Fall 2006


Janna Juday
Western Washington University

Follow this and additional works at: https://cedar.wwu.edu/wwuet

Part of the Geology Commons

Recommended Citation
https://cedar.wwu.edu/wwuet/846

This Masters Thesis is brought to you for free and open access by the WWU Graduate and Undergraduate Scholarship at Western CEDAR. It has been accepted for inclusion in WWU Graduate School Collection by an authorized administrator of Western CEDAR. For more information, please contact westerncedar@wwu.edu.
A CONTEMPORARY REVIEW OF 1975-1976
ELEVATED ACTIVITY LEVELS AT THE MOUNT BAKER
COMPLEX, WASHINGTON, AND CURRENT COMMUNITY AWARENESS OF
VOLCANIC HAZARDS

by

Janna Juday

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

Moheb A. Ghali, Dean of the Graduate School

ADVISORY COMMITTEE

Dr. Sue DeBari

Dr. Chris Newhall

Dr. Scott Babcock
In presenting this thesis in partial fulfillment of the requirements for a master’s degree at Western Washington University, I agree that the Library shall make its copies freely available for inspection. I further agree that copying of this thesis in whole or in part is allowable only for scholarly purposes. It is understood, however, that any copying or publication of this thesis project for commercial purposes, or for financial gain, shall not be allowed without my written permission.

Signature

Date

November 6, 2006
MASTER'S THESIS

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Western Washington University, I grant to Western Washington University the non-exclusive royalty-free right to archive, reproduce, distribute, and display the thesis in any and all forms, including electronic format, via any digital library mechanisms maintained by WWU.

I represent and warrant this is my original work and does not infringe or violate any rights of others. I warrant that I have obtained written permissions from the owner of any third party copyrighted material included in these files.

I acknowledge that I retain ownership rights to the copyright of this work, including but not limited to the right to use all or part of this work in future works, such as articles or books.

Library users are granted permission for individual, research and non-commercial reproduction of this work for educational purposes only. Any further digital posting of this document requires specific permission from the author.

Any copying or publication of this thesis for commercial purposes, or for financial gain, is not allowed without my written permission.

Name: Janna Judd

Signature: 

Date: 12/11/2018
A CONTEMPORARY REVIEW OF 1975-1976 ELEVATED ACTIVITY LEVELS AT THE MOUNT BAKER COMPLEX, WASHINGTON, AND CURRENT COMMUNITY AWARENESS OF VOLCANIC HAZARDS

A Thesis presented
to the faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Janna Juday

November 2006
ABSTRACT

This investigation seeks to understand the changes in the associated volcanic and human systems during and after the 1975-1976 sudden thermal events at Mount Baker volcano. Included are reviews of some of the conclusions made by scientists from the U.S. Geological Survey and universities around the U.S. during that event. A questionnaire was also presented to people in communities around the volcano to outline current understanding of volcanic activity and hazards associated with Mount Baker.

The source of the Mount Baker thermal activity in 1975-1976 was never conclusively identified at the time. There appears to have been a small decrease in the amount of thermal activity since 1975, but thermal activity levels have never returned to their pre-1975 levels. Little has changed in the structure of the volcano: weaknesses identified in 1975-1976 in the hydrothermally altered material that comprises the bulk of the summit of Mount Baker still exist today.

Four hypotheses about the source of thermal activity at Mount Baker in 1975-1976 were presented to scientists that worked on, or are working on, Mount Baker. This method was intended to gain perspective about what has changed in our understanding of volcanic activity in general and about Mount Baker. The results helped focus my research on pertinent data that helped identify probable sources of the thermal activity. Most importantly, gas analyses have identified the presence of carbon dioxide and hydrogen sulfide in a plume above the volcano indicative of magma present in the volcanic system. Thus, activity in 1975-1976 might have been magmatic in nature and not strictly hydrothermal in nature as has been previously accepted.
This investigation also describes community awareness of volcanic understanding including hazards associated with Mount Baker to better illuminate the connection between a volcano and its surrounding communities. A questionnaire asked individuals around Mount Baker about: 1975-1976 events, Mount Baker volcanics, and volcanology in general. Although construction of the questionnaire proved problematic, some facts are clear. Some individuals have misconceptions about the hazards associated with Mount Baker, including concerns of lava flows disrupting their towns. Individuals are willing to comply with officials in most situations, but not all of them would be willing to leave their homes. Also, most individuals interviewed were unaware of a hazard assessment issued for the public by the U.S. Geological Survey, and individuals have spent little to no time exploring the educational resources already available. These findings indicate that a more active outreach program is necessary to educate the people in surrounding communities about hazards at Mount Baker.

The 1975-1976 events at Mount Baker can be better explained today in light of our new understandings and the technology available to volcanologists. Also, the educational needs of the surrounding communities can be outlined with the use of a community survey, thus facilitating future educational outreach opportunities.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT ....................................................................................................................... iv</td>
</tr>
<tr>
<td>LIST OF TABLES .............................................................................................................. ix</td>
</tr>
<tr>
<td>LIST OF FIGURES ........................................................................................................... x</td>
</tr>
<tr>
<td>INTRODUCTION TO THE THESIS .................................................................................. I</td>
</tr>
<tr>
<td>CHAPTER 1: INTRODUCTION ................................................................................ I</td>
</tr>
<tr>
<td>PART 1: MOUNT BAKER GEOLOGY AND INTERPRETATION ........................................... 5</td>
</tr>
<tr>
<td>CHAPTER 2: Historical Mount Baker Activity pre-1975 ............................................ 6</td>
</tr>
<tr>
<td>Location ............................................................................................................... 6</td>
</tr>
<tr>
<td>Geologic History of Mount Baker ........................................................................ 6</td>
</tr>
<tr>
<td>Pre-1975 Historical Activity ............................................................................. 9</td>
</tr>
<tr>
<td>Synthesis ............................................................................................................ 14</td>
</tr>
<tr>
<td>CHAPTER 3: 1975-1976 Thermal Events at Mount Baker ........................................ 16</td>
</tr>
<tr>
<td>Tephra .............................................................................................................. 16</td>
</tr>
<tr>
<td>Heat Flux and Snow Melt .............................................................................. 18</td>
</tr>
<tr>
<td>Water Chemistry .......................................................................................... 20</td>
</tr>
<tr>
<td>Geophysical Analysis ................................................................................ 21</td>
</tr>
<tr>
<td>Initial 1975-1976 Interpretations ................................................................ 23</td>
</tr>
<tr>
<td>CHAPTER 4: Modern Interpretation of 1975-1976 Events ....................................... 27</td>
</tr>
<tr>
<td>Seismicity ......................................................................................................... 28</td>
</tr>
<tr>
<td>Deformation .................................................................................................. 32</td>
</tr>
</tbody>
</table>
Geochemistry and what it means to future studies ........................................36
Geologic Studies at Mount Baker since 1980 ..............................................38
Evaluation of Four Hypotheses ..................................................................44

PART II: COMMUNITY AWARENESS OF NAT. HAZ. AT MOUNT BAKER ..........52

CHAPTER 5: Introduction .............................................................................53
Cognitive Background ................................................................................53
Politics ........................................................................................................59
Effective Communication ...........................................................................63
Mitigation and Preparation .........................................................................66
Psychologists and the advent of community surveys ...............................70
Community perception ...............................................................................71
1976 Survey: Local response to activity at Mount Baker .........................77
Conclusion .................................................................................................79

Chapter 6: Methods ....................................................................................83
What is needed in a Questionnaire? ............................................................83
2003 Questionnaire for residents around Mount Baker ............................84

Chapter 7: Results and Interpretations .......................................................87
Limitations to the 2003 Survey ................................................................101

Part III: Educational Outreach Plan ..........................................................105

Chapter 8: Education Plan .........................................................................106
Volcano Primer ........................................................................................109
Past the Primer: Gaining People’s Trust .......................................................113
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>List of Mount Baker eruptions</td>
<td>148</td>
</tr>
<tr>
<td>2</td>
<td>Table of data for hydrogeochemistry test comparing 1975 and 2002 readings</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>Table of raw frequency data from community questionnaire</td>
<td>151</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location map of Mount Baker</td>
<td>156</td>
</tr>
<tr>
<td>2</td>
<td>Location map of geologic features of Mount Baker</td>
<td>157</td>
</tr>
<tr>
<td>3</td>
<td>Location map of notable features at Mount Baker</td>
<td>158</td>
</tr>
<tr>
<td>4</td>
<td>Photo looking southwest</td>
<td>159</td>
</tr>
<tr>
<td>5</td>
<td>Contour map of Sherman Crater showing thermal areas for 1908-1956</td>
<td>160</td>
</tr>
<tr>
<td>6</td>
<td>Contour map of Sherman Crater showing thermal areas for 1960-1963</td>
<td>161</td>
</tr>
<tr>
<td>7</td>
<td>Contour map of Sherman Crater showing thermal areas for 1966-1972</td>
<td>162</td>
</tr>
<tr>
<td>8</td>
<td>Cross section of Sherman Crater</td>
<td>163</td>
</tr>
<tr>
<td>9</td>
<td>Contour map of Sherman Crater showing thermal areas for March 24, 1975</td>
<td>164</td>
</tr>
<tr>
<td>10</td>
<td>Contour map of Sherman Crater showing thermal areas for July 20, 1975</td>
<td>165</td>
</tr>
<tr>
<td>11</td>
<td>Contour map of Sherman Crater showing thermal areas for September, 1975</td>
<td>166</td>
</tr>
<tr>
<td>12</td>
<td>Map of Mount Baker region showing towns and populations</td>
<td>167</td>
</tr>
<tr>
<td>13</td>
<td>Chart showing number of respondents in towns and regions</td>
<td>168</td>
</tr>
<tr>
<td>14</td>
<td>Chart showing results of community survey question #4</td>
<td>169</td>
</tr>
<tr>
<td>15</td>
<td>Chart showing results of community survey question #16</td>
<td>170</td>
</tr>
<tr>
<td>16</td>
<td>Detail of Mount Baker showing remnant eruptive features</td>
<td>171</td>
</tr>
</tbody>
</table>
Chapter 1: Introduction

On March 10, 1975, observers near Mount Baker volcano in Washington State noticed a larger than normal dark gray vapor plume rising over Mount Baker (Appendix 4: Ashe 1975). Aerial observations of the Sherman Crater area later that day and in following days found that much of the glacial ice and snow usually present in the crater had melted, exposing bare rock, new pits, and fumaroles. Many new and highly active fumaroles sparked concern for an eruption at Mount Baker, resulting in new monitoring (Frank et al., 1977). Elevated thermal activity levels at Mount Baker kept scientists involved until, in 1980, more immediate threats were realized at Mount St. Helens.

The increased activity at Mount Baker could have affected not only the geologic future of the region, but also the people that live around the volcano. Direct impacts from this activity upon the communities immediately adjacent to the volcano include the Sherman Crater and Boulder Creek drainage areas being closed to the public (Frank et al., 1977), campgrounds being closed, and the town of Concrete losing summer income from recreational visitors to the area (Hodge et al., 1979). Although volcanic systems operate independently of human systems (people, communities, property, jobs, etc.), the same cannot always be said about the human systems around a volcano; as population increases, more humans live in active volcanic environments and the human system is affected more directly by volcanic activity.

Because of this association between the volcanic and human systems, in many cases it is useful to not only study a volcano, but also the effects of that volcano on the people around it. The impacts of activity at a volcano can have a very large effect on the human system. For example, even though Mount St. Helens might again have an eruption
that destroys the building lava dome, the effect of that small eruption will have less impact on the volcano than it will upon the surrounding communities. The destruction of the lava dome might erupt a fraction of a cubic kilometer – not even measuring on the Volcanic Explosivity Index. However, the impact upon the surrounding communities could be significant, from possible lahar flows backing up the Toutle River to aircraft being diverted in order to avoid ash clogging their engines. As well, the economic impacts could be large, such as the necessary dredging of the Toutle and Columbia Rivers as well as the possible lost timber revenue in the area. Thus, the volcano could suffer small effects, but the human system around the volcano could suffer greatly.

Volcanologists are the interpreters of volcanoes, trying to decipher volcanic activity and identify the causes and effects of that activity. One of the main reasons that volcanologists attempt to understand these active mountains is to warn and prepare communities around them. Without communication from volcanologists, many eruptions could have been catastrophic. For example, the tragedy of 22,000 deaths in 1985 because of the Nevada del Ruiz volcano in Columbia could have been minimized with better communication between scientists and the surrounding communities (Alexander, 1993).

The research presented here aims to bridge the gap between the volcanic and human systems at Mount Baker volcano in Washington State. At Mount Baker, surrounding communities have never been faced with a disaster related to volcanism. There is a need, however, to educate the communities before an event leaves people without the necessary knowledge of how to react in a dangerous situation.

This thesis has been divided into three parts. The first part discusses the history of the Mount Baker volcanic system (Chapters 2-4). The second part reviews the
community awareness of volcanic hazards and the needs of future education on the topic of volcanic hazards in the region (Chapters 5-7). The final part outlines an educational outreach plan (Chapter 8). This outreach plan is based, in part, upon the results of the volcanic history and community awareness chapters. It is this part that makes the connection between the volcano and the surrounding communities.

Chapter Two is a brief review of the past history of the Mount Baker complex. It covers the geologic history as well as historical observations at Mount Baker up to 1975.

Chapter Three is a discussion of the 1975-1976 thermal activity. This includes analyses of crater observations, seismic, geochemical, gravity, and tilt measurements. Conclusions by scientists that worked on Mount Baker regarding the source of the thermal activity are also included.

Chapter Four is a modern interpretation of the 1975 thermal event, including discussions of some of the new technology that may help better decipher the source of activity in review. Scientists that worked on Mount Baker during the 1975-1976 thermal events were interviewed about what they think now after the intervening 31 years with new tests and understanding of volcanology. There are new interpretations of volcanic systems that may shed light on the source of the Mount Baker activity.

Part Two reviews community awareness of natural hazards in the Mount Baker region. Chapter Five is a discussion of the need for educational research on volcanic and natural hazards awareness. Chapter Five also includes a section on a 1976 study of local response to the 1975-1976 thermal events.
Chapter Six is a discussion of the methods used to conduct the volcanic hazards questionnaire. Covered in the chapter is a section on the populations polled, the questionnaire itself, and the tests used to analyze the questionnaire.

Chapter Seven presents the results and interpretations of the volcanic hazards questionnaire. There were many useful responses as well as advice from the people who responded to the questionnaire. Most of the responses will be useful in the future to design an educational outreach into the Mount Baker region.

Chapter Eight comprises Part 3 and is an outline of an educational outreach plan based on the results from Parts 1 and 2. This last chapter represents the synthesis of two very different systems, the volcanic and the human, and outlines ways in which the human system can help prepare to deal with volcanic activity in the Mount Baker region in the future.

It is through a thorough understanding of both systems that a useful plan can be created to prepare populations in volcanic regions to deal with volcanic activity. To look at the volcanic system without designing methods for the human system to survive near it, is to disregard one of the goals of volcanology.
PART I:

Mount Baker Geology and Interpretation
Chapter 2: Historical Mount Baker Activity pre-1975

Location

Mount Baker is located at the north end of the Cascades Range in the United States in northern Washington State (Figure 1). With a summit elevation of 3285 meters (10788 ft.), Mount Baker is a relatively quiet Quaternary stratovolcano made up mainly of andesitic lava flows and breccias (Hyde and Crandell, 1978; Hildreth et al., 2003). Mount Baker is in fact one of the largest andesitic complexes in the region, composed of an estimated volume of 72 km$^3$ of volcanic material (Hickson, 1994). Mount Baker volcano is formed by magmas related to the subduction of the Juan de Fuca plate below the North American plate at roughly a rate of 4.5 cm/yr (Riddihough et al., 1983).

Geologic History of Mount Baker

Before construction of the current Mount Baker stratocone, there were a series of other volcanic structures in the area (Table 1). The formation of Kulshan caldera at ca. 1.15 Ma (see Figure 2) was the largest eruption in the Baker region, ejecting more than 50 km$^3$ of rhyodacite magma from a shallow chamber and ending in a caldera collapse (Hildreth, 1996). Since this eruption, there have been many changes, from the volcanic vent location to eruption style (see Hildreth et al., 2003 for a more inclusive list of eruptions at Mount Baker). The Black Buttes stratovolcano, located just west of the site of the current Mount Baker, was formed after the Kulshan eruption along with a complex of nearby smaller vents (0.5-0.2 Ma, Hildreth et al., 2003).
The current edifice of Mount Baker began construction about 40 ka on top of the remains of the Black Buttes. The last major period of eruptive activity was about 12 ka. The current Mount Baker edifice is mainly andesitic in composition, compared to the rhyodacitic Kulshan caldera magmas.

The last major magmatic eruption of Mount Baker was at roughly 6.5 ka (Kovanen et al., 2001; Hildreth et al., 2003). There have been some reports of small ash eruptions from 5.5 to 5.7 ka with numerous lahar flows even more recently (Kovanen et al., 2001). This eruption left behind pumice and ash covering more than 20 km² (Hildreth et al., 2003). There is also a white-to-yellow/orange second layer coupled with the andesitic ash suggestive of a hydrothermal explosion that followed the initial volcanic eruption. These deposits came from Sherman Crater (see Figure 3), not the summit of Mount Baker (Hildreth et al., 2003).

The geologic history of the current Mount Baker for roughly the past 14,000 years indicates very few large explosive eruptions (Hyde and Crandell, 1978; Hildreth et al., 2003). The current Mount Baker cone has a history of pyroclastic flows, lahars, tephra eruptions, and lava flows (Kovanen et al., 2001). It has had very few catastrophic explosive eruptions with Volcanic Explosivity Index greater than 3 recorded in visible deposits (Kovanen et al., 2001). Most of the past lava flows are andesitic, basaltic, or a basalt-andesite mixture (Green, 1988). There are geologic records of lahar flows reaching as far as 35 kilometers downriver along the middle fork of the Nooksack River originating from Mount Baker (see Figure 2). Dates have been identified for this flow between 5650 and 5710 +/- 110 ¹⁴C year BP (Kovanen et al., 2001), which corresponds to ~6600 years ago (Scott et al., 2000).
Mount Baker has been eroded by multiple glaciations. Easterbrook and Rahm (1970) noted that as much as 250 m had been eroded in certain river valleys, making it difficult at times to interpret the geologic history of Mount Baker. More recent research has found even more valley erosion, from 500 to 800 m (Hildreth et al., 2003). These numbers indicate that the rate of downcutting ranges from 0.6 to 1.1 m per 1000 years on Glacier and Bar creeks respectively (Hildreth et al., 2003, see Figure 3).

There has been little evidence of more recent magmatic eruptions at Mount Baker. Although there have been historical accounts of ash eruptions, many were dismissed as implausible (Hildreth et al., 2003). This could be in part due to glacial erosion or the small amounts of ash produced. If the amounts of ash produced were small enough, they could have been eroded away, leaving no record behind. In fact, there could have been intrusions and many small eruptions in which no trace was preserved.

Fumarolic activity and hydrothermal alteration that have been documented for over a century have a serious impact upon the type of hazards that Mount Baker presents. Since Pleistocene glaciation, “clayey mudflows”, possibly lahars, formed on Mount Baker and moved many kilometers downslope (Hyde and Crandell, 1975, p. 13). Most originated around Sherman Crater or the Dorr Fumarole field. Other lahar flows have avalanched into surrounding valleys leaving behind recognizable hummocky terrain on the valley floors: for example in the Rainbow Creek valley (Hyde and Crandell, 1975, see Figure 3). Many of these lahar flows have evidence of hydrothermally altered material that traveled east into the Baker River Valley and west into the Middle Fork of the Nooksack River (Hyde, 1974). Some of this hydrothermally altered material can be found on 20th century moraines in the Middle Fork Nooksack Valley, probably as a result of one
or more small eruptions from the Sherman Crater area. An eruption, or sequence of eruptions, left altered rock on Deming Glacier, which then deposited the material as supraglacial debris on moraines (Fuller, 1980, see Figure 3).

**Pre-1975 Historical Activity**

Vague accounts describe some kind of volcanic activity at Mount Baker around 1843 (Whitney, 1889). Some accounts describe debris flows around the summit area, some possibly reaching Baker River (Majors, 1978). Other accounts go so far as to describe the Skagit River being dammed by the volume of debris (Majors, 1978). Although some of the descriptions might be exaggerated (Hildreth et al., 2003), as is possible with all second-hand stories, it is likely that something did take place to foster the telling. In fact, recent study has shown that there appears to be juvenile glass present in 1-3 cm traces in material that correlates to the 1843 activity and that lead back to Sherman Crater, indicating more recent magmatic activity than previously believed (Tucker and Scott, 2006). The lack of eruptive traces could be in part due to glacial erosion or the small amounts of ash produced. If the amounts of ash produced were small enough, they could have been eroded away, leaving no record behind. In fact, there could have been intrusions and many small eruptions in which no trace were preserved.

Early climbers to the summit described in some detail the features of Sherman Crater. The earliest description from the 1860s describes the crater as snow-free and the walls covered in many colors with black rock covered in sulfurous yellows and reds and greens (Majors, 1978). The crater was described as approximately 270 m wide (Coleman, 1869). During an August 1868 visit, Coleman described lava flows out of the east breach that were not snow covered (Coleman, 1869, see Figure 4). Bare rock in this location is
unusual as the east breach is currently the head of the Boulder Glacier and therefore remains snow covered year round. Bare rock could indicate lava flows around the top of the Boulder Glacier area fairly recently.

Davidson (1885) noted that he and others had witnessed eruptions at Mount Baker at multiple times from the 1850s to the 1880s. In 1854, Davidson was taking elevation measurements of Mount Baker from Obstruction Island in the Rosario Straight in Washington Sound when his view of the summit of Mount Baker was obstructed by smoke or ash, not cloud. The plume rose to roughly 650 meters above the summit. Davidson's view remained obscured until the following day when he observed that the summit area was either covered by ash or the snow had been melted away. Because of the 62.8 kilometers between his station and the summit, he was unable to discern which was the case. Again in 1870, while passing through Admiralty Inlet and the Strait of Juan de Fuca, Davidson witnessed a dark ash plume reach approximately 250 meters over the summit of Mount Baker (Davidson, 1885).

Henry Landes (1907), a writer in Mazama, wrote about the unique features of Mount Baker's summit area. He especially noted the fumarole activity at Dorr Fumarole Field on the northeast side. This field covered about 2 acres at the time he visited it in 1906. The snow was completely melted down to bare rock, apparently an andesite, and much of the visible rock had been hydrothermally altered to clay or mud (Landes, 1907). Large amounts of steam and sulfur were noticed from several miles away. The fumaroles also issued boiling water and small rivulets, which joined into a small stream and disappeared beneath the ice further down slope (Landes, 1907). During this ascent and during a later one in 1920, Landes noted that the previous winter's snows were melting
entirely to old snow and rock, making climbs more difficult for those interested in studying Mount Baker (Landes, 1907, and Parker, 1920). A report of the 1909 ascent also talked about the lack of new snow or glacier and how the party had collected sulfur crystals from on the snow outside of the crater (Sholes, 1920).

In 1919, Sherman Crater was known by climbers to have two very active fumaroles. One was constantly emitting sulfurous fumes and steam and the other was more intermittent (see Figure 5). The snow surrounding the fumaroles in the crater was reportedly covered with sulfur crystals (Adams, 1919). In this report, the author talks of a colleague, Charles F. Easton, who noted a change at Mount Baker at the same time as the 1906 San Francisco earthquake. Easton was apparently in the process of making sketches of Mount Baker with the aid of a telescope, and had to redo his sketches due to sudden changes in the summit area. He reported that Sherman Peak dropped approximately 500 feet, and that later investigation showed rocks had tumbled off of Sherman Peak into the crater to support his claim (Adams, 1919). This report has been held suspect (Hildreth et al., 2003), but at least does indicate some event around Mount Baker at the time, as indicated by the confirmation of rock debris in Sherman Crater from Sherman Peak (Adams, 1919). Although the event might not have been the magnitude reported (500 feet; Adams, 1919), there might still have been some event witnessed by Charles F. Easton, and supported by later visual reports from hikers to Sherman Crater.

By 1939, Coombs described sulfuric activity as filling most of the crevices and porous material in the snow-filled crater. This activity had transformed much of the material in the vent to a white opal and kaolin, and had coated many rocks with a "porcellaneous cover of opal" (Coombs, 1939, p. 1500). The heat from this activity also
generated a crater lake in the 1950s within Sherman Crater. The cause of the lake was unknown at the time (Frank et al., 1975). After 1939, steam and fumarolic activity seemed to lessen and there were fewer reports of steam plumes.

Steam plumes were again a common occurrence in the early 1960’s (see Figure 6). These thermal areas, according to photographic records, have changed little from earlier records. They increased slightly in scope through the late 1960’s and into 1972 (see Figure 7, Frank et al., 1977). Since then, steam plumes have remained a characteristic of Mount Baker activity visible to all in the region when weather conditions permit (Easterbrook, 1975).

There is also a geologic record of debris avalanches off of the Sherman Crater rim occurring roughly every 2-4 years of varying sizes with most traveling at least part way down Boulder Glacier. These avalanches of material increased the amount of particulate matter in Boulder Creek, leading to the creation of a large lobate alluvial fan into Baker Lake from Boulder Creek runoff (Frank, 1976). Aerial vertical photos of Mount Baker from 1940 show slumping from the northeast slope of Sherman Peak, which never turned into an avalanche (Frank et al., 1975). These images were compared by Frank with images of a September 3, 1973 avalanche, which stripped 7,400 m² of snow-covered area to bare ground and traveled 2.6 km down Boulder Glacier. Hydrothermally altered material was exposed at the source area and the margins of the slope, and steam was emanating from previously hidden small vents. Melted snow and ice formed streams down the exposure (Frank et al., 1975).

This type of avalanche was commonplace at Mount Baker. In fact, photos from a 1920 ascent of Mount Baker showed nearly identical slump features along a different
section of the Sherman Crater Rim as the 1973 avalanche (McNiel, 1930). These types of avalanches have been documented in 1958, 1960, 1962, 1966, 1969, as well as in 1973, using annual aerial photos taken since 1958 (Frank et al., 1975). Thus, there is a record of avalanching hydrothermal material from Sherman Crater, especially from Sherman Peak.

Kiver (1974 b) discovered an extensive ice-cave system on Sherman Crater. These caves are formed by the circulation of warm air from fumaroles that melt the overlying snow and ice on its way to the surface of the glacier (Kiver, 1974 b). Thus, ice caves like this represent a type of thermometer of fumarolic activity: as activity increases, so will the quantity and dimensions of the caves, until caves collapse from the amount of melting involved. The more heat there is available from rising magma or a geothermal system, the more warm air there will be to melt ice and snow beneath the glaciers. “Thus the study and continued observation of these caverns furnishes a sensitive means of detecting changes in geothermal activity and possibly predicting impending eruptions” (Kiver, 1974 b, p. 8). This prediction was at least partly reinforced when Kiver found, upon returning to Mount Baker in 1975 after the onset of thermal activity in Sherman Crater, that the cave system had been greatly reduced by the large amount of collapse and calving due to melting from increased fumarolic activity; one side had lost an estimated 300 feet of passageways to collapse. Existing caves were much larger, both wider and taller but much weaker, and the actual total length of the cave system had been reduced by the large amount of collapse (Kiver, 1975-1976).

The ice cave system at Mount Baker showed many changes. Ice cave systems in general remain relatively unchanged as long as the snow fall pattern and quality and
quantity of heat moving through remains constant. Changes in the characteristics of heat flow will change the ice passages (Kiver, 1976). At Mount Baker during an August 1974 trip, Kiver and his colleagues found the system to be saturated and dangerous. The ceiling constantly dripped and formed streams and pools on the floors of the caves. The party even found rapids formed by steep descents of water into the Sherman Crater center. One area was so saturated with water that quicksand had formed, forcing the company to retreat (Kiver, 1975). Kiver also found that in 1974, even before the thermal event of 1975-1976, the roof of the Mount Baker ice cave system was melting at a rate of 6 m/year near a fumarole. This was in contrast to melting rates at Mount Rainier of 2.0-3.0 m/year (Kiver, 1974 b). Average free air temperatures at Mount Rainier were roughly 4°C during their trip to the summit (Kiver and Mumma, 1971). At Mount Baker, however, average free air temperatures were 5°C and paths and walls were water saturated. The temperature difference could be due in part to the 1220 meter difference in their heights, but the standing water at Mount Baker was not.

**Synthesis**

There have been many changes at Mount Baker during the historical record. Even if one doubts the accuracy of reports from early explorations (e.g. Hildreth et al., 2003), there had to have been some changes to inspire such stories. These reported events are not merely steaming events, due to sudden cold temperatures as often reported on calm winter days, but events often with corresponding debris evidence. During the early 1900s, when explorers were reporting small eruptions and changes occurring at the summit, Mount Baker was probably undergoing a certain amount of activity. Even if some distant reports could be discounted as smoke from wildfires or unusual cloud formations,
climbers were corroborating at least some of the reports with firsthand accounts of rock debris and evidence of avalanching as they climbed Mount Baker. Evidently, there was a lull in activity from the early 1900s to the 1960s, when steam plumes again became commonplace sights over Sherman Crater.

There are some interesting implications to Kiver’s findings. One question would be: Was the 1974 exploration team already witnessing an increase in thermal activity? It is possible, since Mount Baker ice caves had not been explored before, that the amount of melt water present in the caves (such as the dripping, standing water, streams, quagmires, and the rapids, Kiver, 1975) were all indicators of increased thermal activity. Mount Rainier’s caves had an estimated melt rate of 2.0-3.0 m/year versus Mount Baker’s rate of 6.0 m/year. That could be a result of changes already in process at Mount Baker in 1974. Unfortunately, now the only way to verify this conclusion at Mount Baker would be to continue study of the ice cave system there and identify what happens to the ice caves when thermal activity change subsides: do the caves then stabilize and reduce the amount of melt waters present? This is an excellent example of the need of baseline measurements already taken to which new measurements can be compared for a conclusive analysis of ongoing changes at a volcano.

Still, Mount Baker has shown varying degrees of activity for many centuries. There is a great deal of skepticism (Hildreth et al., 2003) of historical accounts. Some, however, have now been verified with the finding of juvenile material (Tucker and Scott, 2006), and even if a part of these reports is true, then it is clear that Mount Baker has been visibly active throughout written history for the region.
Chapter 3: 1975-1976 Thermal Events at Mount Baker

The 1975 sudden thermal increase at Mount Baker was the first volcanic activity in the contiguous states since Lassen Peak erupted in a remote northern area of California State in 1914 (Holway, 1914). There was no precursory activity, such as earthquakes, to prepare scientists or the surrounding communities for this new activity. Because of the lack of scientific knowledge about Mount Baker, concerns for an eruption were paramount among scientists who responded to the event. Until 1975, activity at Mount Baker had remained docile, including fumarolic activity and debris avalanching. But in 1975, the volcano became much more visibly active to surrounding communities, not just climbers visiting Sherman Crater (Anonymous, 1975c).

On March 10th of 1975, a larger and darker than normal vapor plume was seen above the summit of Mount Baker causing concern among community members used to seeing less than 100 meter white steam plumes. Initial observations by Frank et al., (1977) found many new fumaroles in Sherman Crater, which were also emitting fine-grained ejecta, never before seen from the fumaroles (Frank et al., 1977). This was reported as the first significant volcanic activity in the Cascades in 60 years (Warrick, 1975).

Many aspects of the 1975-1976 activity were studied to attempt to identify the source and potential impact on the region. Following is a brief synopsis of some of these studies, including analysis of tephra, heat flux and snow melt, water chemistry, and geophysical analyses.

Tephra

X-ray diffraction analysis was a powerful tool to identify the composition of material around the active fumaroles in Sherman Crater. This tool allowed identification
of a broad variety of minerals that imply different origins for the thermal activity. The components of the volcano and vent system were divided into different regions of activity, such as small fumaroles, main fumarole, white and gray tephra, and an ice lake that occurred in the middle of Sherman Crater. Each ejecta component reflected properties of the internal workings of the volcano. The small fumaroles ejected cristobalite, quartz, sulfur, and pyrite, whereas the main fumarole ejected mostly silica phases opal/tridymite/cristobalite, plus pyrite, and scoria or lithic fragments (Frank, 1983). The tephra layers suggested that this material was derived from deeper sources, because the mineral components match older volcanic layers from deep within Mount Baker. These represent hydrothermally altered material from eruptions prior to 1975. Similar material included debris fill in Sherman Crater with multiple clays, including smectite, silica, kaolinite, feldspars, and gypsum (Frank, 1983) (Figure 8).

The crater rim also had layers of older debris, including a notable number of friable clots that were interpreted to be pseudomorphs of vesicular lapilli (Frank, 1983). There were also large gypsum crystals (up to 1 cm) that were interpreted to be post-depositional growth from eruptions possibly as old as 6,000 years B. P. based on correlations with stratigraphic layers at the base of Mount Baker (Frank, 1983). The lapilli found in the pre-1975 tephra layer around Sherman Crater indicate no pre-depositional alteration, which means that up until the time of their eruption, some thousands of years ago, they were un-altered materials. After deposition, however, these were highly altered and clays replaced the tephra and clastic material. This fallout could possibly originate from the 6.5 ka eruption date (Hildreth et al., 2003) or the 1843 event.
Most of the erupted particulate material from the fumarole vents appeared to be merely reworked material from vent walls; out of 7 samples taken from around Sherman Crater 40-50 volume percent was found to be unidentified alteration minerals. Another 30-40 volume percent was found to be "spherules of orthorhombic sulfur", mostly covered in a layer of euhedral pyrite crystals (McLane et al., 1976, p. 89). The caveat was that at least one particle, tentatively identified as a Pele's hair was collected over the Sherman Crater fumaroles at an altitude of 2900 m that appeared fresh or unaltered leading some to speculate that new magmatic material was present (Radke et al., 1976). Beyond the presence of this one unsubstantiated fresh glass particle no mineral components found could corroborate that there was new magma generating the thermal flux (Eichelberger et al., 1976). Thus, most of the material found during 1975 investigations revealed that ejecta from the 1975 fumaroles were from older material within the volcano.

