

(2001)

R290

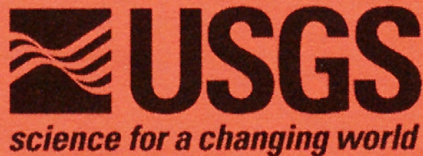
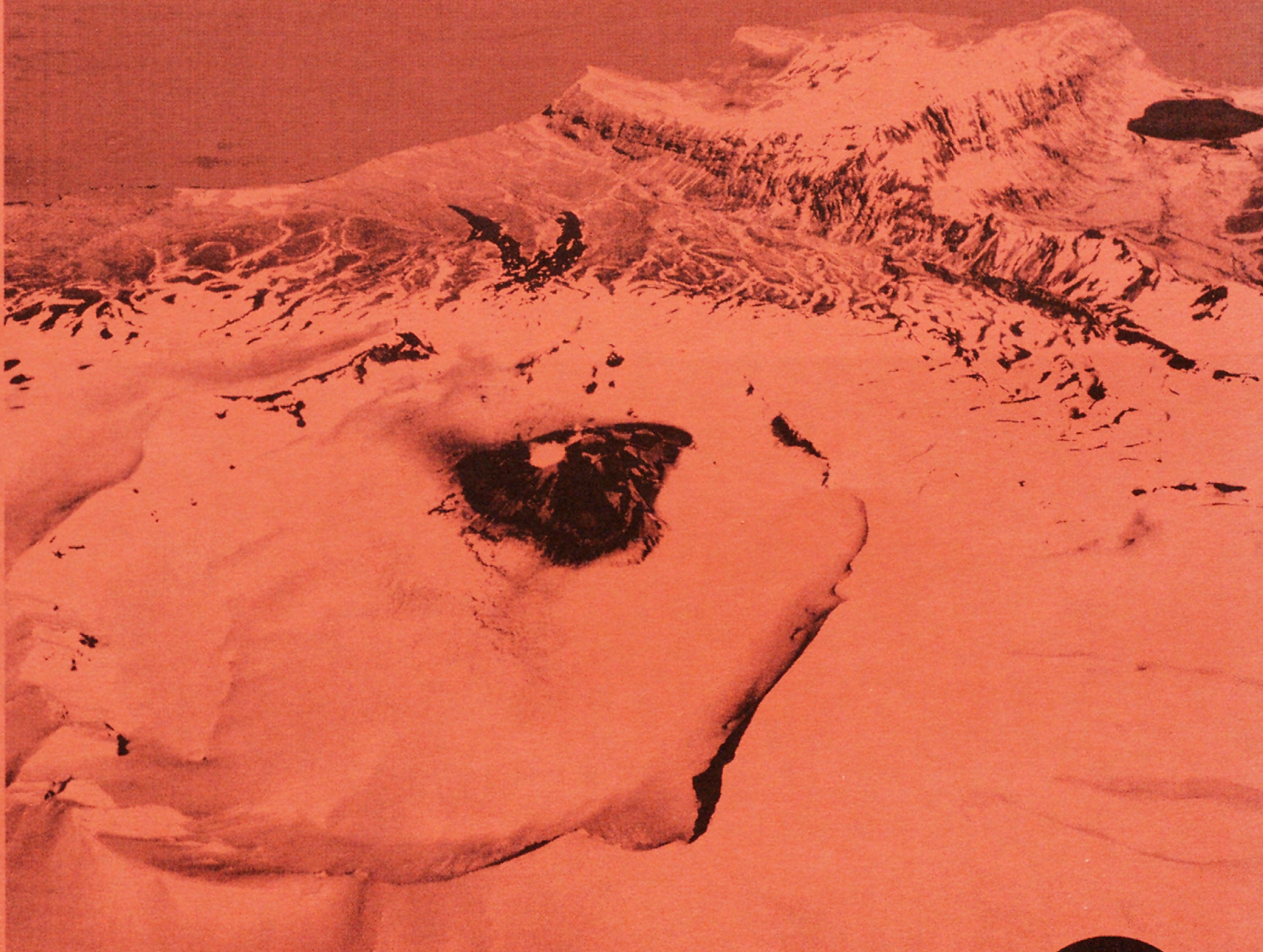
no. 98-360

U.S. Department of the Interior

U.S. Geological Survey

Preliminary Volcano-Hazard Assessment For Akutan Volcano, East-Central Aleutian Islands, Alaska

Open-File Report 98-360



This report is preliminary and subject to revision as new data become available.
Any use of trade, product or firm names is for descriptive purposes only and
does not imply endorsement by the U.S. Geological Survey



The Alaska Volcano Observatory (AVO) was established in 1988 to carry out volcano monitoring, eruption notification, and volcanic hazards assessments in Alaska. The cooperating agencies of AVO are the U.S. Geological Survey (USGS), the University of Alaska Fairbanks Geophysical Institute (UAFGI), and the Alaska Division of Geological and Geophysical Surveys (ADGGS). AVO also plays a key role in notification and tracking of eruptions on the Kamchatka Peninsula of Russia as part of a formal working relationship with the Kamchatkan Volcanic Eruptions Response Team (KVERT).

Cover: Akutan Volcano, June 7, 1983. View is to the north towards Long Valley. Dark linear features are lava flow of 1978. (Photograph by North Pacific Aerial Surveys, now called Aeromap, Inc.)

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

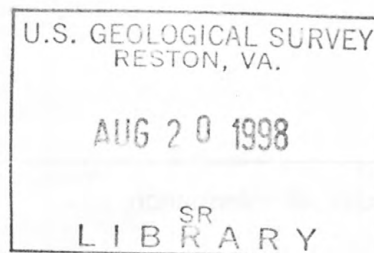
Preliminary Volcano-Hazard Assessment for Akutan Volcano East-Central Aleutian Islands, Alaska

by

Christopher F. Waythomas, John A. Power, Donald H. Richter,
and Robert G. McGimsey

Open-File Report 98-360

This report is preliminary and subject to revision as new data become available.
Any use of trade, product or firm names is for descriptive purposes only and
does not imply endorsement by the U.S. Geological Survey



Alaska Volcano Observatory
Anchorage, Alaska
1998

4. Diagram showing chronology of known eruption-related events of Holocene age at Akutan Volcano	7
5. Diagram showing summary of known historical eruptive activity at Akutan Volcano	9
6. Photograph of ash plume from the intracaldera cone of Akutan Volcano during the 1976-77 eruption	10
7. Epicenter map and cross section showing earthquake hypocenters at Akutan Volcano from March through August 1996	11
8. Epicenter map and cross section showing earthquake hypocenters at Akutan Volcano from August 1996 through March 1998.	12
9. Photograph of ground cracks on northwest flank of Akutan Volcano	13
10. Map showing location of ground cracks on Akutan Island	14
11. Simplified sketch of a stratovolcano and associated hazardous phenomena	15
12. Sketch map showing average wind direction and likely travel paths for volcanic ash clouds from Akutan Volcano	17
13. Map showing location and size of volcanic fallout	18
14. Photograph of typical exposure of coarse-grained fallout tephra produced by the caldera-forming eruption of Akutan Volcano about 1600 years ago	19
15. Map of Akutan Island and areas that could be affected by pyroclastic flow and surge.	20
16. Map of Akutan Island and areas that could be affected by lahars, lahar-runout flows, and floods.	22
17. Photograph of Akutan Volcano and breach through caldera rim on the north side of the volcano	23
18. Map of Akutan Island and areas that could be affected by lava flow.	24
19. Map of Akutan Island and areas that could be affected by debris avalanche.	26
20. Photograph of large boulders on surface of cohesive lahar deposit near the mouth of Long Valley	27
21. Map of Hot Springs Valley showing location of fumarole field and thermal springs	28
22. Map of Akutan Island and areas that could be affected by rockfall avalanches.	30
23. Map showing location of seismic monitoring stations on Akutan Island.	32
24. Diagram showing Alaska Volcano Observatory's level of concern color code.	33

CONVERSION FACTORS

Multiply	By	To obtain
centimeter (mm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.62	mile
square kilometer (km ²)	0.39	square mile
square meter (m ²)	10.76	square foot
cubic meter (m ³)	35.3	cubic foot
meter per second (m/s)	3.28	foot per second
meter per second (m/s)	2.24	mile per hour
degree Celsius (°C)	°F=1.8 x °C+32	degree Fahrenheit (°F)

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Preliminary Volcano-Hazard Assessment for Akutan Volcano, East-Central Aleutian Islands, Alaska

By Christopher F. Waythomas, John A. Power, Donald H. Richter, and Robert G. McGimsey

SUMMARY OF VOLCANO HAZARDS AT AKUTAN VOLCANO

Akutan Volcano is a 1100-meter-high stratovolcano on Akutan Island in the east-central Aleutian Islands of southwestern Alaska. The volcano is located about 1238 kilometers southwest of Anchorage and about 56 kilometers east of Dutch Harbor/Unalaska. Eruptive activity has occurred at least 27 times since historical observations were recorded beginning in the late 1700's. Recent eruptions produced only small amounts of fine volcanic ash that fell primarily on the upper flanks of the volcano. Small amounts of ash fell on the Akutan Harbor area during eruptions in 1911, 1948, 1987, and 1989. Plumes of volcanic ash are the primary hazard associated with eruptions of Akutan Volcano and are a major hazard to all aircraft using the airfield at Dutch Harbor or approaching Akutan Island. Eruptions similar to historical Akutan eruptions should be anticipated in the future. Although unlikely, eruptions larger than those of historical time could generate significant amounts of volcanic ash, fallout, pyroclastic flows, and lahars that would be hazardous to life and property on all sectors of the volcano and other parts of the island, but especially in the major valleys that head on the volcano flanks. During a large eruption, an ash cloud could be produced that may be hazardous to aircraft using the airfield at Cold Bay and the airspace downwind from the volcano. In the event of a large eruption, volcanic ash fallout could be relatively thick over parts of Akutan Island and volcanic bombs could strike areas more than 10 kilometers from the volcano. The greatest volcano hazards in order of importance are:

- **Volcanic ash clouds**

Clouds of fine volcanic ash will drift away from the volcano with the wind. These ash clouds are a hazard to all aircraft downwind. Airborne volcanic ash can drift thousands of kilometers from its source volcano. Ash from the recent Akutan eruptions fell primarily on the volcano flanks and did not interfere with air travel.

