factors except accumulation sources can be identified from map analysis.

Accumulation sources are direct snowfall, wind drifting, and avalanching. To determine accumulation sources requires direct examination of the snowpack on the glacier. Avalanche accumulation can be recognized by the uneven, and in places blocky, nature of the surface where avalanches have deposited snow. Wind drift accumulation can be recognized by rapid changes in snow depth in the lee of ridges and changes in glacier slope. Direct snowfall has a fairly consistent depth for a given altitude and few rapid changes in snow depth.

From a comparison of annual mass balance measurements and from observation of the area of accumulation above the annual snowline, both completed annually on 11 glaciers and at least once on 37 other glaciers, the area of accumulation above the annual snowline necessary for equilibrium could be estimated.

In the North Cascades, if avalanche accumulation is received, then between 60 and 65 percent of a glacier's area

Table 2. Terminus behavior of North Cascade glaciers as noted in 1955 by Hubley (1956), in 1961 by Meier and Post (1962), in 1967 by Post and others (1971), in 1975 by the USGS (Muller, 1977), and by the North Cascade Glacier Climate Project in 1988 and 1992. Data reported as percentage of the total number of glaciers observed

Year	Glaciers examined	Advancing (%)	Stable (%)	Moderate retreat (%)	Rapid retreat (%)
1955	63	61	21	5	13
1961	137	2	46	48	4
1967	22	32	36	18	14
1975	13	69	8	8	15
1988	107	3	15	60	22
1992	48	0	4	41	51

must be in the accumulation zone above the snowline, at the end of the summer for it to be in equilibrium. If a glacier does not receive avalanche accumulation, then 65 to 70 percent must be above the snowline for equilibrium.

NCGCP has monitored the snowcovered area on 47 glaciers annually at the end of the hydrologic year (Pelto, 1987, 1988). From 1985 to 1992, only 49 percent of the average North Cascade glacier remained snow covered at the end of September. This indicates significant negative balances, which have resulted in glacier retreat.

Characteristics Affecting Glacier Health

Glaciers cease to exist when there is not enough accumulation to support flow. Glaciers that have an insufficient accumulation zone to survive the present climate regime usually have several of the following characteristics: southern orientations, poor radiational shading, direct snowfall accumulation only, a location east of the Cascade Crest, and a low altitude with respect to the local snowline. Any glacier with three of these characteristics is likely to disappear in the next few decades. A survey of North Cascade glaciers indicates that between 120 and 140 glaciers have three of the aforementioned characteristics. East of the Cascade Divide most glaciers have these characteristics and are likely to disappear soon. Glaciers that fall into this category now have thin concave termini and accumulation zones of limited extent and limited altitude range.

By comparing the retreat rate of 107 North Cascade glaciers for which these geographic characteristics are known, the effect of each characteristic on glacier health is evident. A location west of the Cascade Crest, a northward orientation, multiple accumulation sources, a high mean altitude, and substantial radiational shading are geographic characteristics that tend to slow retreat. A location east of the Cascade Crest, direct snowfall accumulation only, poor radiational shading, and a low mean altitude are associated with more rapid retreat.

GLACIER RESPONSE TO CLIMATIC WARMING

At the end of the Little Ice Age, warming of only 1.2°C (2.1°F) (Burbank, 1981) led to an average North Cascade glacier retreat of 550 m (1,800 ft), the disappearance of approximately 300 glaciers, and a minimum loss of 30 percent of the volume of North Cascade glaciers.

The USGS defines glaciers as any perennial snow-ice mass larger than 0.1 km^2 (0.03 mi^2). This means that aerial photographs can be used to distinguish glaciers (Post and others, 1971). Between 1990 and 1992, NCGCP confirmed by field measurement of glacier area that 17 of the 756 glaciers identified by the USGS in 1969 no longer meet the definition.

Of the 107 glaciers first observed by NCGCP in 1984, three no longer exist. Lewis Glacier near Rainy Pass stagnated in 1987 and melted away in 1989. Klenhi Glacier on Mount Daniel melted away in 1992. David Glacier on the north side of Mount David disappeared in the late 1980s.

In the Cascade Pass area, two small glaciers in Torment Basin and two beneath the Triplets and Cascade Peak have altitude ranges of less than 500 ft (150 m). In 1985, 1987, 1990, and 1992, these glaciers were entirely in the ablation zone. If present conditions continue, they will disappear.

In the Mount Stuart area, 15 glaciers existed in 1969; today 12 are left, and of these, 4 are on the verge of vanishing. At the turn of the century, Snow Creek Glacier comprised three ice masses separated by narrow bedrock ridges and covered 2.0 km^2 (about 0.8 mi^2). Today, there are nine ice masses covering just 0.4 km^2 (0.15 mi^2), and three of these ice patches are not moving.

In 1971, Hinman Glacier on Mount Hinman was listed as the largest glacier between Mount Rainier and Glacier Peak. It had an area of 1.3 km^2 (0.5 mi^2) (Post and others, 1971). By 1992, the glacier had separated into three masses with a total area of just 0.4 km^2 (0.15 mi^2). A new 0.4-km^2 lake has appeared where the glacier is still shown on USGS topographic maps.

On the current (1965 edition) USGS topographic map of the Mount Daniel area, Lynch Glacier is shown with an area of 0.9 km^2 (0.35 mi^2) and occupying the basin that now holds Pea Soup lake. Lynch Glacier receded out of the basin in 1983. By 1992, air-photo mapping showed that Pea Soup lake had an area of 0.35 km^2 (0.13 mi^2) and Lynch Glacier had shrunk to 0.5 km^2 (0.19 mi^2).

If our climate warmed 2.0°C (3.6°F) in the near future (as is typically projected for a greenhouse warming), then, on the basis of observed lapse rates of temperature (Porter, 1977), the average glacier snowline would rise nearly 300 m (975 ft). For example, Sahale Glacier near Cascade Pass extends from 7,350 to 8,600 ft, an altitude range of 1,250 ft (380 m). It has a fairly uniform slope and a present annual snowline at 8,100 ft (2,470 m). With this snowline elevation, the glacier will be in equilibrium at half its present size. If the

Table 3. Change in terminus position of 47 North Cascade glaciers between August 1984 and August 1991(*) or August 1992. Glacier locations are indicated in Figure 1

Loc. no.	Glacier	Terminus change (m)	Latitude	Longitude
1	Bacon Creek	-13	48 40	121 30
2	Black	-14*	48 32	120 48
3	Cache Col	-29	48 27	121 03
4	Chimney Rock	-21	47 30	121 17
5	Colchuck	-24	47 29	120 50
6	Colonial	-38	48 40	121 08
7	Columbia	-31	47 58	121 21
8	Daniels	-45	47 34	121 10
9	Davis	-25	48 44	121 12
10	East Curtis	-22	48 49	121 37
11	Eldorado	-17	48 31	121 08
12	Fisher	-27	48 33	120 51
13	Foss	-48	47 34	121 12
14	Hadley	-18	48 49	121 49
15	Hidden Creek	-17	48 44	121 30
16	Ice Worm	-41	47 34	121 10
17	Isella	-33	48 14	120 52
18	Johannesburg	-22	48 28	121 06
19	LeConte	+10*	48 22	121 02
20	Lewis	-82	48 31	120 48
21	Lower Curtis	- 4*	48 50	121 37
22	Lyall	-39	48 29	120 45
23	Lyman	-62	48 10	120 54
24	Lynch	-46	47 34	121 11
25	Mazama	-47*	48 48	121 48
26	Middle Cascade	-41	48 25	121 03
27	Mixup	-29	48 27	121 02
28	Mutchler	-18	48 24	121 15
29	Noisy Creek	-26	48 40	121 32
30	North Watson	-33	48 39	121 34
31	Overcoat	-24	47 30	121 18
32	Hinman	-141	48 34	121 14
33	Ptarmigan	-33	48 49	121 45
34	Quien Sabe	-53	48 30	121 03
35	Rainbow	-68	48 48	121 46
36	Ruth	-16*	48 52	121 32
37	Sahale	-31	48 49	121 02
38	Shoales	-28	48 49	121 46
39	Sitkum	-51	48 07	121 08
40	Snowking	-12	48 25	121 17
41	Spider	- 8	48 10	120 53
42	Stuart	-36	47 12	120 54
43	Walrus	0*	48 03	120 58
44	White Chuck	-32*	48 13	121 25
45	White Salmon	-24	48 50	121 37
46	Wilman	-19	47 58	121 22
47	Yawning	-20	48 27	121 02

snowline rises to 8,300 ft (2,530 m), however, the accumulation zone will be too small to sustain the glacier. Any glacier on which the difference in elevation from the present day annual snowline to the upper accumulation zone is less than 300 m (980 ft) will not survive.