Heat Flux and Snow Melt

The 1975 activity involved a greater than tenfold increase in the heat flux in Sherman Crater, from an average of minimum heat-flux density of 8-11 MW pre-1975 to an average of 150-200 MW in 1975 (Frank et al., 1977).

Studies of the amount of heat and its location yielded interesting results, especially over the 1975 year. First estimates of the locations of thermal areas from photographic records found larger than previously seen thermal areas in March of 1975 (Figure 9). By early summer, the area had increased (Figure 10) and by fall, new thermal areas had been identified as well as the increased area of previously identified thermal areas (Figure 11). Some of the areas were difficult to identify since continued calving of
snow into the fumarole pits masked some locations, such as the north pit (Frank et al., 1977). Together, the estimates show that the thermal areas in Sherman Crater were increasing in size and locations throughout the year of 1975.

Fumarole temperature measurements taken at Sherman Crater in the summer of 1975 using a radio telemetry system documented temperature ranges between 89° and 92° C daily at a fumarole on the west rim of Sherman Crater (Sato et al., 1976). Glaciers melted, exposing bare rock, which remained bare through the fall. Of an estimated total surface area of 185,700 m² in the Sherman Crater, a total of 35,200 m² (19%) remained snow free through August (Rosenfeld, 1977). By summer, a very small and shallow lake had formed, or at least melted through its overlying snow layers, at the bottom of Sherman Crater and many of the fumaroles had combined forming long fissures and crevices (Frank et al., 1977). The increased heat flow also melted out new ice caves, enlarged existing caves, collapsed many of them, formed many new crevasses in the Sherman Crater area, and also melted the roughly 30 meters of snow that falls in Sherman Crater each winter (Kiver, 1976). Heat also influenced the growth and flow of glaciers that originate at the crater area (Nitsan, 1976). At some time during the 1975-1979 activity, this heat caused a "considerable decrease" in the volume of ice within the crater (Rosenfeld, 1980, p. 69).

From 1975-1979, melt-waters carried a large amount of sediment to lower elevations in the Boulder Creek drainage and Baker Lake (Fretwell, 1976). This material included silts and hydrothermally altered material from Sherman Crater, which mostly traveled down Boulder Creek into Baker Lake (Bortleson et al., 1977).
Water Chemistry

Water analysis was used in 1975-1976 to analyze the melting snows and ice in Sherman Crater. Tests included pH tests to monitor the acidity of this melt-water. These tests indicated that the acid load from the summit was concentrated in one creek drainage on the southeast side of the mountain in Boulder Creek. During the summer of 1975, the pH for Boulder Creek averaged around 3.9, whereas surrounding creeks around the area averaged 7.2 (Bortleson et al., 1977). These numbers indicated that there was a significant amount of acid trapped within this one creek, which was a lone drainage for the melt-off area at Sherman Crater (Bortleson et al., 1977). The other creeks appeared to be reasonably isolated from the Sherman Crater snowmelt and acid waters from acidic gases out of the fumaroles. The isolation of this creek meant that a larger run-off, such as a debris or lahar flow could be trapped within Boulder Creek valley and thus travel farther than if it were spread over multiple valleys (Frank, 1983).

Similar tests were conducted in Baker Lake itself and the results lead to further concerns about the movement and impact of acidic waters to the Baker Lake Dam. It was found that acid waters were remaining concentrated, indicated by pH levels as low as 3.8-4.0 in Baker Lake, for roughly 1.8 kilometers through the lake moving as a wedge towards the outflow over the Baker Lake Dam (Bortleson et al., 1977). These levels resulted in concerns over the possible reactions of this wedge of acidic waters on the integrity of the dam. Local officials worried about whether the acidic water could possibly begin to deteriorate the concrete of the dam if it reached that point in such high concentrations (Bortleson et al., 1977). These concerns were never fully realized since the concentrated wedge of acidic waters never reached the Baker Lake Dam; the acid-rich
waters dissipated by the time it traveled 1.8 km south of the Boulder Creek drainage (Bortleson et al., 1977).

Dissolved constituents and specific conductance measurements of the runoff streams showed that Boulder Creek had a significantly larger amount of dissolved material than any other surrounding creek area (Bortleson et al., 1977). Boulder Creek had the highest concentrations of dissolved silica, calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, iron, arsenic, boron, and selenium: at least double and triple the concentrations of these elements in surrounding creeks. Specific conductance showed readings of 240 microhms in Boulder Creek and only 50 in nearby streams. All of these measurements indicate that Boulder Creek was the biggest carrier for material originating from Sherman Crater (Bortleson et al., 1977). The increased melt-waters also included an increase in the amount of dissolved constituents in Boulder Creek (Frank and Krimmel, 1980). The burden of altered sediments, being so concentrated on Boulder Creek from the thermal activity above, coupled with the knowledge that most altered material is poised above the Boulder Creek drainage (such as Sherman Peak and Lahar Lookout) makes it logical that any larger flow from Sherman Crater would be concentrated on the Boulder Creek area (Frank et al., 1977).

Geophysical Analyses

Studies done during the 1975 thermal event, including seismicity, gravity, tilt meter, gas geochemistry, petrography, and hydrology, generated contradictory interpretations about the origin of the 1975-1976 thermal activity. For example, tilt meter results showed indications of subsidence in the Sherman Crater and summit areas, without any corroborating seismic data, while gravitational tests indicated inflation of
certain areas around the summit, such as the middle of Sherman Crater (Malone, 1977). There were, however, gravitational changes around Sherman Crater over the summer of 1975, which indicated a mass deficit of 0.4 mGal (Malone, 1977). In other studies such a mass deficit was interpreted to represent magma movement or vesiculation (Rymer, 1995). However, at Mount Baker, due to the lack of corroborating tilt data, the gravity measurements were attributed to snowmelt and accumulation (Frank et al., 1977).

Beginning in 1972, the Pacific Northwest Seismographic Network (PNSN) had established seismographic stations in many locations around the Pacific Northwest (Malone, 1997). This included one station near Mount Baker (Frank et al., 1977). This station was augmented with the placement of 6 more on Mount Baker in the spring and summer of 1975 and these stations recorded little to no seismic activity during the 1975-1976 thermal events (Malone and Frank, 1976). Although most activity at Cascade volcanoes remained at background low levels after the Mount Baker thermal events, with the exception of the Mount St. Helens area, there were some notable events. There were three deep long-period events at Mount Baker between 1980 and 1997 located within 5 km of the summit at depths of 20-30 km. None of these events were paired with eruptive activity (Malone, 1997).

Most of the very small low-frequency seismic events during the thermal events at Mount Baker were identified as ice movement from glaciers (Malone and Frank, 1976). The notable exception was on April 27, 1975, when the level of background activity suddenly rose for a few hours before subsiding. This happened a few more times throughout the summer, with decreasing intensity. It was interpreted as changes in the
fumarole and venting system of the Sherman Crater area that caused changes in the overlying ice which caused clusters of seismic events (Malone and Frank, 1976).

**Initial 1975-1976 Interpretations**

From the results of the 1975-1976 investigations around Mount Baker it appeared that most of the Sherman Crater area was hydrothermally altered. This caused serious concerns among scientists about the structural integrity of the summit area during thermal fluxes in 1975 (Frank, 1983); altered material is weaker and less cohesive than is solid rock. A lack of substantial new material was a clear indication that no new material was being ejected, but rather that material was being reworked by an influx of thermal energy from an unknown source.

To explain the gravitational measurements of the 1975-1976 thermal events, Malone (1976) proposed a model of a hydrothermally heated cylinder with a radius of 0.4 km below Sherman Crater. He hypothesized that such a scenario could have been caused by changes in the plumbing system at depth and that the heating would have caused expansion and allowed a rapid movement of heat to the summit area (Malone, 1976). The problems with this hypothesis include the lack of continued seismic evidence of any changes and the lack of flank movement seen with tilt measurements. In order for there to be expansion of the summit, accounting for the gravitational measurements, there should have been corroborating tilt measurements indicating inflation (Malone, 1976). Without any of these typical indicators, it is hard to explain the evidence of sudden changes in thermal fluxes and gravity changes which continued through at least 1978 (Malone, 1979).
Thus, the most that has been concluded by previous studies is that thermal energy from an unknown source instigated the melting of the glaciers and the creation of many new fumaroles within Sherman Crater, just south of the summit of Mount Baker.

Understanding the nature of this source has a great impact on the risk analysis of Mount Baker: magmatic origins could suggest future eruptions whereas a shift in the hydrothermal system and continued degassing of existing volcanic vents could indicate merely continued long term degassing.

Yet, there was a significant change in the hydrothermal system of Mount Baker at this time. The amount of heat being discharged so completely changed the Sherman Crater area in 1975 and 1976 that bare rock was exposed where none had ever been seen before (Frank et al., 1977). New fumaroles and old fumaroles combined to make long hydrothermally active fissures around the crater floor, parts of the crater wall collapsed into Sherman Crater and a small lake was formed (Frank et al., 1977). A series of photos showing the evolution of vents can be found in Easterbrook (1975).

The cave system that had been explored in 1974 had been completely reworked by August of 1975 (Kiver and Steele, 1976). So, the ice cave system at least was in a state of flux, making it inherently different than that of Mount Rainier, whose system has been well documented and had been mostly unchanged (Kiver, 1975-1976). The differences in the cave systems of Mounts Rainier and Baker could have been indicative of a difference in thermal activity. Kiver visited Mount Baker in 1974, just 7 months before the March 10 steam plume heralded changes at the volcano. The saturated ground and quickly melting glacial cave system could have been a precursor of changes to come, indicating that the volcano was already showing signs of increased thermal activity. The
large amounts of water running in streams and forming quagmires could have been created by changes in the plumbing of the mountain, either from rising magma at depth or from shifts in the hydrothermal system. Mount Rainier's mostly dry system could have been characteristic of a system mostly in balance, whereas Mount Baker's soggy system could have been characteristic of a system in flux, where caves melt rapidly to allow steam to escape. Rapids and standing water could have indicated that there was not enough porosity within the rock and clay to accommodate the increased water or that the system was already reaching saturation levels.

It is clear that Mount Baker has gone through many changes in its recent past history, as viewed through the eyes of the explorers and scientists who studied it. It is also clear that there was a change in the thermal balance in 1975. By reviewing the past activity reported in historical documents, we can see this change is not unprecedented, however. There is now evidence of magmatic activity during the 1843 activity (Tucker and Scott, 2006) which indicates ongoing or repetitive magmatic activity of some kind. If even part of the anecdotal history is true from early explorers' records, Sherman Crater was lacking in snow, and although it may not have been fully bare, bare rock and vivid colors coated the walls of the crater in the late 1800s (Majors, 1978). Other records talk about a lava flow, which may not have been new, but heat from the crater had at least melted off the snow outside of the east breach (Coleman, 1869). Thus, by many different reports, there was an increased thermal activity in the late 1800s. This was apparently associated with some small eruptions of unknown source - it was unknown whether they were magmatic or hydrothermal in origin (Davidson, 1885). These observations make the activity in 1975 seem less unusual; increases in the thermal activity, small non-
magmatic eruptions, and even small magmatic eruptions are not unprecedented at Mount Baker.

In addition, the concerns at the time for collapses or avalanching of hydrothermally altered material were well founded. Many times in historic record there are accounts of debris avalanches, such as in 1920 (McNiel, 1930), 1958, 1960, 1962, 1966, 1969, as well as in 1973, and these are just the ones identified with annual photographs of the summit area (Frank et al., 1975). Although it is difficult to identify whether Easton’s report of a disfiguring collapse of the Sherman Peak area in 1906 (Adams, 1919) is accurate, it is clearly evident that Mount Baker experiences small collapses on a regular basis. With a past history so full of debris avalanches, it can be assumed that more will happen in the future, therefore easily bolstering concern for a collapse in 1975.
Chapter 4: Modern Interpretation of 1975-1976 Events

In the years since the onset of thermal changes at Mount Baker, new information, measurements, and technology has helped volcanologists better understand what the data from Mount Baker in 1975-1976 meant. In addition, new methods have arisen to attain new types of data to better augment that understanding. I focus on seismic and geochemical analysis here, with some examples of other methods.

As well as reviewing past information and applying new theories on the inner workings of volcanoes to that data, I also interviewed scientists involved in studying Mount Baker. This included scientists involved in the initial response to Mount Baker, as well as some still involved in monitoring. I devised a series of questions that I asked each scientist (Appendix 1) and used their responses (Appendix 2) to reevaluate the data from Mount Baker. Five scientists responded to the same series of questions regarding activity at Mount Baker both in 1975-1976 and currently. Scientists included Steve Malone, Ken McGee, Seth Moran, Don Swanson, and David Frank, all of whom either work for, or have worked for the U.S. Geological Survey. They were first asked about detection levels of 1975 instrumentation, then actual observations both then and currently, and lastly they were asked for their responses to the four hypotheses. The hypotheses included 3 magmatic options and one nonmagmatic hypothesis. Responses allowed me to narrow my focus of research to the most pertinent data. This included the lack of seismic data available in 1975 and our understanding of aseismic magma movement and most importantly recent airborne gas studies that have identified indicators of magma in the Mount Baker system. The results are that with new studies showing the levels of carbon
dioxide and hydrogen sulfide above the volcano, some scientists that previously
believed the Mount Baker activity to be hydrothermal now agree that it could have been
magmatic in nature.

The possibility of a magmatic source at Mount Baker is a change from
scientists to seriously study the volcano for fear of an impending eruption. By 1979, the
eruption had not occurred, thermal levels were decreasing, and scientists had concluded
that the activity was caused by shifts in the hydrothermal system without fresh magma
being present. This conclusion was partly based on the lack of significant seismic signals
indicating magma rising into the Mount Baker system. Lack of juvenile ejecta from the
fumaroles, lack of clear and significant deformation, and the gradual lessening of activity
reinforce this conclusion.

However, the science of volcanology has changed and improved substantially
since 1975. Scientists’ understanding of different seismic signals and the interaction of
groundwater with rising magmatic gases, for example, have served to change
interpretations of volcanic activity. With this understanding, it is necessary to revisit
previous ambiguous events such as those at Mount Baker in 1975-1976.

Seismicity

In 1975, there was little evidence of seismic activity at Mount Baker. Besides a
few increases in low-frequency background activity (Malone and Frank, 1976), there was
little else seismically, to indicate any changes at Mount Baker. Today, though, we better
understand the full range of seismic signals that indicate magma movement into a
volcanic system. The recent development of portable broadband seismic instrumentation,
new analysis techniques and the use of larger, more robust, digital networks have helped generate a comprehensive understanding of a wide range of seismic characteristics (Chouet, 1996). This allows us to review 1975 events to identify possible changes in interpretations.

Firstly, the few transient events that did take place at Mount Baker in 1975-1976, as recognized by high-frequency seismometers, were dismissed at the time as being largely generated by glacial movement (Malone and Frank, 1976). These kinds of transient seismic activities were localized unpredictable events without precursory activity or any correlations with other explanatory activity except for glacial ice movement; for example, there were no obvious signs of avalanching material or plumes of ash associated with the seismic activity. This conclusion was based on previous studies conducted on Mount St. Helens that were able to correlate lower-frequency events with glacial movement (Weaver and Malone, 1976). Due to the nature of the high frequency seismometers available in 1975, the low frequency data was less than clear. It was only in comparison to other similar events that correlations could be made. Although increases in low-frequency events had been identified at some volcanoes immediately before eruptions and had been suggested as precursory phenomenon, this was questioned by other scientists. In the 1973-1974 study at Mount St. Helens, the glaciers at the summit provided alternative sources for the low-frequency events (Weaver and Malone, 1976).

More recently, however, some of these low frequency events have been identified as fluid pressurization in the conduit (McNutt, 2000a). Instead of glacial ice movement, at least some low-frequency events with certain signatures have been found to be due to conduit fluid movement. Based on this new discovery of low-frequency seismic
propagation, it is possible that bubble formation and collapse or the pressurization of fluid processes generated at least a few seismic events at Mount Baker instead of glacial ice movement. This is impossible to verify without returning to the seismic record from Mount Baker at the time. It has been noted that earthquakes caused by fluid pressurization in a conduit produce more monochromatic and lower frequency signatures (C. Newhall, personal communication, 2006), so it is possible that earthquakes at Mount Baker truly were generated by ice movement.

Secondly, new seismometers introduced in the 1990s identify signals on different frequencies, allowing new measurements to be taken. These new frequencies show us previously unseen signatures. Broadband seismometers allow very-long-period (VLP) earthquakes to be identified (McNutt, 2000a). Although these events are not necessarily precursory to an eruption, they do indicate magma or other fluids moving through the volcanic plumbing system. They have been recognized during eruptions and even in very active fumarolic volcanic settings. Thus, although VLP events have not yet predicted eruption phenomenon, they are diagnostic to fluid movement in a system. These broadband seismometers can recognize signatures from 0.02 to 50 Hz (McNutt, 2000b), whereas high-frequency seismometers like those that were in use at Mount Baker in 1975-1976 can only identify signatures from 1 to 20 Hz (Malone, 1977).

Broadband seismometers were not in use in 1975-1976 during the Mount Baker thermal activity. Only high-frequency seismometers were used. If broadband seismometers had existed and VLP events had been recognized, however, it might have aided in identifying the quantity and potentially the source (if coupled with other data) of the thermal activity.
Also, new satellite data has allowed remote sensing of volcanic changes (Harris et al., 2003). Most importantly to a review of Mount Baker is the discovery of aseismic magma movement at certain volcanic centers. At the Three Sisters volcanic center in Oregon, USA, interferometric synthetic aperture radar (InSAR), found a broad area of uplift that had not been identified by the active seismic network in the Cascades: it is an aseismic intrusion of magma at ~6.5 km depth just west of South Sister volcano (Gerlach et al., 2002). In another example, Westdahl Volcano, in Alaska has been monitored by InSAR. Despite no unusual seismic activity and typical background activity (~ M < 3 earthquakes per year) Westdahl inflated around 17 cm from September 1993 to October 1998 (Lu et al., 2000). Thus, although seismic activity is often a good indicator of volcanic activity, aseismic volcanic activity can and does occur.

The general idea of aseismic magma movement is based on the characteristics of the country rock through which the magma is moving. It is a rate-state phenomenon. Magma moving quickly into a hard rock country rock would need to break the rock in order to move through, unless it moves slowly – first heating and softening the rock before moving into it. However, magma moving into a weak, clayey, volcanic edifice could potentially ooze through the weaker material, unless it moves too quickly and snaps the country rock quickly. Earthquakes are based on the fracturing of hard rock, but if there is no hard rock to break, or if it is melted and moved slowly then there would be no earthquake generated from the magma movement.

This new discovery of aseismic movement around volcanic centers presents more questions than answers about volcanic systems. How many other volcanic systems have
aseismic magma intrusions that we do not know about? What does this mean for those centers that have had ambiguous events in the past, such as 1975-1976 at Mount Baker?

It now appears at least possible that Mount Baker was undergoing aseismic magma intrusion. The few seismic events that occurred were identified as low frequency events, and were interpreted as glacial ice movement (Malone and Frank, 1976). There could have been more to the signature if only the seismometer could have read it. For example, very-long-period events might not have been recorded on the short period seismometers used at the time.

Unfortunately, data was either not recognized or not collected at Mount Baker in 1975-1976 that could prove or disprove any of these possibilities. However, since seismic events such as long period, very-long-period, and aseismic magma movement have occurred in other similar volcanic settings, none of these possibilities should be discounted.

**Deformation**

Deformation studies at Mount Baker from 1975-1976 provided some ambiguous results. Gravity measurements indicated changes around the summit, potentially from elevation increase or mass withdrawal (Malone, 1977). Neither of these could be substantiated, however, without further studies. Snow accumulation and melt could further have confounded measurements, but do not fully explain the gravity readings. Mass withdrawal of the amount required to explain the measurements would most likely have been accompanied by seismic readings of some kind (Malone, 1977). Tiltmeter data was equally as ambiguous, showing areas of subsidence and inflation around the summit (Frank et al., 1977). Many of these measurements were uncorroborated with other
tiltmeter stations or other geophysical data. Explanations for the changes ranged from magma withdrawal from an upper level chamber, loading from snow accumulations, or snow ablation in late summer, to potential confounds with weather conditions and unstable stations (Frank et al., 1977). Problems with these hypotheses were manifold. The possibility of mass withdrawal from an upper level chamber conflicted with gravity results which generally showed elevation increases (Malone, 1977). The idea that loading from snow caused subsidence does not account for stations registering subsidence during the time period of August through October - a time of summer snow ablation, not accumulation. Finally, the explanation that weather conditions and potentially unstable tilt meter systems caused the conflicting measurements appears to be corroborated by the lessening of noise recorded in early December 1976 when fresh snows could have dampened the effects of poor weather conditions (Frank et al., 1977).

Today, more and more geophysical data are being acquired through satellite assistance. InSAR has become a great tool providing interferograms or maps showing where there are changes in contours based on satellite image comparison (Murray et al., 2000). Global Positioning Systems (GPS) is also being used to more accurately and easily measure horizontal distances without the confounding effects of weather interfering with the readings. Gravity readings tend to be ambiguous without simultaneous ground deformation readings. This means that for places like Mount Baker, where the ground deformation readings were highly suspect (potentially confounded by the extreme weather conditions on an icy peak) the gravity measurements have little corroboration (McNutt et al., 2000). Ground deformation requires, like seismic readings, other corroborating data to help scientists understand and forecast volcanic activity. Despite the
best laid geophysical network, some eruptions have little to no precursory deformation to warn scientists (McNutt et al., 2000).

Studies around the world’s volcanoes have shown that hot springs and wells surrounding volcanoes can also show the effects of rising magma (Newhall et al., 2001). Many hot springs and wells dry up, overflow or have temperatures rise or fall before and after seismic and volcanic activity (Newhall et al., 2001). Some deformation characteristics could be due to hydrothermal system changes which may or may not be due to fresh magma intrusions. Investigations have identified that much of the data scientists use to identify activity at a volcano are greatly influenced by hydrothermal ground water interactions. For example, heat from a rising magma body slightly increases pore pressures in a volcanic system, as will mechanical compression. Increased pore pressures mean inflation of a volcano while the release of those pressures, either through cracking of hydrothermal seals, or withdrawal or cooling of the magma body, will lead to deflation (Newhall et al., 2001). Deep magma reservoirs could thus influence a volcanic system; a system where there appears every indication of eruptive potential (inflation, seismic activity, changes in gas discharge, etc.) could in fact be influenced by some compressional forces due to changes in the hydrothermal system. Heating or compressional forces increasing the pore pressure of a system create volumetric strain on the volcano, which may or may not lead to an eruption. However, deep magma intrusions would have such a subtle effect that their influences might not be visible to the geodetic survey at the surface; the ground can be so soft that effects could be further dampened, increasing the chance of aseismic movement. Reid (2004) found that remote intrusions affecting hydrothermally altered edifice rocks can increase the effects of fluid
pressurization. More porous rock allows pressure and thermal energy to dissipate more quickly, whereas the clays and alternating layers of broken and altered rock can slow down dissipation and increase the effects of pressure upon the edifice (Reid, 2004). It was also found that pressure and thermal energy transmitted from a remote intrusion take long periods of time, from months to years to slowly build and then dissipate, making identifying the changes more difficult (Reid, 2004).

Unfortunately, even if it did occur, any pore pressure indication of intrusion does not exist around Mount Baker. There were no reports of changes in the hot springs, in 1975-76: access to these popular sites was also limited when the Baker Lake area and the surrounding campgrounds were closed. Also, there was little reason for scientists to focus on hot spring changes since the correlation between hot springs and well activity and volcanic activity was not well understood at the time. Thus, there are no measurements of well temperature or levels, no records of VLP events, identifiable and significant inflation-deflation sequences, or any record of changes in water characteristics around Mount Baker (except for the water quality effects on Boulder Creek drainage).

A new model has also been developed to identify zones of potential flank collapses on volcanic edifices (Reid et al., 2001). This model utilizes a slope stability method that incorporated geologic mapping and subsurface geophysical imaging. This model can be used to determine distributions of strong (fresh) and weak (altered) rock. Such a model could be used at many different volcanoes, but could be particularly useful at Mount Baker where concern over large amounts of hydrothermally altered material at Sherman Crater spurred the US Forest Service to close campgrounds in 1975.
Geochemistry and what it means to future studies

Volcanic gases are important indicators of the internal workings at volcanoes. Carbon dioxide \((\text{CO}_2)\) is less soluble than other gaseous constituents of magmas, and would therefore be one of the first components to exsolve and rise to the surface (Tazieff, 1983, Gerlach et al., 1997). Carbon dioxide is also one of the least water-soluble gases emitted from volcanoes. As such, \(\text{CO}_2\) is a better indicator of volcanic activity than other gases which might be scrubbed out by groundwater interference. One difficulty in testing for volcanic \(\text{CO}_2\) is the ability of a technique to differentiate between emitted \(\text{CO}_2\) and atmospheric \(\text{CO}_2\). In addition, current methods of testing for \(\text{CO}_2\) make accurate analyses difficult because measurements need to be taken so close to the vent. As \(\text{CO}_2\) is emitted from a volcanic vent, it can quickly become confused with atmospheric \(\text{CO}_2\) in the surroundings. Therefore, accurate measurements would be difficult during eruptive periods where safety necessitates particular distances increasing the likelihood of inaccurate measurements (Gerlach et al., 1997). More recent studies have been better able to correlate the emission rates of gases from volcanic vents and the affects of scrubbing. During precursory volcanic activity, \(\text{CO}_2\) and \(\text{H}_2\text{S}\) are better gases to monitor, during the height of activity \(\text{CO}_2\), \(\text{H}_2\text{S}\), \(\text{SO}_2\), \(\text{HCl}\), and \(\text{HF}\) are better gases to monitor, and during post-eruptive stages \(\text{CO}_2\) and \(\text{H}_2\text{S}\) are better gases to monitor (Symonds et al., 2001). Sulfur dioxide is scrubbed out quickly in the beginning if there are sufficient ground waters, before a volcano dries out from continued activity and the ground water is boiled off (Gerlach, 2003).

It appears, though, that as accurate as \(\text{CO}_2\) is in identifying rising magmatic gases because of its insolubility in water, \(\text{SO}_2\) is better during times of heightened activity. If
large quantities of SO$_2$ are detected, especially considering its water-solubility, it should be considered an indication of magma intrusion (Symonds et al., 2001). The correlation spectrometer (COSPEC) has been used to analyze the sulfur dioxide emissions at volcanoes around the world, again, used mainly as a descriptive tool, not a predictive one (Stoiber et al., 1983). Developed in the 1960s by Barringer Research out of Toronto Canada to monitor SO$_2$ levels in industrial smokestacks, it has since been used to monitor SO$_2$ output in volcanic systems (Stix and Gaonac’h, 2000). COSPEC readings have been used to help aid in accurate predictions of certain volcanic eruptions, such as that of the June 1991 eruption of Mount Pinatubo (Daag et al., 1996). In eruptions like that of Mount Pinatubo, SO$_2$ played a major role and is an indicator of volcanic activity. As our understanding of volcanic environments increases, scientists are better able to identify the gases that are most present or indicative of different stages of activity.

There has also been a significant amount of research conducted on the effects of ground water on rising magmatic gases (Symonds et al., 2001). It has been noted that groundwater has a buffering effect upon fumarole temperatures. For example, rising hot gases first raise the temperature of adjacent ground water on their path to the surface, so that fumarole temperatures on the surface have been buffered by the groundwater below the surface. Also, before water-soluble gases such as SO$_2$ and HCl reach the surface, the rising magmatic gases must first dry out the surrounding ground waters; continued presence of groundwater along the chimney to the surface will further mask the amount of water-soluble gases from a fumarole (Newhall et al., 2001). In more permeable volcanic environments, ground waters can have more influence on rising magmatic gases, whereas impermeable environments do not allow groundwater movement and limit
interference between gases and groundwater (Symonds et al., 2001). For example, at Crater Peak, Mount Spurr Volcano, Alaska, the effect of ground water served to greatly diminish the amount of SO$_2$ until just before or during eruptions (Doukas and Gerlach, 1995). Investigators found that CO$_2$ levels were more reliable than were SO$_2$ due to scrubbing of sulfur from groundwater, thus masking the levels of SO$_2$. At “wet” volcanoes, such as Mount Baker, where glacial ice and snow melt scrub out SO$_2$, measuring CO$_2$ and H$_2$S becomes increasingly important during quiescence (Symonds et al., 2001). At these volcanoes, SO$_2$ increases are critical to identifying influxes of new magmas. In a system where SO$_2$ is otherwise undetectable from scrubbing, a sudden appearance of SO$_2$ can be an indication of potential future activity (Symonds et al., 2001).

Crater Peak, Mount Spurr Volcano, Alaska, is highly permeable and has a ready supply of water available from snow and glacial melt. This allows abundant water to reach rising gases from magma and mask readings. Furthermore, melt waters could even quench rising shallow magma intrusions (Doukas and Gerlach, 1995). Mount Baker has similar melting glaciers soaking into the breccias and hydrothermally altered material around Sherman Crater that could provide ample groundwater, allowing rising magmatic gases to be masked. This could, similar to Crater Peak, mask the nature of the rising magmas.

**Geologic Studies at Mount Baker since 1980**

After January 1, 1977, fumarolic activity in Sherman Crater moved (Easterbrook, 1980). Before this time, throughout the 1975-1976 activity, energy was more concentrated on the northern and eastern rims of Sherman Crater and melted a pit in the central part of the Sherman Crater glacier. After 1977, the pit was gradually closed in,
and by 1979 was completely closed in (Easterbrook, 1980). Activity along the western rim also melted large amounts of ice along the western wall. The northern fumarole remained active throughout this time and new activity punctuated the north and northwest rims areas (Rosenfeld, 1980). However, even as the pit lake iced over and activity moved around Sherman Crater, large steam emissions reaching 600 – 900 m, increased from an average 2-4 times a year between 1975 and 1977, to 10-12 times a year between 1977 and 1979 (Easterbrook, 1980).

From 1980 to 1989, scientists with U.S. Geologic Survey Cascade Volcano Observatory installed trilateration and distance-measuring networks on Mount Baker, among other volcanoes (Iwatsubo and Swanson, 1992). These networks can be used to measure any horizontal changes in the shape of the volcanoes. Thus, if there was any inflation around the volcano, surveys using this network would be able to identify and locate where and how much (Iwatsubo and Swanson, 1992). There were no deformation changes at Mount Baker from 1981-1983 based on surveys done at the time (Chadwick et al., 1985). However, these stations were only studied from 1981-1983 and have not been reoccupied recently due to the protection of the Mount Baker region from motorized vehicles. Due to the amount of equipment necessary to take the distance measurements and trilateration readings it is infeasible to reoccupy the stations without the use of helicopters. New work is being conducted, however, to use Global Positioning Systems to reoccupy bench marks around Mount Baker to assess surface deformation changes (J. Crider personal communication, 2006).

Plume analysis conducted in 2000 showed that there is less CO$_2$ and H$_2$S present in the plume than in 1975 (McGee et al., 2001). Total emission rates of H$_2$S in 1975 were
around 30 td\(^{-1}\) (Radke et al., 1976), whereas measurements in 2000 showed only 5.5 td\(^{-1}\) (McGee et al., 2001). Also, the maximum H\(_2\)S readings in 2000 were 75 ppb, which is only half of the 1975 readings. The cross-sectional area of the 1975 plume was 3 times greater than that measured in 2000 (McGee et al., 2001). Despite the apparent decrease in concentrations, there are some changes recently.

A 1997 study found that the average ratio of CO\(_2\)/H\(_2\)S was 18 (ranging from 13 to 22). The 2000 study, which found an average ratio for CO\(_2\)/H\(_2\)S of 25 is higher than the 1997 study. There are possible explanations for this, such as the difference between the 1997 study’s direct measurements from fumaroles and the 2000 study attaining their readings from the plume. It is believed that the plume measured in the 2000 study was well mixed and represented an average of all of the gases from the fumaroles, whereas the 1997 study attained direct measurements which could be biased by the characteristics of the fumaroles they measured and how representative they were to the overall emissions at the time (McGee et al., 2001).

Carbon dioxide, as described above, is one of the first gases to be released from a rising magma body, so it is an excellent early indicator of magma degassing. At Mount Baker, McGee (et al., 2001) found that there was 187 ± 26 td\(^{-1}\) emitted. It has been suggested that the Cascade volcanoes have typical emission rates of anywhere from 0 to 200 td\(^{-1}\) (K. McGee, personal communication, 2005). The presence of significantly measurable CO\(_2\) is indicative of degassing magma. However, the limitation is that there is no way to tell whether this was from before or during the 1975 activity since there were few airborne measurements taken during the 1975-1976 thermal events (K. McGee, personal communication, 2005).
Thus, even now, Mount Baker has not returned to pre-1975 conditions. Although surface activity is not as extensive at this time, compared to 1975-1976 fumaroles (D. Swanson, personal communication, 2003), bare rock is still exposed in the Sherman Crater area, more so than before the 1975 event (D. Frank, personal communication, 2003).

Boulder Creek drainage is still carrying a larger acid load than surrounding streams, as shown by a 2002 study I conducted (see Table 2). The 2002 measurements show similar values to those found in 1975. The pH levels, although not exactly the same, show similar concentrations of acidic material in the Boulder Creek drainage. In 1975 pH values were 4.2 for Boulder Creek, 7.4 for Park Creek, and 6.7 for Sandy Creek. In 2002, those values have risen but the lower pH levels remain in the Boulder Creek area where pH values were 5.2 compared with 6.5 in Park Creek and 7.0 in Sandy Creek.

Temperatures at Boulder Creek are also still higher than surrounding creeks: Boulder was at 7.2°C in 2002 versus 8.4°C in 1975, whereas Park Creek was 5.4°C in 1975 and 6°C in 2002, and Sandy Creek which was 5°C in 1975 and 4.9°C in 2002.