- **Volcanic ash fallout**

Accumulations of several millimeters or more of fine ash were reported in the Akutan Harbor area in 1911, 1948, and 1989. Fine ash is a nuisance and may cause respiratory problems in some humans and animals. A thick ashfall can disrupt many human activities and may interfere with power generation, affect visibility, temporarily foul drinking-water supplies, and could damage electrical components and equipment. Resuspension of ash by wind could extend the unpleasant effects of ash fallout.

- **Pyroclastic flow and surge**

Hot material expelled from the volcano may travel rapidly down the volcano flanks as flows of volcanic debris called pyroclastic flows and surges. At Akutan Volcano, pyroclastic-flow deposits have not been found more than about 9 kilometers beyond the volcano and either did not develop or were restricted to the caldera during historical eruptions. Pyroclastic flow and surge pose little hazard except to people on the volcano's flanks.

- **Lahars, lahar-runout flows, and floods**

Hot volcanic debris that interacts with snow and ice can form fast-moving slurry-like flows of water, mud, rocks, and sand that flow down the volcano flanks into gullies and valleys. These flows are called lahars if they consist primarily of mud and rock debris, floods if they consist mostly of water, and lahar-runout flows if

THE ALASKA VOLCANO HAZARD ASSESSMENT SERIES

This report is part of a series of volcano hazard assessments being prepared by the Alaska Volcano Observatory. The reports are intended to describe the nature of volcanic hazards at Alaska volcanoes and show the extent of hazardous areas with maps, photographs, and other appropriate illustrations. The reports are preliminary and subject to revision as new data become available.

their composition is between that of floods and lahars. Lahars, lahar-runout flows, and floods may form during winter-spring eruptions of Akutan when snow on the volcano is abundant. Lahars, lahar-runout flows, and floods tend to follow streams and drainages, and may extend to the coastline. Lahars, lahar-runout flows, and floods pose no hazard except to people directly in the flow path. No structures are presently at risk from these flows.

- **Lava flow**

Streams of molten rock (lava) may extend a few kilometers from an active vent. Akutan lava flows move slowly, only a few tens of meters per hour, and pose little hazard to humans. Some lava flows may develop steep, blocky fronts and avalanching of blocks could be hazardous to someone close to or downhill from the flow front. In winter, lahars may develop ahead of a lava flow advancing over snow, ice, or both.

Other hazardous phenomena that may occur but are either uncommon, or not expected during typical eruptions of Akutan Volcano, or not directly related to volcanic activity include:

- **Debris avalanche**

A debris avalanche is a rapidly moving mass of solid or incoherent blocks, boulders, and gravel initiated by a large-scale failure of the volcano flank. Only a few debris avalanche deposits are known at Akutan Volcano and the possibility of a future debris avalanche is relatively remote.

- **Volcanic gases**

Most volcanoes emit gases in concentrations that can be harmful to humans. The frequently windy conditions at Akutan and a lack of closed depressions that could collect gases inhibit the buildup of volcanic gases. Thus, the hazard from volcanic gases is minimal, unless one is actually in or around a vent where fresh degassing magma is present.

- **Volcanic earthquakes**

Earthquakes are common at most active volcanoes. However, earthquake activity need not indicate an impending eruption, and many eruptions have occurred without precursory earthquake activity. If volcanic earthquakes at Akutan Volcano are large, frequent, or both, they could pose a hazard to people, equipment, buildings, and structures on the island.

- **Volcanic tsunamis**

During a significant eruption, large volumes of volcanic debris may rapidly enter the sea, volcanic explosions may occur, or sectors of the volcano may slide seaward creating impulse waves called volcanic tsunamis. Evidence for tsunami generation at Akutan Volcano has not been found and the hazard from volcanic tsunami is probably minimal. Tsunamis associated with large regional tectonic earthquakes pose a far greater hazard to Akutan Island.

- **Rockfall**

Steep bedrock cliffs along the coastline of Akutan Island are prone to failure and have generated large rockfall avalanches. Rock avalanches of any size could be hazardous to people or boats on or near the coastline. Small localized tsunamis could develop if large-volume rockfall avalanches enter the sea, especially in restricted coves, bays, and bights with deep water.

SUGGESTIONS FOR READING THIS REPORT

Readers who want a brief overview of the hazards at Akutan Volcano are encouraged to read the summary and consult plate 1 and the illustrations. Individual sections of this report provide a slightly more comprehensive overview of the various hazards at Akutan Volcano. A glossary of geologic terms is included and a term defined in the glossary is italicized at its first appearance in the text. Additional information about Akutan Volcano can be obtained by consulting the references cited in the text, or by consulting the AVO home page on the worldwide web (www.avo.alaska.edu).

INTRODUCTION

In March 1996, a brief period of intense seismic activity heralded the possibility of renewed eruptive activity at Akutan Volcano, one of the most frequently active volcanoes in the Aleutian volcanic arc (fig. 1; Miller and others, in prep.). During the seismic crisis, it was not possible to provide a comprehensive assessment of potential volcano hazards because only preliminary information about the geology and eruptive history of the volcano was known. Fortunately, the March 1996 *seismic swarm* passed without an eruption; however, the high frequency of historical eruptions at Akutan Volcano indicates that future eruptions are likely. In order to prepare for future eruptions of the volcano and to better understand the possible risks, a study of the geology, eruptive products, and associated hazards of Akutan Volcano was undertaken during July and August 1996.

Acknowledgments

It would have been difficult to conduct field investigations on Akutan Island without the generous support of the Akutan City Corporation and the city mayor Mr. Joseph Bereskin. The Aleutian East School District is gratefully acknowledged for providing us access to the Akutan School building. The Trident Seafood Company of Seattle, Wash. helped with numerous logistic details as did several members of the Akutan village community. Rod and Leslie Rozier shared their knowledge of the island and were extremely valuable contacts during the March 1996 seismic crisis. We thank C.A. Neal, R.B. Moore, and T.E.C. Keith for review comments.

Purpose and Scope

This report summarizes the principal volcano hazards associated with eruptions of Akutan Volcano. Hazardous volcanic phenom-

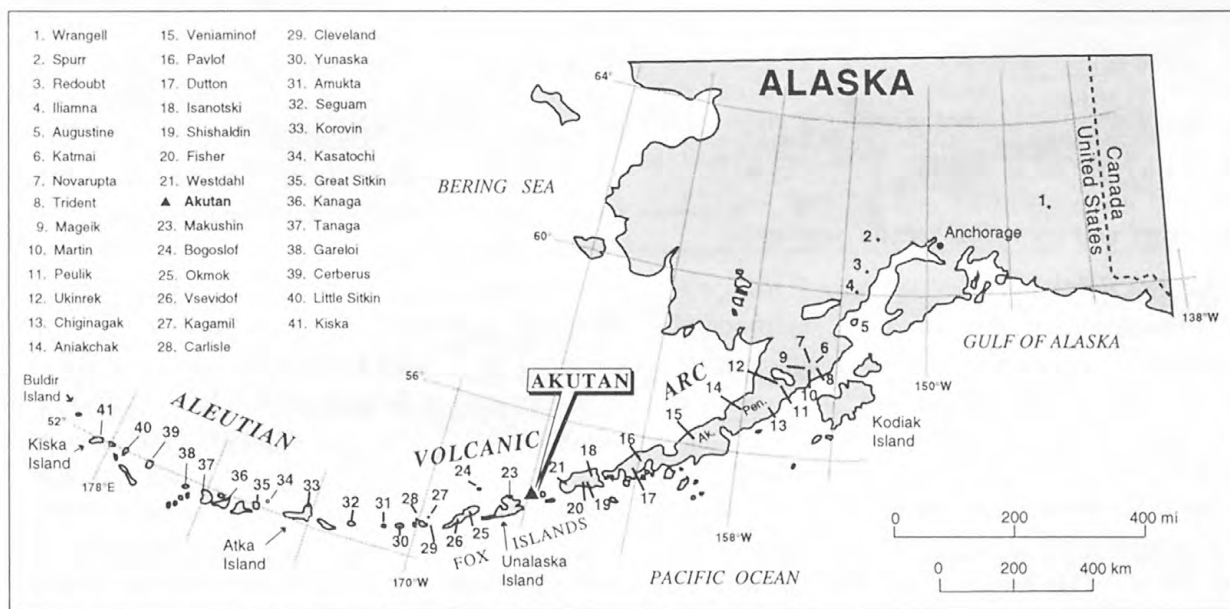


Figure 1. Location of Akutan Volcano and other volcanoes in the Aleutian Arc. All of these volcanoes have exhibited some kind of volcanic activity in the last 200 years.

ena that occur on the volcano as well as distal effects of eruptions are described. A discussion of volcano-seismic activity also is included to explain the implications of the March 1996 seismic crisis. The present status of monitoring efforts to detect volcanic unrest and the procedure for eruption notification and dissemination of information also are presented. A series of maps and illustrations that indicate hazard zone boundaries are included. A glossary of geologic terms is at the end of the report. Terms defined in the glossary are italicized at their first appearance in the text. A summary map showing all known volcanic hazards on Akutan Island (plate 1) is included in the pocket at the back of the report.

PHYSICAL SETTING

Akutan Island is located in the east-central Aleutian Islands and is part of the Fox Islands group (165° 46' west longitude, 54° 08' north latitude; fig. 1). The City of Akutan is about 56 kilometers east of Dutch Harbor and Unalaska and about 1238 kilometers southwest of Anchorage. More than 400 people live in the City of Akutan, but the majority of these people are transient employees at a commercial fish-processing plant. Year-round residents are involved with subsistence hunting and fishing and some are locally employed.

Akutan Volcano is a cone-shaped, low-profile *stratovolcano* composed of interbedded lava flows, *volcaniclastic* debris, and *tephra* (fig. 2). The summit of the volcano is defined by a circular crater or *caldera* about 2 kilometers in diameter and 60 to 365 meters deep (fig. 3). At least three lakes are inside the caldera, all of which were ice-covered when visited in July 1996. The largest lake has an area of about 1.5 square kilometers. Perennial snowfields, ice cliffs, and small glaciers also are present within the caldera. Topographic maps of the volcano show small valley glaciers extending from the crater rim; however, no

such glaciers were observed nor did we note any evidence of recent melting or ice retreat during our observations of the summit area in 1996. The caldera is breached on the northeast side (fig. 2) and recent lava flows and *lahar* deposits extend from this area downvalley. There are no other breaks in the caldera rim. Several large glacial valleys head on the lower flanks of the volcano (fig. 3). These valleys have been partially filled with volcanic deposits, especially in their upstream reaches.