Approximately 60 North Cascade glaciers could survive 2°C (3.6°F) warming. The remaining 690 would disappear within 40 years. Thus, within a few decades, half the North Cascade glaciers could disappear if the greenhouse warming follows the anticipated trend.

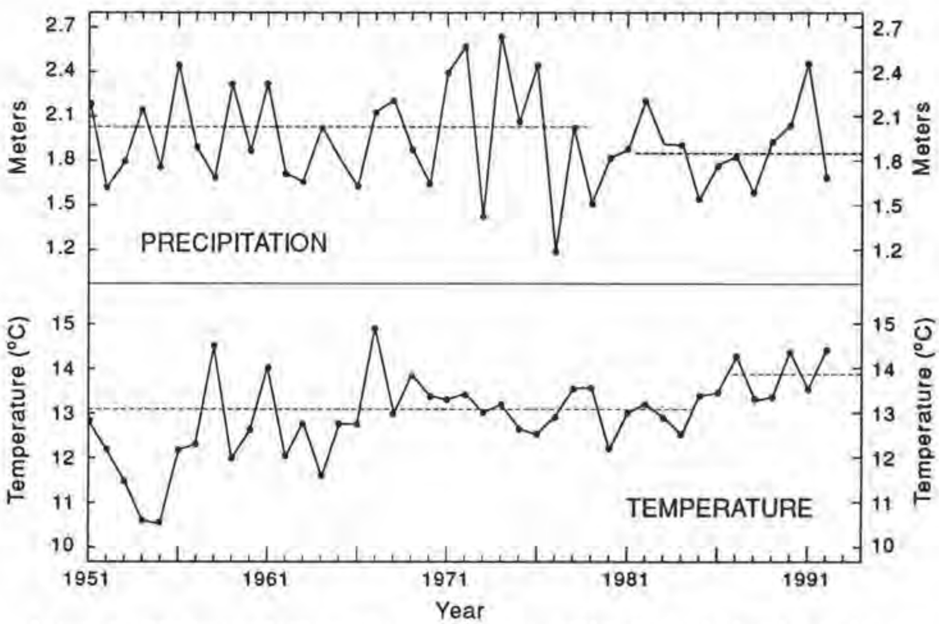

Figure 3. Mean annual ablation season temperatures (May–September) and annual accumulation season precipitation values (October–April) at Stampede Pass. The dashed lines represent the mean for the different periods. Note the decline in precipitation beginning in 1977 and rise in summer temperature in 1985.

MELTWATER STORAGE

During spring and early summer, accumulated layers of snow and firn on a glacier act as an unsaturated aquifer, soaking up (Bazhev, 1986) and holding approximately 50 percent of all meltwater generated on the glacier (Krimmel and others, 1973). The larger this aquifer, the more meltwater it can store and the longer the delay in release of glacier runoff. The size of the aquifer is determined by measuring the thickness and extent of the snow and firnpack (Bazhev, 1986). The other factor affecting delay is the weather during the melt season.

Table 4 indicates that, in an average year, peak spring runoff from basins with a significant percentage of glacier cover is delayed by 4 to 6 weeks relative to peak spring runoff from unglaciated basins (Pelto, 1992; Fountain and Tangborn, 1985). Water retention in glaciers also reduces peak spring flows and lengthens the high spring-summer runoff period. This offers opportunities for water managers to more efficiently use the runoff. However, in 1986, 1987, 1990, and 1992, thin snowpack led to a delay in glacier runoff of only 2 weeks. This situation raised flood danger because peak glacier runoff overlapped peak non-glacier snowmelt runoff.

More important to water supply management is the reduction in summer glacier runoff due to glacier retreat. As glaciers shrink, the surface area available for melting is reduced and the volume of glacier runoff must decline. Initially, higher than normal melt rates cause retreat, and the increased runoff may offset the runoff decline due to the loss of glacier area.

Comparing Basins Types

During dry summers, glacier runoff is typically higher than normal and can buffer the effects of low summer flows. This is illustrated by runoff measurements in neighboring lightly and heavily glaciated basins (Table 5). Newhalem Creek and Thunder Creek basins were chosen because their climatic conditions and geographic characteristics are similar. During droughts, stream flow at the USGS gaging station on Newhalem Creek, whose basin is lightly glaciated, drops on average 34 percent below the long-term mean. In contrast, an 18 percent drop is noted at the USGS gaging station on Thunder Creek, which drains a heavily glaciated basin. Droughts were defined as periods when winter precipitation was below the long-term mean and the combined mean July and August precipitation was less than 6 cm (2.3 in.) at the eight North Cascade weather stations.

Comparing runoff measured at stream gages placed by NCGCP on neighboring glaciated and unglaciated basins of the North Fork Skykomish River, Stehekin River, and Baker Lake indicates that between July 15 and September 15, water release averaged 0.22 m^3/m^2 in glacier-free alpine areas, whereas it reached 2.1 m^3/m^2 in glacier-covered areas, or 950 percent more runoff for glaciated areas than for unglaciated areas. This means that a basin with 1.5 percent glacier cover, for example, receives approximately 14 percent of its mid- and late-summer supply from glacier runoff.

Regions recently deglaciated are still in high alpine areas with substantial snowpack. Thus, runoff should be higher there than for most glacier-free alpine areas. To determine the actual runoff decline due to decreased glacier area, runoff was monitored from the Lewis Glacier basin at a gage placed 100 m (330 ft) beyond the terminus. This small outlet stream was fed only by glacier melt; no other snow patches existed in the basin. In August 1985, Lewis Glacier had an area of 0.09 km^2 (0.04 mi^2) and released 0.15 million m^3 (5.3 million ft^3) of runoff. By August 1990, Lewis Glacier had disappeared, and runoff dropped to 0.04 million m^3 (1.4 million ft^3), just 27 percent of the glacial flow despite approximately the same monthly precipitation.

Baker Lake: A Case Study

Baker Lake is fed by 60 glaciers that have a total area of 15.3 km^2 (5.9 mi^2). (See cover photo.) Glacier runoff was determined from direct measurement of glacier ablation on four glaciers in this basin. The 60 glaciers released an average of slightly more than 25 billion gallons (9.4 million m^3) to Baker Lake between May 15 and October 1. This is 40 to 45 percent of the total summer runoff into Baker Lake (Pelto, 1991). If glacier retreat continues at its present pace, within 15 years summer glacier runoff in the basin will have declined by 4 to 6 billion gallons (1.5–2.3 million m^3).