All other concentrations of sodium, magnesium, potassium, and chloride are all higher in Boulder Creek than other drainages in both 1975 and 2002. The most notable exception is Calcium where measurements are inconsistent and range from 14 to 2.94 mg/L across the Creeks from 1975 to 2002. That could very well be due to experimental error or environmental conditions, since Ca might combine with sulfate as an ion pair and therefore be more difficult to get an accurate reading (Frank, 1983).

Clearly, there was a change in at least the hydrothermal workings of Mount Baker in 1975. This change is ongoing, one that continues to affect the volcano as recently as
studies conducted in 2000 (McGee et al., 2001); activity levels have never returned to pre-1975 levels. All of this information means that whatever the change was at Mount Baker in 1975, it had to have been a change that could influence the volcano for years after the initial event. A simple shift in the hydrothermal plumbing means that a very large well of energy must have been tapped to generate the amount of ongoing thermal flux. If the shift had merely tapped a pocket of thermal energy high within the volcano edifice, the thermal flux would gradually decrease as the energy within the pocket was used. As it is, there is still a lot of heat dissipating from the Sherman Crater area. In order to support the magnitude of the ongoing thermal energy, something more deep and large, such as tapping hot gases from magma or a large well of hydrothermal energy would be required to sustain the thermal energy from Mount Baker. Tapping something more shallow or superficial would not be sufficient to sustain the current energy output. Recent satellite thermal imaging has shown that, instead of dropping off, the thermal energy has moved around in the Crater area, from the east breach area to the north-west wall (D. Frank, personal communication, 2003).

One possible source of the heat is magma far beneath the volcano. It is possible that degassing of a magma body could generate a thermal increase such as the rise in 1975 Mount Baker levels, from 8-11 W/m² pre-1975 to 150-200 W/m² during 1975 (Frank et al., 1977), without generating seismic waves from deep seated magma movement itself.

Even today, without the high rate of thermal flux within Sherman Crater, debris flows pose a risk to those communities around the base of the volcano. Lahar Lookout has not become more stable in the intervening 28 years. Quite the contrary, it will have
become more unstable as hydrothermal fluids and weathering continue to deteriorate the rock into clays. A debris avalanche, such as one from Lahar Lookout, would not need any volcanic activity precursors, either. Such a debris avalanche could be triggered from an earthquake in the region, or critical slope angles could be overcome without a seismic trigger and the edifice could crumble (Frank, 1977). Studies of massive collapses around volcanoes have shown that magma intrusion into the edifice is not necessary, especially when a shallow hydrothermal system is present (Reid, 2004). Remote magma intrusions that are difficult to identify can cause subtle changes in the volcanic edifice which lead to collapse (Reid, 2004). This hazard should not be underestimated, considering that water levels of Baker Lake Reservoir are currently at normal levels; they are no longer maintained at low levels as they were during 1975-1976 when there was a fear of a flow overtopping the Baker Lake Dam. Such a flow would put many communities at risk, as scientists foresaw in 1975. It was a concern in 1975, and it remains a risk even today.

As well, the presence of crater lakes such as the lake in Sherman Crater in 1975 has concerned many scientists about the possibility of the lake becoming dammed by ice and generating a large flood when the dam broke (Delmelle and Bernard, 2000). Similar lakes have apparently been seen at other times (Frank et al., 1975) leading some to believe that it exists most of the time, but is typically hidden by overlying ice and snow. Studies have suggested that characteristics of the ice and snow in Sherman Crater indicate that there has been a lake present at many times under the crater glacier (Frank et al., 1975). The visible lake in 1975 drained through the East Breach, under Boulder Glacier. Boulder Glacier drains into Baker Lake via Boulder Creek, above the Baker Lake Dam.
Evaluation of Four Hypotheses

In order to better understand what happened at Mount Baker in 1975, I proposed four hypotheses to explain the activity (Appendix 1). Three hypotheses include magmatic activity, and the fourth describes a non-magmatic process of hydrothermal changes. Although conclusively eliminating any one of these hypotheses is difficult, a couple of them make more sense in light of the available data. Understanding the nature of this source has a great impact on the risk analysis of Mount Baker: magmatic origins could suggest future eruptions whereas a shift in the hydrothermal system and continued degassing of existing volcanic vents could indicate merely continued long term degassing of a magma body.

These hypotheses were then taken to scientists, as described above, and their responses were used to help narrow my focus for research. Although such an interview process is unorthodox in postulating the source of activity at a volcano, in the case of Mount Baker, it is very useful. Since 1976, there have been many changes in scientific understanding of volcanic activity. Many of the new tests and monitoring activities were not available for the scientists to use during the thermal events at Mount Baker. The only way at this point in time to better understand what happened then, without the results from many of these tests and monitoring activities, is to return to the scientists who studied the volcano at the time. These scientists are the only ones able to compare what they saw and found at the time to current hypotheses since not all of their observations were published. So, a few scientists who worked on Mount Baker during the thermal events or who have studied Mount Baker since then were asked to evaluate the four hypotheses and to explain what they believed and why.
The first hypothesis postulates that there was a deep magmatic intrusion in 1974 or 1975 that instigated the increased thermal output in 1975. There is a great deal of contention about the idea of a magmatic intrusion at Mount Baker (S. Malone, personal communication, 2006). Most seismologists agree that any magmatic intrusion must be accompanied by earthquakes of some kind. However, recently, magma intrusions have been found through the use of InSAR data without corroborating seismic signals. Locations such as the one near South Sister volcano, Oregon, have an inflation rate of 0.006 km\(^3/y\) based on InSAR data, and have an inferred magma depth of ~6.5 km (Gerlach, et al., 2002) without any seismic activity. This discovery indicates that magma intrusions do not always generate identifiable seismic signals and at least allows the possibility of intrusions without corresponding seismic activity. A deep aseismic intrusion would explain the gas readings, and the depth could explain the fact that there was no seismic signature. As well, because of the depth, there would have been little to no deformation visible at the summit of Mount Baker or in Sherman Crater (C. Newhall, personal communication, 2005). The best way to verify this particular hypothesis would have been to have significant CO\(_2\) readings conducted in 1975. As it was, there were very few that were not problematic. If those measurements had been taken, though, and large amounts of CO\(_2\) were found, as compared to the numbers found in 2000, this would have indicated fresh magma. Fresh intrusions give off a lot of gas early and then gradually decrease (K. McGee, personal communication, 2006). Without those numbers, however, it is very difficult to eliminate this hypothesis. There is no data at this time that can conclusively support or discount this hypothesis at Mount Baker.
The second hypothesis postulates that there was a magmatic intrusion prior to 1972 when the seismic net was installed around the Cascades, including Mount Baker. Thus, any seismic activity would have occurred before the installation of any seismometers to record them. Again there is little evidence to support this conclusion above the other hypotheses. However, reports of eruptive activity in the middle 1800s (Davidson, 1885) suggest that a magmatic intrusion occurred a little over a hundred years ago. This at least reinforces the possibility of a more recent intrusion that would have affected Sherman Crater – if there was magmatic activity that recent, it is at least reasonable to assume that Mount Baker could produce more magma. The question remains, though, how long would it take a body of magma to degas or cool completely? Some large magma bodies (>100 km$^3$) are known to have continually degassed for longer than a 1000 years (Kazahaya and Shinohara, 1996). Thus, the potential exists that Mount Baker had a large magma intrusion (although probably a great deal less than 100 km$^3$) in 1843, when it was said to have erupted (Tucker and Scott, 2006), and that it has been continuing to degas up until now. Carbon dioxide measurements in 1975 would have helped for comparisons. If the source of the 1975 activity was a fresh magma intrusion, then CO$_2$ readings would have been initially very high in 1975, but if activity was due to an old intrusion, then CO$_2$ numbers would have been similar to McGee et al.’s 2000 readings (2001), indicating an already degassed magma body. Today, Mt. Saint Helens has gas poor readings indicating that magma is probably from either 1980 or 1988 and continuing to slowly degas (K. McGee, personal communication, 2006). Again, there is no data to conclusively support or discount this hypothesis.
The third hypothesis postulates that there was a rate change in magma convection in the conduits below the summit of Mount Baker, allowing more gases to escape. Magma convection is instigated by even small density differences (Kazahaya et al., 1994). So, as magma rises in a conduit and begins to degas it becomes denser and will begin to sink, allowing non-degassed magma to rise. Magma convection in a conduit is one of the mechanisms of quiescent degassing at volcanoes (Kazahaya and Shinozuka, 1996). There is no data that can prove that this occurred at Mount Baker in 1975. The change in magma convection rate could have been slow such as suggested by remote magma intrusion studies where the effects seen in the volcanic edifice were subtle and possibly undetectable (Reid, 2004). A remote magma intrusion could have instigated a slow change in magma convection rate but the increase in pore pressures and thermal energy could have been slow or subtle enough to not be visible. This could be likely considering the changing ice caves that Kiver found in 1974 (Kiver, 1974a and 1974b). If changes were occurring slowly over a period of time – for example a year or two – then there might not have been an abrupt trigger event, like conduits breaking open to allow more convection for degassing magma. Kiver could have found the beginning of increased thermal output in 1974 due to increased convection in magma conduits. Then, this energy output could have reached its peak in 1975-1976 and slowly decreased over the following years. Current data would then be measuring the effects of a continually degassing magma body at depth with magma convection continuing. Again, though, there is little conclusive data to prove or disprove a rate change in magma convection in the conduits of Mount Baker in 1974-1976.
The last hypothesis, and the one most widely accepted until recently, postulates the one non-magmatic possibility studied here: that seals in the hydrothermal system at Mount Baker broke open to release previously trapped gases. This theory was based on the idea that there was and is no new magma at Mount Baker and that the increased thermal activity in 1975-1976 was based on just hydrothermal gases being released.

The hypothesis that magma was not involved could arguably be eliminated. There was still a measurable amount of gases, especially CO$_2$, emitted from Mount Baker as recently as 2000 (McGee et al., 2001) which indicate that magma was, and is, degassing. Clearly, there is magma present in the system somewhere and it is reasonable to believe that it was present during the 1975-1976 thermal events even though there is no conclusive proof as to when the magma was emplaced. Although it could be argued that magma emplacement occurred after the 1975-1976 thermal events, there is little evidence that could support this such as another thermal energy increase or seismic signals of magma movement. In 2000 the measured plume had both CO$_2$ and H$_2$S present, both indicators of degassing magma (McGee et al., 2001). The fact that there was, and is, little to no SO$_2$ is not surprising considering the effects of ground water scrubbing on rising magmatic gasses.

Now, if we accept that the events at Mount Baker in 1975-1976 were somehow magma related it still remains unclear as to exactly what and how those events transpired. Volcanic activity at Mount Baker has only been seriously studied since 1975 when concerns of an eruption first materialized. Although there were studies done prior to the 1975-1976 work (see, Kiver 1974a and b), Mount Baker was most comprehensively studied with the onset of 1975-1976 activity. This allows scientists, then, around a 30
year window with which to study the volcano. Although there were many reports of activity before this time, as well as minimal physical geology traces recorded in the surrounding rocks, there are no corroborating results for seismic activity, gasses, and deformation. The information prior to 1974 is anecdotal at best and sensationalized at worst. Through this 30 year window we can see that activity was probably magmatic in nature, but the details of that activity are difficult to reconstruct.

In order to discriminate among these three magmatic hypotheses, there needs to be some measurable difference between them. The issue of CO$_2$ measurements in 1975 might have helped: scientists would have been able to see whether initial measurements were significantly higher than 2000 readings from McGee et al. (2001), thus indicating fresh magma. Since clear CO$_2$ measurements were not taken in 1975, we are unable to use this comparison.

Could activity at Mount Baker have resulted from a combination of these hypotheses? In light of the data available and the possibilities, the activity could have been instigated by an old magma body receiving a small new pulse of magma, increasing the magma convection rate and maybe opening up new conduits to Sherman Crater. This would explain the ongoing activity at Mount Baker over the years, the changes seen in 1974-1976, gas readings (both in 1975 and now), the lack of seismicity, and the magnitude of changes seen in the crater. Scientists that were interviewed mostly agreed that the Mount Baker system is a relatively open one – leaky. Gases and heat seem to be perpetually escaping from Sherman Crater (C. Newhall, personal communication, 2005; K. McGee, D. Frank, and S. Moran, personal communications, 2006). Thus, there probably has been ongoing activity throughout recorded history, as seen in anecdotal
reporting of steam plumes and fumarolic activity in Sherman Crater. This supports the idea that a body of magma has been present below Mount Baker, probably deep to account for the low numbers of seismic events. So, if this older body of magma were to have a small, newer, fresher, and hotter intrusion, it would renew the thermal energy and increase the output of gasses and heat at the surface, and if it were small enough and/or slow enough (and/or in soft, deformable country rock) it would not register on the seismic net.

These hypotheses help narrow the focus of research a little in a situation that is poorly understood. The activity at Mount Baker was ambiguous in its source, and a conclusive interpretation of possible magmatic activity in 1975-1976 may require a new insight into volcanology to illuminate another facet of the activity. For example identifying aseismic magma movement at volcanic centers like Three Sister, Oregon, helps support the possibility that magma can move into volcanic terrains without earthquakes. Up until 2000, activity at Mount Baker was attributed to be hydrothermal changes, without any associated magmatic activity. McGee et al.'s 2000 research (2001) showed the level of CO$_2$ emissions at Mount Baker which indicated a magmatic source. Aseismic magma movement was found at Three Sister volcano, Oregon (Wicks et al., 2002), which allowed the possibility of magmatic intrusions without seismic records. Now, scientists are more willing to consider a possible magmatic answer to Mount Baker's questionable source of activity.

Reliable forecasting of future volcanic eruptions will have to include a comprehensive study of the volcano. Not just seismic data, or gas geochemistry, but the use of all characteristics of the volcanic activity will be necessary to understand and
therefore predict future behavior (Scarpa and Gasparini, 1996). More recent work has found that it is at least partially possible to characterize the magma plumbing system of a volcano (Scarpa and Gasparini, 1996). The character of the plumbing system, coupled with a comprehensive past history and current activity analysis might be able to get scientists closer to predicting an eruption.

Currently, Mount Baker continues with increased thermal energy, beyond 1974 levels. Bare rock and more fumaroles than were present before 1975 are still visible in Sherman Crater.

Volcanoes work on much longer time scales than humans do, so it is possible that only time will enlighten us as to the real source of the 1975 thermal event at Mount Baker. The future may show Mount Baker settling back into its quiet steaming state, as the magma body cools, such as what has been reported in the early 1900s up until 1975. Or, eventually, Mount Baker could return to its active state prior to 1900 when small eruptions were normal. Or, it could be that Mount Baker acts slowly, with changes indicating that thermal events such as the one of 1975-1976 are precursory events, for a more active period. Regardless, the 1975-1976 events and recent studies indicate that changes are still taking place within the volcano and that the short term geologic future of the volcano is still unknown.
PART II:

Community Awareness of Natural Hazards at Mount Baker
Chapter 5: Introduction

Introduction

Understanding the volcano is only part of the volcanic risk equation in this region. There are many people that live within hazards' reach of Mount Baker as defined by the US Geological Survey Hazards zonation map (Gardner et al., 1995). The people in these communities need to be included in future educational campaigns to help them better understand the risks associated with Mount Baker and how to prepare for them.

At any time, Mount Baker could recommence volcanic activity that could place communities around the area in jeopardy. This makes a risk awareness analysis necessary to prepare for educating at-risk communities. In order to best serve the communities around Mount Baker and other hazardous areas, it is necessary that officials, scientists, and emergency management alike, inform themselves about the communities in question. The most reliable way for officials to protect people is to understand them, their needs, their misconceptions, and how best to deal with them in times of crisis. As well, people surrounding Mount Baker need to be educated as to what the risks are, how best they can mitigate the majority of them, and how, in a worst-case-scenario, to deal with an eruption in a logical and safe manner.

Cognitive Background

The issue of safety around volcanoes is influenced by the perception of the people that live with this risk. These people live with this risk from day to day and either accept it or are ignorant of the possibility. For example, in the seismically active Parkfield, California area, people were educated about the potential for an earthquake. Studies
showed that these people have either accepted and acted upon the prediction and the corresponding suggested mitigation actions, or they disregarded the prediction completely (Mileti et al., 1992). A question that surrounds low probability events, such as volcanic eruptions, is how people are capable of recognizing such a low probability event, or whether they actually do (Douglas, 1996). The information available for people with such a risk as a volcanic eruption tends to be technical, making it even more difficult for a lay person to understand the reasoning behind a scientist’s decision or to appreciate the pertinence of the information (Douglas, 1996). This makes communication between the scientists who understand the phenomenon and the layperson difficult, and allows misunderstandings to arise. It also allows people to easily disregard or not recognize the need to prepare for a low probability event; if the information is difficult to understand or confusing there is little to entice people into action.

People confronted with a hazard on a regular basis, such as coastal erosion which occurs on a daily basis, are much more aware of the risks and are more likely to practice countermeasures to ensure their own safety (Tobin and Montz, 1997). People who are rarely faced with hazards, such as volcanic hazards, are much more ignorant about the reality and dangers of those risks. People in low risk areas tend to have difficulty articulating their thoughts or understandings of those risks (Tobin and Montz, 1997). So, when dealing with people around Mount Baker where residents are rarely faced with immediate volcano hazards, officials must understand that residents may be ignorant of risks or have difficulty answering or explaining their beliefs and understandings of the hazards associated with Mount Baker.
In other cases, our ability to forecast an eruption event can give people in at-risk communities a false sense of security (Abramovitz, 2001). These people might feel that because scientists have improved their ability to understand what is going on at a particular volcano that it is safe to build and live in hazardous areas. Also, especially here in the United States, people can be reasonably assured that in the event of a disaster that they will be rescued, physically and financially (Abramovitz, 2001). Here, even without insurance, people will most likely be reimbursed, at least in part, for any losses and be provided compensation for injuries through both government and private organizations. Organizations like Red Cross and many local donation groups offer help in times of crises and need to help those that have suffered from natural disasters.

The stress associated with natural hazards might also cause people to adopt incorrect assumptions or beliefs (Tobin and Montz, 1997). For example, people in flood plains might believe that floods happen “every 7 years” in an attempt to impose order and remove the fear from a hazard (Tobin and Montz, 1997, p 161). Or, in cases where a natural hazard is monitored, people might believe that the hazard is managed and is thus no longer of concern. For example, on the volcanically active Volcano Island in Taal Lake, Philippines, there was concern about an eruption in 1988 and the safety for people who live on the island. The residents, however, felt little concern since a building on the island had been dedicated to the Philippine Institute of Volcanology and Seismology. The building had been built to help monitoring efforts after an unexpected eruption of Taal in 1965 killed many residents. Residents believed that the presence of the Institute, and specifically this building used for monitoring purposes, would act as a form of “volcanic eruption insurance policy” (Blaikie et al., 1994, p. 186). They believed as well that it
would ensure their personal ongoing safety on the island despite the fact that there
were not enough boats to evacuate the island in the case of an emergency (Blaikie et al.,
1994). This erroneous belief put the residents in jeopardy both because of their ignorance
of the danger and their putting faith in something that really had no means of protecting
them, thereby ensuring mistrust if and when a future eruption did devastate the
community and the Institute failed to protect them (Blaikie et al., 1994).

The cognitive process that leads to a person remaining in a dangerous or
hazardous area is very complicated. Although it would seem that a person’s actions
would aim to reduce vulnerability to a hazard many times that does not happen. There are
many possible reasons for this, including the powerlessness a person might feel in the
face of natural hazards, or that the amenities far outweigh the risk of a natural hazard in a
certain area, or even the difficulty of moving away from a hazard is too great (Tobin and
Montz, 1997). All of these probably play a role in the areas surrounding Mount Baker.
These people live in a lush and beautiful land from which they are loath to relocate. The
proximity to skiing, camping, and any number of outdoors activities prompt many people
to ignore potential volcanic hazards that might arise. The fact that associated hazards
have not manifested themselves in an overt manner since the 1975-1976 volcanic events
only serves to encourage people to remain in potentially dangerous areas.

One must also consider the time intervals between hazardous events. In the case
of a volcanic eruption, which only happens rarely in populated areas, it is difficult to
impress people with the danger of a possible eruption due to the time interval since the
last eruption. This time lag between events can lead people to ignore a threat, believing
that it will never occur in their lifetime (Tobin and Montz, 1997). This effect of recency
on people’s memories provides further complications. The more recent the event, the more aware and clear will be the people when they remember or talk about the hazard. The unfortunate associated problem with recency is that the farther one gets from the event, the less and less the people will remember: “...15 years after an event, knowledge of its particulars will be minimal and no longer directly impact decision making” (Tobin and Montz, 1997, p. 157). This could mean that at Mount Baker, many people may have forgotten that there was fear of Mount Baker erupting or of large debris avalanches from the summit area in 1975-1976. Indeed, while conducting the survey portion of this research, people told me that they remembered something about the 1975 events but that they had mostly forgotten about it. The effect of time passing can hamper officials’ efforts to galvanize a community into action that could mitigate disastrous effects or even save people’s lives.

Another problem with the populations around Mount Baker might be the publicity during the 1975-1976 crises, which culminated in no disaster other than lost revenue. In cases where warnings, evacuations, or closures are not followed by the awaited disaster people might ignore future similar warnings (Tobin and Montz, 1997). For example, where meteorologists have warned of tornadoes or hurricanes, people evacuated, and no tornado or hurricane followed, the next time there is a warning, people are less likely to comply with evacuation requests from the meteorologists (Tobin and Montz, 1997). At Mount Baker, while talking with people in the surrounding communities, a few people told me stories about how they had been removed from campgrounds or closed out of recreational sites. When the activity at Mount Baker subsided and they were able to return to their recreational activities, without any serious volcanic impact on their lives,
they were unhappy with the officials that interrupted their activities and made them leave. One even vowed to never evacuate or leave the area again since officials had proven to her that they did not understand the volcano well enough. A few other people told me that their parents or their older family members had never seen any serious threat from Mount Baker, and they agreed, believing that Mount Baker would never impact their lives.

Other studies have found that only a direct impact upon one’s life typically increases threat knowledge or risk perception (Johnston et al., 1999a). Yet, even with this increased knowledge, people are not necessarily more likely to prepare themselves or look for information about future hazards. Once a community has endured a relatively small impact, residents believe that they can cope with the same or even worse in the future and tend to reduce their preparedness, or assume that future events will be equally benign (Johnston et al., 1999a).

Alternatively, people might choose to completely disbelieve the impact of a potential risk. An extreme example is Harry Truman at Mount St. Helens in 1980. He so vehemently denied the possible risk associated with the mountain that he was killed when it erupted (Tobin and Montz, 1997).

Confusion sometimes arises from the fact that risk communication must address two sometimes very different factors: one is the scientifically documented risk; the other is the public perception of that risk. These two may or may not agree with each other (Weitz and Benjamin, 2001). For example, at Mount Baker many people that talked with me perceived that there was nothing that they could do if Mount Baker erupted, that they were in fact too close to the volcano to be saved. The reality is far from that, since most
people live quite some distance and even those closer to the volcano could climb into the surrounding hills to get above any possible lahar flows and would be protected from the worst of any activity but a directed lateral blast.

Politics

At Las Casitas volcano in Nicaragua, Hurricane Mitch saturated and weakened the sides of the volcano, resulting in massive lahars killing 1,400 people. If preparedness measures had been in place, and emergency planning had started when the storm first hit, not days later, these people could have been warned and been saved. Instead, political confusion hampered efforts to inform people of the dangers – namely, officials in charge denied that there was even a crisis (Abramovitz, 2001). Little can be done to modify an eruption, so the burden of protection lies most heavily upon land management policies (Scandone, 1983). Curiously enough, one of the findings of retrospective reviews of responses to volcanism in the Cascades is that, before the 1975-1976 thermal activity at Mount Baker, volcanic hazards were not included in US Forest Service operating procedures for the Mount Baker-Snoqualmie National Forest and North Cascades National Park. As well, volcanic hazards were not considered in development or land-use management procedures even in Hawaii where volcanic activity is commonplace (Hodge et al., 1979).

In just about any volcanically active area, one of the few reliable means of saving life and property is to limit development in hazardous regions (Scandone, 1983). Yet this is difficult to do without political support. Much of what and how legislation is passed is based upon partisan politics and whose political agenda will be protected or furthered (Blaikie et al., 1994). This means that as one politician creates means to protect the
public, the next politician in office can remove those protections in order to help the
economy or support special interest groups. It is politically easier to spend money on
something visibly helpful, such as rescue and relief, than it is to spend money preparing
for an event that might not ever happen during a politician’s term in office (Abramovitz,
2001). It is difficult to protect and reinforce political measures designed to protect the
people from natural hazards when the natural hazard is intermittent at best, or a rarity,
such as volcanic events. The political environment often changes infinitely faster
compared to the rise of magma into a chamber. Therefore, a necessary element to
community hazards awareness is some “institutional memory” or “collective memory”
where a description of events, problems, and hazards is used to help communities
anticipate possible future events (Blaikie, 1994, p. 223). During the survey process at
Mount Baker, a real estate salesman showed me paperwork for the Lake Tyee area where
the original land purchaser was required to sign a waiver of liability stating that they had
read the attached paperwork on Mount Baker volcano and accepted all responsibility for
any damages by the volcano. At face value, this seems minimally appropriate to disclose
any potential risk associated with the volcano. However, as the salesman went on to
explain, only the original owner would ever have to view the waiver or the attached
paperwork; any later owners were not required to sign, or even view the disclosure on
volcanic activity that might effect them in the future.

Risk perception is an inherently political problem. It is impossible to disentangle
politics from the risk (Douglas, 1996). A man from the town of Concrete, near Mount
Baker, talked about the injustice of scientists advising US Forest Service officials into
making the decision to close the Baker Lake area: “the decision (to close) should have
been ours... We were not consulted. This thing could go on for years....” (Foster, 1975, p. A-1). This man owned a resort on Baker Lake, and is not a scientist, and yet he felt he should have been involved in making the decision to close the area down. His decision is mostly financially related considering the lost revenue from summer tourism.

Even today, the decision-making process surrounding risks and management of hazards is inherently politically motivated, and without necessary communication between the community and the scientists or other management agencies, there will continue to be these misunderstandings which slow down the education and safety process. Instead of being “a decision dictated to the public by the federal bureaucracy” (Anonymous, 1975d), an effort needs to be made before a hazard becomes a disaster (even a financial or public relations one) to involve the public. The public needs to at least understand the decision making process and thus needs to be educated before a need arises (Ruckelshaus, 1983).

Politics are inherent in risk says Douglas (1996): the basic question of risk analyses is always about “what is acceptable risk?” This question in turn will always be affected by the political outlook and aims. This concept of political risk is well illustrated by political events surrounding the Mount Baker increased thermal activity in 1975-1976. If one reads the series of newspaper clippings from 1975 pertaining to the Mount Baker activity, one will see the progression from concern and preventative actions to political agendas and cries of foul play. A brief overview begins with an article about how campgrounds were closed on Baker Lake due to concerns of debris avalanches into the lake and large waves compromising the dam (Green, 1975). Puget Power Company agreed to keep water levels lower in an attempt to accommodate any potential wave
action in the reservoir. The US Forest Service agreed to close Boulder Creek drainage, and it was agreed by all officials to keep the Baker Lake area closed to all non-essential traffic (Frank, et al., 1977).

Another article interviewed people from the community of Concrete, a town in part dependent upon Baker Lake summertime activities. These people complained about the lost revenue from summer campers and boaters and the negative effects of news clips talking about the volcanic activity at Mount Baker. These negative effects of the media coverage, they believed, would only be exacerbated by closures of the Baker Lake areas (Foster, 1975). Within 10 days, Senator Lowell Peterson, from Concrete, was supporting the complaints (Anonymous, 1975a) and articles throughout the summer and into October lambasted the scientific community and government officials for making the decision to close the Baker Lake area (Anonymous, 1975d, and Anonymous 1975e). Senator Peterson even referred to officials’ decisions to close areas as “brainwash” and claimed that USGS members were attempting to reinforce their recommendations of closures by maintaining them (Anonymous, 1975d). As USGS scientists tried to explain their concern, taking Second Congressional District Representative Lloyd Meeds on a helicopter ride to show him their concerns, Senator Peterson claimed that scientists were merely trying to defend their decision, regardless of the good of the people (Anonymous, 1975d). Congressman Meeds also furthered the campaign to open the parks (Anonymous, 1975b).

This political melee over the safety of the public at Mount Baker turned community members in Concrete against the US Forest Service. The US Forest Service had been the organization to make the public announcements of closures and remained in
the media spotlight because of their role (Hodge, et al., 1979). The media repeatedly belittled the scientific warnings and claimed that the closures were unnecessary until many people in the region became wary of government or scientific intervention and argued that control should return to the people in the communities (Anonymous, 1975e). Yet, even while community members were fighting to get campgrounds reopened, there were people from Tacoma, Washington, to Nanaimo, British Columbia, calling scientists in the region afraid their fine china would be destroyed by an eruption or afraid to drive down Interstate-5 because of possible eruptions from Mount Baker (Zoretich, 1976).

Thus, in preparing to enter communities near Mount Baker and ask about volcanic activity at Mount Baker and 1975-1976 activities, there was concern from members of US Geological Survey and myself of raising old issues of economic hardship and political ill-will. It was hoped that enough time had passed between the old 1975-1976 politics and the current study, but, just in case, questions were studied and carefully worded (for example we eliminated the use of the word “evacuate”) to avoid any potential concerns or revival of old fears.

**Effective Communication**

Many situations have occurred in volcanic environments where the human catastrophe could have been prevented by better communication and more trust between the community and managing agencies. In 1985 at Nevado del Ruiz volcano in Colombia 22,000 people were killed due to a lack of communication and the inaction of a government unwilling to accept the political and economic cost of evacuating if the eruption had not materialized (Alexander, 1993). The community should have been included on the education and decision process, and not just been given print information
that meant little to readers. With useful outreach and education, people might have evacuated more willingly when told and the government might have acted on public safety.

Misunderstandings, like those at Nevado del Ruiz (Alexander, 1993), impede the educational process and make it more difficult for scientists to do their jobs effectively. Instead of reporting on pertinent activity, volcanologists have to also explain or review misunderstandings or false claims by others to clarify information and educate the public. One example is the man around Mount Baker in 1975 who wrote: “We have seen far more steam activity from the earth in both Yellowstone National Park and the Bumpas Hell area of Mt. Lassen National Park than is displayed from Sherman crater. And those areas attract hundreds of thousands of visitors each year” (Anonymous, 1975e). The real issue forcing the closures at Mount Baker by October 1975 had more to do with the weakness of summit materials due to hydrothermal alteration than with the steaming of the Sherman crater area (since there had been no study indicating fresh magma and concern for an eruption was beginning to wan), but this man was ignorant or unconcerned by those reasons. Having been published in the newspaper also gives this man’s erroneous argument credence and will therefore make it more difficult to correct the misunderstanding as other people read his argument and agree with him.

In order to be best prepared for any natural hazard the public needs to take an active part in educating themselves and in preparing for future events. Clearly, officials can not be present in each household to encourage people to evacuate. Ultimately, it is up to the people in the homes and neighborhoods to make the correct and safe decisions and help each other. Therefore, it is always a goal of emergency planning to generate a sense
of small-scale self-sufficiency (Alexander, 1993). A lack of neighborhood organization can increase the vulnerability of a group to disaster (Blaikie et al., 1994).

As well, communities that have a feeling of self-sufficiency and confidence in themselves and their community’s ability to cope with a crisis lessen the stress in the community (Miller et al., 1999). In volcanically active regions where communities have prepared for possible activity, feelings of vulnerability and helplessness have been lessened and the community has coped better with the effects of that activity (Miller et al., 1999). This preparation can be achieved by well-coordinated educational programs in communities to educate them ahead of time about the possible hazards in their area.

Education is necessary to safely guide people from a dangerous area. Education can also help explain how residents can best prepare for and live with potential volcanic activity. In any situation, information about a volcano can become misunderstood, or during the course of an event can become outdated, thus requiring people to be aware and educated about what is happening in their area at a certain time (Johnston and Ronan, 2000). If volcanic activity at Mount Baker suddenly increased, people could become confused about the hazards to be aware of: for example, the residents of the town of Concrete would need to be aware of an eruption, possible debris avalanches down the Boulder Creek drainage, and the very remote possibility of the collapse of the Baker Lake Dam. An eruption would require residents to evacuate the area whereas debris avalanches or a breach of the dam would require residents to get to high ground. Unfortunately, when people most need information it might not be available due to power-outages, communications failure, or other technical difficulties. Such a situation would require people to make decisions on their own without immediate scientific technical input. Thus,
people need to be able to make educated decisions about their own welfare and safety without a direct order from an emergency management agency (Miller et al., 1999).

Mitigation and Preparation

With the numbers of natural disasters increasing each year (Abramovitz, 2001), it is necessary to identify means to mitigate disasters before they occur. A few years ago, it was found that investing $1 million into mitigation practices such as land use policies, creating hazard maps, debris control dams, and moving people out of hazardous areas could save $7 million in disaster recovery costs (Abramovitz, 2001). The U.S. Geological Survey, in cooperation with the World Bank found that, in the 1990s, global financial losses due to natural disasters could have been diminished by $280 billion. The only requirement to that reduction: spend $40 billion in mitigation strategies and preparedness education (Abramovitz, 2001). Through spending a fraction of what was lost, billions of dollars could have been saved, as well as lives. Some of these relatively simple measures, such as risk assessments, hazard maps, and the like, can save not only time (since they would not have to be created at the time of the crisis), but also lives in emergency situations (Crandell et al., 1979).

During the 1975-1976 thermal events at Mount Baker, scientists from the USGS took a mostly advisory role in managing the closures around the volcano. The US Forest Service was the agency that closed the campgrounds and Boulder Creek drainage to the east of Mount Baker, while the USGS undertook monitoring tasks around the active areas (Frank, et al., 1977). At Mount Baker, nothing more significant than steam plumes and increased acid loads in Boulder Creek occurred.
In other cases, such as Mount St. Helens, the role of the USGS became more important due to the amount of activity. Again, the scientists from the USGS maintained an advisory role in managing admittance to the volcano. Scientists viewed themselves as technical advisors, and passed their reports on to other officials in the US Forest Service and Emergency Management offices (Saarinen and Sell, 1985).