An active intracaldera cinder cone about 200 meters high and about 1 kilometer in diameter occupies the northeastern portion of the caldera and has been the site of all historical eruptive activity (fig. 2; Simkin and Siebert, 1994; Byers and Barth, 1953; Finch, 1935). Intermittent vigorous steaming from three *vents* at the summit of the cone was observed in July 1996.

PREHISTORIC ERUPTIVE HISTORY

Prior to our studies in 1996, limited information was available about prehistoric eruptions of Akutan Volcano. In 1948, reconnaissance-level geologic mapping and observations were made by Byers and Barth (1953), who commented on the age, characteristics, and significance of volcanic rocks and deposits on Akutan Island. Among other key observations, they identified an older crater, partially truncated by the present summit caldera (fig. 3), and made a map of the caldera as it appeared in August 1948. The existence of unconsolidated volcanic deposits of *Holocene* age was briefly reported by Motyka and Nye (1988) and Reeder (1983), but no systematic study of such deposits had been undertaken. The following is a preliminary outline of the prehistoric eruptive history, based on geologic mapping, and analysis and dating of volcanic rocks and unconsolidated deposits on Akutan Island (fig. 4; Richter and others, 1998; Waythomas, in prep.).

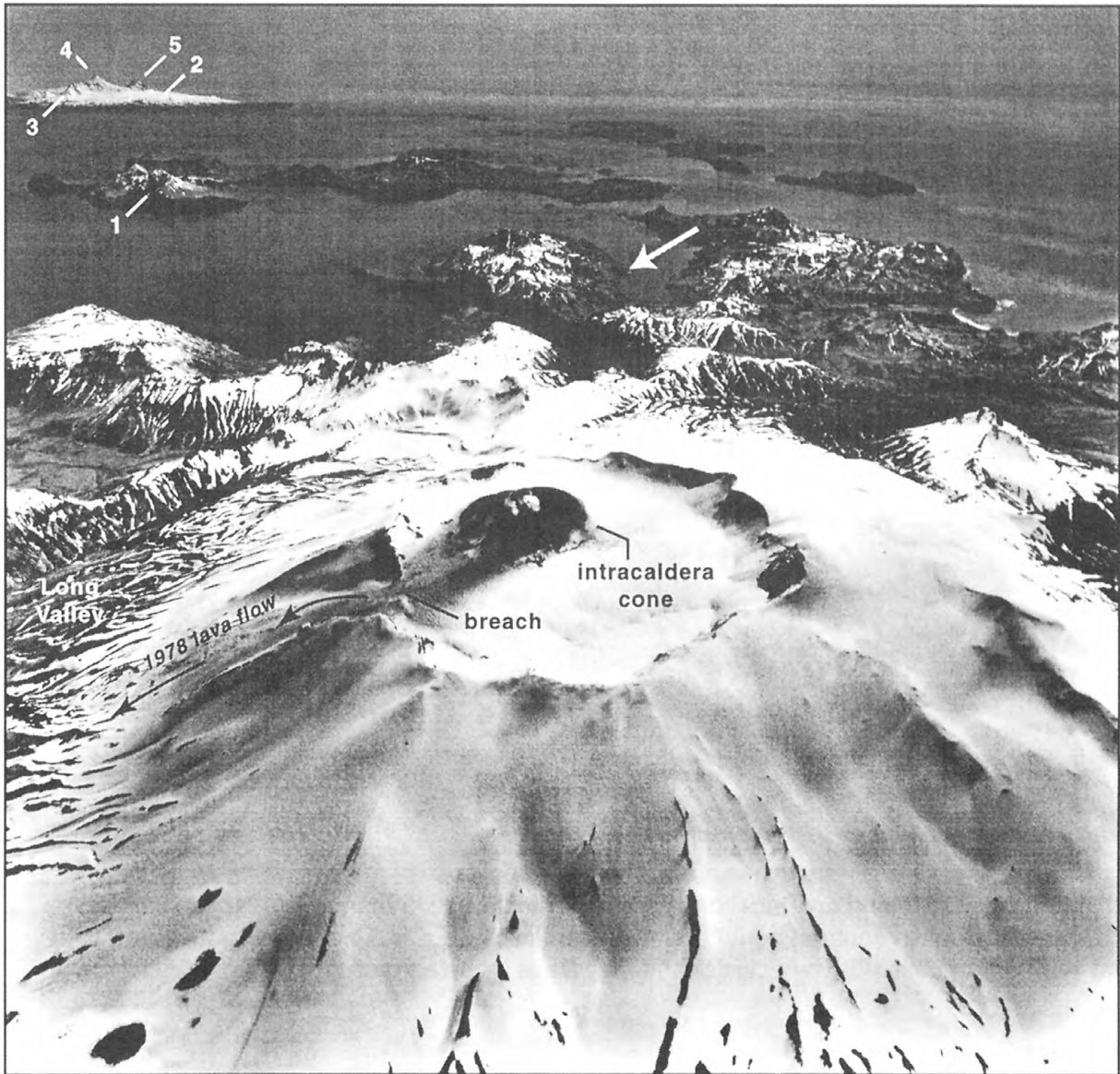


Figure 2. Aerial view of Akutan Volcano, June 1983; view is to the east. Arrow locates City of Akutan. Small steam plume is visible at summit of intracaldera cone. Dark area around intracaldera cone is ashfall from 1983 eruption. Also indicated is flow path of 1978 lava flow and location of Long Valley. Volcanoes in background are (1) Gilbert, (2) Westdahl, (3) Pogromni, (4) Shishaldin, and (5) Isanotski. Photograph by North Pacific Aerial Surveys (now called Aeromap, Inc.).

Lava flows and volcaniclastic deposits from both the modern Akutan stratocone and an ancestral cone make up most of the western part of Akutan Island. The eastern part of the island is made up of older volcanic rocks that are about 1.5 to 3.3 million years old (Richter

and others, 1998). The volcanic rocks on the east side of the island were probably erupted from an ancestral Akutan Volcano and possibly from volcanic centers offshore from the present island.

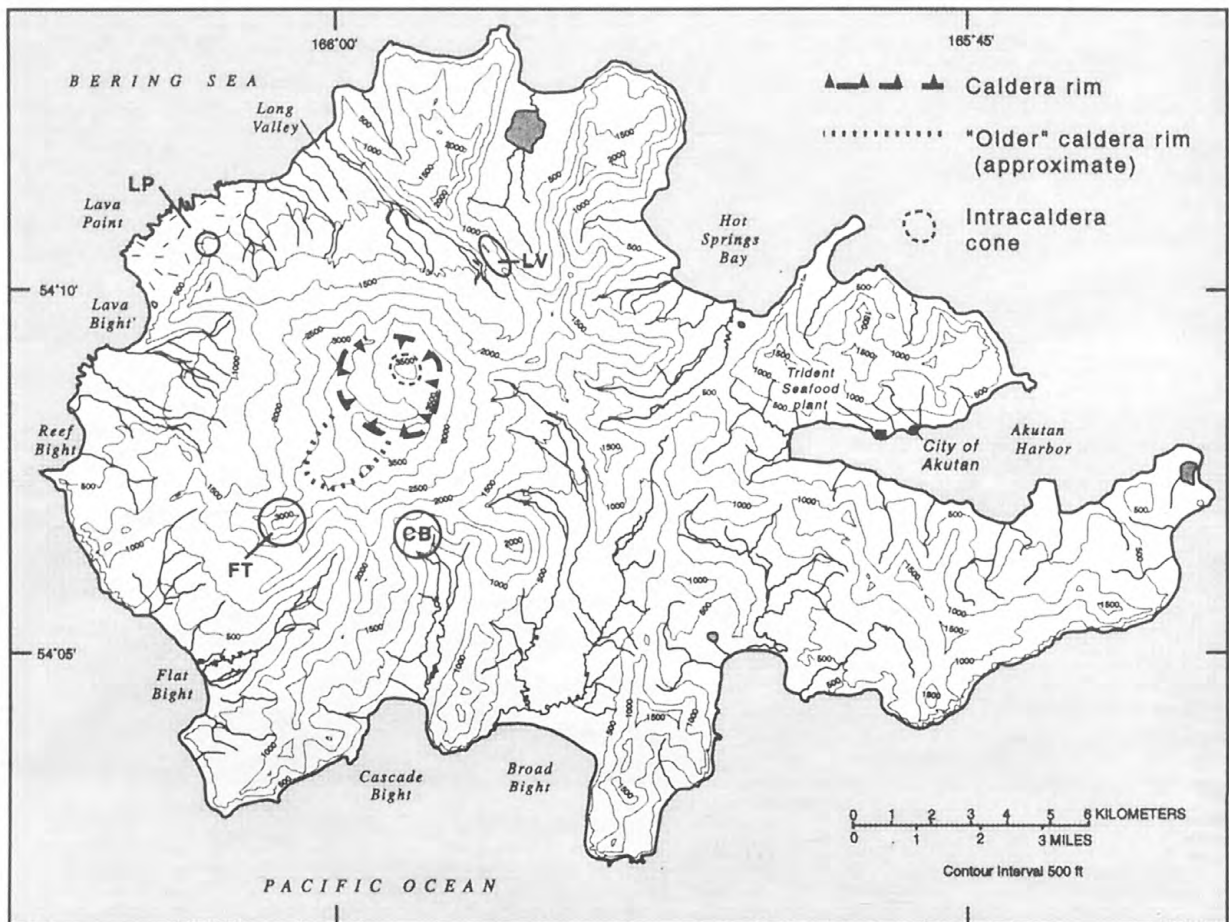


Figure 3. Akutan Island and location of place names mentioned in text. Also indicated are satellite eruptive centers, peripheral to Akutan caldera. CB, Cascade Bight center; FT, Flat Top center; LP, Lava Point center and lava flows (stippled pattern); LV, Long Valley center.

About 2 kilometers southwest of the summit caldera, remnants of an older caldera wall (fig. 3) protrude above a surficial mantle of *pyroclastic flow*, lahar, and tephra deposits prevalent on the upper flanks of the volcano (fig. 3). The age of the eruption that formed the older caldera is not known but is possibly of late *Pleistocene* or early *Holocene* age. Recently obtained *radiometric ages* on lava flows indicate that the modern Akutan stratocone and older caldera were constructed over the past 500,000 years (Richter and others, 1998).