The U.S. Army Corps of Engineers buys a certain amount of reservoir storage in Baker Lake each spring; this volume is left empty to hold any floodwaters. If the recent trend of early glacier runoff continues, more storage will have to be bought

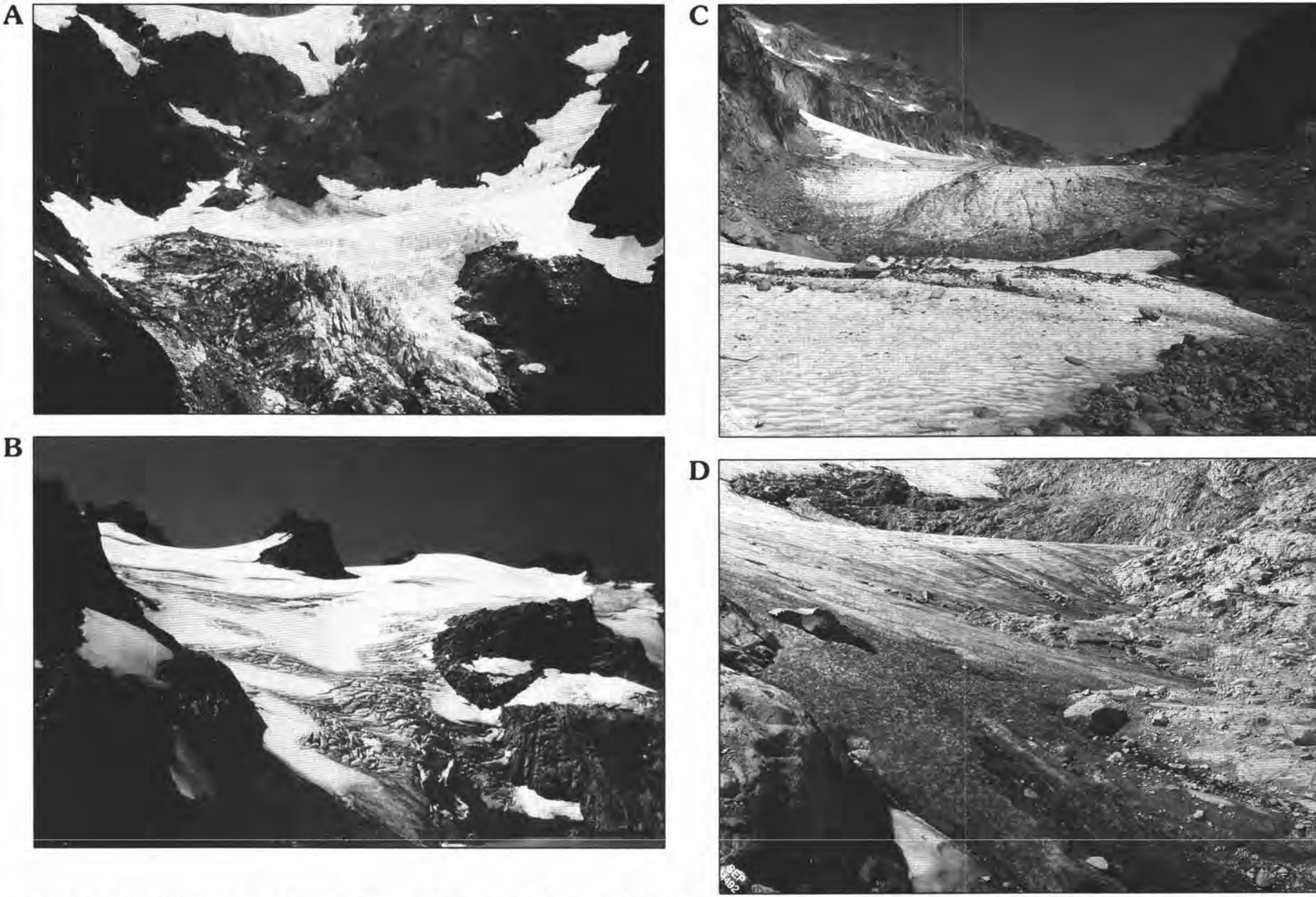

Figure 4. A glacier's front is active when it is advancing or in equilibrium. **A**, Lower Curtis Glacier on Mount Shuksan, 1985 – an active front distinguished by extensive crevassing and a rapid increase in thickness upglacier from the terminus, resulting in a strongly convex shape. **B**, Lynch Glacier on Mount Daniel, 1986 – a moderately active front, indicative of slow retreat, that has limited crevassing and a moderately convex surface at the terminus. **C**, Columbia Glacier at Monte Cristo in 1986 – a moderately retreating terminus that has few crevasses and a thin, flat terminus. **D**, Foss Glacier, Mount Hinman, 1986 – a rapidly retreating terminus that is not crevassed and has a flat or even concave surface at the thin terminus.

in some years to protect against flooding. If the glaciers are monitored, managers will be prepared to purchase more storage when a warm summer (reducing glacier snow and firn pack) is followed by a moderately wet winter. During dry winters, low snowpack accumulation in unglaciated areas would not significantly augment the early peak in glacier runoff. The magnitude of the decline in glacier runoff and summer runoff would dictate how much additional water needs to be stored early in the summer to maintain sufficient late summer streamflow in the Baker River. NCGCP has in place a program to determine the changing contribution of runoff from glaciers to Baker Lake.

WATER SUPPLY FROM NORTH CASCADE GLACIERS

North Cascade glaciers are an important natural resource because they contribute 20 to 25 percent of the region's total summer water supply. We rely heavily upon glacier runoff to meet basic water demands, including hydropower generation, irrigation, and fisheries. In the past, water resources have been sufficient, regardless of climate. However, the continued rapid development in the Puget Sound region has increased demand. At the same time, average annual precipitation has been 15 percent below the long term mean since 1977, reducing water supply. Mean streamflow from July 1 to October 1 at the USGS gaging station on the Stehekin River at Stehekin was 46.3 m^3/s (1,635 ft^3/s) for the years 1951 to 1976; for 1977 to 1990, it was 36.5 m^3/s (1,290 ft^3/s), a 22 percent decline. The consequence was water shortages in the North Cascades area, necessitating rationing in some areas in 1985, 1987, and 1992.

Summer glacier runoff is the product of the mean ablation on these glaciers and their total area. Runoff rates are highest from June through September when the glaciers normally release approximately 230 billion gallons (87 million m^3) of water (Meier, 1969; Pelto, 1992). Glacier runoff is highest during warm, dry summers when the total water supply is low. This also is the period when precipitation and non-glacier runoff are lowest. Glacier runoff was comparatively stable and high from 1944 to 1980 (Tangborn, 1980), possibly lulling many into ignoring the role of glaciers in the water supply of the North Cascades.

The amount of runoff in a given year is determined primarily by annual precipitation. However, the timing of release of 230 billion gallons (87 million m^3) of summer glacier runoff to North Cascade streams is determined by the volume of glaciers, the volume of glacier aquifers, and weather conditions. Shrinking glaciers result in reduced runoff. Low flow in the late summer now threatens aquatic life in streams and lakes during dry years. Given present climate trends, this problem will become more severe.

With the increasing demand for water, all available information will be needed to make water management decisions that will best serve the needs of the area's population and aquatic ecosystems. The rapid changes in runoff occurring in the Skykomish, Stehekin, and Baker Lake basins emphasize the futility of managing our water resources without considering the changing influence of glaciers. If demand for water from the region's rivers continues to increase, then maintaining the present flow levels through the summer will require different water-management practices and must include analysis of glacier fluctuations.