Unfortunately, many of these reports about Mount St. Helens never made it to the public. Public officials made the decision whether information was disseminated or not, which sometimes meant that a report never got to the people it was intended to help (Saarinen and Sell, 1985). For example, only 2 of the 60 contact numbers for officials to keep apprised were east of the Cascades, and those 2 were in Yakima. No other officials were kept informed east of the Cascades. This meant that people in eastern Washington were unaware of the dangers that Mount St. Helens posed to their own region. They viewed Mount St. Helens as a “distant Cascade peak” and one that posed little threat to their homes and daily lives (Saarinen and Sell, 1985, p. 36). If municipal officials in eastern Washington had been given reports from the USGS, they would have been aware of the hazards. Instead, the eruption caused most roads to close, left motorists stranded, and in at least one community in eastern Washington all of the emergency vehicles were out of commission due to ash in their engines. Again, access to hazards reports could have at least helped these areas prepare for a full-scale eruption or know what to expect if the effects reached them (Saarinen and Sell, 1985).

Another problem with information was who received it. It turned out that amateur radio operators intercepted many of the USGS radio transmissions. Any information that they overheard was then reinterpreted and passed to whomever they decided, which led to
rumors and many misinterpretations (Saarinen and Sell, 1985). The media would also misquote, misinterpret, and generally sensationalize much of the information they received (Saarinen and Sell, 1985).

There is a real problem between scientists and officials regarding the types of information that scientists present. Scientists are concerned with scientific endeavors and have little time to translate scientific fact into usable public announcements. The translation process often becomes the domain of other agencies involved in the official framework (Johnston, et al., 1999b). This means that there needs to be enough communication between officials to accommodate for the inherent vagueness of scientific output — to understand the uncertainties involved in scientific forecasting. Emergency management officials and others will need to specify what kind of information they need from scientists and insist on understandable explanations (Johnston et al., 1999b).

At Mount Baker, there is an Emergency Response Plan. The Mount Baker/Glacier Peak Coordination Plan was created by members of the U.S. Geological Survey, U.S. Forest Service, and emergency managers from Snohomish, Skagit, and Whatcom Counties, the State of Washington, and the Province of British Colombia. The plan and group were organized with the idea of organizing actions between the groups in order “to minimize loss of life and damage to property before, during, and after a hazardous geologic event at either volcano” (Mount Baker/Glacier Peak Coordinating Committee, 2001, pg. 11). The group also maintains that they will “strive to assure timely and accurate dissemination of warnings and public information” (Mount Baker/Glacier Peak Coordinating Committee, 2001, pg. 11). The plan outlines past activity as well as possibilities for future events, and then continues on to outline a plan of response. The
U.S. Geological Survey would first expect to establish a volcano observatory in the area, and install monitoring instruments. Based on the discoveries and recommendations from the findings, the U.S. Geological Survey would then define future expectations and allow the rest of the organization to begin to implement warnings and alerts. Within the plan are contact numbers and interagency responsibilities for each group. For example, local jurisdictions must be responsible for their own county organization of emergency activities, and the contact numbers for each county emergency management office is listed. Flow charts are included, outlining the structure of responsibility and organization of different groups and individuals, from U.S. Federal response, to regional incident commanders. As well, a Mount Baker/Glacier Peak Facilitating Committee (FAC) has been established with members from related county emergency management teams, Washington State Division of Emergency Management, Washington State Department of Natural Resources, U.S. Geological Survey, U.S. Forest Service, and the British Columbia Provincial Emergency Program. This group is designed to maintain preparedness during times of quiescence at the volcanoes. The outlined activities during quiescence are outlined as: “Prepare emergency plans and programs to ensure continuous readiness and response capabilities.” They have outlined the ways to do this as: 1.) “coordinate, write, revise, and exercise this volcano response coordination plan” 2.) “develop and evaluate alert and warning capabilities for the volcanic hazard risk areas”, and 3.) “review public education and awareness requirements and implement an outreach program on volcano hazards” (Mount Baker/Glacier Peak Coordinating Committee, 2001, pg. 24).
The Emergency Response Plan is a beginning. Most volcanoes now have some educational campaign working or at least in the beginning stages of analyzing the necessary work to be done. For example, at Mount Baker, I have undertaken the initial survey of necessary outreach for the surrounding communities. Emergency planners now have a list of contact numbers and officials to organize into action in the case of volcanic unrest. There have been many studies conducted on how to educate and approach communities and what information with which to provide them. With the problems associated with the Mount St. Helens eruption, there is even a list of problems and pitfalls for emergency planners to avoid. The future is looking much brighter for dealing with volcanic crises and at risk communities.

Psychologists and the advent of community surveys

Recently, there has been much study of the connection between the human and the volcanic systems. More specifically, psychologists and volcanologists alike have endeavored to identify the comprehension of individuals of the risks and hazards associated with volcanoes (Perry and Lindell, 1990; Johnston and Ronan, 2000).

In order to best prepare individuals and communities for hazards, investigators have identified certain communication and educational necessities. Firstly, it is necessary to identify the risks to each community (ash fall, lahars, lava flows, etc). Secondly, it is necessary to identify the educational needs of those individuals: do people understand the risks to their communities associated with their volcano? Do people believe that lava flows are a risk to their community when in reality there is little chance that lava will be found anywhere near their community? Thirdly, it is necessary to use the first two steps to identify what an educational outreach program should include. This includes how to
reach individuals in different communities, and how best to educate them with the information that’s necessary and suitable to their needs.

This thesis undertakes this study for the Mount Baker volcanic region. The first part of this study identifies the first step (identifying the geology of the region and the hazards associated with volcanoes), and this chapter outlines the second step: identifying the educational needs of the individuals at risk from volcanic activity at Mount Baker volcano. The last chapter outlines methods for educational outreach programs in the Mount Baker area.

Community Perception

Each community perceives threats differently. Depending on the unique characteristics of each community, the educational needs will be different. By studying each community, an educational outreach program can be tailored to meet each community’s needs. Some individuals or communities place more concern on economic threats to their community, whereas other individuals or communities might be more concerned with physical threats. This characteristic can influence the importance that a community or individual places on a risk (Miller et al., 1999). In a study in New Zealand (Miller et al., 1999), the majority of individuals responding to the questionnaire depended upon an active volcano for their livelihood, but the volcano had done little physical harm. So, for them, economic concerns were more salient than physical threats. It is necessary to identify concerns of each target community and focus education and preparation strategies to address those concerns, rather than issues that the community perceives as unimportant (Miller et al., 1999).
One of the most important steps in mitigation is to perceive that a risk exists in the first place and then to translate that recognition into mitigation actions. Lack of personal belief that a hazard can occur can lessen the amount of preparation in which individuals partake (Johnston and Benton, 1998). Despite increased threat knowledge and risk perception, many studies have found that this does not necessarily equate to increased preparation or willingness to comply with officials by individuals or communities (Johnston et al., 1999a). Increased awareness of an environmental hazard does not translate into actions or behaviors that might mitigate negative outcomes, such as compliance with officials (Perry and Lindell, 1990). Direct experience increases the numbers of individuals seeking information on the risk (Ronan et al., 2000). Direct experience also increases the belief by individuals that they will be affected by the hazard in the future (Becker et al., 2001). Research at Mount St. Helens found supporting evidence that residents affected more by activity at Mount St. Helens, such as having ash fall or correlating damage from the volcano, were more aware of the hazard and the associated threats (Perry and Lindell, 1990). Proximity to a hazard is a good predictor of threat awareness: the closer an individual is to a hazard the more aware they are of the hazards associated with the threat (Greene et al., 1981). Perceived risk has been associated with proximity to the volcano, perceived likelihood of another event and the potential impact, as well as past experience with the hazard (Johnston et al., 1999a).

People who have a low risk perception will be more likely to believe in individual choice and control about a potentially hazardous situation (Nomura et al., 2004). This could potentially lead to non-compliance among people with a low risk perception. As
well, people with a low risk perception were found to be more likely to ignore regulations for their safety than other people (Nomura et al., 2004).

The amount of searching for information that individuals perform has been used as an indicator for changes made in threat knowledge and their future actions (Johnston et al., 1999a). This was chosen out of other identified factors such as the salience of the hazard, the amount of damage in past activity, and the amount of hazard information searching. Thus, people who have had more contact with a hazard, or have looked for more information can be assumed to change their actions appropriately.

The source of hazard knowledge has been attributed to many different factors. Hazard knowledge and knowledge of appropriate mitigation adjustments has been related to the age, familiarity with the hazard in question, and length of the person’s residence in the area; the longer that someone has remained in an area with hazards, and the older they are both increase the awareness and knowledge of the hazard (Murton and Shimabukuro, 1974). Age and residency of individuals near a hazard have proved to be more important factors of threat knowledge than socioeconomic and location factors in some studies (Murton and Shimabukuro, 1974).

Also, residents do not attribute their actions solely to disseminated hazard preparation information. People seek out other people’s opinions and search for information on their own before acting (Mileti et al., 1992). Studies have found that residents often discuss hazards issues with friends, family, and relatives. It has been found that although not much hazard information may be imparted, the more communication there is the more hazards adjustments people take (Perry and Lindell, 1990). However, most of the actions that they do take are part of the hazards preparation
information, but people attribute their actions to their own information seeking and to interactions with other people (Mileti et al., 1992).

One study found that residents questioned about the Parkfield Earthquake prediction dichotomized risk information. Residents accepted, personalized, and acted upon hazard warnings, or they ignored the warnings entirely (Mileti et al., 1992). It could be that people do not think of risks in terms of probabilities, but rather simplify the concerns into personal concerns or disregard them as unimportant (Mileti and Fitzpatrick, 1993).

Most individuals will rate their own preparation for a hazard as better than average or better than other individuals in their community. They also rate the local government as better prepared than the central government (Johnston et al., 1999a).

Some agencies have been perceived as more credible than others, but people seek out many different sources for their information, making the need for coordination and an integrated approach more necessary (Ronan et al., 2000). In many communities, the media plays an important role in disseminating necessary information to people. People who are concerned over hazards will often look to television, radio, or print media to attain important information on preparation and safety issues regarding the hazard (Johnston et al., 1999a). In times of crisis, individuals will seek out information multiple times a day. For example, at Mt. St. Helens during the spring of 1980 and before the eruption, approximately 50% (of 174) individuals reported receiving volcano related information at least twice a day or more, 90% of those received information 4 times a day or more (Greene et al., 1981). However, the media can often generate problems with sensationalized and inaccurate reporting (Becker et al., 2001).
It is also necessary to monitor the information reaching individuals as some information could be incorrect or misinterpreted. For example, the media in certain situations has been known to sensationalize events, making them appear far worse or farther reaching than is the truth (Ronan et al., 2000). However, the media and information sources could be used as a tool to reach residents, if instructed on the accurate information necessary to the public (Ronan et al., 2000). When the media is monitored to assure accuracy, they can be a very useful tool in disseminating hazards information to individuals who need it.

Due to this diversity in information sources, it is important to diversify the means of information dissemination. Different individuals look to different informational sources for their information, and it is important to officials to use many different methods of educating communities and individuals to the pertinent risks and hazards (Johnston et al., 1999a, Ronan et al., 2000). It is also important to begin information dissemination long before the hazard materializes. Preparing the communities and individuals ahead of time is the best way of helping communities and individuals to understand what the hazard is and the potential impacts (Greene et al., 1981). Once information has reached the public, it is necessary to clarify concerns or confusion (Greene et al., 1981). If hazards information is held back until the time of crisis, it reduces the amount of time in which officials can accurately clarify and improve the information.

Results show that residents are more likely to adopt protective measures if officials stress their efficacy. Emergency managers will have better success at getting people to adopt protective measures through stressing the efficacy of those measures,
rather than the likelihood of the risk. Even in places where hazards such as earthquakes are commonplace, people adopted protective measures more when the usefulness of those measures was demonstrated (Lindell and Prater, 2002).

A sense of community can also reduce the amount of helplessness or vulnerability that individuals feel about a hazard (Miller et al., 1999). Not all studies have identified this relationship, however, due to differences in community characteristics (Miller et al., 1999). For example, transient populations that might be included in a study, such as seasonal employees for ski seasons or resort seasons, might have established fewer connections and ties to the community in question. The increased level of community solidarity can lead to more security among the community when dealing with something unpredictable such as natural hazards. Similarly, co-operation between organizations and the more guidance and encouragement that these groups offer can help encourage individuals and communities to undertake preparation activities (Ronan et al., 2000).

One of the most important features in other hazards awareness campaigns has been issuing an information brochure to the public. This includes information on what the risk is, where it is and is not, what the timeline for events might be, what people can do to prepare, and where more information is available (Mileti, et al., 1992). Before the brochure is issued, there should be an information campaign to prepare or prime the public for the brochure. After the brochure is issued, there should be other information sources as well: the brochure is not enough. People need to be inspired to take part in preparation activities, so information should be informative, and should capture their interest (Mileti et al., 1992). Communities can be taught to more accurately understand
hazards information and to undertake protective preparations for that hazard (Mileti et al., 1992).

1976 Survey: Local Response to Increased Thermal Activity at Mount Baker

Reaction to the thermal activity at Mount Baker in 1975 gave researchers an excellent chance to observe the interaction between the public and officials (Hodge et al., 1979). Two months were spent in 1976 around the town of Concrete surveying townsfolk as well as recreationists visiting the area, some of whom were restricted from the area the previous year. The goals of this survey included individual’s perceptions of the possibility of dangerous activity at Mount Baker, identifying reactions of individuals to the official action (such as the closures), and individual’s compliance to future warnings from officials (Hodge et al., 1979).

There were strong feelings about officials’ reactions and decisions in response to the concern of debris avalanching from Sherman Crater. The closure of campgrounds around Baker Lake Reservoir led to angry outbursts aimed at officials. This study was able to identify differences in perceptions between residents of Concrete and recreational visitors to the area (Hodge et al., 1979). This difference illustrates the distinct negative bias of residents towards official actions during 1975 and 1976.

For example, residents of Concrete were unwilling to admit to the probability of future volcanic events affecting their community. Visitors to the area were much more willing to admit to the possibility of volcanic events occurring, such as mudflows, falling rock, earth tremor (which may or may not be volcanically triggered), or flooding. For example, residents of Concrete were unwilling to admit to the possibility of avalanches at Mount Baker. This is significant due to the concern in 1975 of avalanches down Boulder
Creek, prompting the closure of Boulder Creek campgrounds and the resort along Baker Lake reservoir, as well as the lowering of Baker Lake reservoir itself to allow for avalanching into the lake (Hodge et al., 1979).

As well, residents of Concrete were more critical of the US Forest Service officials who closed Baker Lake campgrounds. Sixty-five percent of a total of 135 respondents from Concrete thought that the US Forest Service had overreacted, whereas only 45% of a total of 227 recreationists believed the same. The numbers indicate significant displeasure with the closures, but it is mostly the residents of Concrete who felt the US Forest Service had based their closures on overreactions about hazards (Hodge et al., 1979).

Of the residents who supported the decision to close the campgrounds, 76% believed that there had been little economic impact upon Concrete. However, of the residents who disagreed with the decision to close campgrounds, 58% felt that there had been an adverse effect upon the economy of Concrete. Among the recreationists, it was the number of visits to the area that differentiated supports from the non-supporters: the more individuals visited the area, the more strongly opposed to the closures they became. The fewer visits individuals had made to the area, the more they agreed with the decision to close the campgrounds (Hodge et al., 1979).

Concrete residents also appeared less forgiving in future dealings with the officials. When asked whether they would respond to future warnings about activity at Mount Baker, Concrete residents (from a total of 135) were 71.3% in agreement that they would disregard future warnings. Recreationists (from a total of 227) were less adamant,
with only 25.2% admitting that they would disregard warnings, and 34.9% admitting that they were unsure of their future decision (Hodge et al., 1979).

This study from Hodge et al. (1979) illustrates some of the difficulty in dealing with certain populations about volcanic hazards. The responses to this survey were very strongly aligned with the representative experiences of the respondents. For example, the residents of Concrete were more derisive of officials due in large part to the perceived economic hardship so elaborately described by the media. The reality actually shows that this economic hardship might have been exaggerated: at the same time as the 1975 closures around Baker Lake there was an unusually rainy season leading to a slump in many recreational towns, the novelty of the relatively new North Cascade Highway was waning, decreasing the traffic through Concrete, and the lumber industry was experiencing a depression. All of this means that the 25% sales drop in the community of Concrete may have been at least 20% due to events other than the closure at Baker Lake, thus leaving an estimated 5% blame on volcanic and official interference (Hodge et al., 1979). Regardless of the reality of the economic hardship and the media interference, the perception of the residents could lead to future concerns for any educational outreach programs presented by officials.

Conclusion

There is a need for a predetermined plan for public education of the hazards involved with Mount Baker. The USGS had a difficult time keeping up with requests during the Mount St. Helens crisis due to a lack of manpower, leading to 20 hour work days for weeks at a time (Saarinen and Sell, 1985). It was convenient that Mount St. Helens already had a hazards map created (Saarinen and Sell, 1985). Scientists need to
figure out how to get this information, such as a hazards map, to local administration and politicians. They also need to identify a way to make sure that their information is acted upon (Scarth, 1994). As was seen at Mount St. Helens, there were times when good information was not passed to all of the necessary people and communities, such as eastern Washington being unaware of the far-reaching effects of a volcanic eruption (Saarinen and Sell, 1985). It is necessary that scientists, or some other predetermined individual or organization, begin to take responsibility not just for getting information published, but to see that other officials are aware of it, understand it, and are using that information.

What has changed since the Mount Baker thermal event and the Mount St. Helens eruption? There are hazards maps for Cascades volcanoes, community education programs around particularly dangerous volcanoes such as Mount Rainier, and even emergency management cooperation around many volcanoes. Preparation within government agencies has increased dramatically since 1975 activity.

At Mount Baker, a coordination plan has been developed for the Mount Baker-Glacier volcano region. This was published in 2001 and includes a plan of observation and deployment of monitoring tools (Mount Baker/Glacier Peak Facilitating Committee, 2001). The plan also includes contact numbers and a list of responsibilities for members of the Mount Baker/Glacier Peak Facilitating Committee (FAC). The FAC includes local, state, federal, provincial, and Canadian government groups. The plan has been designed to provide an immediate response group of officials to decide on appropriate measures to take.
The problem now is the cooperation with the public. Around Mount Baker, people are confused about the hazards, for example believing that lava flows are a concern in their communities when no community lies within a lava hazard zone (see Chapter 7: Results). Although communities around Mt. Rainier have been canvassed and are working with USGS scientists, many other volcanoes have yet to be addressed, such as Mount Baker, Glacier Peak, and Mt. Adams, in Washington, and Mount Hood and Three Sisters in Oregon, and Mount Shasta and Lassen in California.

There needs to be more interaction between scientists, emergency management and the general public living in the area of a volcano. With volcanology, it is difficult to make a prediction of an eruption since the same precursory activity can end with nothing happening, a small ash eruption, or a full-scale catastrophic eruption. Yet, with an effective risk management program, some degree of forecasting must be utilized to best educate and prepare communities, and to gain their trust (Alexander, 1993). By including the populace, at least to some degree, in the preparation for a particular risk, responsibility can be shared between the risk management agency and the public to alleviate the pressures of inaccurate or difficult prediction capabilities. The lack of local awareness and involvement will inevitably lead to a more vulnerable public (Blaikie et al., 1994). As it is at Mount Baker, there is little visible scientific coordination with the public, and as seen in 1975, the public who lives around Mount Baker may become upset with the sudden appearance of officials making decisions about access and usability of Mount Baker recreational sites.

There have been many problems between scientists, officials, media, and the public in dealing with volcanic events in the past few decades. By taking note of what
happened and why these problems happened officials can turn problems into lessons that will help teach in future events.

It is also necessary for officials and scientists to maintain a relationship with the communities at risk, even when there is nothing wrong and no changes have been documented. Even when there is no new information to report, it is possible to answer questions that the public might have, giving officials a chance to correct misconceptions before it is too late or a catastrophic event occurs, destroying any chance to adequately prepare the populace (Weitz and Benjamin, 2001). In the future, if there is a relationship developed between scientists, emergency management, and the public around Mount Baker, it is possible that increased trust and understanding could prevent confusion and mistrust such as occurred in 1975.

Increased education will bring an increased understanding of the inherent uncertainty of a prediction or forecast and therefore an increased capacity to accept that uncertainty, and reduce the need for blame for a prediction gone wrong (Jamieson, 1996). By reducing the need for blame, an environment of trust can be built where the communities at risk are willing to comply with officials in times of need (Perry and Hirose, 1991). By thoroughly understanding the situation and the potential impact, the public will be more willing to evacuate, as much because they trust their officials, as because they have personally experienced the hazard (Perry and Hirose, 1991).
Chapter 6: Methods

What is needed in a Questionnaire?

What is the best way to assess the needs and awareness of the public? It is difficult to ascertain what information about a risk might frighten or challenge preconceived notions. The questions asked must therefore be presented in a neutral manner so that people are not unduly biased or frightened by any inferences made (Kammen and Hassenzahl, 1999). It is possible that people might become unnecessarily frightened by risks when first presented by their possibility, and so people must also be told of the hazard's limitations and capabilities as well (Slovic, 1991); for example, a lava flow will only reach so far and effect so many people. This education will ensure that people living well outside of a hazardous area are not frightened by the possibility a risk might present to them personally (Johnston et al., 1999b).

These problems in presenting risks all depend on the people's responses to many questions about what people believe and know about the hazard. Before any questions about beliefs or attitudes can be asked, one of the first needs is to measure awareness (Sudman and Bradburn, 1982): for example, does a person even know that Mount Baker is a volcano? In response to the 2003 questionnaire three people asked me, while in the process of responding to the questionnaire, if it was true that Mount Baker is a volcano, one of whom had spent his entire life within sight of Mount Baker. Without knowing a respondent's basic awareness, it is impossible to get an accurate accounting of what a person knows or believes about it (Sudman and Bradburn, 1982).

The order of questions has been shown to lead to different types of responses (Sudman and Bradburn, 1982). For example, if one were to first ask the question "Do
you like Mount Baker", a favorable response might be prompted; after all, one can ski, hike, and camp all over the mountain. Whereas if one were to first ask about what they know about the volcanic activity of Mount Baker, and then "Do you like Mount Baker", a more negative response might be provoked as people are first reminded of destruction, lost revenue, or economic difficulties before being asked whether they like Mount Baker or not.

**2003 questionnaire for residents around Mount Baker**

The community survey portion of this project was conducted in late February 2003. The questionnaire was 6 pages long and included a 1 page introductory statement explaining the purpose of the survey to subjects (see Appendix 3). The questionnaire was entirely confidential, participant names did not appear on the survey. There were a total of 27 questions, one of which was a ranking question (#1), and another was a matching definitions question (#3). The remainder of the questions were multiple choice, check all that apply, or fill in the blank. The last 10 questions were about personal demographic information asking for the subject’s hometown, employment status, income, etc. Questions were chosen for their pertinence to geologic concerns (such as whether people can correctly identify definitions of geologic terms) as well as the need to adequately understand the demographics of the area. Members of Cascade Volcano Observatory, Western Washington University geology and psychology departments, as well as associates who had no geology background previewed the questions for readability, pertinence, and length. The questionnaire was meant to be short and easy enough for people to complete, as well as thorough and usable.
Communities were chosen for their proximity to Mount Baker or their inclusion in the hazards zonation map (Gardner et al., 1995). Concrete, Glacier, Maple Falls, Deming, and Everson-Nooksack were chosen because of their locations within recognized USGS Hazards zones for lahars or pyroclastic flowage hazard (Gardner et al., 1995). Other small towns, such as Van Zandt and Acme, were chosen for their close proximity to Mount Baker, and thus the potential perception of being in a hazards zone (see Figure 12).

Due to the low populations in most communities and the difficulty of attaining enough feedback in any other way, I presented the questionnaire as a convenience sampling. I handed out all of the questionnaires myself in order to control the presentation and neutrality of the interactions with the subjects (Alreck and Settle, 1985). There was concern that by mailing out questionnaires, there would not be enough responses from each community. The communities in question are small enough that if only small percentages of subjects responded the quality of the study could have been compromised (Alreck and Settle, 1985). I approached individuals in businesses and individuals in the town proper. Business owners, workers, and clientele, as well as people in libraries, schools, and some parks were asked to complete the questionnaire. In all, responses were acquired from coffee shops, small stores, restaurants, schools, post offices, the US ranger station in Glacier, and libraries. Questionnaires were also left at some businesses for other workers, clientele, or family members to fill out. In most cases I waited for people to finish the questionnaire or returned to pick up the completed questionnaires, but in a few cases, questionnaires were mailed to my address in the geology department (~10 questionnaires). Another 20-25 surveys were read out loud for
The 150 completed questionnaires were collected from 7 communities out of a total of 215 passed out. Everson - Nooksack, Deming, Kendall, Maple Falls, Glacier, Van Zandt, Acme, and Concrete were the towns that I specifically left questionnaires in. Many people who did not live in the hazard zones were found to work in the hazard zones, so that a few people from seemingly unaffected communities were polled as well (see Figure 13). The questionnaires from respondents who only work in the hazard zones, but do not live there, were included in the results because of the amount of time these people spend in the hazard zones; these people would thus be affected by geologic events at Mount Baker.

It was believed by US Geological Survey members and me that surveying individuals in these communities also offered an excellent opportunity to provide information on Mount Baker activity and volcanic hazards. To that end, after participants returned the completed questionnaire, I supplied information packets (US Geological Survey Fact Sheet- 059-00: “Mount Baker – Living with an Active Volcano”; Scott et al., 2000), provided by Whatcom County’s Emergency Management offices in Bellingham, to those who were interested. Most participants were very interested in reading more information on Mount Baker and volcanic activity and I was able to direct them to the contact information and website addresses on the back of the fact sheet.
Chapter 7: Results and Interpretations

Analysis of the questionnaire results was conducted using the Statistical Package for the Social Sciences (SPSS). Raw frequency information can be found in Table 3.

Sixty-seven percent (of 150) respondents are female, compared to the U.S. Census Bureau results for Whatcom County where 50.7% of the total population was female in Whatcom County in the year 2000 (U.S Census Bureau, 2000). Therefore the sample is not entirely representative, which I believe is due to the characteristics of the towns and sampling techniques. Many of the towns are farming or logging communities, thus a large number of the men are involved in daily activities that I was unable to access; the women work in the businesses in town and were therefore more easily accessible to me. The explanation for the gender differences could be an overgeneralization, but regardless, it does appear that gender has very little correlation to other variables, meaning that there are few unique variables between the genders. The largest correlation between gender differences and other variables was $r = 0.208$ for the correct identification of the definition of ‘fumarole’ (question #3). More women than men were willing to comply with officials in question #16, but the difference was not statistically significant. The lack of correlation between gender differences and other variables, such as knowledge or awareness of volcanic activity, reduces the concern of not having a representative sample due to the high proportion of women respondents.

Results of questions #1 and #2 are presented in Table 3. Results from question #1 show that most respondents view floods as the most likely natural disaster to potentially disrupt their community. High wind storms and forest fires were the next most likely. Volcanic eruptions were the fourth most likely natural disaster respondents felt could
impact their community with earthquakes and landslides being the least likely
disasters. Results for question #2 show that most people (80% or more of respondents)
have a flashlight and batteries accessible, have a fire extinguisher, smoke detectors, and
first aid kit, and that someone has learned first aid in the household.

Question #3 presents the first interesting frequency information. Sixty-eight
percent of respondents were able to correctly identify the definition of a lahar flow, 78%
correctly identified the definition for fumarole, 85% identified the definition of a lava
flow, and 66% identified the definition of a pyroclastic flow. It is a concern that there was
possibly a false large number of correct answers. My concern is that this question could
have been answered at least in part by a process of elimination. If a subject were to
correctly identify 2 terms, they would have had an increased likelihood of identifying the
other 2. In view of this, if I was given the opportunity, I would rework this question to

Example 1:
Please match these terms with the appropriate definition:

a.) Lava flow
b.) Lahar flow
c.) Pyroclastic flow
d.) Fumarole

read as 4 terms with either 8 definitions (example 1) or give each term 4 definitions
(example 2). In this way, the subject could identify any number of incorrect definitions or
the subject could identify the same definition for multiple terms.
Example 2:

Please match these terms with the appropriate definition:

a.) Lava flow
   - * a water-saturated debris flow including rocks and mud
   - * a crack through which gases and steam are emitted
   - * a cohesive unit of molten rock
   - * a turbulent current of superheated gases and ash

b.) Lahar flow
   - * a water-saturated debris flow including rocks and mud
   - * a crack through which gases and steam are emitted
   - * a cohesive unit of molten rock
   - * a turbulent current of superheated gases and ash

c.) Pyroclastic flow
   - * a water-saturated debris flow including rocks and mud
   - * a crack through which gases and steam are emitted
   - * a cohesive unit of molten rock
   - * a turbulent current of superheated gases and ash

d.) Fumarole
   - * a water-saturated debris flow including rocks and mud
   - * a crack through which gases and steam are emitted
   - * a cohesive unit of molten rock
   - * a turbulent current of superheated gases and ash

Due to the confusion surrounding question #3 described above and the potential for falsely high numbers of correct matches of definitions, it is difficult to identify what influences the knowledge or ability of a subject to accurately choose the correct definitions. The other question regarding a subject's knowledge is a self-perception question (#6) and is thus inherently less reliable.

Question #4 asks about what volcanic hazards a subject thinks would most likely affect their community. It was found that, even though no community around Mount Baker is at risk of a lava flow, 46% of 150 subjects thought that a lava flow was a serious threat to their community (see Figure 14). Some of these subjects live as far away as 50 miles, and yet they are still concerned by lava flow hazards from Mount Baker. Forty
percent of the subjects said they are concerned by all of the listed hazards, volcanic
gases, volcanic ash, volcanic mudflows, and lava flows.

Interestingly, subjects think that their households are reasonably prepared for a
volcanic eruption. In question #5, 51% of people responded that they felt that their
household was either somewhat or very prepared. They also thought that they were better
prepared than their neighbors. This is supported by other studies which have found
similar biases indicating that individuals view themselves as better prepared than most
(Johnston et al, 1999a). Sixty-five percent viewed their neighborhoods as being either not
very prepared or not at all prepared. Fifty three percent viewed the government as being
somewhat prepared or very prepared. This is interesting when compared to question #6
where 57% of subjects answered that they don’t feel knowledgeable about volcanic
activity at Mount Baker.

Even though 83 people felt unknowledgeable about volcanic activity, 90% (136
people) correctly believe that Mount Baker will erupt sometime in the future (question
#7). Seventy-three percent said that they know that Mount Baker is continuously
monitored for activity levels (question #8). Although the monitoring question could have
been misleading; I noted while conducting the survey that some subjects assumed that
Mount Baker is monitored, but many subjects were not positive. Many people answered
that yes, Mount Baker was continuously monitored not because they know that, but
because they assume it is: some people responding to the questionnaire while I wrote
down their responses told me to mark that “yes, Mount Baker is continuously monitored
for potential activity” while they explained to me that were not sure whether there was
monitoring or not, but that they assumed Mount Baker must be watched. As well, many
people filling out their own questionnaires talked their answers through out loud to themselves, thus allowing me to hear how they arrived at their decisions. Therefore, the responses to this question could be falsely high.

Responses to question #9 show that few people have looked for volcano or Mount Baker information. Thirty percent of the respondents had never looked up any volcanic information at all, such as watching movies like “Dante’s Peak” or “Volcano”, talking with friends about volcanoes, or read any newspaper articles on volcanoes. Many only marked one item, such as “friends or relatives” or “Movies (‘Dante’s Peak’, ‘Volcano,’ etc.).” The highest response was 36% have read information in the newspapers. This is supported by other studies finding that the media plays an important role in disseminating hazards information (Johnston et al., 1999b). Twenty-nine percent have watched documentaries (such as “Fiery Planet”), and only 27% have picked up books on volcanoes. Twenty five percent also look to friends or relatives for information, correlating with past research that shows social networks play a huge role in disseminating information (Perry and Lindell, 1990). Responses of other surveys have found that newspapers accounted for the most chosen method of receiving hazard information, followed by television, then radio (Perry and Lindell, 1990; Johnston et al., 1999a). The Mount Baker survey achieved the same results, considering that documentaries were not part of the Mount St. Helens survey, and would be considered part of the ‘television’ category.

It was also found that information specifically designed for the public about Mount Baker was only rarely accessed. While the USGS has generated web pages devoted to Mount Baker, and even has a hazards report available on-line, only 17% of
people have looked up information on-line (and not necessarily from the USGS website). Only 13% from question 9 have looked to government agencies for information—such as the USGS. Question #10, specifically asking about the USGS hazards report, shows that only 31% even know that it exists, and only 5% of those people have actually read it.

When asked about 1975 activity, 32% of subjects lived around Mount Baker in 1975, and 51% knew about at least some of the activity. But, only 45% knew that there was scientific monitoring of Mount Baker in 1975, 28% knew that Baker Lake had been lowered to protect the dam, and only 32% knew that campgrounds had been closed around Baker Lake. There appeared to be no differentiation between the amount of Mount Baker knowledge and whether respondents lived in the area at the time. This is in contrast to some studies that have shown direct impacts from hazards influences people to increase their threat knowledge (Johnston et al., 1999a). However, other than possibly economically, there was little impact from 1975-1976 activity upon the surrounding communities. There was no loss of life, property, or even possessions. Thus, there was little encouragement for the residents around Mount Baker to further educate themselves about the hazards since the impact was negligible.

Today, many people use Mount Baker for recreational activities. Of the people questioned, only 28% of subjects have never seen steam plumes rising from Mount Baker. The reason so many subjects have seen steam plumes can probably be explained by the frequency of visits to Mount Baker each year, and especially by those visiting different areas more than once a year. This ranges from 41% to 59% of subjects who visit sites more than once a year for skiing, hiking or camping, visiting the ranger station at
Glacier, visiting Heather Meadows, hunting, fishing, and going on scenic drives or photography shoots.