At least four additional volcanic centers lie beyond the modern Akutan cone (fig. 3). The youngest center produced lava flows and a cinder cone in the Lava Point area (fig. 3). The age of the Lava Point flows is unknown, but the flows exhibit fresh-appearing rubbly (*aa*) surface morphology and the cinder cone shows little evidence of post-eruptive weathering or slope modification, which indicate a young age. Historical reports of volcanic activity at Lava Point are sketchy and ambiguous (Byers and Barth, 1953). Another eruptive center at the head of Cascade Bight (fig. 3), near the

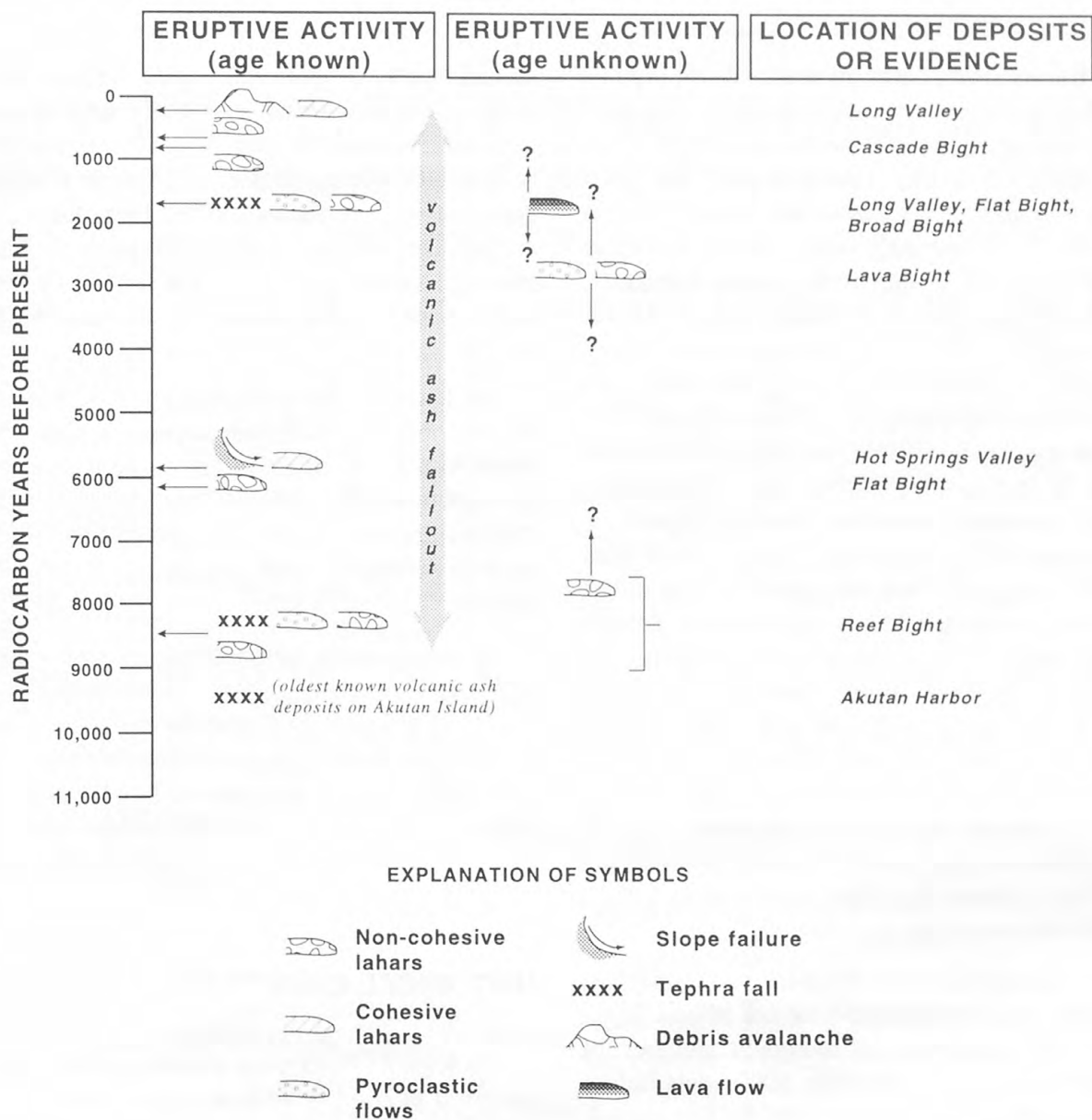


Figure 4. Chronology of known eruption-related events of Holocene age at Akutan Volcano as determined from study of deposits in the immediate vicinity of the volcano.

base of the modern Akutan cone, includes at least one lava flow, remnants of a volcanic vent, and numerous *dikes*. The lava flow is about 15,000 years old (Richter and others, 1998). The third and largest center beyond the modern Akutan cone is the Flat Top center, located southwest of the summit caldera (fig. 3). This center is made up of a series of lava

flows about 25,000 years old, remnants of a volcanic vent, and a radial dike complex. The fourth oldest of the peripheral centers is the Long Valley center, located north of the summit caldera (fig. 3). This center consists of a series of elongate *lava domes* or shallow intrusions that are about 58,000 years old (Richter and others, 1998).

Radiocarbon dates on peat and soil organic matter from bank exposures in the Akutan Harbor area indicate that volcanic *ash* began accumulating on Akutan Island about 9500 years ago. Some of the volcanic ash layers found in this area are distinctly light colored and these ash layers could be from distant volcanoes, probably west of Akutan Island (fig. 1). Volcanic ash from Akutan Volcano is typically dark brown or black, and ash of this color first appears in the stratigraphic record about 8500 years ago at Reef Bight, and about 6100 years ago in the Akutan Harbor area. The oldest dated volcanic mudflow (lahar) deposit is exposed at Reef Bight (fig. 3) and is more than 8500 years old. This lahar deposit is the oldest known evidence of Holocene eruptive activity at Akutan Volcano. A younger sequence of deposits at Reef Bight consisting of coarse black ash, pyroclastic flow, and lahar deposits, is evidence for a second eruption or series of eruptions that began soon after 8500 years before present and may be correlative with the formation of the older caldera. A third, but undated lahar at Reef Bight documents a third Holocene eruption.

At least three lahar deposits and numerous, coarse-grained, black ash layers in Flat Bight (fig. 3) document an unknown number of minor eruptions from about 6000 years before present to about 1400 years before present.

A slightly clay-rich lahar in Hot Springs Valley (fig. 3) probably formed from a minor collapse of the volcano flank, perhaps in the area of an active *fumarole* field in the upper part of the valley. No obvious *scarp* is present. Although not exposed at the coast, this lahar probably reached Hot Springs Bay about 6000 years ago.

A widespread, 1-to-2-meter-thick, coarse-grained volcanic ash deposit (tephra) and associated pyroclastic-flow and lahar deposits in Long Valley and Broad Bight (fig. 3) are correlated with the eruption that formed the present caldera about 1600 years ago. This eruption

spread black, *scoria*-rich, *lapilli* tephra over most of Akutan Island, especially east of the volcano. Volcanic bombs, 7 to 10 centimeters in diameter, were found in the Akutan Harbor area and were probably ejected from the vent during the caldera-forming eruption. The caldera-forming eruption is the largest known eruption of Akutan Volcano in the past 8000 years.

At least one lahar deposit and a sequence of thin, black, sandy ash layers in Cascade Bight (fig. 3) document minor eruptive activity directed down this valley 470 to 600 years ago. One or more of the lahars found in Flat Bight may be correlative with this period of eruptive activity.

A conspicuous tan-colored, slightly clay-rich lahar in Long Valley, containing large blocks of volcanic rock, may have formed during a minor flank collapse of the caldera rim. This lahar deposit is undated, but because it lacks a mantle of volcanic ash and has only a thin soil developed on it, it could be only a few hundred years old.

HISTORICAL ERUPTIONS

At least 27 individual volcanic events have occurred at Akutan Volcano since about 1790 (fig. 5; Simkin and Siebert, 1994; Miller and others, in prep.) and the most recent eruption occurred in 1992 (McGimsey and others, 1995). Additional events likely have gone unreported because of the remote location and frequent poor visibility around Akutan Island. Recent eruptions produced small amounts of volcanic ash that formed diffuse clouds rising to altitudes of about 2000 meters or less (fig. 6) and ash fallout was mainly in the immediate area of the intracaldera cone (fig. 2). Many historical eruptions have been *strombolian* style eruptions characterized by a series of pulse-like explosions or bursts, sometimes audible in Akutan village (Byers and Barth,

Year A.D.	Type of activity	Comments
1790	"Smoking"	<i>Strombolian eruption:</i> Small to moderate size eruptions associated with low-level emission of ash, eruption of lava, and occasional small pyroclastic flows. Ash plumes generally rise to less than about 5 kilometers above the vent. Ash usually falls only in area around active vent, but occasionally may fall over significant parts of Akutan Island.
1828	"Smoking"	
1838	"Smoking"	
1845	"Smoking"	
March, 1848	Strombolian eruption	
1852	Strombolian eruption	
1862	"Smoking"	
1865	"Glowing"	
1867	"Smoke", fire, and great noises	
1883	Steam and ash, strombolian eruption?	
1887	Lava flow	<i>Lava flow:</i> Sluggish, slow-moving streams of molten rock. Typically confined to the caldera floor, some have flowed into Long Valley via the breach in the caldera rim.
1892	Strombolian eruption	
1896	"Glowing"	
1907	Continuously active	
1908	Lava flow	
1911	Pyroclastic eruption, ashfall over Akutan Harbor	
1912	"Smoking"	
1928	"Smoking and flaming"	
Dec. (May?), 1929	Strombolian eruption, lava flow, lahar	
May-Aug., 1931	Dark "smoke" and ash, strombolian eruption?	<i>Lahar:</i> Relatively mobile flows of water and rock debris. Can form downvalley from lava flows and pyroclastic flows.
Dec. 1946-Jan., 1947	Strombolian eruption, lava flow	
April 29-Aug.? 1948	Strombolian eruption, ashfall over Akutan Harbor	
Oct. 1951	Strombolian eruption?	
March-May, 1973	Strombolian eruption	
Feb. 11, 1974	Strombolian eruption	
Oct. 15, 1976-May, 1977	Strombolian eruption	
Sept.-Oct., 1978	Strombolian eruption, lava flow	
July 8, 1980	Steam and ash, strombolian eruption?	
June, 1983?	Strombolian eruption?	<i>Smoking:</i> Probably refers to low-level emission of dark ash, steam, or both.
Jan.-March, 1987	Steam and ash, strombolian eruption	
June, 1987	Strombolian eruption	
March-April, 1988	Strombolian eruption, ashfall over Akutan Harbor	
Aug., 1988-Feb., 1989	Minor steam and ash emissions	
March, 1989	Strombolian eruption, ashfall over Akutan Harbor	
Sept., 1990	Minor steam and ash emissions	
Sept.-Oct., 1991	Intermittent steam and ash emission	
March-May, 1992	Strombolian eruption, ashfall over Akutan Harbor	<i>Glowing:</i> Probably refers to low-level lava fountaining or ejection of incandescent blocks.