Table 4. First day of peak spring discharge (defined as the first day of the highest 4-day total discharge) from three North Cascade basins with different percentages of glacier cover. Runoff data from USGS gaging stations

Year	Newhalem	Stehekin	Thunder
1984	May 29	May 29	June 20
1985	May 17	May 14	May 18
1986	May 18	May 19	May 26
1987	Apr 28	Apr 29	May 7
1988	Apr 13	Apr 14	May 11
1989	Apr 5	Apr 15	June 1
1990	Apr 11	Apr 14	June 16
Mean	Apr 30	May 2	May 28
% of basin area glaciated	0.4	3.1	14.1

Table 5. Stream flow at USGS gaging stations on Newhalem Creek (lightly glaciated basin) and Thunder Creek (heavily glaciated basin) during drought conditions and percent depletion in streamflow from mean flow conditions; mean August flow is for 1955–1990

Date	Newhalem (m^3/s)	Thunder (m^3/s)
Aug. 1969	2.0	20.1
Aug. 1970	1.7	23.4
Aug. 1979	1.8	27.3
Aug. 1985	1.8	22.0
Aug. 1987	1.9	22.6
Mean Aug. flow	2.8	28.1
Depletion	34%	18%

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Note: Because the glaciers are rapidly changing, NCGCP is establishing an archive of photographs of North Cascade glaciers to serve as a record of glacier variations. The collection will be duplicated and housed in both Sedro Woolley and Seattle under the aegis of the National Park Service and will be annually updated. Though the project cannot compensate you for the photographs, you will be fully credited in the archive. Please send contributions, with as much documentation as possible, to NCGCP. ■

Surficial Geologic Map of Seattle Now Available

Geologic map of surficial deposits in the Seattle 30′ x 60′ quadrangle, Washington, by J. C. Yount, J. P. Minard, and G. R. Dembroff, has been released as U.S. Geological Survey Open-File Report 93-233. It is comprised of two oversize sheets, scale 1:100,000.

It sells for $12.75 paper; $1.50 microfiche. Order from:

U.S. Geological Survey Open-File Report Sales
Box 25286, Bldg. 810, MS 517, DFC
Denver, CO 80225-0286

Hecla Honors Republic Unit Workers for Outstanding Safety Record

Hecla Mining Company's underground hardrock gold mine in northeast Washington set a safety record by going the entire year of 1992 without a lost-time accident. The last lost-time accident at the Republic unit was in September 1991, bringing the total length of the safety record to nearly 18 months.

Each of the Unit's 124 employees was awarded a ¼-ounce pure gold medallion for the accomplishment. The medallions were designed by the Unit's draftsman, Shannon Sheridan, and show the Republic mill on one side, with the Republic decline, headframe, and front-end loader on the other side. The safety medallions were made from gold mined and milled at the Republic unit.

Ron Clayton, Republic Unit manager, said it's very rare for an underground hardrock mine or any other industrial operation to go more than a year without any lost-time accidents. Clayton said the record is not due to luck. "It takes a lot of hard work to get to this point," he said. "We have a full-time safety supervisor who works with all department heads. Each department has its own safety committee, which reviews accident reports, talks about how those accidents could be prevented and makes sure the employees are very safety conscious. These people meet on their own time, and we have many more people ready to volunteer as members on the committees." Clayton said safety is the most important piece of everything done at the Unit. "People watch out for themselves and each other...that's part of their job. Our employees readily accept this responsibility and deserve the credit for this significant accomplishment."

Hecla Mining Company is headquartered in Coeur d'Alene, ID. During its 102-year history, Hecla has been a leading producer of silver and lead, and more recently, a significant supplier of gold and industrial minerals.

(From a March 11, 1993, Hecla press notice)

Radon Potential of Washington from a Geologic Viewpoint

by Venice L. Goetz

Introduction

In mid-1992, the Division of Geology and Earth Resources (DGER) entered into a cooperative agreement with the Washington Department of Health (DOH) to produce a 1:250,000-scale map showing the geologic potential for generation of radon in Washington. The work was partially funded by a grant from the U.S. Environmental Protection Agency (EPA). The map, completed May 31, 1993, will be one of several layers that constitute a final Geographic Information System (GIS) product that will help planners make decisions about how and where to mitigate radon hazards in the state. The geologic layer, which is derived from DGER state geologic map quadrants or component 1:100,000-scale maps, will show geologic units grouped into five categories defined by the potential of that unit to generate radon. Other map layers to be used to examine mitigation strategies will include:

- the Washington state radon database
- soil permeability
- soil moisture and water-table levels
- county and township/range boundaries
- cultural and hydrographic information
- the National Uranium Resource Evaluation (NURE) aerial gamma ray (radiometric) data.

Supplementary layers may be added in the future.

Radon as a Hazard

The level at which indoor radon causes cancer is controversial. Epidemiologic data from studies of uranium, iron-zinc-lead, and fluorspar miners who were exposed to radon gas for prolonged periods underground show that radon is linked to lung cancer—radon-induced lung cancer developed in 3–8 percent of the miners. The findings exclude cancer caused by smoking and other causes (F. T. Cross, 1987, cited *in* Gundersen and others, 1992). The Surgeon General has declared that radon is the second leading cause of lung cancer in the United States following smoking (U.S. EPA, 1992). The EPA recommends mitigation if air in a building contains greater than 4 picoCuries/liter (pCi/l) of radon.

Some Radon Facts

Radon-222 is a naturally occurring radioactive gas produced by the decay of uranium-238 (Fig. 1). The gas is not easily detected—it is odorless and invisible. Radon-222 has a half-life of 3.823 days and is parent to, among other radioactive daughter isotopes, polonium-218, polonium-214, and bismuth-214. The polonium isotopes emit alpha particles, have half-lives of 3.05 minutes and 164 microseconds respectively, and are the lung-cancer-producing culprits. Bismuth-214 is the isotope measured in the NURE surveys.

When radon decays, its daughter isotopes, which are particulate, adhere to very fine material like dust and smoke. Out of doors these particles are usually dilute and do not constitute a health hazard. When these materials are inhaled with indoor air, the particles adhere to lung tissue. Because of their short half-lives, polonium-218 and polonium-214 may not be exhaled before their alpha particles irradiate lung tissue. Damaged lung tissue may eventually develop cancer.

Radium-226, the immediate parent of radon-222, has a half life of 1,622 years. Radium and radon occur in most soils because uranium is generally present in all rocks from which soils develop. The radium content of soil and availability of radium from mineral matter, the permeability of soil, and soil moisture content are major factors that influence radon potential (Duval and Otton, 1990). The decay of radium in a soil grain produces energy that sends radon atoms out into a pore space or to be embedded in or adsorbed onto another grain. The release of radon atoms from decaying radium is called alpha recoil (Tanner, 1980, *in* Gundersen and others, 1992). The amount of radon released into a pore space (the emanating fraction) depends on how close the radium is to the soil grain surface (Tanner, 1986). If the radium is not close to the surface, radon may not be able to escape the grain.

A small amount of moisture in soil pore spaces will inhibit the movement of radon atoms and cause them to remain within pore spaces rather than be embedded in another soil grain, thus increasing the chance that the radon will move with other soil gases (Gundersen and others, 1992). However, a high water table and consequent saturation of pores can block radon movement, and the radon will effectively decay in place (Duval and Otton, 1990).

Radon moves by molecular diffusion and by convection. Convection, the most important mode of transport, is created by the circulation of heated and cooled air in nature and in buildings. In manmade structures, this movement of air causes a pressure difference between a building and the underlying soil. Radon then moves from the soil to areas of lower pressure in buildings; in a sense, the building "sucks" on the ground beneath it. Thus, barometric pressure changes and indoor heating practices may affect radon gas movement. Radon seeps into buildings through openings such as cracks and joints in the foundation, sumps, and utility entries.

Methodology

Information used to assess the geologic radon potential of Washington consists of DGER's 1:250,000-scale state geologic maps (southwest quadrant map – Walsh and others, 1987; northeast quadrant – Stoffel and others, 1991; southeast quadrant – J. E. Schuster [DGER] and others [work in progress]; and the northwest quadrant – R. L. Logan [DGER] and others [work in progress]) and a DGER database of uranium mine and prospect locations, analyses of rock chip, stream-sediment, and soil samples from northeastern and north-central (northern Chelan county) Washington and seven locations elsewhere in the state (B. B. Bunning, formerly DGER, unpub. data). NURE flight-line data are used qualitatively in conjunction with estimates of the uranium content of specific rock types determined by extrapolation from known worldwide abundances.

