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MOUNT BAKER'S CHANGING FUMAROLES

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Introduction

On March 10, 1975, a dark fume cloud rising a few hundred meters above the subsummit crater (Sherman Crater) of 3,286-m-high (10,781-ft-high) Mount Baker (Figures 1 and 2) in the North Cascade Mountains of Washington generated considerable concern among scientists, government officials, and local residents (Frank and others, 1977; Kiver, 1975; Malone and Frank, 1975;

and Rosenfeld and Schlicker, 1976). The substantial increase in gas volume, temperature, and certain gaseous components makes Sherman Crater one of the more interesting fumarolic areas in the conterminous United States.

Because no significant additional volcanic manifestations have occurred since 1975, the intense concern over the mountain's immediate future has subsided. Nearby reservoirs have been raised to normal levels and most restrictions on public use of the area have been removed.

The present

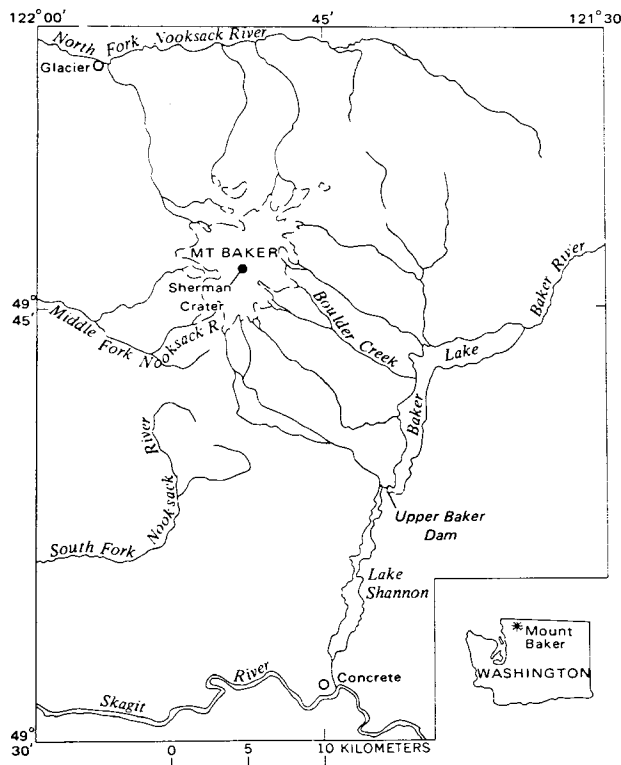


Figure 1. Index map of Mount Baker, Wash.
(Reprinted from Frank and others, 1977)



Figure 2. Sherman Crater viewed from south in March 1975. Note vapor plumes from west rim (left) and East Gap areas. Summit crater is ice filled and thermally inactive.

activity, however, could yet prove to be a pre-eruptive phenomenon. Even if the volcano does not erupt, continuing shifts in fumarole location and the elevated level of thermal activity have greatly increased the probability of large, destructive mudslides and avalanches.

A geothermal ice cave and fumarole study initiated in 1974 in Sherman Crater and continued to the present enables documentation of some of the physical and chemical conditions before and after the March 1975 event. The knowledge and experience gained at Mount Baker should prove useful in evaluating future thermal manifestations from Mount Baker and other dormant volcanoes in the Cascade Mountains of both Washington and Oregon.

Fumarolic Activity, Pre-1975

No doubt Mount Baker's fumaroles have been active since at least the 1840's, when relatively reliable accounts indicated minor eruptive activity. Gibbs (1874) noted that since the 1843 eruption, ". . . smoke is frequently seen issuing from the mountain." Whether the reference to "smoke" indicates fumarolic vapor or the more violent but minor eruptive activities of 1846 (Plummer, 1893), 1854, 1858, 1859, and 1870 (Davidson, 1885) is not clear. E.T. Coleman's party, during the first successful

ascent of Mount Baker in 1868, and subsequent climbing groups reported sulfurous fumes and fumarolic activity in Sherman Crater (Coleman, 1869).