Figure 5. Summary of known historical eruptive activity at Akutan Volcano (modified from Miller and others, in prep.; Simkin and Siebert, 1994; and Byers and Barth, 1953).



Figure 6. Ash plume from the intracaldera cone of Akutan Volcano during the 1976-77 eruption. Ash plumes like this one are typical of most historical eruptions of Akutan Volcano. Ash fallout is usually confined to the caldera and upper flanks of the volcano. Photograph by USGS.

1953). Such eruptions are commonly accompanied by lava flows and rapid ejection of glowing bombs and blocks. Eruptions in 1978, 1974, 1947, and 1929 produced lava flows that spread over most of the caldera floor; in 1978 and 1929, lava flowed part way down Long Valley through a breach in the caldera rim (fig. 2). A small lahar associated with the 1929 lava flow partially inundated valleys northwest of the caldera and may have flowed to the sea.

During eruptions in 1911, 1948, 1987, and 1989, ash fell over the Akutan Harbor area and on the City of Akutan, about 10 kilometers east of the volcano (Finch, 1935; Byers and Barth, 1953; Miller and others, in prep.). Details about other historical eruptions are limited and observations amount to brief reports of the volcano steaming, “smoking”, or emitting “puffs” of ash (fig. 5; Simkin and Siebert, 1994; Byers and Barth, 1953; Finch, 1935).

MARCH 1996 VOLCANO-SEISMIC ACTIVITY

During March 1996, Akutan Island was shaken by two energetic earthquake swarms that were strongly felt in the City of Akutan. The first swarm began early on March 10 and lasted more than 19 hours. A second strong swarm began late in the afternoon of March 13. Residents of Akutan felt the ground shaking almost continuously during both of these swarms. The shaking was strong enough to damage water pipes, crack plaster in buildings, and displace lightweight items on shelves. On March 14, the shaking was violent enough to ring the bell in the Russian Orthodox Church. In response to the earthquake swarms, the Akutan school was closed for two days and several families and several dozen workers from the nearby seafood processing plant left

the island. Residents of Akutan continued to feel occasional earthquakes for several months following the March 1996 swarms.

The closest operating seismic station at the time of the March 1996 earthquake swarms was at Dutton Volcano, near the City of King Cove, some 260 kilometers east. This station was able to record only a few hundred of the largest earthquakes out of the thousands that occurred. The March 11 swarm was composed of more than 80 earthquakes greater than magnitude 3.0 and the largest was 5.2. The largest earthquake during the March 13 swarm was a magnitude 5.3 and during this swarm there were more than 120 magnitude 3.0 earthquakes.

In response to the March 1996 earthquake activity, the Alaska Volcano Observatory (AVO) established an emergency network of four seismic stations on Akutan Island. Using this temporary network of stations, several thousand local earthquakes were recorded between March 18 and August 1996. The distribution of locatable earthquakes recorded by the temporary network forms a prominent cluster at the head of Akutan Harbor (fig. 7). Because there were no seismic stations on the west side of the island it was difficult to detect and locate earthquakes in this area and many shallow earthquakes probably occurred between the volcano summit and Lava Point (fig. 7). Earthquake activity at the head of

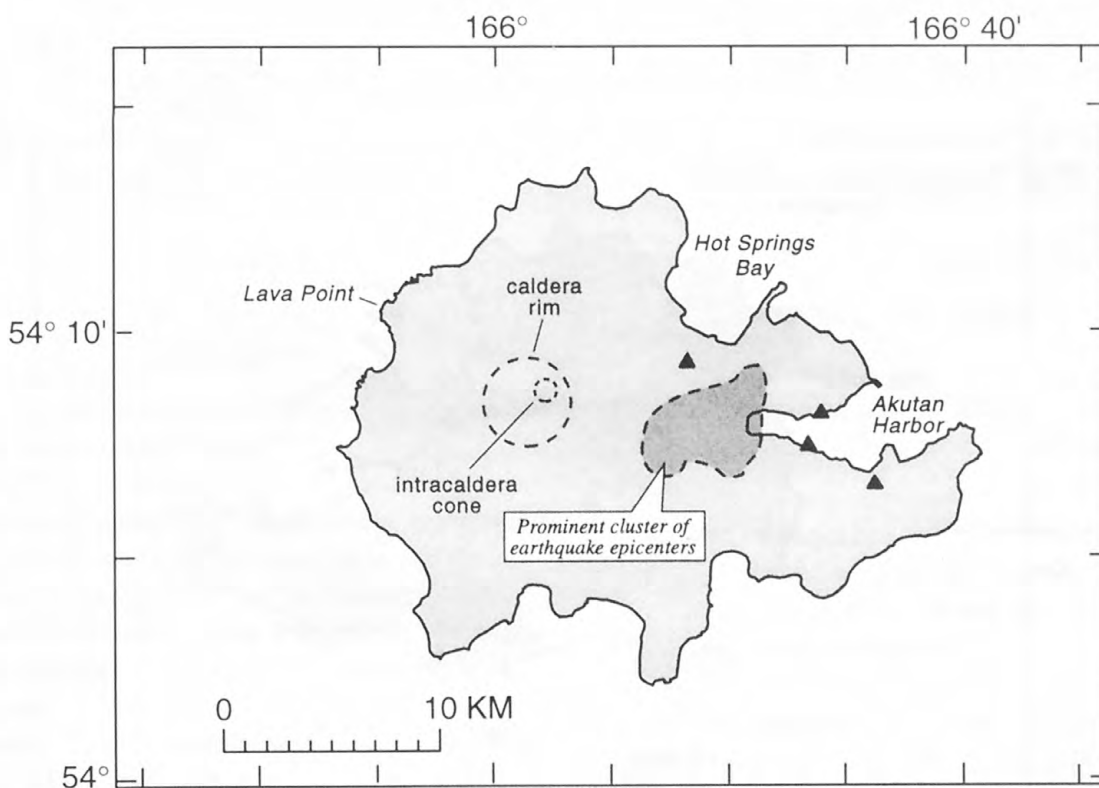


Figure 7. Akutan Island showing cluster of earthquake epicenters detected from March through August 1996. Solid triangles show locations of temporary seismic stations installed in March 1996. The majority of earthquakes recorded by the temporary network occurred in the shaded area.

Akutan Harbor declined from April through July of 1996.

During July 1996, AVO deployed a network of six permanent seismic stations on the island. The installation of these stations improved AVO's ability to detect and locate earthquakes on all quadrants of the volcano. From July 1996 to March 1998, most earthquakes occurred on the northwest side of the island near Lava Point and under the volcano summit (fig. 8).

Numerous fresh, linear ground cracks were discovered in three areas on Akutan Island during field studies in the summer of 1996 (fig. 9). Ground breaks and cracks likely formed during the strong seismic swarms in March. The ground cracks extend discontinuously from

near Lava Point to the southeast side of the island (fig. 10). The most extensive ground cracks are between Lava Point and the volcano summit. In this area, the cracks are confined to a zone 300 to 500 meters wide and 3 kilometers long. Vertical displacement of the ground surface along individual cracks is 30 to 80 centimeters. The ground cracks probably formed as magma moved toward the surface between the two most recently active vents on the volcano. Ground cracks on the southeast side of the island occur on known faults, indicating that they probably formed in response to motion along these preexisting structures. No ground cracks were found at the head of Akutan Harbor even though this was an area where numerous earthquakes occurred from March through July, 1996.

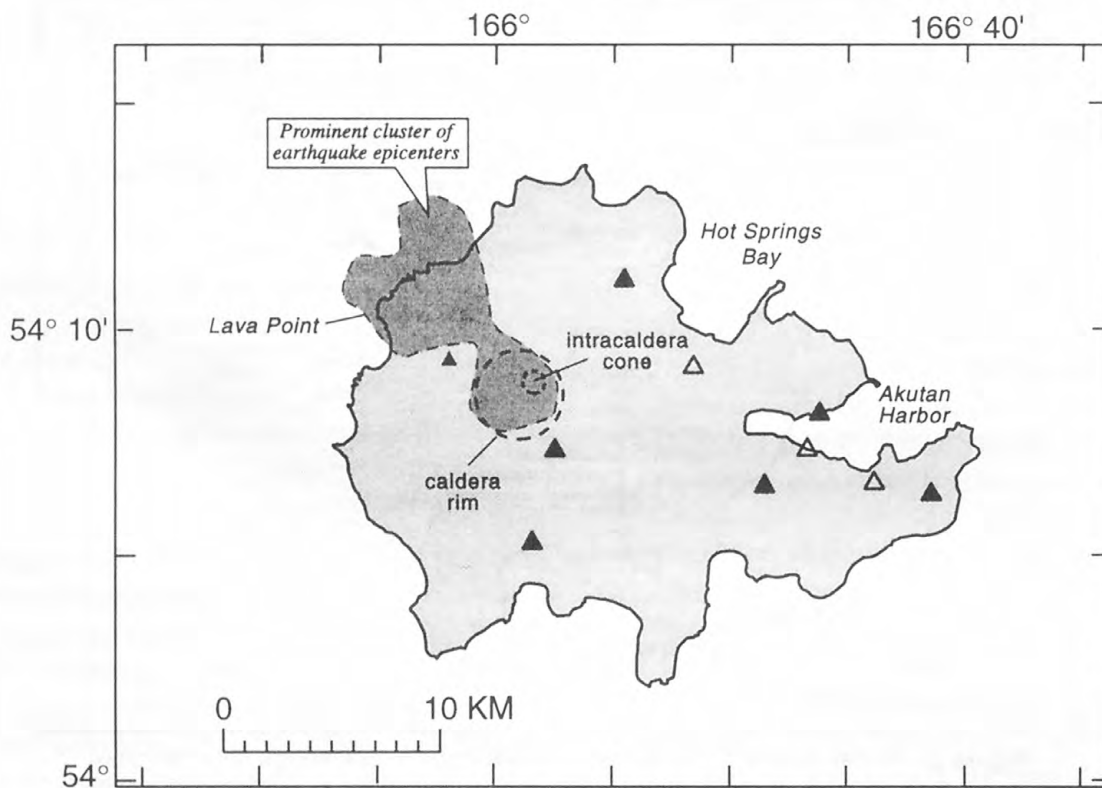


Figure 8. Akutan Island showing cluster of earthquake epicenters detected from July 1996 through March 1998. Solid triangles show locations of permanent seismic stations; open triangles show locations of temporary seismic stations removed in August 1996. The majority of earthquakes recorded by the seismic network occurred in the shaded area.