Statistically, approximately 2.5 ppm equivalent uranium (uranium content back-calculated from daughter-product concentrations) can generate about 4 pCi/l radon (R. R. Schumann, U.S. Geological Survey, oral commun., 1993). On this basis, almost all rock in northeastern Washington would have to be considered to have high potential for radon generation. Because the point of the project was to identify township-size or larger parcels, each of which could be assigned a rank of radon potential determined by rock type, this ratio (~2.5 ppm eU:~4 pCi/l) was ignored. Also, because radon delivery is not 100 percent efficient, this threshold does not actually produce 4 pCi/l in a home.

Geochemical data for uranium are available only for the northeastern and north-central part of the state and a few scattered locations elsewhere. To rely solely on geochemical data would have precluded evaluation of the potential in the rest of the state. Therefore a method had to be devised that used all available information: geologic, geochemical, and radiometric. Geologic literature contains information about the composition of various rock types on a worldwide basis. For example, organic-rich black shale contains an average of 8.2 ppm uranium (data from Clark and others, 1966, *cited in* Brookins, 1990, p. 31) because uranium in solution is precipitated in chemically reducing environments. Therefore, black organic-rich shales in Washington are considered uranium hosts. In addition, the DGER geochemical data were used. However, the combination of the geologic maps and the NURE radiometric data provides the best available coverage for the state because both are fairly consistent and complete. Geologic maps, however, yield more predictable information than NURE data because NURE data measurements are subject to error due to:

- precipitation – rain (or snow) intercepts radioactive aerosols and deposits them on the ground so that measurements of radioactivity are underestimated
- temperature inversions – if variations from the norm occur, then atmospheric corrections in data analysis become skewed
- variations in soil moisture – moisture can impede the progress of radioactive aerosols
- variations in vegetative cover – vegetative cover can weaken the gamma flux from the ground, and it can reflect radio waves from the radar altimeter, causing incorrect altitude measurements and influencing altitudinal corrections of data (Moed and others, 1984).

In northeastern Washington, 8.8 ppm uranium is the rock average for granitoids (Nash, 1979), although the worldwide mean is 4.8 ppm (data from S. R. Taylor, cited *in* Levinson, 1979). The DGER database shows that in northeastern Washington, many of the granitic rock samples contain considerably more than 50 ppm uranium! Worldwide uranium averages for other rock types are less than 10 ppm:

- organic-rich black shales – 8.2 ppm (data from Clark and others, 1966, cited *in* Brookins, 1990, p. 31)
- common shales – 3.5 ppm (data from Clark and others, 1966, cited *in* Brookins, 1990, p. 31)
- limestones – 2.0 ppm (data from Taylor, 1964, cited *in* Levinson, 1980, p. 44)
- basalts – 0.6 ppm (data from Taylor, 1964, cited *in* Levinson, 1980, p. 44)
- ultramafic rocks – 0.001 ppm (data from Taylor, 1964, cited *in* Levinson, 1980, p. 44)
- syenites – 3.0 ppm (data from Evans and Goodman, 1941, cited *in* Turekian and Wedepohl, 1961).

Therefore, for the whole state, values greater than 50 and less than 10 ppm were considered in defining categories of highest and lowest potential, respectively. One variable used to distinguish the categories was an average uranium concentration (in ppm) for a given map unit derived from values in the DGER database. Distributions of uranium concentrations from this database were evaluated by making histograms for each sample type and for each map unit. The resulting data were separated into ranges from less than 10 ppm to greater than 50 ppm by 10-ppm graduations.

Examination of the data led to development of five categories of potential for generation of radon (Table 1). For Category II only, two 10-ppm subsets were combined so that 30–40 and 40–50 ppm uranium were grouped together, for reasons discussed below.

The NURE data, which were recorded by airborne instruments along fairly evenly spaced flight lines (averaging 6 mi apart), show bismuth-214 concentrations in the upper 30 cm of soil and rock (Duval, 1990). The radon-222 content can be directly extrapolated from this daughter isotope because radon's first and second daughters have such short half-lives (polonium-218, 3.05 minutes; lead-

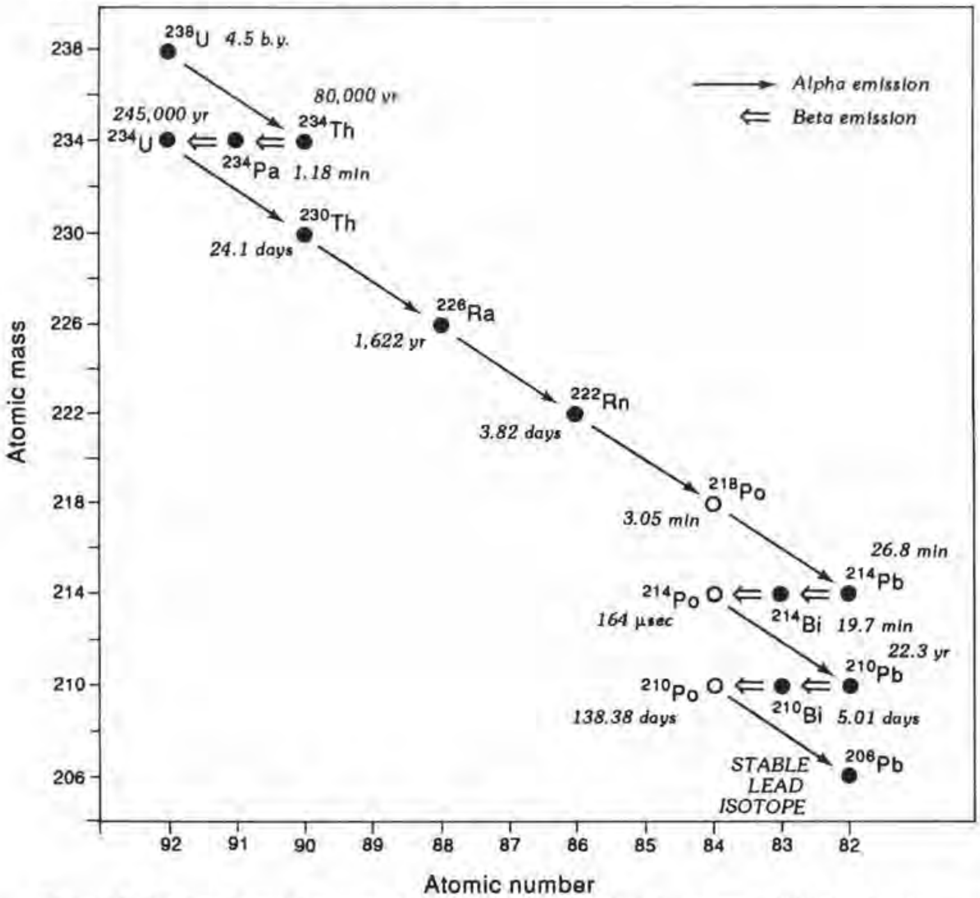

Figure 1. The uranium decay series (modified from Tarbuck and Lutgens, 1990) showing the radioactive decay of ^{238}U through ^{222}Rn to ^{206}Pb, a stable isotope of lead. Hollow circles represent short half-life isotopes that are emitters of alpha particles (helium nuclei). These isotopes have been associated with lung cancer. U, uranium; b.y., billion years; Th, thorium; Pa, protactinium; Ra, radium; Rn, radon; Po, polonium; Pb, lead; Bi, bismuth.