By 1940, when the first vertical air photos of Mount Baker were taken, fumarole activity had increased over the late 1800-early 1900 level (Frank and others, 1977). In the 1940 photographs, fumarole vents and ice cave entrances were apparent on the west and northwest rim, and sub-ice fumaroles had melted an estimated 1,220 m (4,000 ft) of ice cave passages at the base of the crater ice fill. The largest fumarole was at the base of an ice pit 20 to 30 m (65 to 100 ft) deep near a crater rim breach called the East Gap.

Air photos taken during the period from 1940 to 1974 show additional snow melt areas, indicating an increased heat flux. The largest change occurred in the southwest part of the crater, where an ice pit 46 m (150 ft) deep and 32 m (110 ft) wide appeared some time between the 1960-63 airphoto flights (Figure 3).

In August 1974, maximum fumarole temperatures were at the boiling point of water (89-90°C) for this elevation of 2,950 m (9,650 ft). Volcanic gases were measured with commercially available detector tubes in which a known quantity of gas is pumped through a glass tube filled with chemical reagents. The length of the colorimetric reaction of the reagents is proportional to the amount of a specific gas in the sample after pressure and temperature corrections are made. The results are reproducible to within ± 10 percent. In 1974, the CO₂ content of gases taken from the west rim fumaroles measured 19 percent; H₂S content was 0.0074 percent.

Recent Fumarolic Activity

An estimated tenfold increase in heat flux in March 1975 was accompanied by the appearance of new, superheated fumaroles (maximum measured temperature 131°C), numerous cooler fumaroles, a fallout layer of dust from a new vent in the East Gap, a doubling of CO₂, a thousandfold increase in H₂S, and considerable melting of the crater ice fill (Figures 4 and 5). Any one of these changes could be a precursor to a true magmatic eruption. The grey dust cloud in early 1975 was associated with an enlarging steam vent in the East Gap. The ash and pumice fragments ejected are now regarded not as new magmatic material but as older debris torn from the enlarging vent wall (Frank and others, 1977).

The enlargement of the sub-ice cave system (Figure 6) and the crevassing and collapse of the crater ice fill proceeded rapidly during 1975 (Figures 7 and 8) but subsequently slowed as ice came into equilibrium with the new thermal conditions. Occasional major shifts in fumarole location are still occurring and can cause some new adjustments in the ice fill. The present trend seems to involve increasing fumarole activity on the west rim (Figure 9) at



Figure 3. Southwest ice pit that appeared between 1960 and 1963. Large fumarole at base increased in intensity in 1975 but had moderated greatly by summer of 1977. (Photo courtesy Fred Munich)



Figure 4. East Gap superheated fumaroles building sulfur cones. Small puddle of molten sulfur was found just inside vent in foreground. (Photo courtesy Fred Munich)



Figure 5. Crater lake and large ice pit generated by increased fumarole activity in 1975. Lake is 40 x 60 m (130 x 200 ft) long, 1 m (3 ft) deep, and has water temperature of 20°C. Water flows through syphon at base of ice wall into East Gap beyond. Increased melting produced rapid subsidence and synclinal form in dark, annual accumulation layers on 27-m-high (89-ft-high) ice wall. (Photo courtesy Fred Munich)