Because people use Mount Baker recreational sites so often, question #16 asked subjects if they would be willing to comply with officials in a few different hypothetical scenarios if there were changes at Mount Baker (Figure 15). Ninety-five percent said they would be willing to learn safety procedures, 91% said they would be willing to stay away from certain areas around Mount Baker, and 91% said they would be willing to spend less time outside due to ash fall. Only 75% of subjects said they would be willing to leave their homes. During the surveying, one woman asked me if this question was saying that officials would “ask” her to leave or whether they would “tell” her to leave. Her explanation was that if she were told the reason and then asked to leave, she would leave without hesitation, but if officials were to demand her to leave without explanation or recourse, she would never leave her home. Other subjects asked similar questions leading me to believe that this question should be approached in the future in a few different ways by different questions. There needs to be a way to ask this question both ways, one implying a demand to evacuate (example 1), and another question explaining and requesting people to leave (example 2).

It was interesting to note that 86% live there because they like the area, and not

<table>
<thead>
<tr>
<th>Example 1: If you were told by officials to leave your home tomorrow, would you comply?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes_____ No_____</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example 2: If there were changes at Mount Baker and officials explained that they were concerned of an potential eruption and asked you to evacuate, would you comply?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes_____ No_____</td>
</tr>
</tbody>
</table>
due to family or job requirements. This could, in part, help explain the woman’s concern about being asked or demanded to leave her home. Seventy four percent of individuals own or are in the process of buying their homes. This indicates that people are invested in their homes and communities, as opposed to merely renting or moving through because of job requirements.

There were no statistical correlations found between income, gender, or employment and how much people know about volcanic activity at Mount Baker, as identified by the definitions question (#3). Using the Pearson product-moment correlation coefficient to compare answers from the matching definitions question (#3) to other variables, it was found that there was very little correlation with a number of variables. For example, household income had a small correlation with definitions of $r = .094$, and gender $r = .208$, where an $r$ value of $.50-1.0$ is considered a large correlation. Employment was equally as small with an $r$-value $= .156$. The number of years lived in their community also had a small correlation with the ability to match the definitions ($r=.064$). A subject’s self-perceived knowledge of volcanic activity had a correlation with the definitions of $r = .199$ and their knowledge of 1975 activity also had a small correlation of $r=.129$. This lack of correlation between volcano knowledge and whether they lived in the area is logical considering the effects of recency on residents’ awareness, or placing importance of a threat (Tobin and Montz, 1997). All of this information shows that I was unable to identify the overall reason behind these subjects’ ability to accurately choose correct definitions as identified by this questionnaire. Again, however, this could be in part due to the construction of question #3, as discussed above. A better constructed measure would be more likely to identify the source of people’s knowledge.
There were some small exceptions to the lack of correlations, such as the correlation of definitions with degree of education. There is a small correlation ($r = .264$) with degree of education and specifically the definition of “fumarole”. This would indicate that, to a small extent, the subjects with a higher level of education got this definition correct more often. As well, an $r$-value of .206 was found with degree of education and the definition of lava. Overall, it was found that the degree of education had a small correlation ($r = .206$) with the overall correctness of question #3. This was calculated by generating an index number for question #3 (Cronbach alpha coefficient of .856), where each correct answer is added up and the total is the index number – the higher the index number, the more correct the subjects were in matching definitions to the terms. This means that to a small degree, the higher the degree of education the more correct the subject was overall in question #3.

The index number for question #3 was also correlated ($r = .231$) with the index of information seeking (question #9). So, the more a subject has sought information, the more correct they were in question #3. This conclusion, however weak, is supported by other studies that have shown that information seeking leads to more hazard knowledge (Johnston et al., 1999a).

These are all weak correlations with question #3, and do not completely or strongly explain how subjects are influenced to correctly identify definitions. This lack of correlation may be partially explained by the concerns mentioned above about question #3; if there are a falsely high number of correct answers from subjects being able to guess correctly through a process of elimination, it may not be possible to accurately correlate responses. This problem with question 3 could be inhibiting me from getting a clearer
picture of correlations between variables. A future study would need to correct the problem with question 3 to get a more accurate view of what influences subjects’ ability to identify correct definitions.

For some questions with multiple responses, such as question #2, an index value was created. As mentioned above, the index number is generated by adding up the number of checked responses to get a total value. In some cases, some responses were dropped to get a more pertinent index number. For example, in question #2, response A, “have a flashlight accessible and have checked the batteries”, was less pertinent to the overall response to question #2 and was dropped from the index value, as were G, H, I, K, and L (“Store wrench near shut-off valve”, “Chosen an emergency contact person outside of the Northwest”, “Someone in the family has learned to put out fires”, “Bought additional insurance”, and “Have identified at least some of the natural disaster...”, respectively). These 5 responses are apparently not important to a “natural disaster preparedness index value”. This means that the fact that a family has food and water stockpiled, portable radio and spare batteries, a fire extinguisher, smoke detectors, a first aid kit, and someone in the family has learned first aid is more important to the index value than extra insurance and the like. The leftover values, B, C, D, E, F, and J, are the responses used to get a total number. This number was checked for internal consistency and was found to have a Cronbach alpha coefficient of .73 (a Cronbach alpha over .7 is recommended). This index number can then be used to correlate with other questions and variables.

The index value for question #2 (Cronbach alpha coefficient of .73) was found to have a moderate correlation with the self-perception of household preparation for a
volcanic eruption from question #5 (r=.390). This indicates that the more prepared a household is for any natural hazard emergency, the more prepared they feel for a volcanic eruption.

An index number for volcano information seeking (from question #9) was calculated with a Cronbach alpha coefficient of .72 and this was found to have a moderate correlation with a subject's view of their own knowledge of volcanic activity (r=.393). This means that the more a subject has looked for volcano information, the more knowledge they feel they have on volcanoes. The concern with this finding is that just because a subject has gone looking for information regarding volcanoes, does not necessarily mean they know more, or that the information that they have found is accurate. However, just because individuals have searched for hazards information, does not translate into preparedness actions (Johnston et al., 1999a). Regardless, this information seeking has raised the subject's confidence level in his or her own knowledge.

An index number was created for activity and visits around Mount Baker from question #15. This number was generated to a Cronbach alpha coefficient of .89. This index number was then correlated with other questions. The first moderate correlation found was with the degree of education (question #24 where r=.374). This indicates that the higher the degree of education, the more visits and activities the subject participates in around Mount Baker. Secondly, a small correlation was found with education and the index number for information seeking (Cronbach alpha coefficient of .72). The correlation was found to have an r-value of .276. This means that, to a small extent, the more education a subject has the more they have searched for information on volcano
hazards and have participated in around Mount Baker. Similarly, other studies have found that hazard knowledge correlates to their familiarity with the hazard in question, so at Mount Baker, where people are visiting the volcano more and are therefore more aware of the hazards, people are also seeking out information (Murton and Shimabukuro, 1974).

A small correlation (r=.257) was also found between the index number for information seeking (Cronbach alpha coefficient of .72) and an index number for natural disaster preparedness (question #2 where r=.73). This shows that the more a subject has sought volcano information the more natural disaster preparedness measures they practice. This is similar to conclusions found in other studies where more information seeking leads to more preparatory changes (Johnston et al., 1999a).

One odd finding comparing what hazard zone respondents live in and how likely they think a volcanic eruption is to disrupt their community (Question #1d) indicates that people closest to the volcano, in both pyroclastic and lahar hazard zones, view volcanic eruptions as the least likely natural disaster that could affect their community. Eleven percent of 137 respondents live in both lahar and pyroclastic hazard zones and listed volcanic eruption as the least likely natural disaster that could affect their community, compared to flood, high wind storms, earthquake, landslides, and forest fires. Three percent of respondents living in this same hazard zone felt that a volcanic eruption was either possible or very possible. This is compared to respondents who live in inundation and lahar zones where 9% said that volcanic eruptions were either not very likely or least likely, and 8% said that a volcanic eruption was very possible to possible to disrupt their community. This is interesting because it would be thought that being closer and in more
hazardous zones around Mount Baker, these people might be more likely to include volcanic hazards in a higher likelihood of affecting their communities, instead, these respondents think that volcanic eruptions are the least likely hazard in their areas, even despite the more hazardous zones labeled by the USGS. There are some explanations for this, however. For example, it could be that familiarity with the volcano has lead individuals close to Mount Baker to ignore or belittle the risk in their own minds. In a sense, nothing serious has happened with the volcano, and thus never will: a normalization bias (Ronan et al., 2000). This is similar to the example above where people living on the volcanically active island of Volcano Island in Taal Lake, Philippines, had little concern for the volcanic activity because of the presence of a scientific outpost there (Blaikie et al., 1994). Residents of the Mount Baker region could have dealt with their fears in a similar manner by assuming that scientists were monitoring the volcano and that therefore the dangers were minimized.

Another factor that could lead to less concern for volcano hazards by people in surrounding communities is that at Mount Baker, the closer one is to the volcano, the less one can see the volcano. There are numerous hills close to Mount Baker that obscure the line-of-sight. Thus, towns such as Glacier that sit closest to Mount Baker actually see less of the volcano, than do other towns farther away where steam plumes are readily visible. This too, could lead to less concern by the individuals closer to the volcano.

Different communities also place different emphasis upon different threats (Miller et al., 1999). For example, the towns of Glacier and Concrete both rely heavily upon recreation activities centered on Mount Baker. This means that economic threats from Mount Baker will be more salient than physical threats (Miller et al., 1999). Thus,
questions regarding the physical threats (such as being able to see steam plumes on Mount Baker) could possibly be less pertinent to the towns of Glacier and Concrete.

There is much can be concluded from studies around Mount Baker volcano. Firstly, the communities closest to Mount Baker are more focused on economic rather than physical threats. This was evident in the 1976 survey conducted by Hodge et al. (1979) where residents of Concrete were more concerned by the economic hardships produced by closures in the area compared to the potential physical threat from Mount Baker. This is also implied in certain results from the current survey. Residents closer to the volcano were less concerned with the volcanic hazards than with other natural hazards (question #1). This could be in part due to a normalization bias, but could also be due to the dependence of those towns on the economic benefits of recreational activities around Mount Baker.

Secondly, there is confusion among residents around Mount Baker about the hazards that could affect them. Some individuals incorrectly believe that they are at risk of certain risks, such as lava flows (question #4) even though the likelihood of that risk becoming a hazard is minimal considering the distance from the volcano of many of the respondents. There is little understanding of the limitations of hazards and the reach of those effects by the residents at risk.

Thirdly, few people around Mount Baker are searching for information about volcanoes or Mount Baker (36% of 150- question #9). Even fewer people (31%) know about the hazards report created for Mount Baker, and only a few people (5%) have ever read it.
Fourthly, seventy-two percent have seen steam plumes from Mount Baker. So, people are aware of some kind of activity but when one compares this result with the previous results, it is disconcerting that people have seen activity (72%) but have not searched out information on Mount Baker or volcanoes.

Fifthly, individuals said that they would be willing to comply with officials to learn safety procedures, stay away from certain areas, and spend less time outside due to ash fall (question #16), but would be less likely to comply with requests to evacuate.

Lastly, the reason that individuals might be less likely to evacuate their homes could be in part due to their investment in their homes and communities. Residents around Mount Baker (86%) live there because they like the area, rather than the potentially transient obligations to jobs or family. As well, 74% of respondents either own or are in the process of buying their homes. This means that people are economically invested in their homes and the area, potentially making them less willing to leave the area.

Limitations of the 2003 survey

There were some limitations to the results, regarding some confusing or inaccurate measures (such as the concerns already discussed regarding question #3). The length of the questionnaire is always a concern. If it is too long, then people will be less willing to invest the time to complete it. This current survey took an average of 10 to 15 minutes to complete the 27 questions. Some other surveys that were researched in the process of preparation were found to be longer and more involved. For example, one published study completed in Italy studied the perceptions of residents near the volcanoes Vesuvio and Etna. Researchers there used a 50 question survey including open ended and
Likert Scale items (Davis and Ricci, 2004). Another study in New Zealand studying the effects of 1995-1996 eruptions of Ruapehu on perceptions of residents in two towns also used a 27 question survey, but also included more complicated free answer and comment areas (Becker et al, 2001). Thus, the current Mount Baker survey is, if anything, shorter than other surveys in similar studies.

There is some concern that inclusion of any anecdotal information is unreliable. However, other studies have also included anecdotes. A study conducted at Mount St. Helens included a story from interviews conducted there (Perry and Lindell, 1990). As long as the fact that the story is from only one or two people during the course of the survey, and not representative of the overall results, than the information and help that the anecdote can provide can be useful. A good example is the woman at Mount Baker who asked for clarification on question #16 regarding compliance with officials if there were changes in volcanic activity at Mount Baker. Her question regarded leaving home and if the nature of the question was about officials demanding or asking for people to leave. This anecdote can be useful in the future for officials to remember the difference between demanding and asking people to comply with their advice; it may be the difference between convincing residents to do as officials need and having residents refuse to comply.

Another concern for the Mount Baker survey is the means of dissemination. It would have been ideal to randomize the dissemination, or to control who received it through picking phone numbers or a similar method. However, other studies used similar methods of convenience sampling. The study completed in Italy also recruited volunteers in a similar manner from public areas such as stores, cafes, and markets (Davis and Ricci,
Thus, it must be noted that there could be some unknown biases attained by the convenience sampling, which potentially is the case for other published studies as well. However, as described above, there appeared to be little difference between the genders to warrant concern over that bias, and because of the seeming lack of correlations between the demographics and the results of the perception sections of the survey, the survey method appears adequate.

These concerns need to be taken into consideration in the future of hazards outreach in this area, but this questionnaire was a useful measure of many characteristics of these towns. The initial inspiration for this survey was not a complete and decisive tome on the beliefs and attitudes of residents around Mount Baker, but rather an initial snapshot of what the problems associated with educational outreaches into these areas might be. Scientists needed a beginning idea of what to expect from the people in communities around Mount Baker: are people aware that Mount Baker poses a threat (mostly, yes)? Are people afraid of Mount Baker (no)? Would people be willing to comply with officials (in most cases, yes, but less would be willing to leave their homes)? Have people read or looked for information on Mount Baker (mostly, no: typically, they wait passively for the information to come to them such as through the news or television, or they talk with friends or family about concerns)? Are people interested in Mount Baker activity (yes, most people took handouts on Mount Baker activity, and many asked for other resources)?

This information will be available to the USGS and any other organizations interested in working with or educating these communities on general or specific volcano hazard information. It is also useful information for emergency managers in the area and
will hopefully help them to work more closely with members of these towns and with fewer misunderstandings.
PART III:

Educational Outreach Plan
Chapter 8: Education Plan

There is a significant problem associated with presenting information such as preparedness measures to people: they may have recognition of the information being available and where it was, but it is less likely that they can recall exactly what that information was (Paton, 2000). A study conducted in Auckland found that many people remembered seeing information in a leaflet or in the Yellow Pages, but that very few people were able to either recite or recall what that information was (Paton, 2000). This means that people may be relying on the fact that they have seen information, regardless of whether they can remember what that information was; people could be overestimating how much knowledge they have of a particular topic (Paton, 2000). Thus, in preparing an educational outreach program, it is necessary to devise means in which people will remember what to do, through humor, mnemonic devices, or through constant attention being paid to preparation techniques.

The more people in a community that participate in preparatory actions the better able is that community to respond to emergencies and hazards. Communities that have a lot of community programs, activities and functions, where much of the community is included, are found to be more resilient to adversity (Paton, 2000). It should be considered that community educational hazards programs that include a high level of community participation could foster not only community development, but also a higher level of community self-sufficiency. By incorporating people into hazards scenarios and encouraging community involvement and suggestions, the information will be more salient and usable by them (Paton, 2000). In many communities, only emergency service personnel work on preparation scenarios, but in smaller communities, a higher percentage
of the populations are volunteers and active participants in emergency services. In the small communities around Mount Baker, it should be easy to incorporate much of the community into hazards educational outreach to include more people, engender community strength, and help people withhold more preparedness information.

The communities at risk from hazards at Mount Baker remain confused about the risks associated with Mount Baker. As shown by the responses to question #10, asking about whether people are aware or have read the USGS hazards report for Mount Baker; the USGS has information available about Mount Baker that is not reaching this population. Question #4 asked what volcanic hazards subjects think could affect their communities and responses show that many people are confused about the possible hazards and how much impact those hazards could have upon their communities. Many are unaware of the amount of monitoring at Mount Baker, although they assume that it is being studied.

Of concern to emergency management officials is how people respond to the need to evacuate from hazards. At Mount Baker, 25% of subjects are unwilling to leave their homes if asked to (question #16). One subject from the town of Concrete vividly remembers being kicked out of a campground when the grounds were closed around Mount Baker in 1975. This woman says that she would never evacuate again, after seeing how inaccurate the forecast of activity at Mount Baker was in 1975. She and her family complied with closures in 1975, but she said that she never would again. As well, the other woman previously described who made the distinction between being asked and being told to evacuate is another example of the stubbornness that officials could meet in
an emergency situation. This is important information for emergency managers dealing with this population in times of crises.

After the events of 1975-1976 where campgrounds were closed and revenue lost, it is even more important to establish positive relationships with the people in these communities. Without a positive framework of trust in place between communities, officials, and scientists, it will be more difficult to galvanize people into actions to save themselves when a crisis does occur. Even if nothing happens in the next 50 years, by beginning an educational outreach into communities around Mount Baker, people will be better able and more willing to comply with officials when it becomes necessary. And, by establishing positive links between communities and officials, people will be more willing to comply with officials for other kinds of natural disaster crises. As correlations showed between the index value for question #2 (emergency measures practiced at home) and question #5 (household preparation for a volcanic eruption), the more people prepare for any natural disaster, the more prepared they feel for volcanic eruption. It can also be hoped, conversely, that the more people work and prepare for volcanic eruptions or crises, the more prepared they will feel for other natural disasters. And, as past research has shown, working with people on a regular basis can stop misconceptions and erroneous beliefs before they influence an individual’s response to a crisis (Weitz and Benjamin, 2001). Thus, by better understanding the risk, and because of an individual’s trust of officials through past interactions, individuals will be more willing to comply with officials than otherwise (Perry and Hirose, 1991).
A Volcano Primer

To begin an educational outreach program focusing on natural hazards in the Mount Baker region is a first step in making valuable connections with the communities in the region. The people in communities around the volcano have a lot to learn about their favorite recreational sites around Mount Baker.

Following is a general explanation of community awareness and volcano education. Lastly is a plan for the communities around Mount Baker.

The first necessity in approaching these communities is presenting a basic volcano primer. This primer should include the most basic facts about the volcano. Firstly, this primer should include the fact that Mount Baker is a volcano, to assuage any doubt by people who might be ignorant of this fact. Other basic information that needs to be covered is: vocabulary, history of the volcano, risks, potential hazards, the capabilities as well as the limitations of those hazards, and the basic preparation techniques that people can implement to help in the future.

The first thing the primer needs to include is basic volcano vocabulary, like the USGS Fact Sheet for Mount Baker 059-00 (Scott et al., 2000). Scientists understand and use scientific jargon regularly throughout their literature such as lahar, pyroclastic flows, ash fall, lava flows, risks versus hazards, and hazards zones. I would argue that there is still confusion about certain terms, such as ‘lava flows,’ ‘fumaroles,’ and ‘pyroclastic flows,’ at Mount Baker despite the high number of correct identifications in question number 3. Confusion about the extent of lava hazards is an example of this confusion. Even if a resident might know what the hazard is, such as a lava flow, they do not fully comprehend the capabilities or limitations of those hazards. This is a problem when
officials introduce hazards information to the residents. So much of the information
that officials have to offer is based on the jargon of scientists (Douglas, 1996), that
hazards communication can be lost in the confusion of jargon. People need to understand
what these terms mean before they can appreciate how they can affect their communities,
and the USGS Fact Sheet for Mount Baker 059-00 (Scott et al., 2000) is a good beginning
to open the lines of educational communication.

Once a basic vocabulary has been established, a simple history of Mount Baker
will help people to understand what has happened in the past. As well, talking about what
has already happened will facilitate a discussion about what to expect in the future. The
fact that Mount Baker has little history of violent eruptions, compared to Mount St.
Helens, but does have a history of lahar and debris flows will help people to appreciate
the differences between their volcano and those elsewhere in the region. Mt. Rainier also
has a history of lahar and debris flows, but on a much larger scale than anything recorded
at Mount Baker, thus further individualizing Mount Baker from other nearby volcanoes.
Each volcano is different, but the public has little initiation into the different
characteristics and what that means for their own future. By discussing the history of
Mount Baker in brief, it will help to make a distinction and highlight the specific
concerns associated with Mount Baker versus other more well-known volcanoes such as
Mount St. Helens and Mt. Rainier.

Next, after these terms have been introduced and explained, and the expected
cconcerns at Mount Baker have been introduced, people need to understand how these
risks can affect their homes, towns, and roads out of the area. An ash fall will affect a lot
of people, especially their machines, whereas a lahar or debris flow will affect fewer
people directly, but will necessitate some people leave roads behind and climb into
the surrounding hills.

People also need to know the limitations of these hazards. Some people from the
town of Van Zandt told me that they understood that there was little that they could do to
escape since they were so close; that all they would be able to do was “say goodbye”
before their town was overrun. The reality is quite different, however. The town of Van
Zandt is approximately 30 km west of Mount Baker and quite protected with a series of
hills between them and the volcano. Only a westward directed lateral blast from an
eruption would probably destroy the town of Van Zandt. Any other effects, such as a
lahar, would be escapable, as long as the residents were educated about how to react.
Thus, it is necessary to explain the limitations of the hazards as well as the capabilities of
those events.

Each community also has different risks associated with it. The town of Glacier
sits very close to Mount Baker, and several drainage valleys for the volcano empty into
the valley around the town of Glacier. Thus, the people in the town of Glacier not only
have risks associated with lahars, like some towns downstream, but Glacier could also be
overrun by pyroclastic flows (Gardner et al., 1995). This means that the people in Glacier
need to know what to do in the event of an eruption including how to escape pyroclastic
flows. Towns further downstream might have to manage with lahars, but not the
pyroclastic flows. The town of Concrete, on the south side of Mount Baker, might have
concerns, not with lahars or pyroclastic flows, but rather with the integrity of the Baker
Lake Dam. In the event of an eruption or debris flow into Baker Lake reservoir, the Baker
Lake Dam could be compromised, necessitating that people downriver - maybe as far as
into the Skagit Valley and Mount Vernon areas - move to higher ground to escape floodwaters.

Once people understand what the risks and probabilities are, and some of the general volcanology of the region, they will be better prepared for the imprecise nature of volcano forecasting. In the future, the risks around Mount Baker may change. For example, instead of the thermal energy being centralized in Sherman Crater, potentially in the future, the focus of thermal energy may move to Dorr Fumarole Field (Figure 16). This would put the town of Glacier at a higher risk for many hazards and potentially some of the towns further downstream of the Nooksack River valley. By having a rudimentary education of the potential risks at Mount Baker, the people around the volcano will be better able to understand and accept the changes and potential future activity, instead of meeting reports of changing activity with rank disbelief.

After people understand the types of risks and hazards that they might encounter in the future, they will better understand what they can do to prepare for that future. That could mean creating roads into the hills for low-lying communities at risk of lahar or flooding from a potential dam breach, or designating pick-up locations in the hills for potential lahar and pyroclastic flow stranded victims. It could also mean officials designating an escape route from certain areas. On a household scale, this could mean keeping canned foods, water, and other necessities aside in a box or bag that could be taken quickly in an evacuation.

At the least, by educating people of the possibilities, beginning with a volcano primer, it allows people to consider what they might do in a worst-case scenario. Although Mount Baker has little history of violent eruptions, lahars and debris flows are
serious concerns. Such hazards as debris flows need little to no obvious volcanic activity to initiate as well, further complicating forecasting or warnings to the surrounding communities. Small events with little outward evidence, such as small magma intrusions that could increase porewater pressures could initiate debris flows without much visible activity to galvanize residents into preparatory actions. The people in these areas should know and understand those hazards and be able to prepare for them now, while time allows.

**Past the primer: gaining people's trust**

By beginning with simple, easy-to-understand information, and reducing the amount of confusion and misinterpretations, officials will gain more trust from the communities and the people there. Increased trust means that if confusion does arise in the future, people might be more willing to approach officials or emergency management to ask questions and get more information. It will help to foster a relationship between officials and residents in case something does happen at Mount Baker: by gaining the trust of people now, officials can help assure their trust and compliance when it is really needed (Perry and Hirose, 1991).

Once the basic primer has been established (in the case of Mount Baker this could be Fact Sheet 059-00 (Scott et al., 2000), officials can include more complicated and robust information. With the basic principles available to the public, it is possible to build on the simple ideas to accomplish more sophisticated results, remembering that the goal is small-scale self-sufficiency in these communities (Alexander, 1993). For example, residents will better understand what a lahar flow means after receiving the Fact Sheet and can then be educated on what to do in the case of a flow. Residents need to have an
Acting in an emergency can only be done well with previous knowledge of what to do or how to react. If one considers the ramifications of the 780 people from the town of Concrete getting in their cars and trying to outrun a collapse of the Baker Lake dam down towards the towns of Sedro Wooley or Mount Vernon, the results could be quite tragic: Both Sedro Wooley and Mount Vernon lie downstream of the Baker Lake dam, meaning that even if some people were able to make it the intervening 30 to 40 km downriver, the same direction a flood would follow, both towns of escape might equally be affected by the resulting flood. Driving away from the dam seems like a perfectly reasonable thing to do in a crisis situation. The fact that the greater civilization and Interstate-5 lie to the west, towards Sedro Wooley and Mount Vernon, makes the west a logical destination for many trying to flee an oncoming flood. Unfortunately, the reality is that by moving downriver, people from Concrete, and from every other small town west of the dam in the Skagit River Valley, will only further endanger themselves. Traveling east away from the dam and higher into the mountains or into the hills on either side of the Skagit River Valley would save many people. This information needs to be given to the people at risk in these communities to keep a tragedy like that outlined above from happening. Thus, it is only through previous education that emergency management and scientists can truly hope to help people in these hazardous areas.

Having this necessary information and education will also help the communities in other ways. The ability of each community or neighborhood to understand and act upon hazard information increases the amount of self-sufficiency in each community.
(Alexander, 1993). This in turn will decrease the feelings of vulnerability that each community feels (Blaikie et al., 1994). Each community will have more confidence in their ability to cope and will lessen the stress associated with crises (Miller et al., 1999).

So, with the basics such as vocabulary in mind, emergency management and scientists can approach a more meaningful relationship with these communities. Firstly, officials need to address the issue of the ongoing risk from Mount Baker, despite months, years, and decades of seemingly unchanging steaming. Secondly people need to understand the vague signals from volcanoes coupled with our still limited understanding of volcanic activity. There also needs to be some recognition of 1975-1976 publicity of thermal events and the politics that surround risk and natural disasters.

The people surrounding Mount Baker need to be aware of the possibilities and they need to understand the limitations of volcanic activity forecasting. Despite the best that technology has to offer us today, coupled with the most knowledgeable people in the field of volcanology, there is still the possibility that a volcano can mislead scientists. The same precursory activity can lead to a sudden eruption, a stalling of magma movement to the surface and resulting quiescence, or even further years of increased activity before an eruption.

It is necessary to educate people not just about how intelligent scientists and emergency management is, but also some about their limitations in order to maintain trust within the communities. It is better to be completely honest with the abilities and the limitations so that people do not become mistrustful when something unexpected happens. This will help maintain the trust between officials and people in the communities. For example, during the Mount Baker interview process one woman
explained that she was told in 1975 to evacuate from Baker Lake campgrounds due to potential debris flows from the mountain. When nothing happened, her trust in the scientists, US Forest Service, and emergency management was irreparably harmed. She says that now she would never evacuate again. Her sentiment was also found in the 1976 study conducted at Mount Baker where residents were less forgiving of lost revenue that they blamed on closures around Baker Lake recreational areas and many people said that they would ignore future warnings (Hodge et al., 1979). By admitting limitations in scientific ability ahead of time, officials can help assuage doubt later on and eliminate accusations of wrongdoing. If the time is spent educating the residents now, residents such as the woman above might be convinced to comply with officials.

This limitation on scientific ability to forecast activity could have an immediate effect on education outreach programs. The woman mentioned above, who would never evacuate again because officials were wrong about a debris flow into her campground is a good example. She remembers little of the risks associated with the increased thermal activity, but she does remember quite a bit of the political upheaval that occurred over closures and the economic loss involved. She has a very low opinion of officials who would claim to know about volcanic activity at Mount Baker, and would refuse to comply with their recommendations.

The stubbornness illustrated by some making the distinction between “asked to leave” and “told to leave” needs to be addressed as well. These people may in fact act differently when faced with an emergency, and evacuate without question regardless of how they are presented. After all, it has been noted that people sometimes act differently than they say they will (Tobin and Montz, 1997). As well, significant time has passed
between the 1975-1976 events and possible future educational outreach, but officials need to be aware of the possibility that some residents might be difficult to convince. However, to take a demanding attitude with these people will only cause a greater rift between officials and residents. This could possibly cause some people to remain in their homes out of defiance long after it is safe to. By creating education programs now, some of the fear and doubt in residents can be assuaged before a crisis occurs. By starting the education process now people will become more familiar with the risks that Mount Baker poses and therefore will not be surprised or as fearful of an event in the future. As well, it gives officials time to establish trust with these communities so that when something does happen around Mount Baker, the communities will be more trusting and willing to comply.

There was no previous educational outreach before the thermal activity increase at Mount Baker in 1975, and when officials closed recreational sites around the mountain in order to protect people from potential hazards, residents were outraged. As seen from newspaper reports, they did not understand the need for closures and disagreed with the decisions. The hazards did not lessen in that time period, but political pressures increased and the closures were eventually lifted. This, however, probably did more harm than good. Instead of the scientific research showing that the risk of a debris flow was not as prevalent as previous thought, it was political pressure that weighed in on the issue. Thus, public opinion that scientists and officials were unfamiliar with and knew little of that which they spoke was supported in the end, leaving people such as the woman described above feeling justified in their low opinions of officials. The scientists do not live in the areas around Mount Baker and their seemingly sudden appraisal of hazards associated
Thus, in future educational outreach programs, the 32% (question #11) that lived around Mount Baker in 1975 could potentially have low opinions of officials that need to be addressed and refuted in the future, even though there were no correlations found in this study. Despite some research that has shown that time will ease the sharp feelings after an event and lessen the impact upon future decision making (Tobin and Montz, 1997), it is best to deal with potential problems early on, before new events at Mount Baker. So, in future dealings with these people officials need to be exceedingly honest and straightforward, so that claims of officials overreacting to scientist recommendations (Anonymous, 1975d) can be minimized. Any misunderstandings or apparent withholding of information will be used against officials and will seriously harm the trust being built between the communities and officials.

One way to help maintain this honesty and help foster trust between officials and the public is to maintain communication between the two. Even during times of crisis, there needs to be a way for immediate responses and clarifications to reach the people in the communities around Mount Baker. There needs to be a constant education about what the risks and hazards are, why scientists are studying what they are, and most especially why certain decisions are being made. For example, if adequate explanations had been presented directly to the communities around Mount Baker about why there were certain closures in the area, some of the confusion and negative feelings could have been
alleviated. Confusion and misunderstandings could have been avoided, such as the man who thought that closures were due to an increased steam activity instead of weakening summit materials (Anonymous, 1975e). Little was explained at the time while officials hurried to understand what was occurring at Mount Baker. Future outreach into these communities needs to address the differences between the Mount Baker events of 1975-1976 and new activity.

The easiest way to accomplish this task of gaining people’s trust is fairly simple to outline. Firstly, an outreach program needs to remain honest, as was explained above. Secondly, an outreach program needs to be available to the community for classes, for talks to community groups, to answer questions at any time through online sources or by phone. Thirdly, and most importantly, the outreach program needs to remain available.

One way to foster this trust is to be available to the communities. Officials need to offer talks, question and answer sessions, and offer every opportunity for the people in these communities to ask questions. This will help to stop the confusion of misunderstandings and misinterpretations. In a vacuum of information where little or nothing is provided by officials, people will find their own information and act upon that, regardless of its accuracy. The best way to avoid ignorant actions in dangerous times is through open and continual communication between officials and the public.

After an initial educational outreach program has been conducted, classes taught, presentations conducted throughout the communities, officials present at miscellaneous functions to answer questions, the outreach program needs to maintain a presence in the community. Whether officials attend community functions, offer yearly updates, offer workshops for community groups, or all of the above, officials need to remain visible in
the communities. The only way for communities to remain aware and current of the risks associated with Mount Baker is to have a constant reminder that they exist. There is a need, as mentioned before, for a societal or institutional memory where information is not lost, but is available as a reminder of what it is to live near an active volcano. The most realistic manner to provide this is in the form of a living, talking, walking reminder of Mount Baker's activity. By actively pursuing this outreach, officials can help assure that future activity at Mount Baker will not be met with the skeptical outrage at closures around the volcano such as in 1975, but that the public will better understand the hazards and be at least a little more willing to comply.

Throughout this research I have referred to a nebulous group of "officials." There are many organizations that make up the necessary framework of "officials." For example at Mount Baker in 1975-1977, these organizations included county and state emergency management offices, the US Geological Survey, the US Forest Service who controls the Mount Baker-Snoqualmie National Forest, and other more local agencies such as police, fire, and volunteer organizations. There were also ancillary groups that supported the "officials" such as scientists in universities, Cloud and Aerosol Physics lab, Los Alamos National Laboratory, Oregon National Guard (thermal infrared data), and many other private personnel who all offered observations, testing, and facilities.

All of these organizations will have to work together again with the Mount Baker communities in the future in order to adequately forecast activity at the volcano and remove people from danger. Yet there are problems with this coordinated effort, and those problems could very well affect the ability of the "officials" to conduct their job in the future. Studies conducted after the Mount St. Helens eruption found that most
organizations involved felt adequately prepared for dealing with the eruption, but felt that there was a distinct lack of coordination between the different agencies involved (Paton et al., 1998). Other studies have found problems with: getting necessary information to the different official organizations, too little information reaching the organizations, difficulties with communication between the organizations and the media and public, and inadequate inter-agency communication (Johnston et al., 1999b). Communication with the public is of primary concern since the inception of the Mount Baker/Glacier Peak Coordination Plan which outlines the official network (Mount Baker/Glacier Peak Coordinating Committee, 2001).