Figure 9. Ground cracks on northwest flank of Akutan Volcano. Ground breaks like this were found in a zone about 300 to 500 meters wide and about 3000 meters long on the northwest flank of the volcano. Surficial deposits offset by the cracks consist of coarse tephra and colluvium. See figure 10 for location.

The prominent cluster of earthquakes at the head of Akutan Harbor (fig. 7) was likely caused by the emplacement of magma beneath Akutan Volcano. The most probable location of this magma is 3-5 kilometers below the area of extensive ground cracks between the volcano summit and Lava Point (fig. 10). The large number of earthquakes that occurred at the head of Akutan Harbor does not indicate shallow magma in this area and the development of a new vent here is highly unlikely. When magma moves toward the surface it often initiates earthquakes along faults and zones of weakness in the bedrock. A system of deep faults probably exists beneath the head of

Akutan Harbor and motion along these faults (i.e., earthquakes) could have been caused by moving magma.

Strong earthquakes were reported during eruptive activity in 1947 and 1948 (Alaska Sportsman, 1949) and volcano-related earthquakes on Akutan Island should be expected in the future. Volcanic earthquakes may be a signal that an eruption is likely or imminent, or that magma is simply moving at depths well below the surface. Although the March 1996 earthquake swarm passed without eruptive activity, this may occur again in the future and an eruption could occur with or without felt earthquakes.

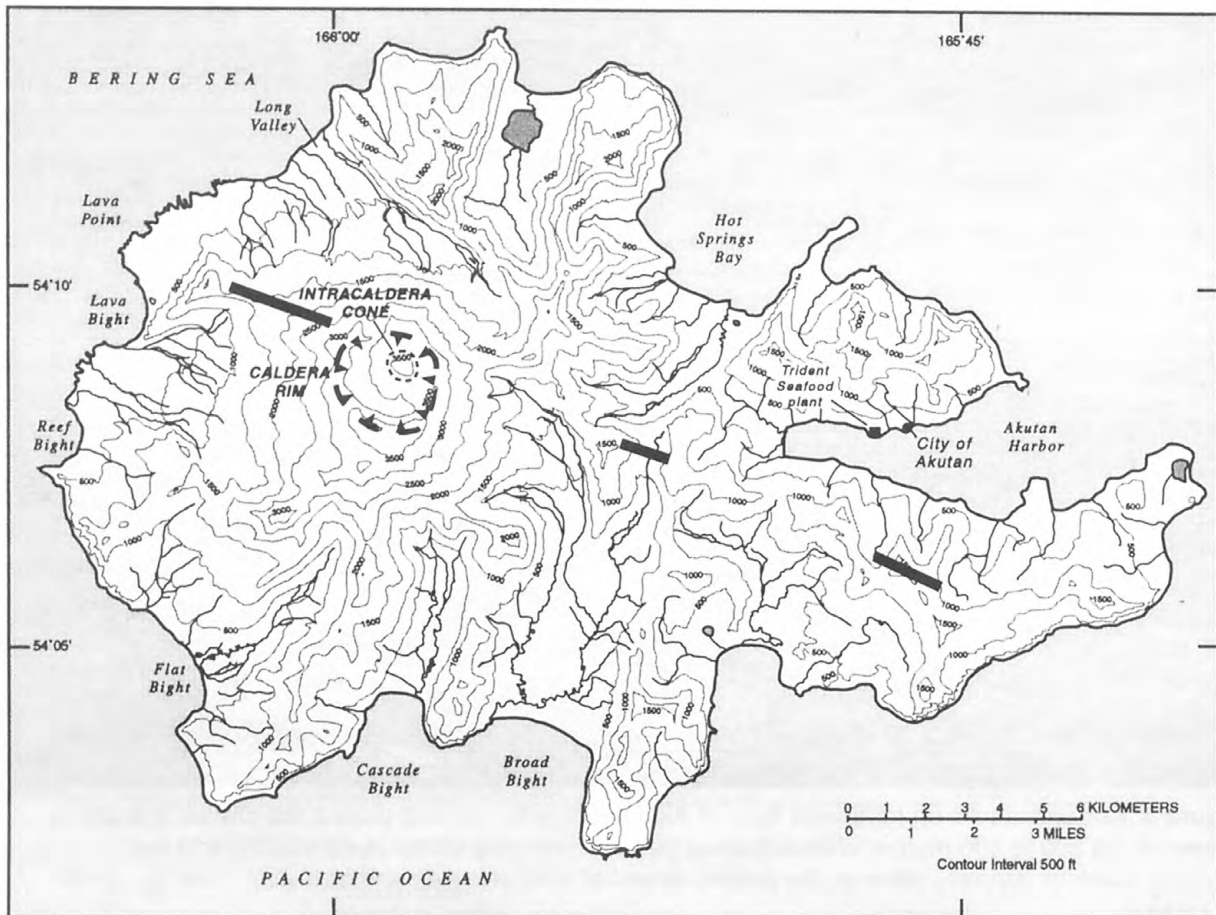


Figure 10. Location of ground cracks on Akutan Island. Bold dark lines indicate location of ground cracks and breaks observed in 1996. The ground cracks presumably formed during the period of intense earthquake swarms in March 1996. The most extensive cracks are on the northwestern side of the volcano between Lava Point and the caldera (see figure 9). In this area, numerous individual cracks are present in a zone 300 to 500 meters wide and about 3000 meters long. Cracks on the eastern side of the island are aligned with preexisting faults.

HAZARDOUS PHENOMENA AT AKUTAN VOLCANO

A volcano hazard (fig. 11) is any volcanic phenomenon that is potentially threatening to life or property. Hazards associated with volcanic eruptions at Akutan Volcano will likely affect only Akutan Island, the immediate coastal waters, and the airspace above or downwind of the volcano. The extent of a particular hazard is in part related to the scale of the eruption. During a large eruption, some volcanic phenomena will affect areas well beyond the volcano, whereas during smaller,

more typical eruptions, the same phenomena may only affect areas in the immediate vicinity of the volcano.

Recently completed geologic studies of Akutan Island (Richter and others, 1998; Waythomas, in prep.) provide a basis for evaluation of various volcanic phenomena and associated hazards. Most hazardous volcanic phenomena are limited to Akutan Island. Only volcanic-ash clouds, *fallout*, and *pyroclastic surge* and flow could affect areas beyond Akutan Island. Large rockfalls from steep coastlines of volcanic bedrock may be a local hazard to boats or people on or close to the shoreline.

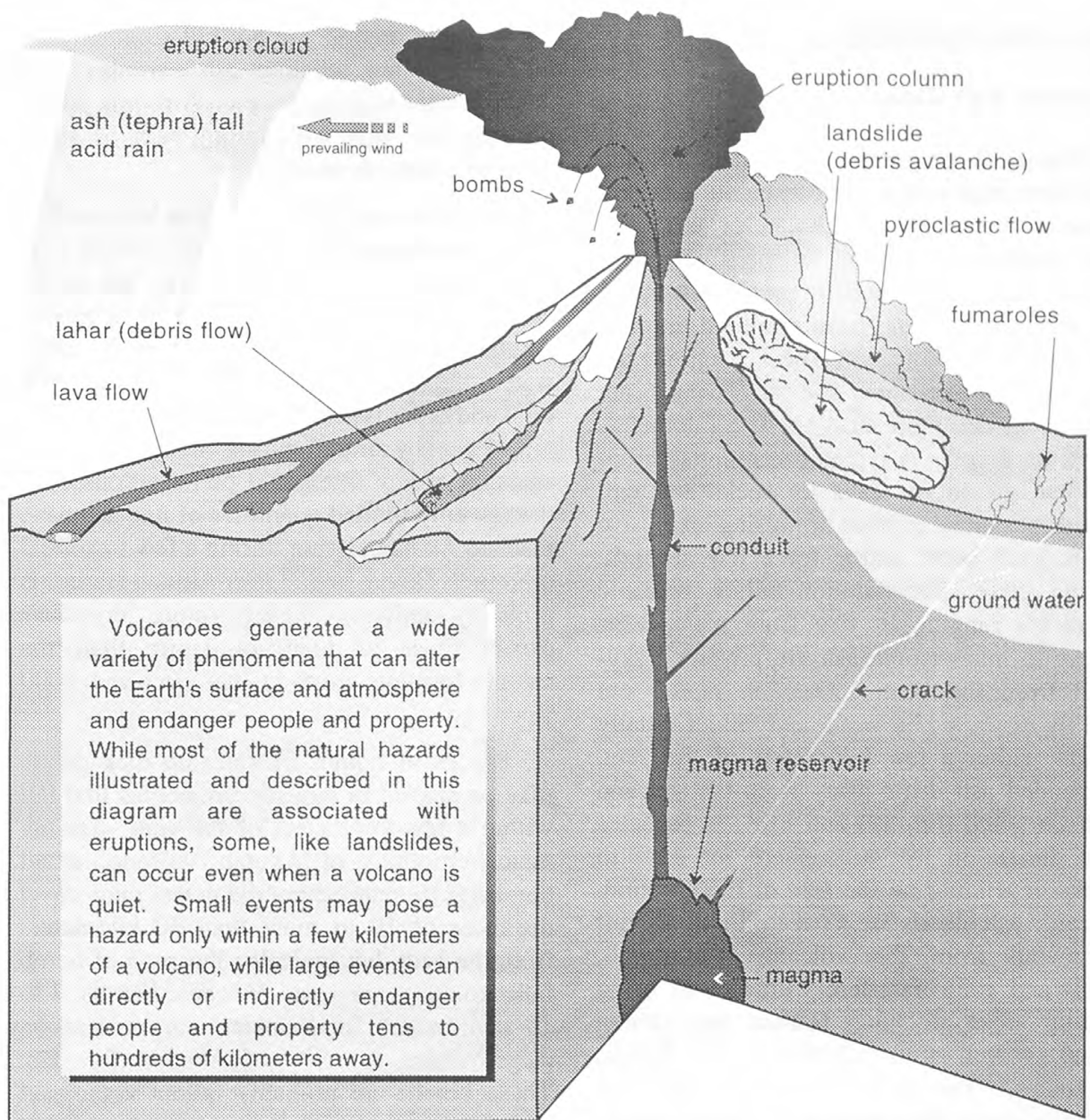


Figure 11. Simplified sketch of a stratovolcano and associated hazardous phenomena (from Myers and others, 1997).