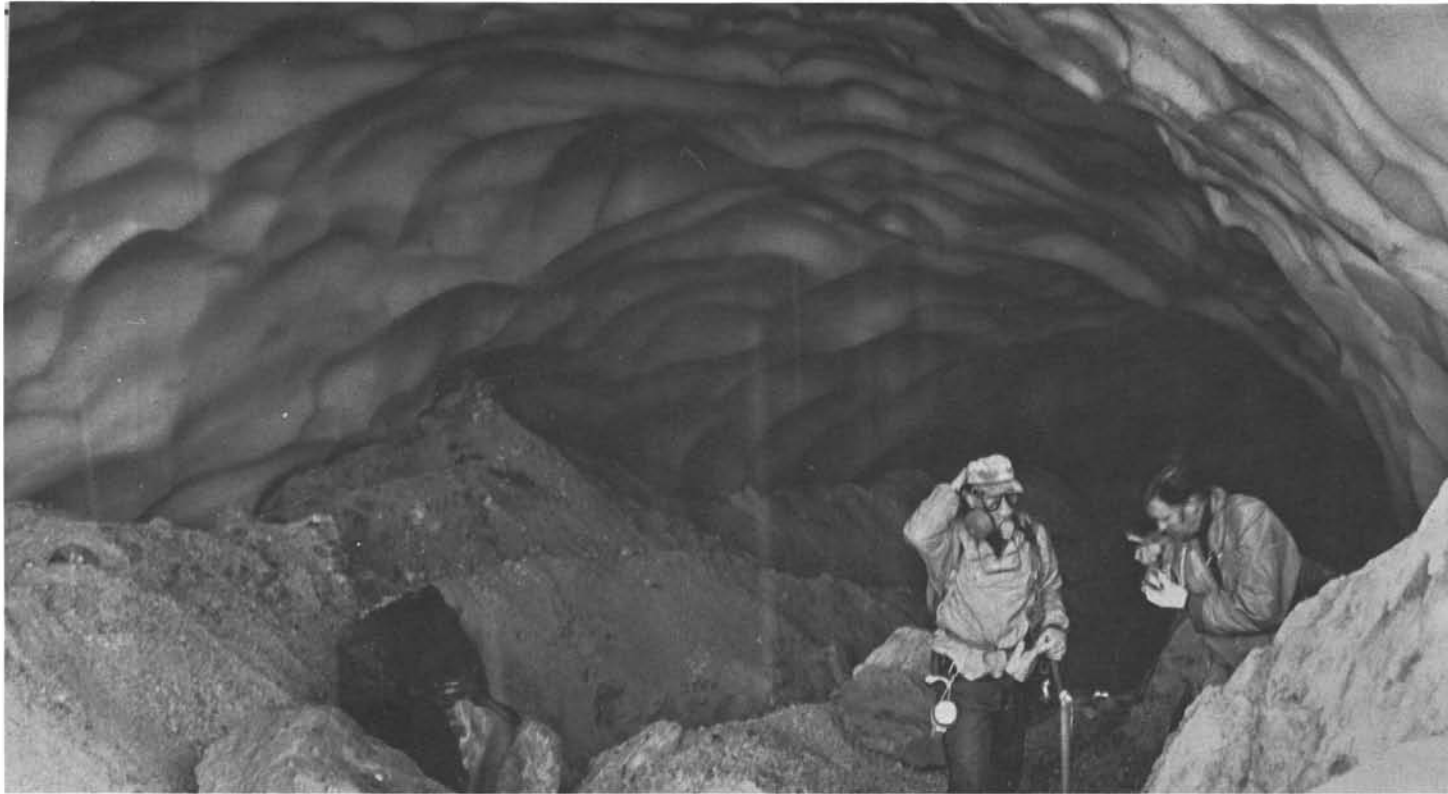


Figure 6. Geothermal ice cave entrance along west rim of Sherman Crater. Fluted ice walls and ceilings and bedrock or rubble floors are typical. Gas masks are necessary for prolonged exposure to sulfur and CO₂ atmosphere. Increased heat flux enlarged cross-sectional area of cave passages approximately 20 percent. (Photo courtesy Fred Munich)



Figure 7. East Gap area in 1975 as large new fumaroles melt away east edge of crater ice fill. (Photo courtesy Fred Munich)



Figure 8. Large, superheated fumarole ($T. > 110^{\circ}\text{C}$) developed in 1975 under glacier on northwest side of crater, creating large ice pit that enlarged in 1976. Overhanging ice collapsed in 1977, and ice blocks buried east side of crater. (Photo courtesy Fred Munich)



Figure 9. View south along part of west rim of Sherman Crater. Some shifting of thermal energy from other fumarole areas to west rim occurred in 1977. (Photo courtesy Fred Munich)

the expense of fumaroles in the central vent (crater lake) and perhaps the East Gap areas. Total gas volume from Sherman Crater since March 1975 appears to be unchanged.