Glossary

half-life – the time required for half of the atoms in a sample of a radioactive isotope to decay.

isotope – one of two or more forms of an element having different atomic weights; daughter isotopes are those produced by a radioactive isotope as it undergoes decay.

alpha particle – a positively charged particle consisting of two protons and two neutrons, emitted in radioactive decay; the nucleus of a helium atom.

beta particle – a high speed electron or positron emitted by an isotope undergoing radioactive decay.

214, 26.8 minutes) as to be negligible. However, it is difficult to use the original NURE data because of inconsistencies in how the work was completed. Different contractors operated the equipment, and instrumental calibrations, background radiation, and flight-line elevations and conditions are not strictly uniform. The quantitative NURE data have been adjusted and recalibrated by Duval (1989) and will be a GIS layer on DOH's comprehensive map. Although the recalibrated NURE data were available for this project, their analysis was beyond the scope of this project. Therefore, the unrecalibrated NURE data were used qualitatively when designating rock units into radon-potential categories. This was accomplished by xerographically enlarging the 1:500,000-scale flight-line maps to 1:250,000 scale and using them as underlays to identify the map units that contain anomalies on the source geologic maps. For example, if a map unit adjacent to an area of high radon potential (determined from geochemical, mine, and prospect data) was suspected of containing uranium because the qualitative NURE data showed an anomaly within the unit, then that unit was included in the high-potential area so that the anomaly would be recorded for consideration by health officials and planners.

Geologic Radon Potential

Rocks that fall into the highest and lowest categories, I and V respectively, have the greatest degree of confidence in the accuracy of the rating because there is a large amount of data to draw on. Category II and IV rocks, rated moderately high and moderately low respectively, have a moderate degree of confidence. The reasoning behind the degrees of confidence is that end members have definitive attributes but intermediary members have more inferred properties. Category III has broad limits because the rocks were evaluated subjectively based on the research results, professional judgment, and experience of the compiler. It is farthest from the end members and has the least degree of confidence.

Category I includes mapped rock units that are shown in the DGER database to host uranium mines and prospects or that assayed greater than 50 ppm uranium. This category has the highest radon potential but may be areally biased since it is likely that more mines and prospects are found on public land. The NURE maps show major anomalies where most of these rocks occur. The most common rock types in this category are two-mica granites and alaskites crosscut by pegmatite and aplite dikes. Late-stage magmatic differentiates are predominant uranium hosts worldwide and in Washington. Tonalitic orthogneisses, quartz monzonites, granodiorites, and granites are also in Category I. Still other high-potential rock types include "heterogeneous" metamorphic rocks, some amphibolites, some quartzites, pelitic schists, banded gneisses, carbonaceous or pyritic and (or) marine metasedimentary rocks, and some alluvium. Uranium has been found in contact zones and faults in metasedimentary rocks and between metasedimentary rocks and granitoids.

Rocks in Category II, moderately high potential, are the same rock units as those in Category I, but have no mines or prospects noted in the DGER database. They may have lower uranium potential than areas with mines and prospects. If Category I rocks represent "identified reserves", Category II rocks are "inferred reserves". Category II rocks assayed from 30–50 ppm uranium. The rocks containing 30–40 ppm and 40–50 ppm uranium were combined as one category because assays of these rocks indicated similar anomalous concentrations compared with worldwide averages.

Category III includes rock types known to have high uranium concentrations worldwide but not hosts to mines and prospects in Washington. Also included are rocks that assayed between 20 and 29 ppm uranium. Felsic volcanic rocks, continental sedimentary rocks derived from granitoids, and marine sedimentary rocks make up this category. Taken together, these rocks may have moderate radon potential.

Rock units that commonly have low uranium content but also have sporadic high concentrations, such as glacial sedimentary units with northern sources, glacial Lake Missoula flood deposits, and units that assayed at or between 10 and 19 ppm uranium, make up Category IV. These present a moderately low potential for radon but can be anomalous.

Rock units that have low potential are in Category V. There are no geochemical data for these units in the DGER database, most likely because they are not associated with uranium deposits worldwide. They probably contain less than 10 ppm uranium. Columbia River basalts and other mafic igneous rocks fall into this category.

Discussion

On the geologic radon-potential map, the categories designated for some rock units may seem incongruous. For example, in the Spokane area, the glacial Lake Missoula flood gravels are mapped as Category IV; these sediments have been shown to contain large amounts of radon gas because they are so permeable and probably because they contain boulders eroded from nearby Category I rocks. Although soil permeability will be a GIS layer for DOH's analysis of radon potential in Washington, it was not a criterion in ranking the geologic radon potential. Rock type was the primary characteristic—the gravels consist of clasts of various rock types, many of northern provenance. Locally the Columbia River basalts contain uranium-rich sedimentary interbeds; however, at the scale of this map, these areas of localized high radon potential cannot be shown. Limestones (Category I or II) are not known to be hosts to uranium deposits worldwide, but our database shows numerous uranium prospects in lower Paleozoic carbonates. This is probably because they are chemically highly reactive rocks and can be hydrothermally enriched in uranium from uranium-bearing granitic intrusions. Recrystallized limestones and dolomites commonly contain elemental residue from the original sediments, and soils derived from

Table 1. Ranking of radon potential based on uranium occurrences and geology of Washington. NURE data are used as a qualitative guide for all the categories. Assays are from DGER uranium database

I. High Potential – Map units that host uranium mines and prospects and (or) rocks that assayed at >50 ppm uranium. Includes late-stage magmatic differentiates, pelitic metamorphic rocks, carbonaceous, pyritic, or marine metasedimentary rocks, and some alluvium.

II. Moderately High Potential – Same map units as those above but without mines and prospects and (or) rocks that assayed at ≥30 and ≤50 ppm uranium.

III. Moderate Potential – Rock types that are known worldwide to contain high uranium concentrations or rocks in Washington that assayed at ≥20 and <30 ppm uranium. Included are felsic volcanic rocks, continental sedimentary rocks derived from granitoids, and marine sedimentary rocks.

IV. Moderately Low Potential – Mapped glacial sedimentary units of northern source, glacial Lake Missoula flood deposits, map units that encompass rocks that commonly have low uranium content but have sporadic high concentrations, and rocks that assayed at ≥10 to <20 ppm uranium.

V. Low Potential – Map units for which there are no data or rocks that assayed at <10 ppm uranium and that are not associated with uranium occurrences worldwide. Columbia River basalts and other mafic igneous rocks fall into this category.

carbonates can have very high radium concentrations because uranium in ground water is easily adsorbed onto iron oxides, clays, and organic material (Tanner, 1986).

The development of the categories for radon generation potential was based on extrapolation of limited empirical data. Geology alone will not be the sole indicator of areas of high radon potential. The final assessment will consider all factors that are known to contribute to the radon hazard. The comprehensive report on radon in Washington, which includes input from GIS, was finished in June 1993.

Note: If you are concerned about radon, you should test. For more information, call DOH at 1-800-323-9727.

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Washington Areas Selected for Water Quality Assessment

March 8, 1993 – Secretary of the Interior Bruce Babbitt announced today the selection of 20 study areas across the country for water quality assessments. These study units are the second leg in the ongoing National Water Quality Assessment (NAWQA) being conducted by the U.S. Geological Survey in cooperation with several hundred agencies.

"Water is an essential component of our nation's economic well-being," Babbitt said. "These assessments provide water-resource and environmental managers with comprehensive information needed to better manage and protect this essential resource."

The 20 newly selected sites include river basins and aquifer systems in parts of 36 states and represent a wide range of environmental settings. Ultimately, the NAWQA program will cover 60 study units that account for about two-thirds of the nation's water use. Assessment of the first 20 study units began in 1991; work on the second 20 will start October 1, 1993; and assessment of the final set is scheduled for 1997.