Areas of Akutan Island at risk during future eruptions are depicted in map form on illustrations that follow and on plate 1. For most volcanic phenomena, hazard-zone boundaries are based on the approximate extent of volcanic deposits identified during our field studies in 1996. Although hazard zones are shown as distinct finite areas, the degree of hazard does not necessarily diminish

at the hazard-zone boundary. Eruptions larger than expected or documented in the geologic record could occur but the probability of this happening is low. Thus, we are reasonably confident that the hazardous areas shown on plate 1 and the illustrations are accurate, but caution residents and visitors that some degree of hazard exists beyond the indicated boundaries.

VOLCANO HAZARDS

Volcanic Ash Clouds

Historical eruptions of Akutan Volcano have been relatively small compared with pre-historical eruptions of Akutan or eruptions from Alaskan volcanoes in the Cook Inlet region (Miller and others, in prep.). Strombolian eruptions are the most common eruptive style at Akutan Volcano. These eruptions are only mildly explosive and ash clouds are unlikely to rise more than about 5 kilometers above sea level. A typical strombolian eruption can go on for days to weeks and will include sustained periods of pulsing, explosive bursts, each burst lasting for a few seconds. During these short-duration bursts, volcanic fragments ranging in size from meter-sized blocks to microscopic ash are propelled skyward from the vent. *Eruption clouds* are quickly dispersed by wind, and fallout usually occurs within a few kilometers of the vent. Suspended ash drifts away from the volcano with the wind (fig. 12) and fine ash particles may remain in the atmosphere for days to weeks depending on the size of the eruption. Volcanic ash clouds are a hazard to all aircraft downwind from the volcano (Casadevall, 1994) and could interfere with aircraft using landing areas at Dutch Harbor and Akutan Island, as well as aircraft flying north Pacific air routes. During sustained eruptions that produce significant quantities of ash, drifting ash clouds could disrupt air travel all along the central Aleutian Islands and Alaska Peninsula.

Volcanic Ash Fallout and Volcanic Bombs

As clouds of fine volcanic ash drift from the volcano, a steady rain or fallout of ash usually occurs. Volcanic ash is one of the most troublesome and hazardous products of explosive volcanism. Because ash may be transported long distances, it has the potential to affect areas many hundreds of kilometers from

the volcano. People are not killed directly by falling ash, but inhaling ash particles is a health hazard to some people. Airborne volcanic ash may mix with falling rain or snow forming a rain of muddy ash.

Ash from eruptions of Akutan Volcano has fallen on all parts of the island. During sustained explosive eruptions, falling ash could create a public health concern for residents of Akutan and could temporarily affect drinking-water supplies, electronic equipment, generators, and other types of machinery. Approaching Akutan by aircraft during an ash-producing eruption of any size could be hazardous even though only limited quantities of fine ash have reached Akutan Harbor during a few historical eruptions. Heavy ashfall over Akutan Harbor is probably unlikely during future eruptions except those as large or larger than the caldera-forming eruption that occurred 1600 years ago.

Blocks or bombs of volcanic rock debris may be ejected as ballistic projectiles that fall within a few kilometers of the vent. During major eruptions of Akutan Volcano, small bombs (<10 centimeters diameter) may travel distances of 10 to more than 30 kilometers from the vent, but typically, the zone of bomb fallout is near the vent. Volcanic bombs, 7 to 10 centimeters in diameter, are present on ridges above the City of Akutan (fig. 13). These bombs are probably fallout associated with the caldera-forming eruption that occurred about 1600 years ago. Should another large caldera-forming eruption occur in the future, bomb fallout would pose a serious hazard to people and structures in the Akutan Harbor area, and severe injury or death could occur if a person were struck by a falling bomb. People and low-flying aircraft would be at greatest risk from bomb fallout if they are within a few kilometers of the vent, and the impact of falling bombs could pierce roofs, windows, building walls, and may damage machinery and boats.

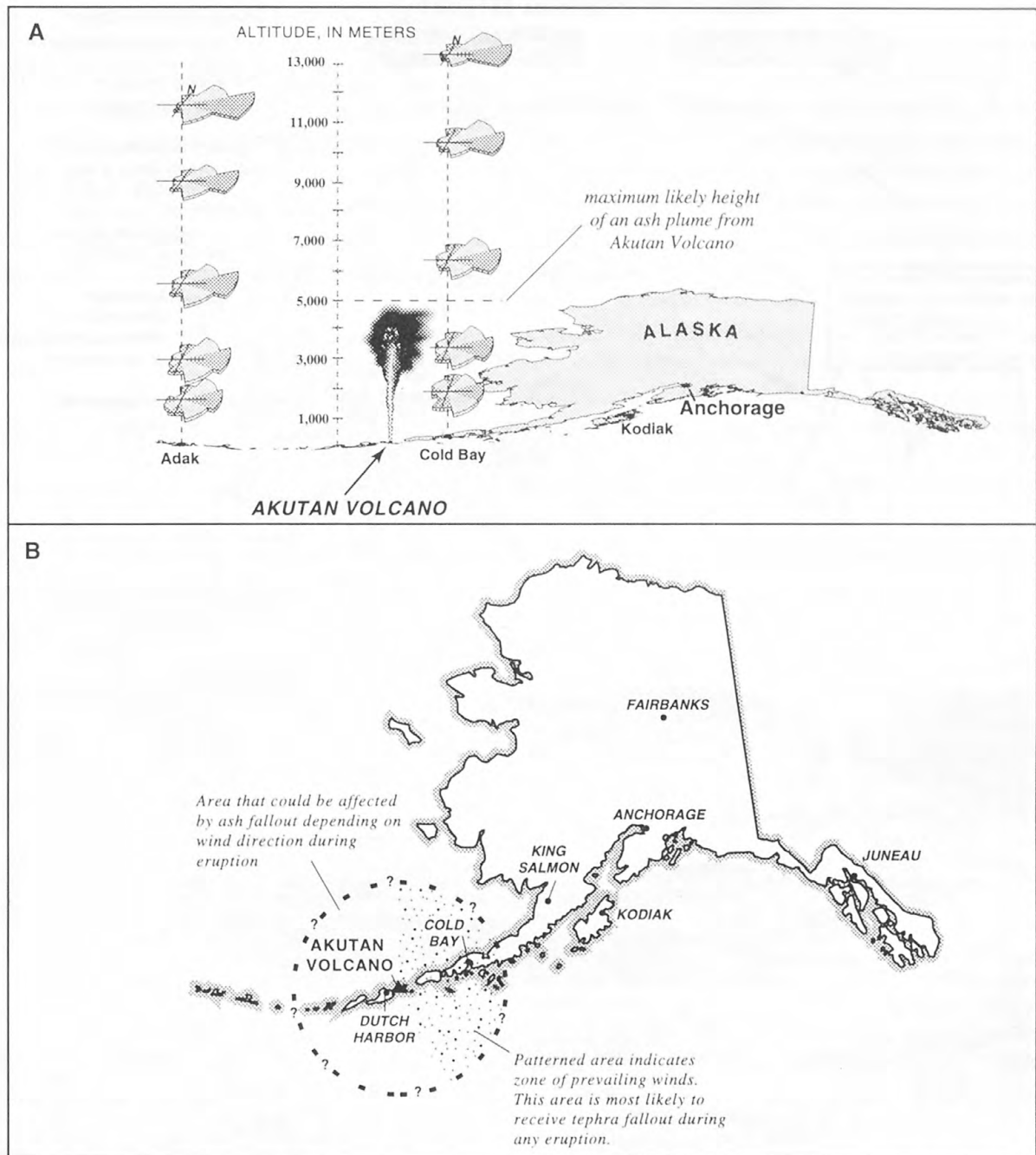


Figure 12. Average wind direction, likely travel paths, and areas of fallout for volcanic ash clouds from Akutan Volcano. (A) Wind data for Adak from 1952-1962; Cold Bay data from 1945-1957. Original data from the National Climatic Data Center, National Oceanic and Atmospheric Administration. Windrose-section lengths are proportional to wind frequency determined by annual percent. (B) Areas likely to receive ash fallout during eruptions of Akutan Volcano. Maximum extent of ashfall uncertain.