The most recent change was first noted during a March 1978 overflight. At the time of this printing, steam is discharging violently from a new vent system along the northwest rim of the crater where only small fumaroles formerly existed. Although discharge has fluctuated during the past few years, the total gas has remained well above 1974 levels and shows no signs of decreasing.

Volcanic Gas Composition

Increases in concentration of sulfur and other gases can be ominous signs preceding major eruptions (Tonani, 1971). Dramatic increases in concentration occurred from August 1974 through early September 1975 in at least the west rim fumarole field. The concentration of CO_2 by volume nearly doubled, and H_2S increased over 1,000 times (Figure 10). Using airplane-mounted instruments, Radke and others (1976) measured a 3.7-fold increase of gaseous sulfur in the steam plume between March 27 and June 30, 1975. With an emission of 4,680 kg (10,300 lb) per hour, Mount Baker became one of the largest sulfur polluters in the Pacific Northwest.

The 1976 and 1977 analyses show a reduction and leveling off of CO_2 and H_2S (Figure 10), suggesting that the volcano is now less likely to erupt than seemed possible earlier. However, gas concentrations remain substantially above the 1974 level and should continue to be monitored.

Some Conclusions and Observations

(1) Small increases in thermal activity preceded by many years the 1975 steam eruption at Mount Baker. Similar types of changes on other Cascade volcanoes, if recognized, might give considerable warning of an impending volcanic event.

(2) Eruptions from at least some of the Cascade volcanoes in Washington and Oregon are inevitable. Long-term detailed geochemical and geophysical studies of all dormant Cascade volcanoes should be initiated so that repose conditions can be better understood and changes that may later prove to have predictive value can be recognized.

(3) The meaning of the increased thermal activity that began in March 1975 on Mount Baker is still unclear. It may have been a pre-eruptive signal, but its true significance may not be realized for many years.

(4) Considerable shifting of vent locations in the crater has occurred since 1975. These dramatic changes are apparently

MOUNT BAKER, WEST RIM
MAXIMUM CO₂ AND H₂S CONCENTRATION

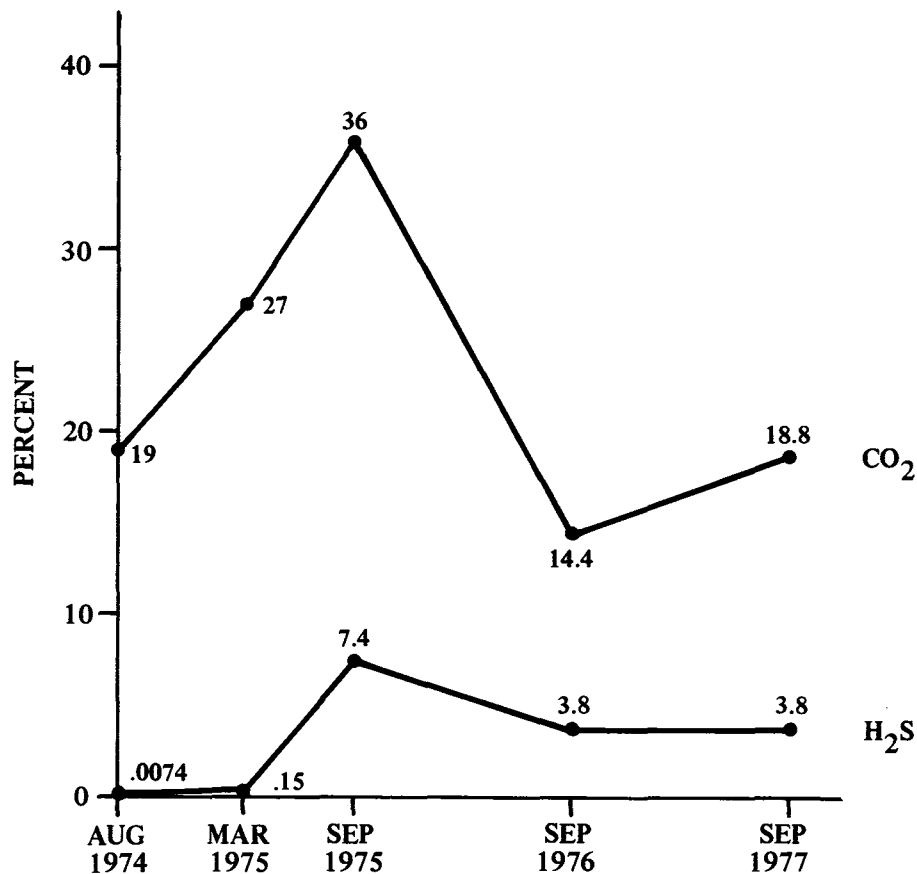


Figure 10. Hydrogen sulfide and carbon dioxide concentrations, 1974-1977.