So, the lines of trust have been opened between some of the officials who would be in charge of volcanic activity emergency management at Mount Baker (Carolyn Driedger, personal communication, 2004). Other communities around more active and potentially dangerous volcanoes, such as Mt. Rainier have been well educated in the hazards associated with their volcano (Johnston et al., 2001). Communities in these areas are currently working with emergency management offices and US Geological Survey scientists to best prepare for lahar hazards that are most prevalent around Mt. Rainier (Johnston et al., 2001). The trust between officials is just as important as the trusts being built between the officials and the public.

A sample educational outreach program for Mount Baker

There are a few different parts that need to be involved in a successful educational outreach program. First, knowledge of the understanding or misconceptions of the people in the surrounding communities needs to be had, so that educators understand the people they are working with, such as from a questionnaire. Secondly, an initial volcano primer
needs to be presented so that the public, emergency management, and scientists all
understand the vocabulary and the history of the volcano in question. Thirdly, a more in-
depth and robust education process needs to be established. Fourthly, a long-term
educational outreach connection needs to be established so that the outreach does not fail
over a long term period.

Around Mount Baker this outline and outreach program should be fairly easy to
implement. To follow the guidelines, a basic questionnaire has been conducted. In fact,
one was presented in 1976 during the thermal events that caused such political havoc
(Hodge, et al., 1979). With two questionnaires and their responses, there is a good deal of
information at least on where people were and how they felt about 1975 officials. There
is less usable data on what they know (for example, there was a problem with my
questionnaire with respect to question #3, the definitions question). Therefore, it could be
considered that with time and money, another questionnaire might be appropriate,
learning from the mistakes and concerns with this questionnaire.

The initial volcano primer, as described above is well established for Mount
Baker. The US Geological Survey Fact Sheet 059-00: Mount Baker – Living with an
Active Volcano (Scott et al., 2000), is an excellent source for this beginner information. I
would also begin generating items that people will want to have in their homes, such as
beautiful posters and coffee table books of Mount Baker that are accompanied by the
hazards information printed on the back or in a chapter. These are items that will be seen
every day in a home, and when the information printed on the back or in a last chapter is
truly needed, it will be easily reachable, whereas a fact sheet or informational packet can
be easily misplaced or lost.
The items above will allow more complex information to be provided to an already interested and primed community. These items are a basis for generating a presentation by officials or a secondary fact sheet for communities. In this presentation or handout, I would include a little more vocabulary, such as risks, hazards, hazards zone, and so on. This could be created as a CD for distribution to schools for education on volcanoes or for use by emergency management in Whatcom and Skagit Counties. I would also explain how to read the hazards zonation map since there was some concern while conducting my questionnaire about how to read these maps. For towns south of Mount Baker, I would also include fact sheets on Glacier Peak volcano, since many towns live within reach of hazards from that volcano. Also, there needs to be more selective data for specific locations. The town of Concrete has very different hazards associated with its location, considering the Baker Lake dam, than does Glacier which lies within possible pyroclastic as well as lahar paths. So, more specific information needs to be included for different locations, including possible mitigation strategies for those locations. For example, as described before, it may be possible to create roads leading into the hills for people to escape lahars or floods.

These presentations or handouts (in CD or paper form) would elaborate on the different risks associated with each town and include a rudimentary introduction to incorporate new viewers unfamiliar with the volcano primer. The most important thing about each presentation is that it is clear and concise, highlighting the most important information. Too much information or too vague information will be lost to the viewers. The least amount of scientific jargon should be used as possible to facilitate the understanding of the public. One of the tools I would encourage is the creation of hazard
scenarios pertinent to each community and encouragement of community participation. By incorporating the viewers into a presentation, it is more likely that information will be retained. In having to think up escape routes, resources to turn to, and means of helping each other in a low-stress environment like a presentation, people will be more likely to recall such information faster in times of crisis when they most need it.

These presentations need to include as many of the pertinent people and offices involved with volcano management around Mount Baker as possible. For example, the emergency management offices in Whatcom and Skagit Counties need to be involved for the town in each county. The US Geological Survey and the US Forest Service need to have at least one knowledgeable member available for questions. Any local or volunteer organizations involved with emergency or volcano management such as search and rescue or ham radio operators, need to have someone present. By providing a united front to the public, as well as having members of these organizations in front of an audience of local people, the public will feel less fear or doubt when confronted with changing risks in the future. These officials are the faces of the organizations that will be in charge of situations at Mount Baker. By putting a face to them, and not having a faceless organization making decisions, people will be less skeptical of the organizations in the future. This is another step towards promoting trust with the public; by having every one of the organizations present and providing a united and intelligent front to the public, there is less room for doubt about the intentions and abilities of those organizations in the future. These presentations could be conducted during pre-organized events, such as “Salmon Days” in the Skagit River Valley or the Mount Vernon “Tulip Festival”, or the Deming Log show. By combining presentations on Mount Baker with pre-established
events, there is a greater possibility of getting people involved. These events already draw a lot of people, thereby increasing the numbers of potential residents that might be present. If presentations include high-impact photos and dramatic locations of interest, more people will be willing to come and listen to discussions of Mount Baker hazards. The information needs to be made fun to watch and be a part of, to make viewers interested and not bored of dry details such as where to go or what to take with them.

After the initial outreach, it is important to continue this contact and communication with the public. Each community needs to know that they have people to contact who will provide information, whether it be members of the US Geological Survey or the Whatcom and Skagit County Emergency Management Offices. Presentations also need to be made available to the communities for an ongoing basis. Perhaps this year, a member of the US Geological Survey presents to the general public, and the year after a member of the Emergency management office presents to kids in schools, and the year after that volunteer ham radio emergency dispatcher talks to emergency offices in the town about what would happen if there was a volcanic situation in their area and what he or she would do to help them. The point is to keep the message that Mount Baker is an active, changing, volcano in the forefront of people’s minds. This will also help to maintain the trust between the people in the communities and the officials in charge of helping them.

There is more to this outreach, though. It is just as important to communicate with the ancillary groups and organizations associated with the communities about possible volcanic activity at Mount Baker. For example, and perhaps most importantly, the media plays a large role in the ability of officials to conduct their jobs. As was seen during the
1975-1976 events, the media exacerbated issues by reporting the negative feelings towards the officials, the economic hardship being endured by citizens losing on summertime revenue, such as the town of Concrete, and the conflicting reports of the scientists. In other regions around the world, the media plays as large of a role (Johnston et al., 1999b). Especially in areas where there has been less of a direct impact from volcanic activity, people rely heavily upon social sources of information such as the media (Johnston et al., 1999b). This is not a problem as long as the media are printing accurate and consistent information, but it will be an issue if sensationalized or inaccurate information is disseminated to the public. Therefore, the media needs to have trustworthy lines of communication already in place with official groups as well as emergency management contact numbers for the Coordination Committee, and any other officials who might be able to discourage erroneous claims.

Perhaps through media workshops during times of crisis at Mount Baker, it would be possible to lessen the amount erroneous information that is printed in the paper. The media prints conflicts and sensational stories, but if the public is becoming better educated around Mount Baker, it is hoped that the media will become better educated as well. For example, the Publisher’s Perspective which derided the officials for closing campgrounds because of increased steam emissions (Anonymous, 1975e) might have thought better than to publish such erroneous beliefs had the publisher been educated by officials beforehand. Thus, I recommend that scientists hold media workshops in order to disseminate accurate information about volcanic activity. It is impossible to control the media, but perhaps it is possible to help retain accuracy by working with the media.
There is little that scientists can do to influence politics in support of safer land management practices, but through the education process at least some pressure can be alleviated. Politicians are ideally controlled by the people whom they represent. Through the education of the people around Mount Baker, it can be hoped that politicians will be influenced to enact measures to restrict the use of lands potentially affected by future volcanic activity at Mount Baker, or at least to support official decisions. For example, during the 1975-1976 thermal events, politicians became involved in attempting to rescind decisions to close campgrounds around Mount Baker. If the people in the surrounding towns, especially the people of Concrete, better understood and appreciated the concerns prompting the closures, there would have been less reason for politicians to disrupt the closures. It is understood that value clashes, such as economic versus safety, can continue to be a concern, but through a strong enough education process, some of the pressures to ignore scientific recommendations can hopefully be alleviated. Today, educational and land use management outreaches are beginning to move people from hazardous areas around many volcanoes, such as those in Japan. Schools, hospitals, and apartment buildings were relocated to less hazardous areas due to the probability of volcanic activity disturbing their previous locations (Okada et al., 2003).

Other ancillary groups include visitors to Mount Baker who will not be involved with ongoing educational programs in the communities. Visitors to recreational sites around Mount Baker need to be made aware of the risks and ongoing changes at Mount Baker to be better prepared for sudden concerns while they are visiting the area. Debris flows from the Sherman Crater area, however remote a possibility, do remain a concern and visitors might not be aware of this. There needs to be informational handouts, signs,
and rangers available with the necessary information. This information needs to be presented in a straightforward and direct manner that does not frighten visitors but educates them about the hazards in the area. By focusing first on some of the more interesting features, such as steam plumes, hot springs, and the surrounding unique environment it might be possible to introduce the active region of Mount Baker in a less threatening manner. This can then be followed by preparation or warnings of where dangerous locations might be, or what to do if something such as a debris flow occurs while visitors are in the area. The idea is to educate these people but in a non-threatening way.

One way to implement long-term educational awareness of Mount Baker might be to participate in festivals and local events. For example, Concrete and the Skagit River Valley celebrate “Salmon Days”, and the Mount Vernon area celebrates the “Tulip Festival”. It would be reasonably easy to organize an adjunct to these festivals, a “Mount Baker Days” fest, a Mount Baker booth to display, or something similar. This would be something celebrating the volcano and its history, both geologic and human history. Incorporate educational events, such as Mount Baker trivia, volcano workshops, scientific talks, tours by officials, a ‘meet the emergency managers in your areas’ events, and anything else that could be created. By just being there, people will learn information about Mount Baker; some people will come for different things, such as the food, amusements, and friends, but by being there they will still learn and have access to useful information and handouts that they can take home. Officials, including interested scientists, can get their faces known to members of the community so that in the future there will be less fear of unknown officials making decisions. By presenting information
about a potentially frightening event, such as a volcanic eruption, in a positive way, such as a festival, some of the fear can be alleviated.

Some studies found that the best mitigation programs will use the points most salient to the community in its campaign (Miller et al., 1999). For example, the people in the town of Concrete are at least partially economically reliant upon Mount Baker for summertime recreational revenue, so a preparation and mitigation program in this community focused on the physical impacts of volcanic activity will be less pertinent to the people in the town of Concrete. An educational outreach program that includes the economic impact upon the town might have more chance of being remembered and acted upon. Thus, presenting some outreach program that discusses the economic impact of volcanic activity on the town of Concrete, but that can also bring revenue into the town, will be beneficial, salient, and have more positive long-term effects.

There are also ways to incorporate people in the communities into community watches of Mount Baker. These people in the communities live around the mountain. These people, if taught what to look for, can be the first ones to describe changes at the volcano. Groups climb the mountain every year, in fact, mountaineering classes are conducted with a Mount Baker climb as the climax of the class. These mountaineering teachers could be asked to take pictures or taught to observe Mount Baker with a more critical eye so that they will see changes each time they climb. This will give the USGS or other officials a fairly continuous photographic record of the mountain, and possibly Sherman Crater. Classes in elementary through high schools around the region where visibility is possible could require students to keep a classroom journal of visible activity at Mount Baker. Give the classrooms phone numbers of weather stations to call for wind
and humidity readings to get a full picture of the correlations between weather and steam plume visibility, and it would be possible to turn the activity into a significant learning experience for the students as well. This would give officials a record of steam plumes and associated weather reports visible to different communities. For example, in one year, a class may generate the results that they witnessed 20 steam plumes on Mount Baker, reaching maybe an average of 100 m over the crater rim. So, the next year, if this same class witnesses 100 steam plumes reaching 200-300 m, that might be information that scientists want to know about. Students closer to the mountain, where visibility of Mount Baker is poor could be asked to view Baker from their homes or while visiting areas around the mountain, such as the ski resorts.

These are small thing for communities to do, but it increases ownership of their mountain. The people in these communities are in a unique position to study the mountain, and although their reports would hardly be scientific, the reports may help in the future in the same way that anecdotal reporting in the 1800 and 1900s helps us today. Regardless, these activities by people around the mountain would help raise awareness of Mount Baker as a volcano, and of a volcano always changing. This would help people be more aware of the risks that the volcano poses and would help to make them aware of the possibility of future change.

Conclusion

Mount Baker was recognized as hazardous in 1975-1976, and because those hazards are still present, namely the increased thermal flux and the ongoing presence of magma in the system, Mount Baker still poses risks to people today. Because of those risks to communities that surround the volcano, it is necessary to better study those
hazards and risks, and to educate the individuals at risk. Through education, these individuals will better understand the hazards of the environment in which they live, and through the education process will learn to trust the officials in charge of assuring their safety. Only by fostering trust between the individuals in these communities and with officials and/or scientists will it be possible to avoid potential disaster in the future.
References Cited


Anonymous, 1975e, “Publisher’s Perspective – Bureaucratic control or people control?”: *Concrete Herald*, October 9, 1975.


Pinatubo, Philippines, PHIVOLCS, Quezon City and University of
http://pubs.usgs.gov/pinatubo/daag1/.

Davidson, G., 1885, Recent volcanic activity in the United States: Eruptions of Mount
Baker: Science, v. 6, p. 262.

Davis, M. S., and Ricci, T., 2004, Perceptions of risk for volcanic hazard in Italy: A
10/11, p. 159-165.

Delmelle, P., and Bernard, A., 2000, Volcanic Lakes: in Sigurdsson, H., ed.-in-chief,


eruptions of Crater Peak, Mount Spurr Volcano, Alaska, in U.S. Geological


Easterbrook, D. J., 1980, Activity of Mt. Baker 1975-1979: Eos, (Transactions,
American Geophysical Union), v. 61, n. 6, p. 69.


Eichelberger, J.C., Heiken, G., Widdicombe, R., Wright, D., Keady, C.J., and Cobb,
35-53.


Harris, A. J. L., Flynn, L. P., Dean, K., Pilger, E., Wooster, M., Okubo, C., Mouninis-Clark, P., Garbeil, H., Thornber, C., De la Cruz-Reyna, S., Rothery, D., and


Rosenfeld, C. L., 1980, Remote sensing of volcanic activity in the Cascade Range: *Eos* (American Geophysical Union), v. 61, n. 6, p. 69.


United States Census Bureau, 2000: From

Warrick, R. A., 1975, Volcano Hazard in The United States: A research assessment:
University of Behavioral Science, U. of Colorado Monograph #NSF- RA- E- 75-012.

Weaver, C. S., and Malone, S. D., 1976, Mt. Saint Helens seismic events: volcanic

Weitz, D., and Benjamin, S. L., 2001, Risk Communication: in Benjamin, S. L., and
Belluck, D. A., eds., 2001, A practical guide to understanding, managing, and
reviewing environmental risk assessment reports: Lewis Publishers, Boca Raton,
Florida.

Whitney, J. D., 1889, in Mt. Baker, its trails and legends: Unpublished manuscript by Mt.
Baker Club in archives of Whatcom County Museum of Natural History.

Wicks Jr., C. W., Dzurisin, D., Ingebritsen, S., Thatcher, W., Lu, Z., and Iverson, J.,
2002, Magmatic activity beneath the quiescent Three Sisters volcanic center,
7, p. 1122.

### Tables

**Table 1**: Mount Baker eruptions as dated by Hildreth, et al., 2003. Locations represented in Figures 2 and 16.

<table>
<thead>
<tr>
<th>Eruption</th>
<th>Location</th>
<th>Calculated Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kulshan Caldera eruption: 50 km$^3$ rhyodacite magma</td>
<td>Northeast of Mount Baker</td>
<td>ca. 1.15 Ma</td>
</tr>
<tr>
<td>Cougar Divide rhyodacites</td>
<td>North of Chowder Ridge</td>
<td>1.018-1.015 ± 0.018 Ma</td>
</tr>
<tr>
<td>Series of rhyodacite lavas, domes, and dikes</td>
<td>Around Kulshan Caldera</td>
<td>1.15 Ma – 0.99 Ma</td>
</tr>
<tr>
<td>Hornblende-Pyroxene Andesite lava</td>
<td>South rim Kulshan Caldera</td>
<td>1.005 ± 0.017 Ma</td>
</tr>
<tr>
<td>Andesite lava</td>
<td>Thompson Creek northwest of Chowder Ridge</td>
<td>878 ± 18 ka</td>
</tr>
<tr>
<td>Andesite lava</td>
<td>Southwest rim of Lookout Mountain, west of Chowder Ridge</td>
<td>859 ± 14 ka</td>
</tr>
<tr>
<td>Pyroxene andesite</td>
<td>Park Creek – Lava Divide</td>
<td>743 ± 72 ka</td>
</tr>
<tr>
<td>Basalt lava-flow</td>
<td>East ridge of Park Butte</td>
<td>716 ± 45 ka</td>
</tr>
<tr>
<td>Pyroxene dacite</td>
<td>Cougar Divide</td>
<td>613 ± 8 ka</td>
</tr>
<tr>
<td>Andesite lava</td>
<td>Lasiocarpa ridge, west of table mountain and north of Sholes Glacier</td>
<td>515 ± 8 ka</td>
</tr>
<tr>
<td>Basalt lava</td>
<td>Rankin Creek</td>
<td>495 ± 18 ka</td>
</tr>
<tr>
<td>Andesites</td>
<td>Forest Divide unit</td>
<td>455 ± 9 ka - 366 ± 10 ka</td>
</tr>
<tr>
<td>Basalt lava</td>
<td>Black Buttes lava</td>
<td>374 ± 10 – 288 ± 15 ka</td>
</tr>
<tr>
<td>Basaltic andesite</td>
<td>Cathedral Crag and Baker Pass</td>
<td>333 ± 12-18 ka</td>
</tr>
<tr>
<td>Pyroxene andesite</td>
<td>Bastille Ridge</td>
<td>322 ± 9 ka</td>
</tr>
<tr>
<td>Andesite lava</td>
<td>Heather Meadows and Table Mountain</td>
<td>309 ± 13 ka – 301 ± 8 ka</td>
</tr>
<tr>
<td>Hornblende andesite</td>
<td>Coleman Pinnacle</td>
<td>305 ±6 ka</td>
</tr>
<tr>
<td>Basaltic andesite</td>
<td>Tarn Plateau</td>
<td>203 ± 25 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Pinus Lake, east of Nooksack Falls</td>
<td>202 ± 9 ka</td>
</tr>
<tr>
<td>Rhyodacite</td>
<td>Boulder Ridge</td>
<td>199 ± 5 ka</td>
</tr>
<tr>
<td>Pyroxene andesite</td>
<td>Deadhorse Creek</td>
<td>192 ± 8 ka</td>
</tr>
<tr>
<td>Pyroxene – hornblende andesite</td>
<td>Table mountain – Ptarmigan Ridge</td>
<td>189 ± 11 ka</td>
</tr>
<tr>
<td>Dacite</td>
<td>Nooksack Falls</td>
<td>149 ± 5 ka</td>
</tr>
<tr>
<td>Pyroxene andesite</td>
<td>Park Creek</td>
<td>140 ± 55 ka</td>
</tr>
<tr>
<td>Olivine-pyroxene andesite</td>
<td>Bar Creek</td>
<td>119 ± 23 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Excelsior Mine, just south of Nooksack Falls</td>
<td>114 ± 9 ka</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Basalt</td>
<td>Northwest of Lake Shannon</td>
<td>94 ± 21 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Boulder-Park Creek</td>
<td>90 ± 52 – 80 ± 14 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>The Portals</td>
<td>76 ± 7 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Swift Creek</td>
<td>48 ± 18 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Ridley Creek</td>
<td>43 ± 5 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Sulphur Creek</td>
<td>36 ± 14 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Baker Pass in Rocky Creek</td>
<td>32 ± 14 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Snouts of Roosevelt and Coleman Glaciers</td>
<td>24 ± 16 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Glacier Creek</td>
<td>14 ± 9 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Crag View</td>
<td>11 ± 9 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Ridge between Roosevelt &amp; Coleman Glaciers</td>
<td>9 ± 7 ka</td>
</tr>
<tr>
<td>Andesite</td>
<td>Sherman Crater</td>
<td>ca. 6.5 ka</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Boulder Creek</th>
<th>Park Creek</th>
<th>Sandy Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.2 5.2</td>
<td>7.4 6.5</td>
<td>6.7 7.0</td>
</tr>
<tr>
<td>Temp. (°C)</td>
<td>8.4 7.2</td>
<td>5.4 6</td>
<td>5 4.9</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>4.9 4.6</td>
<td>1.8 2.8</td>
<td>2 2.5</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>2.9 2.7</td>
<td>1.2 1.2</td>
<td>1 1.4</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>1.5 1.5</td>
<td>0.8 0.6</td>
<td>0.6 0.5</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>1.5 1.7</td>
<td>1 1.3</td>
<td>1.3 0.5</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>14 3.1</td>
<td>5.6 2.94</td>
<td>6.1 3.0</td>
</tr>
</tbody>
</table>
Table 3: Table of raw frequency data from the 2003 Mount Baker survey.

**Question #**                  **Frequency (% of 150)**
1 Which natural disasters do you think are most likely to disrupt your community?
   - Flood: 61 (43%) most likely
   - High wind storm: 54 (39%) most likely
   - Earthquake: 13 (10%) most likely
   - Volcanic eruption: 15 (11%) most likely
   - Landslides: 10 (7%) most likely
   - Forest fire: 25 (18%) most likely

2 Which emergency safety procedures do you or your family practice at home?
   - Flashlight and batteries accessible: 138 (92%)
   - Enough water and food for 3 days: 89 (59%)
   - Portable radio and spare batteries: 88 (59%)
   - Fire extinguisher: 120 (80%)
   - Smoke detectors: 138 (92%)
   - First aid kit: 127 (85%)
   - Wrench for gas shut-off valve: 20 (13%)
   - Not applicable (i.e. don’t have gas): 77 (51%)
   - Emergency contact person: 51 (34%)
   - Someone learned to put out fires: 111 (74%)
   - Someone learned first aid: 123 (82%)
   - Bought additional insurance: 80 (53%)
   - Identified some natural disasters: 118 (79%)

3 Please match these terms with the appropriate definition:
   - Water-saturated debris flow: 101 (68%) correct
   - Crack through which gas and steam: 115 (78%) correct
   - Cohesive unit of molten rock: 126 (85%) correct
   - Turbulent current of gas and ash: 97 (66%) correct

4 If a volcanic event did occur, which hazards would likely disrupt your community?
   - Volcanic gases: 90 (60%)
   - Volcanic ash: 137 (91%)
   - Volcanic mudflows: 117 (78%)
   - Lava flows: 69 (46%)
   - All of the above: 60 (40%)
5 How prepared do you think the following groups are for a volcanic eruption affecting your community?

<table>
<thead>
<tr>
<th>Group</th>
<th>Not at All Prepared</th>
<th>Not Very Prepared</th>
<th>Somewhat Prepared</th>
<th>Very Prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your household</td>
<td>27 (19%)</td>
<td>43 (30%)</td>
<td>64 (45%)</td>
<td>9 (6%)</td>
</tr>
<tr>
<td>Your neighborhood</td>
<td>24 (21%)</td>
<td>52 (44%)</td>
<td>40 (34%)</td>
<td>1 (.9%)</td>
</tr>
<tr>
<td>Your government</td>
<td>18 (16%)</td>
<td>37 (32%)</td>
<td>54 (47%)</td>
<td>7 (6%)</td>
</tr>
</tbody>
</table>

6 Do you consider yourself knowledgeable about volcanic activity at Mount Baker?

- Yes: 64 (44%)
- No: 83 (57%)

7 What is your understanding of the activity at Mount Baker?

- Mount Baker has finished erupting and will not erupt again: 3 (2%)
- Mount Baker will erupt again sometime in the future: 136 (91%)
- Mount Baker is ready to erupt right now: 11 (7%)

8 Is Mount Baker continuously monitored for potential volcanic activity?

- Yes: 110 (73%)
- No: 6 (4%)

9 Have you tried to find out any information, or read anything about Mount Baker from the following:

- Government agencies: 19 (13%)
- Television and radio: 37 (25%)
- Newspapers: 54 (36%)
- Internet: 26 (17%)
- School hand-outs (e.g., brochures, homework, PTA, etc.): 12 (8%)
- Friends or relatives: 38 (25%)
- Social organizations (e.g., the Red Cross, churches, etc.): 4 (3%)
- Workplace: 25 (17%)
- Insurance company or agent: 3 (2%)
- Movies ("Dante's Peak", "Volcano", etc.): 29 (19%)
- Documentaries such as "Fiery Planet", or PBS programming: 43 (29%)
- Books: 40 (27%)
10 Did you know there was a hazards assessment report prepared for the public by the USGS?
Yes, I know it exists but I have not read it 46 (31%)
Yes, I have read it 7 (5%)
No, I did not know it existed 97 (65%)

11 Did you live in the area around Mount Baker in 1975?
Yes 48 (32%)
No 102 (68%)

12 Did you know there was increased volcanic activity at Mount Baker in 1975?
I was not aware of this activity 71 (49%)
I was aware of it, but not concerned for the safety of my community 55 (38%)
I was aware and concerned for the safety of my community 20 (14%)

13 Did you know the following events happened in 1975?
Increased scientific monitoring of the volcano 78 (55%) did not know
Lowering of Baker Lake to protect the dam 102 (72%) did not know
Closing of campgrounds and areas around Baker Lake 96 (68%) did not know

14 Have you ever seen steam plumes rising from Mount Baker?
No, never 40 (28%)
Yes, and they don't bother me 85 (59%)
Yes, and I am concerned that it could be a sign of increased activity 19 (13%)

15 How often do you visit the following areas around Mount Baker?

<table>
<thead>
<tr>
<th>Area</th>
<th>Once a year or more</th>
<th>Less than once a year</th>
<th>Never visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heather Meadows</td>
<td>69 (49%)</td>
<td>36 (26%)</td>
<td>36 (26%)</td>
</tr>
<tr>
<td>Ranger station</td>
<td>58 (41%)</td>
<td>42 (30%)</td>
<td>40 (29%)</td>
</tr>
<tr>
<td>Mount Baker ski area</td>
<td>65 (47%)</td>
<td>51 (36%)</td>
<td>24 (17%)</td>
</tr>
<tr>
<td>Hiking or camping</td>
<td>70 (50%)</td>
<td>46 (33%)</td>
<td>23 (17%)</td>
</tr>
<tr>
<td>X-C skiing/hunting/fishing</td>
<td>55 (42%)</td>
<td>32 (24%)</td>
<td>45 (34%)</td>
</tr>
<tr>
<td>Scenic drives/photo shoots</td>
<td>82 (59%)</td>
<td>36 (26%)</td>
<td>20 (15%)</td>
</tr>
<tr>
<td>Firewood gathering</td>
<td>29 (23%)</td>
<td>26 (21%)</td>
<td>71 (56%)</td>
</tr>
</tbody>
</table>
16 If there were changes at MB, would you be willing to comply with officials if you were asked to:
- Learn safety procedures 138 (95%) yes
- Stay away from certain areas around Mount Baker 130 (91%) yes
- Spend less time outside due to ash fall 131 (91%) yes
- Leave your home 108 (75%) yes

17 Are you male/female?
- Female 100 (67%)
- Male 49 (33%)

18 Age - range from 15 to 74

19 Community you live in - not listed here

20 How long have you lived in your community?
- a matter of months 9 (6%)
- 1 to 5 years 34 (23%)
- 6 to 10 years 24 (16%)
- 11 to 20 years 37 (25%)
- over 20 years 43 (29%)

21 Why do you live there?
- Job requirement 42 (28%)
- Family lives nearby 42 (28%)
- Like the area 127 (86%)

22 What is the status of your home?
- Own it or are in the process of buying it 109 (74%)
- Renting 38 (26%)

23 What is your household's estimated gross annual income?
- under $10,000 11 (8%)
- $10,001 to $20,000 23 (17%)
- $20,001 to $30,000 37 (28%)
- $30,001 to $40,000 22 (16%)
- $40,001 to $50,000 11 (8%)
- $50,001 to $60,000 10 (8%)
- over $60,000 20 (15%)
24 What is your highest degree of education?
- Finished or unfinished high school or GED: 35 (24%)
- Some college education or trade certificate: 63 (43%)
- College or graduate degree: 48 (33%)

25 What is your current employment status?
- Employed full time: 83 (59%)
- Employed part time: 38 (27%)
- Not in paid employment: 7 (5%)
- Retired: 12 (9%)

26 What best describes your family?
- Single adult: 37 (25%)
- Multiple adults and no children: 53 (36%)
- Multiple adults with children: 51 (35%)
- Single adult with children: 5 (3%)

27 What kind of information is of interest to you regarding Mount Baker?
- A map of areas that are at risk from Mount Baker hazards: 113 (76%)
- Info about what to do when Mount Baker becomes threatening: 123 (83%)
- General information about the history of Mount Baker: 96 (64%)
- Mount Baker does not interest me: 4 (3%)
Figure 1: Location map of Mount Baker and the surrounding region.
Figure 2: Location of geologic features around Mount Baker, including Kulshan Caldera and Black Buttes (Modified from Hyde and Crandell, 1978).
Figure 3: Location of notable features around Mount Baker including Park, Boulder, and Sandy Creeks, Boulder Glacier, and Schreiber’s Meadow (Modified from Hyde and Crandell, 1978).
Figure 4: Photo looking southwest showing locations of Mount Baker features, including the East Breach and Grant Peak.
Figure 5: Contour map of Sherman Crater showing thermal areas for 1908-1956. The thermal areas for 1908-1914 are representative of only the smallest visible thermal area due to poor photographic coverage. Contours intervals are 50 meters (Modified from Frank, et al., 1977).
Figure 6: Contour map of Sherman Crater showing thermal areas as interpreted from photographic records from 1960 to 1963. The contour interval is 50 meters (Modified from Frank, et al., 1977).
Figure 7: Contour map of Sherman Crater showing thermal areas interpreted from photograph records for 1966-1972. The contour interval is 50 meters (Modified from Frank, et al., 1977).
Figure 8: Cross section of Sherman Crater looking north showing possible alteration zones in the vent filling material in Sherman Crater (Modified from Frank, 1983).
Figure 9: Contour map of Sherman Crater showing thermal areas as interpreted from photographic records for March 24, 1975. Contour interval is 50 meters (Modified from Frank, et al., 1977).
Figure 10: Contour map of Sherman Crater showing thermal areas interpreted from photographic records for July 20, 1975. Contour interval is 50 meters (Modified from Frank, et al., 1977).
Figure 11: Contour map of Sherman Crater showing thermal areas interpreted from photographic records for the month of September 1975. The dotted line around the north pit indicates approximate location due to continued calving of snows into the pit, hiding the magnitude and true location of the fumarole. Contour interval is 50 meters (Modified from Frank, et al., 1977).
Figure 12: Map of Mount Baker region including towns included in the community survey and their populations (Modified from Gardner, et al., 1995)
<table>
<thead>
<tr>
<th>Town or region</th>
<th>Hazards Zone (see Figure 12)</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacier</td>
<td>Pyroclastic and zone 1 inundation</td>
<td>21 (out of 90)</td>
</tr>
<tr>
<td>Maple Falls</td>
<td>Noncohesive (NC) zone 1 inundation</td>
<td>25 (out of 225)</td>
</tr>
<tr>
<td>Kendall</td>
<td>NC zone 1 inundation</td>
<td>7 (out of 158)</td>
</tr>
<tr>
<td>Deming and vicinity</td>
<td>NC and Cohesive (C) zone 1 inundation</td>
<td>13 (out of ~210)</td>
</tr>
<tr>
<td>Hwy 9 corridor between Deming and Sedro Woolley</td>
<td>No hazards zone</td>
<td>13</td>
</tr>
<tr>
<td>Rockport</td>
<td>No hazards zone</td>
<td>2</td>
</tr>
<tr>
<td>Concrete and vicinity</td>
<td>C zone 1 inundation</td>
<td>23 (out of ~780)</td>
</tr>
<tr>
<td>Skagit River Valley from Concrete to Sedro Woolley</td>
<td>C zone 1 inundation</td>
<td>5</td>
</tr>
<tr>
<td>Sedro Woolley and Mt. Vernon valley</td>
<td>C zone 1 inundation</td>
<td>5</td>
</tr>
<tr>
<td>Unaffected areas from Bellingham to the Border</td>
<td>No hazards zone</td>
<td>13</td>
</tr>
<tr>
<td>Everson-Nooksack</td>
<td>NC and C zone 1 inundation</td>
<td>20</td>
</tr>
<tr>
<td>Sumas</td>
<td>C zone 1 inundation</td>
<td>2</td>
</tr>
<tr>
<td>No personal information</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td><strong>150</strong></td>
</tr>
</tbody>
</table>

**Figure 13:** Chart showing the number of respondents in each town or region around Mount Baker.
Figure 14: Chart showing the results of question #4 ("If a volcanic event did occur, which hazards would likely disrupt your community?").
**Figure 15:** Chart showing the results from question #16 ("If there were changes at Mount Baker, would you be willing to comply with officials if you were asked to:...").
Figure 16: Detail of Mount Baker including Dorr Fumarole Field (Modified from Hyde and Crandell, 1978)
Appendix 1

Questions for Scientist Interviews

Detection Threshold questions:

1.) Given the technology and the state of the science at the time, what was the smallest earthquake, deformation change, gas levels, etc, that you would have been able to detect?

Actual Observation:

1.) There were conflicting reports of tilt data. Frank et al. (1977) reported some deformation related to the tilt data. What is your understanding of deformation at Mount Baker and why?

2.) It was said that the ice caves in the summit craters of volcanoes were a good thermometer of activity levels at volcanoes. So, how did Mount Baker change over the years?

3.) Did CO₂ levels decrease over the years?