The selection of the second set of study sites was made after reviewing the water-quality information needs identified by federal, state, and local water policy and management officials. The selection relied heavily on advice from representatives of a wide array of federal and state agencies that have responsibilities for managing water resources.

The following two study areas include parts of Washington state:

Northern Rockies Intermontane Basins

This study area covers 36,000 square miles in parts of western Montana, northern Idaho and northeastern Washington and includes three major river basins—the Clark Fork–Pend Oreille, Spokane, and Kootenai. The study area also contains the nation's largest Superfund site. Major water-quality concerns include degradation of ground water, surface water, sediment, and biota, which are mostly related to precious metal mining and mineral processing operations. Federal and state natural resource, wildlife, and water management agencies, as well as academic institutions and Indian Nations, plan to use information from the study to support decisions related to water resources, water quality, and the preservation and protection of wildlife.

Puget Sound Drainages

This study area covers 13,600 square miles of the state of Washington and is the most northwesterly major basin in the conterminous United States. The area includes Seattle–Tacoma—one of the largest urban areas in the Pacific Northwest. Significant water-quality problems in the area include the widespread occurrence of toxic organic compounds and trace elements in water resources; high levels of naturally occurring iron, manganese, and arsenic; and saltwater intrusion largely due to ground-water pumping. Other factors in its selection include substantial water use in the area, a large and growing population, and the presence of numerous national parks, Indian reservations, and military bases.

For more information, contact:

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413 National Center, Reston, VA 22092
Phone 703-648-5012

The Changing Role of Cartography in DGER—Plugging into the Geographic Information System

by Carl F. T. Harris

Over the last 10 or 15 years, the role of cartographers has changed. Cartography has expanded from making maps to creating relational databases, thereby broadening the use of maps as analytical tools. The discipline has moved away from creating historical documents toward creating data sets that represent the most current spatial and temporal relations of map information. These complex relations are best represented and used with the aid of computer hardware and software. In the field of cartography, this computer equipment is known as a Geographic Information System (GIS).

The GIS is used as a tool by professionals in almost all disciplines to store, manage, analyze, and manipulate information that is tied together by a common thread—the geographic link. This link exists at a minimum level in the cartographic control points that depict the coordinate system or grid that describes the Earth's surface. Geography is digitally added to the grid and serves as a base for other information, which is added in layers over the geography. GIS technology provides the means to integrate this information and address complex problems in ways that were formerly thought impossible. Figure 1 shows the ways in which various kinds of geographic data might be combined to address a specific need. While the integration of map information is not new, the ease with which it is now possible makes these investigations far more cost effective and achievable. Because of its broad utility, GIS technology promises to become one of the largest computer applications.

The power of a good GIS lies not in the fact that it can generate a map but that it is a database and can be queried to find answers to complex questions. For example, by assigning codes to geologic features in a GIS, a cartographer can query the system to produce a map of all rocks of a particular lithology that lie within a specified distance of a particular fault or other feature. If other data sets are available, then perhaps maps could be made to show relations between specific geologic features or hazards and population density in the state.

The Division of Geology and Earth Resources (DGER) has long recognized the potential of GIS technology for these types of analyses, as well as for its ability to control, update, and house the growing and complex geologic database. Over the past several years there has been a direct correlation between the increased use of GIS technology among government and private organizations and the number of requests to DGER for digital geologic data. At the present time, the best we can do to accommodate these requests is to provide scale-stable mylar copies of our manually prepared geologic maps and let those requesting these maps digitize their areas of interest. The original idea was that these digital data would be returned to this office for incorporation into a state-wide geologic database. The problem is that many organizations producing digital geologic data are only doing so for site-specific areas or are only using the data to produce derivative maps. As a result, most digital geologic data produced outside of this office will not be suitable for incorporation into the official state-wide geologic database.

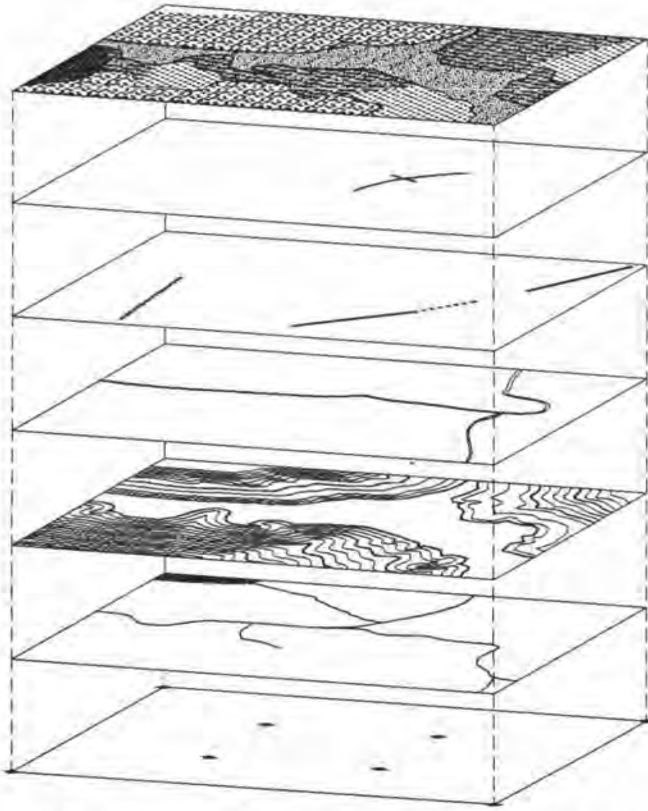

Figure 1. Schematic representation of how map data is housed in a typical GIS. Each layer (referred to as a coverage) represents a specific theme of information. Using the analytical tools of a good GIS, it is possible to gain understanding of some fairly complex relations among themes (even in an example as simple as this).

The Department of Natural Resources (DNR) is a leader in the field of GIS technology. DGER has not had the funding or cartographic staff to implement a GIS project of its own. But now that we have moved into the Natural Resources Building, this situation is changing. DGER has now acquired GIS capability from DNR and will soon be able to supply digital geologic data in addition to its traditional output of "hard copy" geologic maps and reports. The digital data will incorporate years of detailed and regional mapping from many sources into a state-wide 1:100,000-scale database derived from DGER's manually drafted 1:100,000-scale open-file map series being created through the state geological map project. Other databases, such as liquefaction susceptibility maps at 1:24,000-scale, are also envisioned as DGER products.

Assimilation of both small- and large-scale mapping can only be accommodated by careful planning. The bulk of this planning phase includes the development of a coding structure for the database that will be adequate for the state as a whole. This coding structure must include unique attributes for each type of feature found on a geologic map and will also accommodate subtle differences between similar features. For example, with the exception of faulted contacts, all types of lithologic contacts will fall within a unique range of coding values; a specific number within this range will represent each type of contact (that is, known location, gradational, or scratch boundary). With this type of coding available, the user of the database can produce a map of all contacts by specifying the code range or a map of gradational contacts by specifying the unique number used to represent those contacts. This same type of logic is being used to code all linear, point, and polygonal features that are represented on a geologic map.

A staff cartographer will be responsible for map conversion and attribute coding of features on each 1:100,000-scale geologic map. Work has begun in the southwest part of the state; the Centralia quadrangle is nearly complete. The decision to focus on the southwest part of the state reflects the need for digital geologic data to support work under way by the U.S. Geological Survey and to provide geologic hazards data to DNR's Forest Practices Division. When a workable data structure template for coding and cartographic staff time become available, DGER will be able to start releasing complete 1:100,000-scale digital geologic products for southwestern Washington in ARC/INFO® format. This is projected to happen before the end of 1993.

Funds and other resources for this project have not come from increased legislative appropriations, but rather from other divisions within DNR who see both the need for and value of a state-wide geologic data set. DGER thanks the Forest Practices Division and Division of Information Management for all their help in making available the hardware and software, as well as training and guidance, in support of DGER goals.