related to gases finding new pathways through the highly fractured, altered rock in the crater area. This type of change, as well as apparent changes in visible steam emission that accompany cold weather conditions, have no relation to the volcano's eruptive potential.

(5) Floods and mudflows are the most common geologic hazards associated with volcanoes of the Cascade Mountain type, both in Washington and in Oregon. Mudflows are mixtures of water and debris that can move at more than 80 km (50 mi) per hour on steep slopes and cover the valleys below in a matter of minutes. Mudflows are sure to occur in a true eruption but can also be triggered during noneruptive phases by earthquakes, landslides, and steam activity.

The highly altered rock, oversteepened slopes, and abundance of meltwater in the crater area create an ideal situation for generating destructive mudflows. The shifting fumarole activity suggests structurally weak rock and sediment that could be water-saturated and capable of rapid, catastrophic movement.

(6) As man makes increasing use of land surrounding Mount Baker and the other Cascade volcanoes, it becomes imperative to recognize the potential hazards associated with these giant volcanoes and use the surrounding lands in such a way that losses in life and property will be minimized.

Acknowledgments

Sincere thanks to the Explorers Club, Mazamas, and National Speleological Society for their financial assistance and to Rod Barcklay, Gerard and Trudie Bloem, Ernest Gilmour, Steve Harris, Roger Hughes, Steve Malone, Fred Munich, Felix and John Mutschler, Jack and Donna Snavely, William Steele, and Don Swanson for their efforts in making this research possible.

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DOMESTIC EXPLORATION FOR MATERIALS

Philip H. Abelson, *Science* Editor

[Excerpts reprinted by verbal permission from *Science*, July 7, 1978, v. 201, no. 4350, p. 7.]

A civilization with a high standard of living is dependent on adequate supplies of many kinds of materials. Some elements are of critical importance. For example, chromium is an essential component of low-corroding stainless steels. Cobalt is needed to bond diamonds in cutting tools. The United States is dependent on outside sources for supplies of these and more than a score of other elements.

This country began the 20th century with more than its share of easily exploitable domestic resources. American prosperity and assurance of raw materials were reinforced by the results of geologic exploration elsewhere. Therefore, in the 1950's and early 1960's large parts of the world's oil and mineral reserves were owned by American companies. Most of the remaining reserves were under the control of friendly, stable governments. But great changes have occurred. The future of much of Africa is uncertain. American domination of foreign resources has ended. A long-term decline in the grade of domestic ore reserves has continued.

With an economy increasingly vulnerable to disruptions of supplies, with security of supplies uncertain, and with a diminished ability to pay for imports, intensified efforts to lessen U.S. dependence on foreign sources are needed.

Thus far there has been little action by the federal government; on balance, the government has hindered efforts to increase mineral supplies. During the past decade large areas of the most promising public lands have been closed to exploration. . . .

The quest for ore deposits is handicapped by lack of knowledge of how elements are mobilized in the earth. Many of them are present in an average abundance of a few parts per million or less. But when found in ores they may have been concentrated by a factor of 10^4 or more.

Processes relevant to the genesis of ore deposits probably go back to the beginning of the solar system. Apparently this planet was assembled from heterogeneous materials and some of the heterogeneity persists on a large scale. The earth has been a laboratory in which many chemical separations have occurred. . . .

Most of the ore that has been found in this country was discovered by primitive techniques—you might say, by stumbling over it. Recently, the discovery process has been aided by results from Landsat satellites and by the concept of colliding tectonic plates,

but much of the physical chemistry of the mobilization of elements remains a mystery. For example, many ores occur as insoluble sulfides. How were the cations concentrated and brought to their final position? Where did the sulfur come from? If we understood this process and others we could predict much better where and how to explore for ores.