4.) Are there any records of ongoing steam activity, and have reports decreased over the period between 1975 and 2000?

5.) Are there any long term changes of bare patches of ground in Sherman Crater or fumarole temperatures that indicate the levels of ongoing activity at Mount Baker since 1975?

6.) Are there seasonal variations in records of thermal activity; do steam plumes, fumarole temperatures, or bare patches correlate with certain times of the year?
General magmatic Questions

7.) There are models that describe volcanoes as either “tight” (frozen conduits from which relatively little to no gas escapes) and “leaky” (relatively open conduits from which a magma conduit freely degasses).
   a.) How would you describe Mount Baker?
   b.) For how long do you think it has been that way or do you believe Mount Baker has changed from tight to leaky or vice versa?

8.) Given what we know now as low frequency events, would you still interpret them as ice fracture events?

9.) Given InSAR data from 3 Sister, Oregon, and Westdahl Volcano, Alaska, showing aseismic magma intrusion there, is it possible that aseismic magma intrusion occurred at Mount Baker?

10.) There have been gas plume readings conducted at Mount Baker that indicate passive degassing of CO₂ as well as H₂S.
     a.) Is it likely that these measurements indicate potential magmatic intrusion (such as deeper aseismic intrusions)?
     b.) Is it possible that these gas readings are representative of magma intrusion?

Hypotheses of the source of activity at Mount Baker in 1975-1976

I have been working toward identifying the source of the thermal event at Mount Baker. To that end, I have delineated a few hypotheses to test. These have been further broken down into magmatic sources and a non-magmatic source.
Magma intrusion:

There are, as I have broken them down, three possible magmatic sources of the thermal activity at MB, an aseismic magma intrusion, a seismic magma intrusion that occurred prior to the seismic network begun in 1972, and a rate change in magma conduits due to a fresh deep influx of magma.

First Hypothesis

a.) There was a deep magmatic intrusion in 1974 or 1975 that instigated the increased thermal output in 1975.

Does any of your data suggest aseismic magma intrusion at Mount Baker in 1975-1976? Can any of your data disprove the possibility of magma intrusion at Mount Baker?

Second Hypothesis

b.) There was a magmatic intrusion prior to 1972 when the seismic net was installed around the Cascades, including at Mount Baker, and therefore was not registered by the seismometers.

Does any of your data suggest intrusion at Mount Baker prior to 1972? Can any of your data disprove the possibility of an intrusion at Mount Baker?

Third Hypothesis

c.) There was a rate change in magma convection in the conduits below the summit of Mount Baker, allowing more gasses to escape.

Does any of your data suggest a rate change in magma convection at Mount Baker in 1975-1976? Can any of your data disprove a rate change in magma convection at Mount Baker?
No Magma intrusion:
This idea is based on breaking of seals in the hydrothermal system releasing previously blocked gases without a magmatic source.

Fourth Hypothesis

Seals in the hydrothermal system at Mount Baker broke open to release previously blocked gases.

Does any of your data suggest that activity was only from breaking of the hydrothermal seals at Mount Baker in 1975-1976?

Can any of your data disprove the possibility that activity was only from breaking of the hydrothermal seals at Mount Baker?

If you believe the 1975-1976 thermal activity was non-magmatically related, how would you explain the levels of CO$_2$ emitted by Mount Baker today (187 t/d, McGee, 2001)?
Appendix 2

**Brief Summary of Responses from Interviews with Scientists**

Not all of the scientists had a response for every question. This is a brief summary of the most important points from their responses.

**Steve Malone:** He would estimate that the lowest threshold for seismometers around Mount Baker at the time to locate an event would be about M 1.6.

It had been 8-10 years since he’d been to the Sherman Crater or Mount Baker summit area. He has heard reports that the west rim has become superheated now and more active. Activity has decreased since the 1975-1976 thermal levels, but has never returned to pre-1975 levels.

There were some deep long-period earthquakes during the 1990s at depths of around 10-20 km. Mid-crustal earthquakes usually range from 5-10 km.

His first instinct was that activity at Mount Baker was strictly hydrothermal in nature [hypothesis 4] during the 1975-1976 events. He thought that the heat flux was due to breaks in the hydrothermal seals within the plumbing system. His belief was mostly due to the lack of earthquakes at the time. However, there is new data to look at such as airborne studies. He would have to research the gas readings from [McGee, 2001] 2000.

**Seth Moran:** He described the detection threshold to be around .5 to detect, and M 1-1.5 to locate.

Reports of steaming at Mount Baker are given to Cascades Volcano Observatory each time the weather conditions are perfect: clear, cold, perfect dew point, and most especially when the summit hasn’t been visible in a long time.

His strong bias is that there couldn’t have been a magmatic intrusion without some kind of seismic signature; however, there is a chance that a small pulse of magma intruded at depth and stalled out. It has been known to happen.

He explained that a ‘low frequency event’ is a descriptive term and glacial movement is one way to get them: the seismic waves get trapped between the rock and
ice. Although low frequency events can also indicate magma movement, the nature of the ones at Mount Baker probably indicated glacial movement.

InSAR data is very helpful, but it isn’t suited to steep ground with lots of ground cover like around Mount Baker. Therefore, it was helpful at Three Sisters, Oregon, but would probably be less so around a steep volcano like Mount Baker.

His bias would be towards the last hypothesis, that hydrothermal seals broke due to a non-magmatic source since that was what was concluded at the time in 1975-1976. However, it is possible that new data, such as Ken McGee’s work (2001) can shed new light on the event and change that possibility. If the airborne readings are around $187 \pm 26 \text{td}^1$ then a magma source is possible.

Ken McGee: He described that detection threshold for gas readings are very weather dependent: atmospheric conditions must be optimal for good readings. The measurements in 2000 (McGee et al., 2001) were conducted with good weather conditions.

There were few airborne measurements back in 1975 so there is nothing with which to compare 2000 measurements of CO$_2$. If we could see back to CO$_2$ levels in 1975 he would expect to find large quantities of CO$_2$ from a newer source of magma. This is due to the fact that CO$_2$ exsolves deeper and under higher pressures than other gases and can then be recorded earlier during the magma intrusion, unlike SO$_2$ which requires magma to be shallower for it to exsolve. For this reason, if there was a magma intrusion in 1975 he would expect a lot of the CO$_2$ to exsolve early in the intrusion, and then other gases would have appeared later. It is probably impossible to tell now whether the magma intrusion came from 1975 or an earlier intrusion such as the 1843 eruption or even an intrusion without an eruption. Regardless, the 1975 activity had a magmatic component.

Don Swanson: (brief interview) He is left to believe that the events at Mount Baker in 1975-1976 were hydrothermal in nature. He could cite no data to disprove any magmatic hypothesis; however he still believes that activity was due to the breaking of
the hydrothermal seals in the plumbing system of Mount Baker. His expectation if it had been magmatic in nature was that heat would rise into the summit of Mount Baker, not Sherman Crater. If magmatic heat were to rise into someplace other than the summit, there should have been earthquakes to herald the opening of new pathways to Sherman Crater. Furthermore, if there had been an older magmatic intrusion of some kind [for example prior to 1972 when the seismic net was placed around the Cascades] he wouldn’t expect such a long delay for the heat to reach the surface of the volcano. Thus, he is left to favor the non-magmatic hypothesis that the thermal activity at Mount Baker was caused by hydrothermal seals breaking within the plumbing system.

**David Frank:** He told me that Mount Baker has the highest heat flow of the Cascades volcanoes as well as the highest concentration of gases, with maybe the exception of Mount St. Helens. The problem with Mount Baker is the lack of records or studies from before the 1975 activity. This makes any comparative analysis virtually impossible.

He said that even hydrothermal changes would probably have been picked up by the seismic records. The fact that nothing was recorded at Mount Baker (and not just seismically) doesn’t mean that nothing happened. Instruments could have been in the wrong place. The problems with some of the 1975-1976 data is the inconsistency between the different instruments, which makes them hard to reinterpret.

There is a record of past eruptions at Mount Baker such as in 1843 [Tucker and Scott, 2006]. It is difficult to tell conclusively what caused the changes at Mount Baker in 1975, but with the gas readings [McGee et al., 2001], a magmatic source of some kind seems at least possible.
Appendix 3

Community Questionnaire on Volcanic Natural Hazards

Presented by Janna Juday

This is a questionnaire for a research project that I am doing as part of my Master’s of Geology program at Western Washington University. The survey is designed to help assess how much your community knows about volcanoes, especially Mount Baker. Specifically, I would like to identify how communities prepare and react to natural disasters, and in particular volcanic events. The general results from this survey will be available to emergency managers and scientists to develop educational and response measures.

Please understand that there are no signs of any changes at Mount Baker since 1976, and this questionnaire is not intended to cause concern. Results will be available to help create possible future educational programs in your community. Thus, your views are very important to the success of this study and will help immensely with my Masters project. It is not a test. Your responses will be entirely anonymous and will be used solely for the purposes of this study.

In filling out this questionnaire, you will be helping us educate others. In addition, this research will hopefully help you in the future.

For more information, or if you have any concerns about this questionnaire or the research being done, please contact Janna Juday, care of Western Washington University Geology Department, 516 High Street, Bellingham, Wa. 98225-9080.

Thank You!
Natural Disaster and Volcanic Questions:

1.) Which natural disasters do you think are most likely to disrupt your community? Please Rank 1 through 6, where 1 is “most likely” and 6 is “least likely”:
   - Flood
   - High wind storm
   - Earthquake
   - Volcanic eruption
   - Landslides
   - Forest fire

2.) Which emergency safety measures do you or your family practice at home? (check all that apply –NA is “not applicable”, for example, you may not have gas)
   - □ Have a flashlight accessible and have the checked the batteries
   - □ Have stockpiled enough water and food to last three days
   - □ Have a portable radio and spare batteries
   - □ Have a fire extinguisher
   - □ Have smoke detectors
   - □ Have a first aid kit
   - □ Store wrench near gas shut-off valve
   - □ Chosen an emergency contact person outside of the Northwest
   - □ Someone in the family has learned how to put out fires
   - □ Someone in the family has learned how to provide first aid
   - □ Bought additional insurance (i.e., homeowners, contents, etc.)
   - □ Have identified at least some of the natural disasters to which your community might be vulnerable (e.g., earthquake, landslides, flood, etc.)

3.) Please match these terms with the appropriate definition:
   a.) Lava flow __* water-saturated debris flow including rocks and mud
   b.) Lahar flow __* a crack through which gases and steam are emitted
   c.) Pyroclastic flow __* a cohesive unit of molten rock
   d.) Fumarole __* a turbulent current of superheated gases and ash

4.) If a volcanic event did occur, which hazards would likely disrupt your community? (Check all that apply)
   - □ Volcanic gases
   - □ Volcanic ash
   - □ Volcanic mudflows
   - □ Lava flows
   - □ None
   - □ All of the above
   - □ Don’t know
5.) How prepared do you think the following groups are for a volcanic eruption affecting your community?

<table>
<thead>
<tr>
<th></th>
<th>Very Prepared</th>
<th>Somewhat Prepared</th>
<th>Not very Prepared</th>
<th>Not at all Prepared</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your household</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your neighbors &amp; town</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Your government (County, State, Federal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions Concerning Mount Baker Activity:

6.) Do you consider yourself knowledgeable about volcanic activity at Mount Baker?
   □ Yes
   □ No

7.) What is your understanding of the activity at Mount Baker?
   □ Mount Baker has finished erupting and will not erupt again.
   □ Mount Baker will erupt again sometime in the future.
   □ Mount Baker is ready to erupt right now.

8.) Is Mount Baker continuously monitored for potential volcanic activity?
   □ Yes
   □ No
   □ Don’t know

9.) Have you tried to find any information, or read anything about Mount Baker from the following (check all that apply)
   □ Government agencies
   □ Television and radio
   □ Newspapers (circle which one: national, regional, local community)
   □ Internet (circle where you use it the most: Home, Library, Work)
   □ School hand-outs (e.g., brochures, homework, PTA, etc.)
   □ Friends or relatives
   □ Social organizations (e.g., the Red Cross, churches, etc.)
   □ Workplace
   □ Insurance company or agent
   □ Movies ("Dante’s Peak", "Volcano", etc.)
   □ Documentary, such as "Fiery Planet" or PBS programming
   □ Books
   □ Other, please specify ________________________________
10.) Did you know there was a hazards assessment report prepared for the public by the US Geological Survey about Mount Baker?
☐ Yes, I know it exists, but I have not read it
☐ Yes, I have read it
Did this help you? Yes___ No___ why not?________________________
☐ No, I did not know that it existed

11.) Did you live in the area around Mount Baker in 1975?
☐ Yes
☐ No

12.) Did you know there was increased volcanic activity at Mount Baker in 1975?
☐ I was not aware of this activity
☐ I was aware of it, but not concerned for the safety of my community
☐ I was aware and concerned for the safety of my community

13.) Did you know the following events happened in 1975?

<table>
<thead>
<tr>
<th>Event</th>
<th>Yes</th>
<th>No</th>
<th>Disrupted my life</th>
<th>How?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased scientific monitoring of the volcano:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowering of Baker Lake to protect the dam:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closing of campgrounds and areas around Baker Lake:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14.) Have you ever seen steam plumes rising from Mount Baker?
☐ No, never
☐ Yes, and they don’t bother me
☐ Yes, and I am concerned that it could be a sign of increased activity at the volcano

15.) How often do you visit the following areas around Mount Baker?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Once a year or more</th>
<th>Less than once a year</th>
<th>Have never visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heather Meadows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ranger Station at Glacier</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Baker ski area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiking or camping</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-country Skiing, Hunting, or Fishing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenic drives or Photography shoots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firewood gathering</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
16.) If there were changes at Mount Baker, would you be willing to comply with officials if you were asked to:

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Why not?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learn safety procedures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stay away from certain areas around Mount Baker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend less time outside due to ash fall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leave your home</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

****Again, please understand that there have been no changes to cause concerns at Mount Baker. These questions are purely hypothetical.

These next few questions are for general information purposes. Your responses are entirely confidential.

17.) Are you: Female_____ Male_____ 

18.) How old are you? _____

19.) What community do you live in? __________________________

20.) How long have you lived in your community?
   □ a matter of months
   □ 1 to 5 years
   □ 6 to 10 years
   □ 11 to 20 years
   □ over 20 years

21.) Why do you live there? (check all that apply)
   □ job requirement
   □ family lives nearby
   □ like the area
   □ Other __________________________

22.) What is the status of your home?
   □ Own it or are in the process of buying it (own free and clear or have a mortgage)
   □ Renting
23.) What is your household’s estimated gross annual income?
   □ under $10,000
   □ $10,001 to $20,000
   □ $20,001 to $30,000
   □ $30,001 to $40,000
   □ $40,001 to $50,000
   □ $50,001 to $60,000
   □ over $60,000

24.) What is your highest degree of education? Please check only one.
   □ Have not finished high school
   □ High school or GED
   □ Some college education
   □ College degree (A.A., B.A., B.S., etc.)
   □ Trade certificate or professional certificate/diploma
   □ Graduate degree (M.S., PhD, etc.)

25.) What is your current employment status?
   □ Employed full time
   □ Employed part-time
   □ Not in paid employment
   □ Retired
   □ On disability

26.) Which best describes you or your family:
   □ Single adult
   □ Multiple adults and no children
   □ Multiple adults with children
   □ Single adult with children
   □ Other, please specify ____________________________

27.) What kind of information is of interest to you regarding Mount Baker? Please check all that apply.
   □ A map of areas that are at risk from Mount Baker hazards
   □ Information about what to do when Mount Baker becomes threatening
   □ General information about the history of Mount Baker
   □ Mount Baker does not interest me

Thank you so much for your time and input. Your help is greatly appreciated.
Appendix 4

Table of brief observations and notable changes at Mount Baker

<table>
<thead>
<tr>
<th>Date of Observation</th>
<th>Methods</th>
<th>Who Performed</th>
<th>Results</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1843</td>
<td>observations</td>
<td></td>
<td>Ash eruption.</td>
<td>Easterbrook, 1975</td>
</tr>
<tr>
<td>1854</td>
<td>observations</td>
<td>George Davidson</td>
<td>Possible small eruption, viewed from Rosario Straight</td>
<td>Davidson, 1885</td>
</tr>
<tr>
<td>1858</td>
<td>observations</td>
<td>G. Davidson - J. S. Hittell</td>
<td>Eruption on Mount Baker, viewed from Victoria</td>
<td>Davidson, 1885</td>
</tr>
<tr>
<td>1870</td>
<td>observations</td>
<td>George Davidson</td>
<td>Possible small eruption, viewed from Admiralty Inlet</td>
<td>Davidson, 1885</td>
</tr>
<tr>
<td>1940</td>
<td>photographs</td>
<td></td>
<td>Thermal ground in 2 places @ the base of NW rim &amp; 50m downslope of rim</td>
<td>Davidson, 1885</td>
</tr>
<tr>
<td>1956</td>
<td>photographs</td>
<td></td>
<td>NW ice pits have sometimes snowed over, but always melt in during summer</td>
<td>Frank, Post, Friedman, 1975</td>
</tr>
<tr>
<td>1956-1964</td>
<td>photographs</td>
<td></td>
<td>SW pit created sometime during this period, roughly 46 m across and melting 30 m of ice and snow each year. This pit was still visible in 1974.</td>
<td>Kiver, December/January 1975-1976</td>
</tr>
<tr>
<td>1960</td>
<td>observations</td>
<td></td>
<td>No steam activity during the 40s &amp; 50s, started up in 60s.</td>
<td>Easterbrook, 1975</td>
</tr>
<tr>
<td>1960-1970</td>
<td>photographs</td>
<td></td>
<td>Snow free ground from 5,500 m² up to 10,000 m².</td>
<td>Frank, et al., 1977</td>
</tr>
<tr>
<td>Sept. 1963</td>
<td>photographs</td>
<td></td>
<td>Lake emitting vapor - possibly more hidden in ice.</td>
<td>Frank, et al., 1977</td>
</tr>
<tr>
<td>Date</td>
<td>Instrument</td>
<td>Details</td>
<td>Source</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>--------------------------------</td>
<td></td>
</tr>
<tr>
<td>Nov. 20, 1972</td>
<td>thermal infrared</td>
<td>Images taken in an overflight show thermal infrared anomalies covering 8,800 m² of Sherman Crater. The concentration of activity is in the E breach where a total radiant flux was equated to be 1.15 X 10⁶ W. At no time during this year has the E breach been entirely covered in snow, which is believed to mean that snow is melted off as fast as it falls.</td>
<td>Frank, et al., 1975</td>
<td></td>
</tr>
<tr>
<td>Summer 1972, 1973</td>
<td>bimetallic thermometer</td>
<td>T= 90ºC vapor, 60ºC at &lt;1 cm depth, &amp; 90ºC at 50 cm depth, means BP limits fumarole max T.</td>
<td>Frank, et al., 1977</td>
<td></td>
</tr>
<tr>
<td>Apr. 29, 1973</td>
<td>thermograph ic image</td>
<td>Infrared anomalies cover 7,500 m², and about 6% of crater 3000 m² snow free ground - no snow year-round, means snow melts as fast as it falls.</td>
<td>Frank, Post, Friedman, 1975</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 1973</td>
<td>observations</td>
<td>There is an avalanche of material from the NE-facing slope of Sherman Peak. Traveled 2.6 km, and included roughly 35,000 m³ of peak material. Soil and water samples collected around the source of the avalanche have a pH of &lt;2.3. There are residual vapors emanating from around the avalanche scar indicating that possibly there is a combination of factors which lead to these 2-4 year avalanches: there is some geothermal heating below the snow, possibly a large accumulation of snow during the year(s), hydrothermal rock and clay underlie the snow, and saturation of this material from snow ablation and geothermal heating further weaken the stability of Sherman Peak.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 20 or 21, 1973</td>
<td>photographs</td>
<td>Debris avalanche Aug. 20-21 from Sherman Crater rim. 46,000 yards³.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973-1974</td>
<td>observations</td>
<td>Water fountain in a pool 2m across and 30cm deep - this is the place where most active fumaroles have always been known to be hottest and biggest.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 1974</td>
<td>gas observations</td>
<td>Max concentrations H₂S &amp; CO₂ on W rim .0074% &amp; 19%.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 1974</td>
<td>observations</td>
<td>~46 m pit in SW side of Sherman Crater emitted a jet of steam roughly 6.2 m high, and evidently melts 30.8 m of snow that drifts into the pit each winter as well as the surrounding walls of ice.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frank, et al., 1975
Frank, Post, Friedman, 1975
Kiver and Steele, 1975
Kiver, December/January 1975-1976
<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 4, 1974</td>
<td>water-quality</td>
<td>GS Central lab</td>
<td>Boulder Creek pH level at 3.5.</td>
</tr>
<tr>
<td>Mar. 10, 1975</td>
<td>observations</td>
<td></td>
<td>Dark vapor plumes over Sherman Crater - closer look shows new main fumarole on ridge near base of Lahar Lookout.</td>
</tr>
<tr>
<td>Mar. 11, 1975</td>
<td>observations</td>
<td></td>
<td>Large jet present ejecting steam up to 90-125, above floor of crater &amp; 5 other fumaroles, one of which is 30m wide.</td>
</tr>
<tr>
<td>Mar. 11, 1975</td>
<td>aerial photos</td>
<td>D. Noel</td>
<td>Morning photos of the crater show new thermal areas, crevasses, and dirty snow.</td>
</tr>
<tr>
<td>Mar. 11, 1975</td>
<td>aerial photos</td>
<td>H. Lynch, M. Star</td>
<td>Afternoon view shows possibly a 10 times increase in vapor and dirty snow in the crater.</td>
</tr>
<tr>
<td>Mar. 11, 1975</td>
<td>observations</td>
<td>R. Donnelly, L. Hjorten, W. McDaniel</td>
<td>Dark gray material seen on the snow near the crater and light colored plume seen extending 5-8 kilometers to the south. Unusual turbidity seen in Boulder Creek.</td>
</tr>
<tr>
<td>Mar. 11, 1975</td>
<td>aerial photos</td>
<td>D. Easterbrook</td>
<td>Photos show 6 distinct vapor plumes and dust covered snow, largest plume estimated 90-240m jet with cauliflower cloud at 450m above the floor of the crater near the east breach.</td>
</tr>
<tr>
<td>Mar. 13, 1975</td>
<td>aerial photos</td>
<td>C. Miller</td>
<td>Circular crevasses seen around a sinkhole in the middle of the crater. There are 8 distinct plumes, some from crevasses, and gray debris over most of the snow and some yellow debris.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Authors</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------</td>
<td>----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mar. 20, 1975</td>
<td>water-quality</td>
<td>W. McDaniel, M. Meier, J. Hyde, D. Frank</td>
<td>Park and Sulfur Creeks clear, but Boulder Creek shows gray suspended sediment and slight sulfur smell similar to 3/11.</td>
</tr>
<tr>
<td>Mar. 20</td>
<td>water-quality</td>
<td></td>
<td>The pH levels at Boulder Creek mouth 3.4-4.2, with loads 1600-8100 lbs/day as concentrated sulfuric acid till Aug.</td>
</tr>
<tr>
<td>Mar. 24, 1975</td>
<td>vertical photos</td>
<td>A. Post, B. Kimball</td>
<td>Photos show enlargement of crevasses around the sinkhole and the NE rim. Also, 2 new small perforations at the NE base of Sherman Peak. These later appeared as infrared anomalies. E breach appears to be the source of several vapor plumes at the entrance to Boulder Glacier.</td>
</tr>
<tr>
<td>Mar. 24, 1975</td>
<td>aerial photos</td>
<td>R. Krimmel, S. Hodge</td>
<td>There is a greenish cast appearing to be a pond in ice perforation NE of center of the crater (North pit). Also, there is water in E breach near the old major fumarole and creek.</td>
</tr>
<tr>
<td>Mar. 26, 1975</td>
<td>infrared</td>
<td>U of W &amp; US Forest Service</td>
<td>Thermal activity located in east breach &amp; north pit. Also, 2 small ice pits @ NE base of Sherman Peak give off some thermal readings.</td>
</tr>
<tr>
<td>Mar. 27, 1975</td>
<td>gas observations</td>
<td>L. Radke, A. Bittenbinder, &amp; unnamed others</td>
<td>An overflight of Cloud and Aerosol Physics aircraft detected a sulfur plume with a 10ppb contour extending at least as far S as Everett. Photos taken show continued enlargement of crevasses.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Authors/Notes</td>
<td>Details</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>--------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Mar 27 &amp; Jun 30 '75</td>
<td>gas observations</td>
<td></td>
<td>Gaseous sulfur emission rates 0.35 &amp; 1.3 kg s(^{-1}) respective. Production rate of small particles = 2.6X10(^{17})s(^{-1})</td>
</tr>
<tr>
<td>Mar 28 1975</td>
<td>water-quality</td>
<td>M. O. Fretwell</td>
<td>Boulder Creek has a pH of 3.8 and appeared milky, very turbid with a distinct smell of hydrogen sulfide and the rocks were stained yellow-orange.</td>
</tr>
<tr>
<td>Mar. 29, 1975</td>
<td>water-quality</td>
<td>M. Fretwell, G. Bourcier</td>
<td>Elaboration of Mar. 28 readings: pH at Boulder Creek is 3.8, 12 other sites tested, including some measurements in Baker Lake near the dam, all have readings between 6.6 and 6.7.</td>
</tr>
<tr>
<td>Mar. 31, 1975</td>
<td>seismic &amp; observ.</td>
<td>USGS</td>
<td>New seismic stations installed, no seismic activity found.</td>
</tr>
<tr>
<td>Mar. 31, 1975</td>
<td>gas observations</td>
<td>S. Malone, S. Smith, A. Bittenbinder, D. Frank, E. Kiver, W. Steele, A. Post, L. Dayton</td>
<td>Gas analyses conducted on W rim of Sherman Crater show CO(_2) at less than 10%, CO at 150 ppm, H(_2)S at 800 ppm, and temperatures of 86°C. A vertical-component seismometer was also installed on the S rim of Sherman Crater with a telemetry link to UV.</td>
</tr>
<tr>
<td>Mar. 1975</td>
<td>observations</td>
<td></td>
<td>March '75 sees 40m deep ice pit in middle of crater grow. April sees surrounding ice falling in forming a lake 50X70m across, with fumaroles around &amp; in. Roughly 50 cm deep, roughly 2,600 m(^3) of water and T=26°-34°C in summer '75.</td>
</tr>
</tbody>
</table>

Radke, et al., 1976

USGS Memorandum

USGS Memorandum

Radke, et al., 1976

USGS Memorandum

Malone & Frank, 1976
<table>
<thead>
<tr>
<th>Date</th>
<th>Method</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar -winter, 1975</td>
<td>photographs/infrared</td>
<td>2 small ice pits in upper Boulder glacier, coalesced by summer into a trough, this and another similar trough remained hotter then other crevasses around Crater.</td>
<td>McLane, Finkleman, Larson, 1976, prof paper 1000</td>
</tr>
<tr>
<td>Mar. 1975</td>
<td>gas observations</td>
<td>Max concentrations H₂S &amp; CO₂ on W rim .15% &amp; 27%.</td>
<td>Kiver and Steele, 1975</td>
</tr>
<tr>
<td>Mar. 1975</td>
<td>water-quality US Geological Survey</td>
<td>Scientists found that acidity concerns with stream flows off the crater affected only Boulder Creek and Baker Lake.</td>
<td>Frank, et al., 1977</td>
</tr>
<tr>
<td>Apr. 1, 1975</td>
<td>observations</td>
<td>70m depression south of center and collapse of ice roof finds a lake below, melting ice, no steam here.</td>
<td>Easterbrook, 1975</td>
</tr>
<tr>
<td>Apr. 4, 1975</td>
<td>water-quality C. Weaver</td>
<td>Water samples taken at Boulder Creek have a light sulfur smell and high turbidity.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Apr. 9, 1975</td>
<td>water-quality S. Malone, C. Weaver, D. Frank</td>
<td>Water sample from Boulder Creek show a pH of 3.4, and a specific conductance of 560. Baker Hot springs show pH of 8.1, and temperatures of 47°C.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Apr. 21, 1975</td>
<td>aerial photos</td>
<td>Central Pit of about 70 m diameter where ice perforations used to be has ~30m ice walls. Water, rock and mud partly cover the bottom of the pit. Bedrock is now visible at the bottom of crevasses NE of the north pit and has vapor plumes. A new brown coating instead of gray covers parts of Lahar Lookout and nearby areas. The New Main Fumarole now is directed horizontally to the S instead of vertically.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Date</td>
<td>Event Type</td>
<td>Source</td>
<td>Details</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------</td>
<td>-----------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Apr. 27, 1975</td>
<td>seismic &amp; observ.</td>
<td>USGS</td>
<td>Levels of seismic activity rose greatly and then moderated, presumed to be due to venting changes within the volcano.</td>
</tr>
<tr>
<td>Apr. 28-May 4, 1975</td>
<td>observations</td>
<td>J. Eichelberger, T. McGetchin, E. Fukushima, L. Margolin, M. Peek, W. Lockyer, B. Chouet</td>
<td>Temperature of fumaroles on the W rim is ~87-89°C at roughly a 10-30 cm depth. Scientists also witnessed a 4m drop of a 100 by 100 m section of ice above the N pit, and heard loud rumblings several times from May 1 through 2. Gray debris throughout Sherman Crater was visible, as well as green debris around NE part with a 1 cm thick layer deposited over a 3 day period.</td>
</tr>
<tr>
<td>Apr. 29, 1975</td>
<td>water-quality</td>
<td>J. E. Cummins, G. Bourcier</td>
<td>Boulder Creek samples show a pH of 3.8, specific conductance of 440, a temperature of 6.4°C, and a discharge rate of 1,430 l/s. Park creek show a pH of 7.5, specific conductance of 60, a temperature of 3.1°C, and a discharge rate of 1,190 l/s.</td>
</tr>
<tr>
<td>Apr. 29, 1975</td>
<td>aerial photos</td>
<td>A. Post, R. M. Krimmel</td>
<td>White vapor plumes are visible but without any pulsing this time. The central pit is now gray with grounded ice blocks at the margins indicating a depth of less than about 5 m. The N pit has enlarged and appears deeper than the central pit. There is ice pulling away from the W.</td>
</tr>
<tr>
<td>Apr. - Sept. 1975</td>
<td>observations</td>
<td>McLane, et al., 1975</td>
<td>Most abundant spherules of orthorhombic sulfur, about 30-40 % by volume = 15-20%, rest are altered minerals.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Details</td>
<td>Source</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>May 1 1975</td>
<td>temp. &amp; obs.</td>
<td>One fumarole vent in Sherman Crater has a temperature of 88 +/- 1°C are concealed in photos by their cooler plumes.</td>
<td>Eichelberger, et al., 1975</td>
</tr>
<tr>
<td>May 1 1975</td>
<td>observations</td>
<td>A &gt;40 μm fraction of fumarolic ejecta is analyzed and found to have: &quot;40% fine grained agglomerate (mostly analcite), 21% rock fragments, 10% clear glass, 1% brown glass, 5% devitrified glass, 19% opaque minerals (pyrite with minor magnitite and chalcopyrite), 1% quartz, and 3% feldspar.&quot; The similarity with samples from around Sherman Crater indicate that this material is old material from the walls inside the fumarole vents.</td>
<td>Eichelberger, et al., 1975</td>
</tr>
<tr>
<td>May 4 1975</td>
<td>water-quality</td>
<td>Water samples of Boulder Creek show pH of 4.3 with a surface slightly higher than April 9 readings and shows increased turbidity.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td></td>
<td>aerial photos</td>
<td>D. Frank</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M. Sato, S. Malone, P. Mitchell</td>
<td></td>
</tr>
<tr>
<td>May 12 1975</td>
<td>gravity</td>
<td>Gravity decrease between May 12 - Sept. 19, = elevation increase of 1.3 meters.</td>
<td>Malone &amp; Frank, 1976</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Observations</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>May 12-14,</td>
<td>observations</td>
<td>M. Sato, S. Malone, A. Bittenbinder, C. Raymond, D. Frank</td>
<td>Central lake is 70 by 50 m with a long E-W axis and a thick green turbidity. There are 3 clusters of fumaroles on the shoreline with a green and yellow sublimates, and 2 upwellings in the lake indicate submerged fumaroles or springs. There are 2 visible inlets of &lt; 1 l/s but no visible outlet. There is no ice or vapor in the lake. The N pit is enlarged with mud covered rock beneath the ice on the N wall. Fumaroles on W rim similar in size to previous summer, temperature 89-90°C. Pooch Peak appears undercut.</td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 12 -</td>
<td>gravity</td>
<td></td>
<td>Measurements were corrected for tide and earth movements, but it was found that there was a gravity decrease of 0.4 milligal, which is equivalent to an elevation increase of 1.3 m. However, there were no corresponding tilt measurements to corroborate the gravity readings.</td>
</tr>
<tr>
<td>Sept. 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 28, 1975</td>
<td>observations</td>
<td>D. Easterbrook, S. Malone, D. Dethier, W. Wallace</td>
<td>Dark gray material over Sherman Crater, then white plumes 700-800 m above summit lasting 2 hours. No other signs of changes except possible ash near Main Fumarole and a possible snow avalanche from NE slope of Sherman Peak down Boulder Glacier seen in flyovers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Method</td>
<td>Authors</td>
<td>Observation</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>May 28 1975</td>
<td>aerial photos</td>
<td>A. Post, B. Kimball</td>
<td>The white plume appears continuous at about 5 to 10 amount of previous plumes. The N pit is at least 3 times the size of the Central pit. Crevasses indicate that there is increased ice flow from the S rim into the crater. There are 2 new snow-free areas on S side of the summit crater.</td>
</tr>
<tr>
<td>May 28 1975</td>
<td>water-quality</td>
<td>J. Cummans, A. Zander</td>
<td>Water samples at Boulder Creek show pH of 4.1, specific conductance of 200, temperature of 8.4°C, with discharge rates of 3,170 l/s. Park Creek shows pH of 7.4, specific conductance of 46, temperature of 5.4°C, and a discharge rate of 3,590 l/s.</td>
</tr>
<tr>
<td>May 29 1975</td>
<td>water-quality</td>
<td>J. E. Cummans</td>
<td>Boulder Creek pH level is at 4.1 and specific conductance is 200. Park Creek has a pH of 7.4 and a specific conductance of 44. Baker River has a pH of 6.9 and a specific conductance of 44.</td>
</tr>
<tr>
<td>May &amp; Sept.</td>
<td>gravity</td>
<td>Cummans</td>
<td>Gravity change (decrease), possibly due to melting snow.</td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 1975</td>
<td>infrared</td>
<td>OSU &amp; Army Nat. Guard</td>
<td>MCT shows large area greater than 15°C and partially obscured by steam.</td>
</tr>
<tr>
<td>Jun. 1975</td>
<td>water-quality</td>
<td>USGS &amp; US Forest Service</td>
<td>Average concentration of sulfate, iron, manganese, aluminum, arsenic, and fluoride are 10-100 times the concentration in surrounding streams. Boulder Creek pH at 3.9 in the summer and 5 with winter melt, other creeks at 7.2, and acid loads are few to</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Authors</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>June 9-12, 1975</td>
<td>observations</td>
<td>S. Malone, D. Frank</td>
<td>Central pit with a small lake remained at roughly 70 X 50 m with semi-circular crevasses surrounding it enlarging and ice walls calving into it. Central pit depth on June 11 was recorded to be 39 m. Main fumarole every ten second or so sucks back in vapor momentarily and then issues a particularly large whitish plume. Lahar Lookout has two new small fumaroles leaking out plumes. Fumarole activity growing in east breach area. Major gasses were H₂S with additional SO₂.</td>
</tr>
<tr>
<td>June 9-12, 1975</td>
<td>observations</td>
<td>S. Malone, A. Rohay, D. Frank</td>
<td>Fumarole clusters are visible along the SE, SW&lt; NW, and N shores of the central lake. The upwelling in the middle of the lake appears larger and more vigorous than previous observations. At 2 points about 10 m from N and E shores with depths of ~1 m. Temperature is roughly 43°C with an infrared surface temp of 25-26°C. pH is roughly 2.5. Hand-held radiometer shows readings of vapor of 87-88°C. A trough on Pooch Peak shows unusual thermal readings.</td>
</tr>
</tbody>
</table>