DGER has long believed that the most important task of a state geological survey is to keep the state geologic map up to date and readily available in its most useful form. We believe this is a good way for a state geological survey to exert a positive influence on the state's economic development, as well as aid with the protection of the state's ground water and other environmental assets. We hope to make this information available to the citizens of Washington.

Readers who have data to contribute or other input related to the completion of this mapping project should contact the cartographic staff at DGER in Olympia. See page 2 for address and telephone number. ■

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

February 1993 through May 1993

In this issue, we include for the first time a listing of selected papers about the geology of Washington that have appeared in national and international journals, symposia proceedings, and other scientific literature from January 1, 1993, through May 1993. We plan to continue this service in each issue. We'd appreciate your comments regarding this expanded coverage of the literature.

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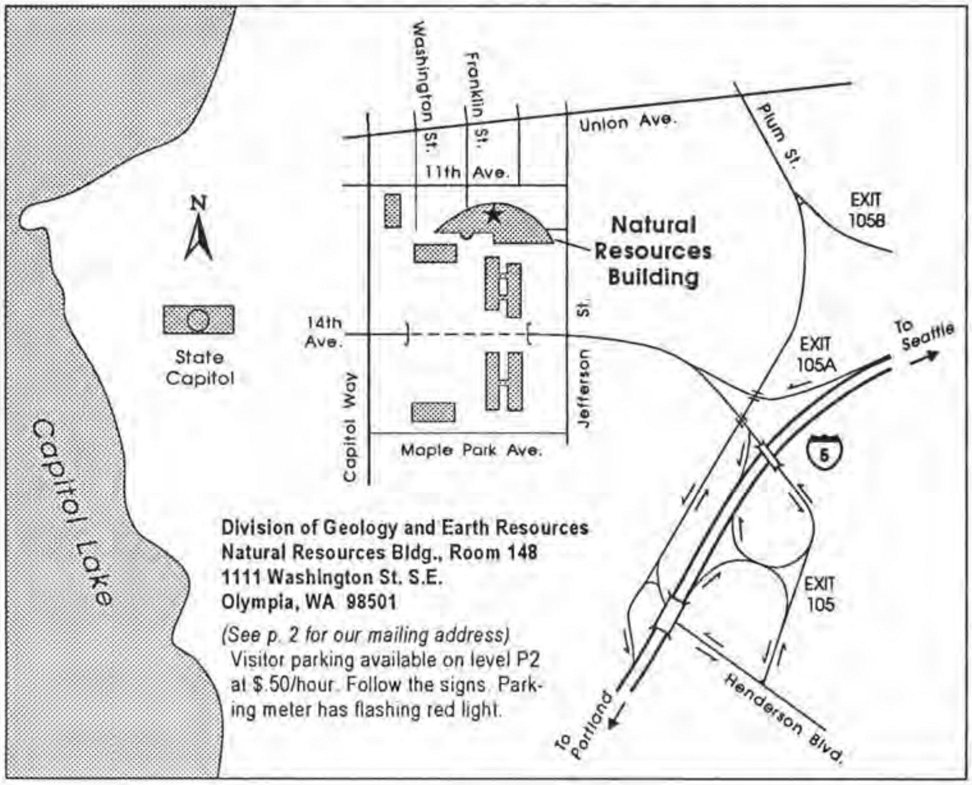

Geologic Hazards Addressed in Tacoma

On June 2, staff geologist Patrick Pringle attended the third Business Disaster Planning Conference, sponsored by the Tacoma–Pierce County Chapter of the American Red Cross, Pierce County Department of Emergency Management, the Tacoma Chamber of Commerce, and the Western Washington Emergency Network. John Nance, author of "On Shaky Ground", opened the meeting. Representatives of the Red Cross, hospitals, utilities, communications, and the military, as well as transportation, fire, and police departments, gave presentations and participated in a panel discussion on earthquake hazards and preparedness and mitigation.

Pringle gave a presentation on the geologic history of, and hazards from, Mount Rainier volcano. He has coauthored several research papers on Mount Rainier with scientists of the U.S. Geological Survey, is the Division representative to the Mount Rainier Decade Volcano project, and will be coordinating a Mount Rainier field trip for the Annual Meeting of the Geological Society of America to be held in Seattle in 1994. Recently he has participated in meetings with officials from the Pierce County Emergency Management Department, the USGS, the Veterans Administration, the City of Orting, and Orting Public Schools to discuss volcanic hazards and related issues.

Corrections

An alert reader points out that we reversed sites 1 and 12 in the map showing the locations of the National Natural Landmarks in Douglas County. Boulder Park and McNeil Canyon are on the west side of the county. Readers may want to make this correction on the map on page 39 of vol. 21, no. 1.

Further study of Republic fossil insects by entomologists shows that specimens G and I in Plate 1 of the article in vol. 20, no. 3, are termite wings, and H is a hemipteran wing.

Division Publications

Roadside geology of Mount St. Helens National Volcanic Monument and vicinity, Information Circular 88, by Patrick T. Pringle. 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 Monument visitor centers.) $3.24 + .26 tax (WA residents only) = $3.50.

Preliminary bibliography and index of the geology and mineral resources of Washington, 1992, Open File Report 93-2, compiled by Connie J. Manson. This 114-page report is available for $3.93 + .32 tax (WA residents only) = $4.25.

Geologic guidebook for Washington and adjacent areas, Information Circular 86. A limited supply of unbound copies are available for a reduced price of $8.00 (includes $.60 tax). This version can be punched for binders or easily disassembled for use on road trips.

Capitol Campus Survey. Steve Palmer and Rebecca Christie have compiled the results of a study of boreholes on the grounds of the State Capitol as one phase of a contract for the Department of General Administration. The bibliography of geotechnical reports is linked to a map showing borehole locations. The report is available for inspection in the Division library.

Out of Print

Seismic hazards of western Washington and selected adjacent areas—Bibliography and index; 1855–June 1988, Open File Report 88-4.

Antimony occurrences of Washington, Bulletin 39.

Barite in Washington, Bulletin 51

Nearly Out of Print

Limited supplies of the following reports are available. Orders will handled on a first come, first served basis. Most major libraries have copies of these reports in their collections, and copies can be consulted in our library.

- Nonmetallic mineral resources of Washington, Bulletin 33
- High-calcium limestones of eastern Washington, Bulletin 48
- Stratigraphy and foraminifera of the Satsop River area, southern Olympic Peninsula, Washington, Bulletin 53
- Building stone of Washington, Bulletin 55
- Lead-zinc deposits in the Kootenay arc, northeastern Washington and adjacent British Columbia, Bulletin 60
- Foraminifera, stratigraphy, and paleoecology of the Quinault Formation, Point Grenville–Raft River coastal area, Washington, Bulletin 62
- Distribution of copper and other metals in gully sediments of part of Okanogan County, Washington, Bulletin 65
- Saline lake deposits in Washington, Bulletin 70
- Myers Creek and Wauconda mining districts of northeastern Okanogan County, Washington, Bulletin 73
- Reconnaissance geochemical survey of gully and stream sediments, and geologic summary, in part of the Okanogan Range, Washington, Bulletin 74
- Annotated guide to sources of information on the geology, minerals, and ground water resources of the Puget Sound region, Washington, King County Section, Information Circular 61
- Mount St. Helens—Annotated index to video archives, Information Circular 76
- Earthquake hypocenters in Washington and Oregon 1982-1986, Information Circular 84
- Preliminary geologic map of the Chewelah Mountain quadrangle, Stevens County Washington, Geologic Map GM-5
- Mineral resources of the southern Hood Canal area, Washington, Geologic Map GM-21
- Geologic map of the Clarkston 15-minute quadrangle, Washington and Idaho, Geologic Map GM-31

County Bibliographies Updated

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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