A decade or more elapses from the time of discovery of an ore body to exploitation. If this country is not to become a pawn in an international game of materials, it must begin to develop a more vigorous materials policy.

* * * * *

MOUNT HOOD GEOTHERMAL RESOURCE ASSESSMENT PROGRAM ANNOUNCED

The Oregon Department of Geology and Mineral Industries plans to drill 10 to 15 holes between 500 to 1,500 ft deep on the surrounding Mount Hood to test temperature gradients. The drilling program, scheduled to begin August 15, 1978, will last for two to three months.

Drilling on the 2,000-ft temperature gradient hole began July 20, 1978, at Timberline Lodge on the south side of Mount Hood. The hole is being drilled by Northwest Natural Gas for Wy'East Exploration and Development Company to test the possibility of the existence of hot water in the Pliocene-Pleistocene flows forming Mount Hood. Craig White, University of Oregon, will age date some of the flows with cuttings from drilling.

Drilling by Northwest Natural Gas is scheduled to commence August 1, 1978, to deepen the Old Maid Flat hole on the west side of Mount Hood from an existing depth of 1,850 ft to 4,000 ft. This hole, which will provide temperature gradient data and chip samples that can be used to determine stratigraphic sequence, is presently in late Miocene-early Pliocene Rhododendron Formation but is expected to reach and test the possibility of hot water in the underlying Miocene Columbia River Basalt. If fluids are encountered, geochemical fluid analyses will be conducted. Basalt chip samples will be analyzed by Marvin Beeson, Portland State University, as part of his study of the stratigraphy of the Columbia River Basalt surrounding Mount Hood.

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GEOLOGISTS APPLY FOR REGISTRATION

As of July 21, 1978, 460 geologist applications and 262 engineering geologist applications have been received by the Geologist Licensing Board. Applications have come from South America, South Africa, Singapore, and Europe. After September 30, 1978, qualified geologists will be required to pass a written examination before being registered.

NEW BIBLIOGRAPHY SUPPLEMENT RELEASED

Latest publication released by the Department is Bulletin 97, Bibliography of the Geology and Mineral Resources of Oregon [Sixth Supplement].

The list was prepared by GeoRef, the American Geological Institute's computer data base service. The Department's librarian cooperated in the effort by obtaining information not already in GeoRef. The result is a most comprehensive compilation.

Bulletin 97 contains some 1,400 items published during the period from January 1, 1970, through December 31, 1975. Contents include a list of some 150 serials, the bibliography itself, subject index, county index, and rock-unit index.

Sale price is \$3.00. See inside front cover for addresses of Department offices where Bulletin 97 may be purchased.

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DRILLING HALTED ON COLUMBIA COUNTY GAS TEST

Reichhold Energy Corporation, Tacoma, Washington, suspended drilling on its fourth shallow gas test hole in Columbia County on July 18, 1978, at a depth of 2,780 ft. The "DSC - Columbia County No. 2" was located in the NE 1/4 sec. 14, T. 6 N., R. 5 W., approximately three-fourths of a mile northwest from the town of Mist. Reichhold also has put down gas test holes in Tillamook, Polk, and Marion Counties. The company has not announced any commercial discoveries for the seven wildcats drilled thus far in northwestern Oregon.

Diamond Shamrock Corporation, Houston independent, was a partner on the last three holes in Columbia County.

* * * * *

MOBIL OIL SPUDS OAKLAND GAS TEST

Mobil began drilling July 10, 1978, on what will very likely be the deepest well yet drilled in Oregon. The company plans to drill to a depth of 14,000 ft at a location 4 mi east of the town of Oakland. The site is located in the SW 1/4 sec. 36, T. 24 S., R. 5 W., Douglas County. Drilling began in the Roseburg Formation (lower part of what was formerly called the Umpqua Formation, lower Eocene age). Mobil hopes to explore pre-Tertiary rocks at this location with natural gas production as the objective.

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