USGS Memorandum
<table>
<thead>
<tr>
<th>Date</th>
<th>Method</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 10-11, 1975</td>
<td>temp. &amp; observ.</td>
<td>West rim fumaroles, $T = 89^\circ - 91^\circ C$, with clayey ejecta like the new main fumarole.</td>
<td>Fretwell, 1977, in Frank, et al., 1977</td>
</tr>
<tr>
<td>Jun. 29, 1975</td>
<td>photographs</td>
<td>White steam plume $&gt; 700$ m above vent lasting almost 3 hours.</td>
<td>Eichelberger, et al., 1976</td>
</tr>
<tr>
<td>Jun. 30, 1975</td>
<td>thermal infrared</td>
<td>Temperatures for the center of the lake were calculated from images to be between 33-40$^\circ C$.</td>
<td>Eichelberger, et al., 1976</td>
</tr>
<tr>
<td>Jun. 30, 1975</td>
<td>water-quality</td>
<td>Boulder Creek shows pH readings of 4.2, specific conductance of 255, and temperature of 9.4$^\circ C$. Park Creek shows pH readings of 7.7, specific conductance of 60, and temperature of 8.9$^\circ C$.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jun. 30, 1975</td>
<td>gas observations</td>
<td>Cloud and Aerosol Physics aircraft surveyed total sulfur and found a 300% increase since the March 27, survey.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jun. 30, 1975</td>
<td>observations</td>
<td>A vapor plume seen from Dorr Fumarole Field about 60 m wide.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>July 3 1975</td>
<td>observations</td>
<td>Airphotos show vapor plumes at a third of what they were on June 30.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>July 3 1975</td>
<td>observations</td>
<td>Airphotos show the lowest amount of vapor in months. There's a new muddy brown lake in an ice cave by the E breach towards the N pit $\sim 20$ m wide. Old lake is still pale green. Crevasse near Boulder Glacier head has enlarged to cavern with no vapor that might connect with subglacial outlet stream.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Authors</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>----------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>July 3 1975</td>
<td>thermal infrared</td>
<td></td>
<td>The lake has a surface temperature of 41°C.</td>
</tr>
<tr>
<td>July 4 1975</td>
<td>gas observations</td>
<td>S. Malone, D. Frank, D. Swanson</td>
<td>An H_2S meter was used in work areas on the W rim. In open breezy areas, H_2S readings are 10-40 ppm, but in sheltered areas with no breeze readings are &gt;50 ppm. Maximum fumarole temperature is ~91°C.</td>
</tr>
<tr>
<td>July 9 1975</td>
<td>observations</td>
<td>A. Post, B. Kimball, R. Graves</td>
<td>Airphotos show a lot of collapsed ice ceilings and walls. Waterfalls are visible in the top 1/3 of Boulder and Squak glaciers. There is also bare rock visible along the summit ice plateau that could be remnants of the Summit Crater rim.</td>
</tr>
<tr>
<td>July 10-11, 1975</td>
<td>observations</td>
<td></td>
<td>Lahar Lookout is found to be unconsolidated and potentially unstable. There is a medium amount of vapor from all fumaroles. Ash is seen in a small high-pressure fumarole plume, not just in the main fumarole. A fumarole along the W rim showed a temperature of 91°C.</td>
</tr>
<tr>
<td>July 12 1975</td>
<td>temp. &amp; observ.</td>
<td>R. M. Krimmel, D. Frank</td>
<td>Models show that the roughly 19% of Sherman Crater is snow-free. Roughly 1/3 of that snow-free ground exceeds 15°C.</td>
</tr>
<tr>
<td>July 20 1975</td>
<td>observations</td>
<td>R. M. Krimmel, D. Frank</td>
<td>Airphotos show ice melt in Sherman Crater is continuing. There is vapor present in the crevasse in the head of Boulder Glacier.</td>
</tr>
<tr>
<td>Date</td>
<td>Method</td>
<td>Author/Source</td>
<td>Notes</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------</td>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>July 24 1975</td>
<td>thermal infrared</td>
<td>J. Davis</td>
<td>There is a medium amount of vapor present in all fumaroles. There is a fan of sandy silty material in what was E breach lake. The central pit lake appears normal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermal infrared survey found that W rim of Sherman Crater is affected by the thermal emission increase. There is a relative increase in snow-free ground on W rim of 30%.</td>
</tr>
<tr>
<td>July 27 1975</td>
<td>observations</td>
<td>H. Donnelly</td>
<td>There were puffs of dark vapor seen forming on the SE slope about midway between Sherman Crater and the timberline below. This continued for about an hour, during which time there were no vapor plumes seen from Sherman Crater. Once the dark vapor plumes dissipated, then vapor was again seen from Sherman Crater.</td>
</tr>
<tr>
<td>July &amp; Aug. 1975</td>
<td>thermistor, electrochemical</td>
<td>Sato, et al.</td>
<td>Fumarole T= 89-92°C varying each day. This was the first time automatic fumarolic data monitored remotely.</td>
</tr>
<tr>
<td>August 4 1975</td>
<td>observations</td>
<td>R. M. Krimmel, D. Hirst</td>
<td>Airphotos show rockfall debris on SE slope with no dark vapor plumes like on 7/27. There are possibly layers of old debris avalanches in widening crevasse in the head of Boulder Glacier.</td>
</tr>
</tbody>
</table>
During this investigation, the central pit lake was pH 2.4, with a temperature of 26°C. The upwelling continues in 3 to 5 places. Depth remains at roughly <5 m. There is a drainage stream confined to a 1 m deep gully that travels from the lake underneath ice bridges to the E breach. There are many high pressure fumaroles on the N bank of this stream. More snow-free ground is visible. Hummocky ground across the floor of Sherman Crater has 50 cm high sulfur cones with vigorous fumaroles. There is a 1-2 m high water fountain in a pool. New main fumarole is 1 X 5 m across and emitting large billowing vapor with no appreciable sound. It also has criss-cross fractures that emit vapor. Many small fumaroles roar some. The most noticeable sound is a high-pitched whine from a very pressurized fumarole in the SW ice pit (Bellybutton Fumarole).

<table>
<thead>
<tr>
<th>Date</th>
<th>Observations</th>
<th>Authors</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 6-8</td>
<td>observations</td>
<td>S. Malone, D. Frank, D. Swanson</td>
<td>The lake at the base of Lahar Lookout is silty and sandy with a braided stream, although the view is partially obscured by collapsed ice. There are many new visible fumaroles, but they might have been covered with ice before. There is also debris from a small rockfall on the SE slope with no vapor.</td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August 6-8</td>
<td>observations</td>
<td>S. Malone, D. Frank, D. Swanson</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>cont'd</td>
<td></td>
<td></td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Date</td>
<td>Method</td>
<td>Team/Individual</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Aug. 8, 1975</td>
<td>thermal infrared</td>
<td>OSU &amp; Army Nat. Guard</td>
<td>Total surface area of the crater = approx. 185,700 m², of which 35,200 m² is snow free, and 12,600 m² is above 15°C, and stayed mostly snow-free throughout the winter.</td>
</tr>
<tr>
<td>August 19 1975</td>
<td>thermal infrared</td>
<td>C. Rosenfeld</td>
<td>A thermal infrared survey found &quot;questionable anomalies&quot; outside the W and NW rims, on E base of Lahar Lookout, and on the NW slope of Sherman Peak. These anomalies are not solar heating.</td>
</tr>
<tr>
<td>Aug. 1975</td>
<td>gas observations</td>
<td></td>
<td>Max gas concentrations of H₂S and CO₂ were 7.4% and 36% respectively.</td>
</tr>
<tr>
<td>Aug. 1976</td>
<td>gas observations</td>
<td></td>
<td>Max concentrations H₂S &amp; CO₂ on W rim 7.4% &amp; 36%. One fumarole has recorded velocities of 74 m/s.</td>
</tr>
<tr>
<td>Aug.-Sept, 1975</td>
<td>observations</td>
<td></td>
<td>Part of main fumarole was a mudpot for some time.</td>
</tr>
<tr>
<td>Sept. 1975</td>
<td>temp. &amp; observ.</td>
<td></td>
<td>Main fumarole merges with others, T reach 131°C, known water fountain dried up - stream T near old main fumarole 18°C-21°C, compared to Aug. 1974 T= 7°C-8°C.</td>
</tr>
<tr>
<td>Sept. 4-7, 1975</td>
<td>observations</td>
<td></td>
<td>The lake at the bottom of the ice pit was 2.5 pH and 31°C at 80 cm from shore.</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Author(s)</td>
<td>Notes</td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>--------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sept. 4-7,</td>
<td>observations</td>
<td>S. Malone, A.</td>
<td>Fumarole velocity of an 8 cm large fumarole on the N shore of the lake was 73 m/s. Fumaroles on the W rim of Sherman Crater show velocities of 51 m/s with 36% CO₂ and 7.4% H₂S.</td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td>Rohay, E.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kiver, W.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Steele, F.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Munich, R.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hughes, G.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bloem, T.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bloem</td>
<td></td>
</tr>
<tr>
<td>Sept. 9/10</td>
<td>observations</td>
<td>Kiver</td>
<td>Explorations of ice caves reveal acid lake with cliffs 140 ft tall.</td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fumaroles in the E breach show temperatures of 103°C. The old main fumarole shows 87-96°C. The lower part of new main fumarole is a mud pot with a stream of mud over the lip. So, the lineations on the main fumarole seen on 8/6 were probably streams of mud. The biggest plume is from the new main fumarole with mud droplets entrained but no pressure. Hotter fumaroles had molten sulfur pools. One outlet creek had a temperature of 18°C at a point 5 m upstream of old main with a pH of 3.0. Dorr fumarole field was normal. Area of mudflows on SE slope of cone (seen 7/27) was related to terminal moraine of small lobe of Squak Glacier. There was no heat found.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept. 18-20</td>
<td>observations</td>
<td>S. Malone, A.</td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td></td>
<td>Rohay, A.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bittenbinder, F.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hartline, D.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frank</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Author</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sept. 30</td>
<td>observations</td>
<td>S. Malone, D. Frank, E. Wildermuth, J. Ramey</td>
<td>Thermistor arrays show the temperature of the E breach fumarole is 131°C, old main fumarole is 102°C, the outlet creek is 15 degrees C with a pH of 2.8, Bellybutton fumarole towards the SW is 84°C, and W rim fumarole is 89°C.</td>
</tr>
<tr>
<td>Sept - Dec</td>
<td>observations</td>
<td></td>
<td>SW pit enlarges, high-pressure fumarole with the highest pitched sound of any others. New pit between SW pit &amp; west rim.</td>
</tr>
<tr>
<td>October 17</td>
<td>observations</td>
<td>P. Hart</td>
<td>Heavy rains cause flooding in streams on the E side of Mount Baker. Boulder Creek has strong enough sulfur odor to make visitors nauseous.</td>
</tr>
<tr>
<td>October 21</td>
<td>seismic</td>
<td>S. Malone</td>
<td>A small earthquake occurred with magnitude M, 1.5. The epicenter is located below Lake Shannon, 1.6 km S of Upper Baker Dam.</td>
</tr>
<tr>
<td>October 21</td>
<td>water-quality</td>
<td>H. Johnson</td>
<td>Boulder Creek has lowered since the flooding reported on 10/17. There is still a slight sulfur smell although the water is clear.</td>
</tr>
<tr>
<td>October 22</td>
<td>water-quality</td>
<td>J. Cummins</td>
<td>Boulder Creek has a pH of 4.9, specific conductance of 156, and a temperature of 5.6°C. Park Creek has a pH of 7.1, specific conductance of 60, and a temperature of 5°C. The peak flow ever reported in Park Creek was 100 times the current flow of 2600 l/s. Boulder Creek is similar with a current visibility of 30 cm.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Details</td>
<td>Source</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Fall of 1975</td>
<td>observations</td>
<td>Boulder Creek has had several flooding episodes throughout the Fall which have been attributed to minor avalanches temporarily blocking the flow of Boulder Creek from Sherman Crater.</td>
<td>Rosenfeld and Schlicker, 1976</td>
</tr>
<tr>
<td>November 18 1975</td>
<td>gas observations</td>
<td>An airborne survey of the sulfur plume found levels similar to 6/30 where levels were 3 times those of 3/27 (where sulfur 10 ppb contour extended farther south than Everett).</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>December-5-1975</td>
<td>observations</td>
<td>Aerial photos show heavy snowfalls but similar heat output from ice pits. A new pit has formed ~5 m across, about 20 m downslope of NW cluster of fumaroles. Also, two oval pits ~30 m long have appeared just outside the crater. One is located outside the base of Sherman Peak. The other is at the head of Boulder Glacier. Neither has vapor. Most of the vapor is from the E breach, but there is some from the central, N and SW pits, as well as from the W and NW rims. Dorr fumarole field is bare ground and has vapor.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>1976</td>
<td>photo &amp; investigation</td>
<td>Fumaroles @ 131°C, lake at 1-3,000m³, and at least 2,000 m³ of fine ash from fumaroles.</td>
<td>Baker Info Committee</td>
</tr>
<tr>
<td>January-18-1976</td>
<td>thermal infrared</td>
<td>Strong anomalies are visible in the small new pit downslope of NW fumarole cluster. Moderate anomalies from 2 oval pits outside of Sherman Crater.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Date</td>
<td>Method</td>
<td>Details</td>
<td>Source</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>February-6-1976</td>
<td>observations</td>
<td>S. Malone, A. Bittenbinder, D. Frank There is a thin yellow sulfur dust widespread throughout the crater. There is gray dust only on snow-free areas, and no new deposits since previous snow fall. Main fumarole plume less dense and drier, with no mud spilling over the lip. There is, however yellow sublimates lining the inside of the rim, and the pressure is the same as before. The temperature in most fumaroles is 90°C, although there are some superheated fumaroles in the E breach reaching 123°C. The small NW pit is now covered but there is a depression marking its location. The two outside pits are the same as in December. The prevalence of activity through the winter &quot;denotes activity that was not fully recognized last summer and may or may not represent increased activity.&quot;</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Feb. 27, 1976</td>
<td>seismometer</td>
<td>U of W geophysics dept A small earthquake occurs (Mw=1) 1 km east-southeast of Sherman Crater at a depth of 3-6 km.</td>
<td>Frank, et al., 1977, prof paper 1000</td>
</tr>
<tr>
<td>Feb. 1976</td>
<td>observations</td>
<td>Mud extrusion stopped, and vapor dried out leaving yellow residue (sulfur) on edges of fumarole.</td>
<td>Frank, et al., 1977</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Artist/Author</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
<td>--------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mar. 4, 1976</td>
<td>observations</td>
<td>R. M. Kimmel, D. Frank</td>
<td>There is a lot of new snow, but still obvious thermal activity in Sherman Crater. The amount and location of the thermal areas remains unchanged. The largest melting is still the E breach, central pit lake, north pit, and W rim. The smaller areas are still SW and NW pits, NW rim and the pits outside of the crater at the head of Boulder Glacier. There are no changes at Dorr. Outside temperature is -7°C at the summit level.</td>
</tr>
<tr>
<td>Mar. 14, 1976</td>
<td>thermal infrared</td>
<td>C. Rosenfeld</td>
<td>There is no unusual ice break up as might be expected with spring and thermal activity melting.</td>
</tr>
<tr>
<td>Mar. 23, 1976</td>
<td>seismic</td>
<td>S. Malone</td>
<td>From 0530 to 0840 there are bursts of increased seismic background activity recorded from Sherman Crater stations.</td>
</tr>
<tr>
<td>Mar. 1976</td>
<td>water-quality</td>
<td>USGS</td>
<td>Radiotelemetry monitor set up on Boulder Creek to warn of unusual pH, water levels, T, specific conductance, and dissolved O.</td>
</tr>
<tr>
<td>Apr. 1, 1976</td>
<td>observations</td>
<td>T. Van Decar</td>
<td>Aerial photos show breakup of 1/3 of the snow pack on N face of Sherman Peak and ice blocks fallen into the E breach. Breakup occurred after 3/14 but cannot be correlated to seismic activity of 3/23.</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Comments</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Apr. 3, 1976</td>
<td>observations</td>
<td>Aerial photos show no further breakup of ice on Sherman Peak. Central pit is shorter and now more circular. There is no change in the lake depth and the upwellings are still present. There is a rock protruding through the snow 20 m E of lake, and there is hummocky snow-covered terrain between the central and N pits which may be evidence of some avalanche off the NW rim. There is more vapor than 3/4/76 and photos show an increase in snow-free ground of 1,000 m² in the past month. This is still less than 1/2 of '75 max area of snow-free ground. There are no changes at Dorr.</td>
<td></td>
</tr>
<tr>
<td>May 20, 1976</td>
<td>observations</td>
<td>Less than ideal conditions for a photo survey still allowed scientists to see that the snow-free ground has increased to 6,000 m² or about 60% of the '75 max snow-free ground. Central pit has expanded to SW but is still smaller than in 1975.</td>
<td></td>
</tr>
<tr>
<td>June 17, 1976</td>
<td>observations</td>
<td>Excellent conditions this time allow scientists to see that ice has fallen into the SW pit which is greatly enlarged since 5/20/76 observations. There is a new small ice pit ~10 m across between the NW and N pits. The central lake has more upwelling 5 m W of main fumarole. There is a yellow tinge to the snow around E breach and SW pits. Snow-free ground is now about 62% of '75 max snow-free ground. There is no change at Dorr.</td>
<td></td>
</tr>
</tbody>
</table>

USGS Memorandum
<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Author</th>
<th>Notes</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 26 1976</td>
<td>water-quality</td>
<td>S. Malone, D. Frank</td>
<td>Boulder Creek was tested about 1 km downstream of the Boulder Glacier terminus and was found to have pH 3.6, temperature of 1.7°C, and no evidence of high water levels.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>July 14 1976</td>
<td>observations</td>
<td>S. Malone, D. Frank</td>
<td>The SW pit has fumaroles. The new pit between the N and NW pits is part of subsiding ice around NW pits. The lake level is slightly higher than previous summer. The vapor plume around old main fumarole appears thicker and more pressurized than previous summer. The plume around the new main fumarole appears less dense and pressurized. Superheated E breach temperatures around 130 degrees C. Water from the outlet creek in the E breach has a pH of 2.8, temperature of 22°C and a flow of 0.2 m³/s. The new ice pit at the N base of Sherman Peak is 10 m across. The new superheated fumaroles on the W rim are 98°C. There are no changes at Dorr.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Reporter</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>---------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Jul. 27, 1976</td>
<td>observations</td>
<td>R. M. Krimmel, D. Frank</td>
<td>A photo survey of the summit with a temperature of 3°C at 10,000 feet. The level of vapor is the same as previous trips with numerous small plumes dissipating by 100 m. The snow is dirtier with more yellow than previous summer, but this could also be due to less gray dust hiding the yellow. The activity on W and SW rims has broken up the ice under Pooch Peak. Circular crevasses have formed around thermal areas on the NW wall as well as around the depression between E breach and Central pit. Snow and ice from the summit plateau is slumping into the crater and there are more crevasses visible.</td>
<td></td>
</tr>
<tr>
<td>Jul. 30-31, 1976</td>
<td>observations</td>
<td>S. Malone, D. Frank, E. P. Kiver, F. Munich, F. Muenchler</td>
<td>Central Lake was studied from a rubber raft and was found to have a general depth of 1 m +/- 0.2 m. Closer to one of the submerged fumaroles the lake was found to be 2 m. The temperature of the lake is in the low 20°C range.</td>
<td></td>
</tr>
<tr>
<td>Oct. 16, 1976</td>
<td>observations</td>
<td>S. Malone, D. Frank</td>
<td>Some fumaroles covered by a thin sheet of ice. There is a depression in Boulder Glacier extending down 1/3 of glacier from a narrow trough about 2/3 up from the terminus.</td>
<td></td>
</tr>
<tr>
<td>Oct. 18, 1976</td>
<td>observations</td>
<td>S. Malone, D. Frank</td>
<td>There is a bowl-like depression in lower 1/2 of Boulder Glacier that glistened as if unusually wet.</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Method</td>
<td>Name</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Jan. 1, 1977</td>
<td>observations</td>
<td>R. M. Klimmel, D. Frank</td>
<td>An overflight found temperatures of -10°C at 3,000 m and the humidity was unusually high - there was ice in the carburator. The overall vapor plume is larger than seen in 1976, but not as large as some in 1975. Sometimes, plumes were seen from Everett reaching 200 m above the summit, or 500 m above the crater floor. There are plumes from the W rim. Some of the increased plume activity could be due to the atmospheric conditions. The crater lake has a thin layer of snow over the SE sector, although there is still upwelling.</td>
<td></td>
</tr>
<tr>
<td>Feb. 15, 1977</td>
<td>thermal infrared</td>
<td>C. Rosenfeld</td>
<td>There is a possible enlargement of the thermal area near the E breach.</td>
<td></td>
</tr>
<tr>
<td>Feb. 24, 1977</td>
<td>seismic</td>
<td>S. Malone</td>
<td>There is a large seismic event of Ml 2.5 beneath the crater.</td>
<td></td>
</tr>
<tr>
<td>Mar. 1977</td>
<td>observations</td>
<td>E. P. Kiver</td>
<td>Temperatures in some vents still exceeded 110°C, but many fumaroles now inactive, including the large lake pit fumarole. H2S concentrations still exceeded pre-1975 levels by 500 times and are still increasing in some areas such as the lake pit. CO2 levels returned to 1974 levels.</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Name</td>
<td>Notes</td>
<td>Source</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Apr. 24, 1977</td>
<td>observations</td>
<td>R. M. Krimmel, D. Frank</td>
<td>Air temperature at the crater is 6°C. There have been few changes since the 1/1/77 observations. The most prominent fumarole is on the W rim where superheated fumaroles were found in '76. The amount of vapor appears similar to '75 in the old and new main fumaroles, and they're between .5 and 1 m across. The lower part of new main fumarole is partially covered in debris and the vapor is less than '75 or '76. There are no new deposits in Sherman Crater and the features are similar to '76 observations. The pits in Boulder Glacier are snow-filled. There are large sulfur deposits still apparent near the E breach. There is still upwelling in the lake. The total amount of vapor appears similar to spring/summer of '76, but most is now coming from W rim (approximately 50% of the total vapor is from here).</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jul. 1977</td>
<td>seismic</td>
<td>S. Malone</td>
<td>There is a shallow earthquake (M 3.5) beneath the Skagit Valley, W of Bacus Hill.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jul. 13, 1977</td>
<td>seismic</td>
<td>S. Malone</td>
<td>There is a buildup of seismic activity culminating in 2400 events with 2 large shocks. All identifiable events are ice events.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jul. 16, 1977</td>
<td>observations</td>
<td>S. Schwarz</td>
<td>There is a report in to S. Malone that there was a large avalanche from the N rim into Sherman Crater. At the time of this observation there was light snow covering the debris.</td>
<td>USGS Memorandum</td>
</tr>
<tr>
<td>Jul. 22, 1977</td>
<td>seismic &amp; observ.</td>
<td>Seismic records show July 13, 1977 had one or two small avalanches of snow and/or debris on north pit.</td>
<td>Frank, et al., 1977</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Observers report that an avalanche occurred sometime after 6/9/77. The avalanche was of ice and snow from the N rim near the N pit. It traveled into Sherman Crater and terminated halfway into the E breach. It partly filled the ice pits near the E breach as well as the central pit. The surface of the deposit is discolored with ejecta or debris from Lahar Lookout. The estimated volume of the avalanche is $0.3 \times 10^6 \pm 0.05 \text{ m}^3$ and the estimated distance traveled is 510 m from roughly 3,060 m to 2,880 m altitude. Its origin looks to be from above the melting around the N pit. There is another estimated 20,000 m$^3$ poised to avalanche as well. This avalanche did not reach SW, W, or NE fumaroles. The fumarole on the SW edge of the N pit has melted through the debris and a plume is visible. The W main fumarole does not appear to be superheated now, with few sulfur deposits. There does appear to be a new small (~5 m) pit/crevasse between the NW and central pits. There is also a curvilinear crevasse around the S margin of the central pit.</td>
<td>R. M. Krimmel, D. Frank</td>
<td></td>
</tr>
</tbody>
</table>

<p>| Jul. 22, 1977 | observations | USGS Memorandum |</p>
<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Author</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 22, 1977</td>
<td>observations</td>
<td>R. M. Krimmel, D. Frank</td>
<td>The Boulder Glacier pit is reopened (~5 m) in the E breach at the N base of Sherman Peak. The E breach also has a small lobe of snow since 6/9/77 that moved from the N slope of Sherman Peak about 11 m across. This overlies the channel in the E breach but does not interfere with the outlet creek.</td>
</tr>
<tr>
<td>Jul. 27, 1977</td>
<td>water-quality</td>
<td>D. Dethier, R. Wilson</td>
<td>Water samples were taken at the Boulder Glacier terminus in the S stream showing pH of 3.6, and at the Boulder Creek bridge pH was 5.3.</td>
</tr>
<tr>
<td>Aug. 3, 1977</td>
<td>observations</td>
<td>D. Frank, J. Travert</td>
<td>An overflight shows that an ice pit has formed in the N margin of the E breach superheated fumarole field. It’s approximately ~15 m across and the nearby snow is yellow. There is subsidence in the central pit. There is also thermal ground in the NW part of Sherman Crater. The W rim and NW pits are continuous in length.</td>
</tr>
<tr>
<td>Aug. 7, 1977</td>
<td>gas observations</td>
<td>J. Bergman</td>
<td>Aerial fire spotters reported a sulfur odor as far NE of Sherman Crater as Chilliwack Lake (~ 40 km).</td>
</tr>
<tr>
<td>Aug. 10, 1977</td>
<td>observations</td>
<td>D. Frank</td>
<td>Aerial flight shows that an ice pit (~ 10 m across) formed over the old main fumarole. There is continued subsidence of debris into the central pit. The crevasse is bigger between the central and NW pits.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Observers</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
<td>----------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Aug. 17, 1977</td>
<td>observations</td>
<td>R. M. Krimmel, D. Frank</td>
<td>A photo survey shows a new ice pit (~15 m across) over the fumarole mound on the N margin of the central pit. There is no ponded water. There is a new cluster of fumarole between the central and NW pits which suggest a topographic dome at the glacier bed in the area.</td>
</tr>
<tr>
<td>Aug. 1977</td>
<td>seismic</td>
<td>S. Malone</td>
<td>There are 2-5 small shallow seismic events W of Sherman Crater, the largest of which is $M_L \sim 1.5$.</td>
</tr>
<tr>
<td>Sept. 13, 1977</td>
<td>observations</td>
<td>S. Malone, D. Frank, M. Templeton, E. P. Kiver, F. Munich</td>
<td>While repairing equipment in Sherman Crater, it is noted that the lake extends under an overhanging ledge of debris from avalanche. There has been no upwelling noted since 8/17/77. There was a debris avalanche down Boulder Glacier from Sherman Peak.</td>
</tr>
<tr>
<td>Date</td>
<td>Type</td>
<td>Author</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dec. 27, 1977</td>
<td>observations</td>
<td>R. M. Krimmel</td>
<td>A photoflight showing 0°C at 3,000 m alt. observes roughly 50% of the previous steam plume from the W rim, 25% from E breach, and 25% from the N and NW pits. There is water in the central pit, but there is less than before and the walls around appear higher. The scar from the July avalanche is healed, and there appear to be no more avalanches or cave-ins. There is, however, an ice and snow avalanche scar from the cliffs about 2750 m on Boulder Glacier that descended to 1000 m. There is a new Boulder Glacier pit (~ 5 m across) about half way through the E breach at the S base of Lahar Lookout. Two pits at the base of the N side of Sherman Peak and the head of Boulder Glacier were open.</td>
</tr>
<tr>
<td>1977-1979</td>
<td>observations</td>
<td></td>
<td>Large steam eruptions increased from 2-4 times a year from 1975-1977, to 10-12 times a year between 1977-1979.</td>
</tr>
<tr>
<td>Mar. 1, 1978</td>
<td>observations</td>
<td>L. Hemry</td>
<td>There is a report of unusually large vapor plumes from Sherman Crater.</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Author(s)</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mar. 1, 1978</td>
<td>observations</td>
<td>S. Malone</td>
<td>During this photoflight, with -17°C at 3,000 m, the vapor plume reaches the summit. There are two new ice pits between the N pit and the NW rim. There could also be another new one low on the W rim. The NW part of Sherman Crater is unusually bare for this time of year. The crater lake is partially iced over. The three Boulder Glacier ice pits are unusually large. There is sulfur dust on the snow, but no gray dust.</td>
</tr>
<tr>
<td>Mar. 15, 1978</td>
<td>observations</td>
<td>D. Frank, B. Kimball</td>
<td>This photo survey shows -20°C at 3,000 m. The new ice pit from the previous survey, between the N pit and the NW rim have coalesced into one large, over 1,000 m², pit of thermal ground with at least 2 large fumaroles and many small ones. There is a SE-NW trending peninsula in the lake, forming since 12/27/77. The ground throughout the crater appears to be hummocky with non-sorted debris and boulders, with a maximum relief of &lt; 50 cm.</td>
</tr>
<tr>
<td>Date</td>
<td>Observations</td>
<td>Author</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
<td>--------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mar. 21, 1978</td>
<td>observations</td>
<td>B. Kimball</td>
<td>There is little change with the new pits, although the 1,000 m² area appears to be subsiding. The N shore of the lake is receding, up to 2 m. The vapor appears normal and reaches 200 m. There is more exposed ground this time than in previous years at this time: 3/21/78 = 23,800 m² snow-free compared to 4/3/76 = 11,700 m², and 4/24/77 = 17,400 m². March of '78 snow-free ground similar to May and July of previous three years. Most activity is on the W and NW rims and in the NW pits. The N and E breach fumaroles have sulfur on the snow. There is gray dust around the N pit.</td>
</tr>
<tr>
<td>Mar.- Aug. 1978</td>
<td>observations</td>
<td>E. P. Kiver</td>
<td>New vent system visible on NW rim with violent discharges where only small fumaroles were located before.</td>
</tr>
<tr>
<td>June 4, 1978</td>
<td>observations</td>
<td>R. M. Krimmel</td>
<td>The temperature during this aerial observation was 8°C at 3,000 m. There are few changes since the March observations. About 50% of the fumarole activity is concentrated on the W rim. The vents on the W rim which are extending towards the SW pits are enlarging. The snow-free area between the N pit, NW pits and the NW rim in increasing. Both increasing snow-free areas are interpreted to be seasonal. The north side of the upper part of Boulder Glacier appears abnormally extended. Steam plumes from the Crater reach 50-100 m high.</td>
</tr>
</tbody>
</table>

USGS Memorandum
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 21 1979</td>
<td>observations</td>
<td>There was no activity in the central pit, but there is new activity between NW rim and the north pits. There was also a decrease in the total volume of crater ice.</td>
<td>Rosenfeld, 1980</td>
</tr>
<tr>
<td>Jul. 1979</td>
<td>observations</td>
<td>There are reports of a large debris avalanche of ice, snow, and rock from 'Mt. Sherman' (Sherman Peak).</td>
<td>Easterbrook, D. J., 1980</td>
</tr>
<tr>
<td>1997</td>
<td>observations</td>
<td>Three large fumaroles in Sherman Crater were measured at 108, 122, and 134°C. Gases were collected from them: no SO₂ was found at all, the CO₂/H₂S ratio ranged from 13-22, with an average of 18.</td>
<td>McGee, et al., 2001</td>
</tr>
<tr>
<td>Date</td>
<td>Event</td>
<td>Description</td>
<td>Source</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Sept. 13, 2000</td>
<td>gas observations</td>
<td>Ground fumarole measurements around this time show fumaroles are between 86 and 134°C. Airborne surveys of H₂S show levels of 75 ppb, CO₂ at &lt;2 ppb and a CO₂/H₂S ratio of 25, almost no SO₂ scrubbing.</td>
<td>McGee, et al., 2001</td>
</tr>
</tbody>
</table>