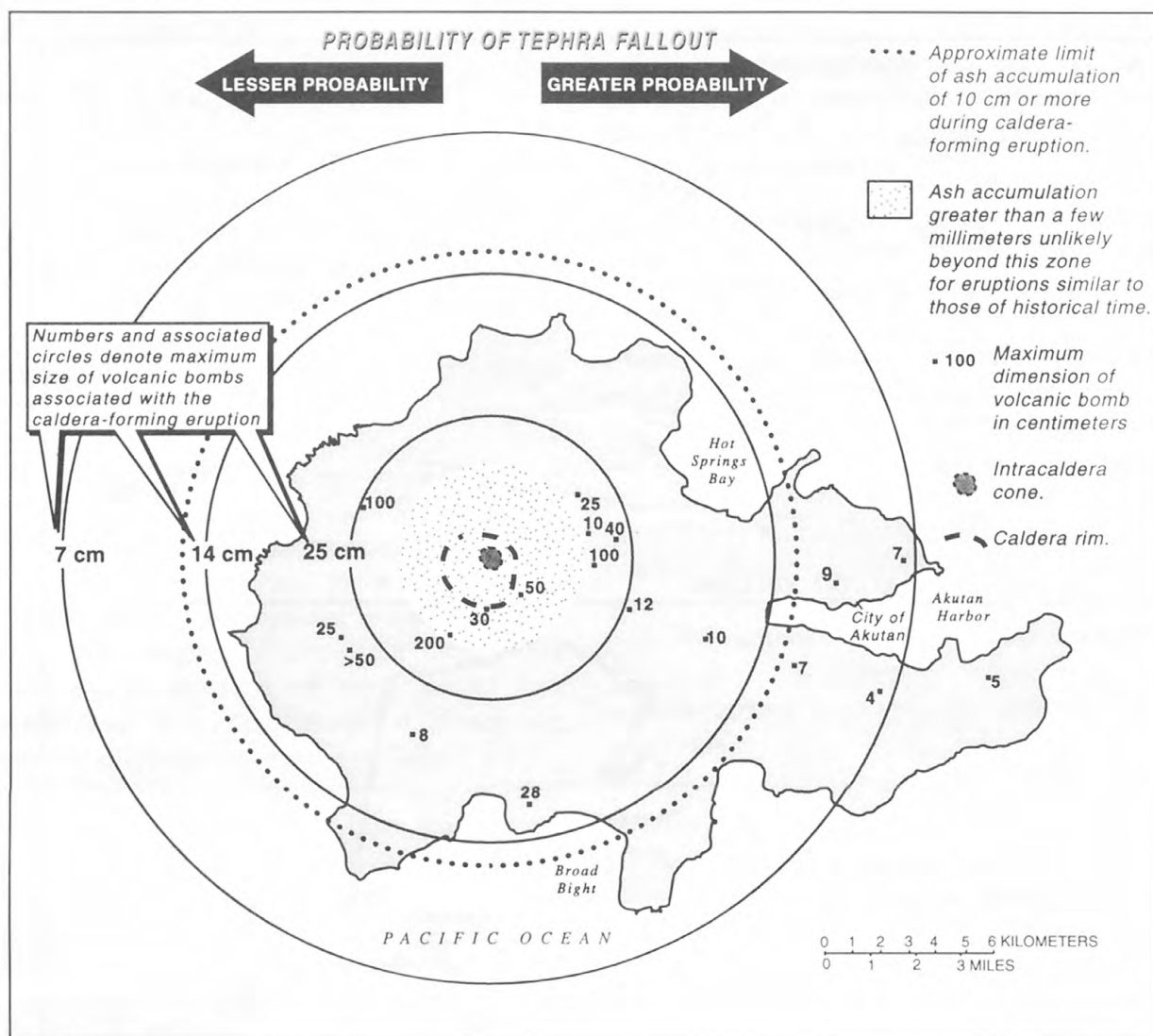


Figure 13. Location and size of volcanic fallout. **Solid circles** indicate the approximate size of volcanic bombs expected during an eruption similar to or larger than the 1600 yr. B.P. caldera-forming eruption. **Numbers** adjacent to small solid boxes refer to maximum dimension (in centimeters) of volcanic bombs found on the ground surface that were ejected during the caldera-forming eruption. The **outer dotted circle** indicates the approximate limit of ashfall greater than about 10 centimeters thickness for a large caldera-forming eruption. For eruptions similar to those that have occurred in historical time, ashfall beyond the stippled zone is possible but unlikely to be more than a few millimeters thick and bomb fallout is likely only around the vent. **Arrows** at top indicate the relative probability of tephra fallout as a function of the prevailing winds.

Ashfall from recent eruptions reached only a few kilometers beyond the vent (fig. 13), but during eruptions in 1911, 1948, 1987, and 1989 a light ashfall occurred over Akutan Harbor including the City of Akutan. The movement of an ash cloud depends on the direction

and speed of the wind. Areas most likely to receive ashfall are those downwind from the vent; the thickness of ash fallout also will decrease in a downwind direction. Ash fallout is more likely to occur in areas east of the vent because the strongest and most consistent

from the west, southwest, and northwest (fig. 12). However, strong storm-related winds may deliver ash to areas west of Akutan Island such as Unalaska Island and Dutch Harbor (fig. 12). It is impossible to predict how much ash will be produced during an individual eruption. During the largest known prehistorical eruption of Akutan Volcano, up to 2 meters of scoriaceous lapilli tephra fell on parts of Akutan Island about 1600 years ago (fig. 14). Future eruptions are likely to produce only limited quantities of fine ash that could fall over the Akutan Harbor area. Even a light dusting of ash could interfere with social and economic activities in the City of Akutan for hours to days.

Pyroclastic Flow and Surge

A pyroclastic flow is a hot, dry mixture of volcanic rock debris and gas that flows rapidly downslope. These flows are relatively dense and tend to follow topographically low areas such as stream valleys. A pyroclastic surge is similar to a pyroclastic flow but contains more gas and air and is therefore more dilute and less dense. A pyroclastic surge moves more rapidly than a pyroclastic flow, may not be confined by topography, and could climb up and over ridges. Pyroclastic flows and surges are fast-moving and could be lethal to anyone in the flow path. Incised river valleys on parts of Akutan Island, particularly in the upper



Figure 14. Typical exposure of coarse-grained fallout tephra produced by the caldera-forming eruption of Akutan Volcano about 1600 years ago. This tephra is found in several places on Akutan Island, and in some locations is about 2 meters thick. Increments on shovel handle are 10 centimeters. At this particular location, northeast of the volcano on the coast in Hot Springs Bay, the tephra is 1.95 meters thick.

parts of major drainages on the volcano flanks, could be hazardous areas during eruptions that produce pyroclastic flows and surges.

Pyroclastic flows and surges at Akutan Volcano would form primarily by collapse of the *eruption column* as it falls back toward the volcano. Pyroclastic-flow deposits preserved around the volcano indicate that pyroclastic flows and surges developed during prehistorical eruptions (fig. 15). Pyroclastic flows of limited extent may have formed during a few historical eruptions (Byers and Barth, 1953)

but associated deposits have not yet been identified.

Pyroclastic flows and surges from most eruptions would be expected to reach at least several kilometers beyond the vent and could be directed along any azimuth, but would mainly follow the primary drainages that radiate from the caldera (fig. 15). A pyroclastic-flow deposit exposed in a sea cliff at Reef Bight (fig. 15) is about 7 kilometers from the caldera of the modern Akutan cone and about 5 kilometers from the older caldera. The pyro-

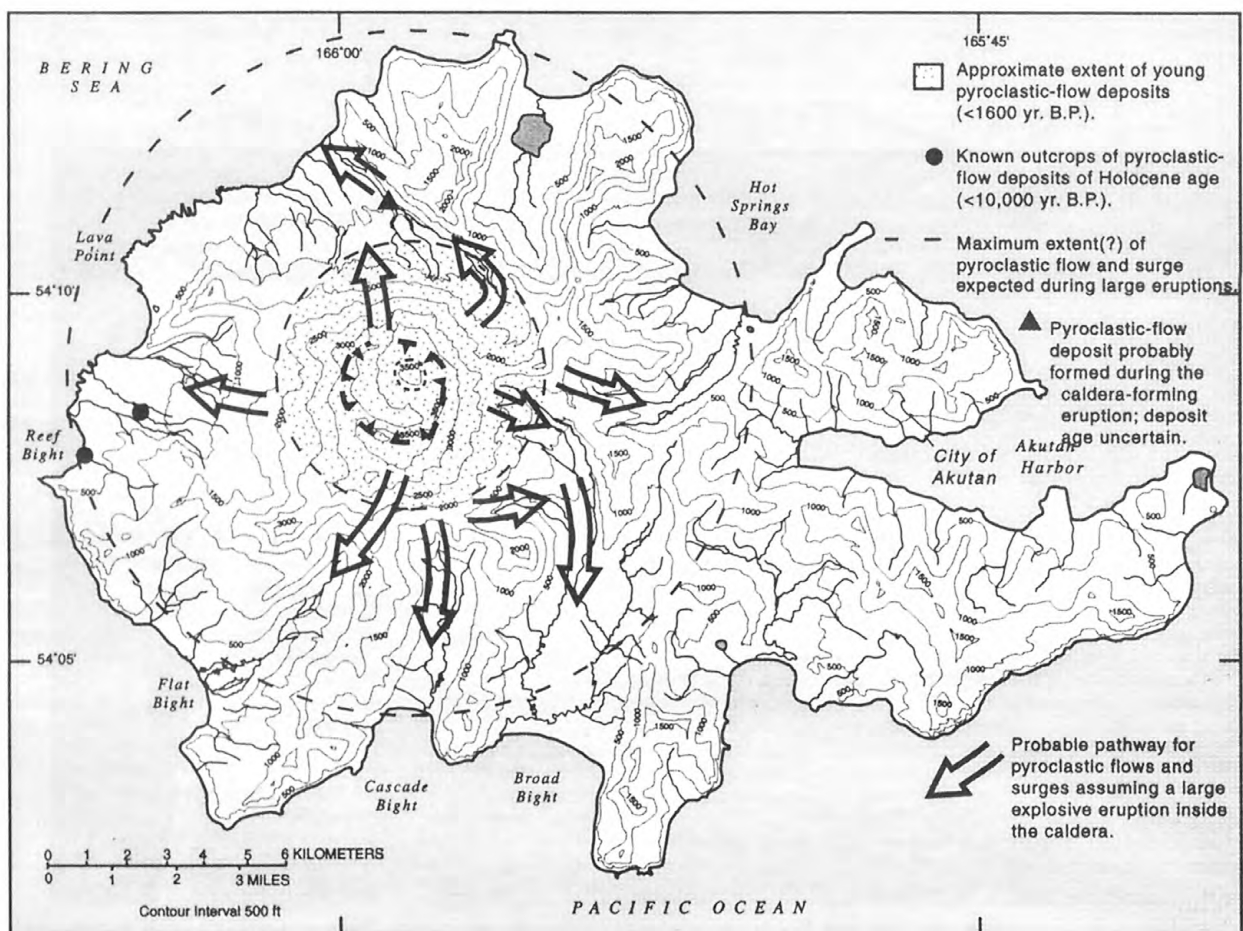


Figure 15. Akutan Island and areas that could be affected by pyroclastic flow and surge. Areas outlined by arrows and the stippled zone around the caldera would be more hazardous during all eruptions relative to areas of higher topography such as ridge tops or divides. Pyroclastic flow deposits were not identified in the Lava Point area and it is unlikely that future eruptions from this center would generate pyroclastic flows.

clastic flow deposit at Reef Bight indicates that pyroclastic flows have traveled at least 5 to 7 kilometers beyond their source vents. The extent of known pyroclastic-flow deposits is the basis for the hazard zone boundary shown on figure 15 and plate 1. Travel distances greater than 5 to 7 kilometers may be possible during large rare eruptions, but pyroclastic flows and surges moving down the flanks of the volcano soon reach water or encounter major topographic obstacles, and traditional methods for estimating travel distance, which assume level overland flows, may not be appropriate. Pyroclastic flows and surges may travel over water as they did during the exceptional eruption of Krakatau near the island of Java in 1883, where pyroclastic flows and surges reached islands more than 40 kilometers from their source (Carey and others, 1996). Pyroclastic flows and surges extending this distance from Akutan Volcano would be unlikely except for a rare, extreme eruption, much larger than any of the known historical or Holocene eruptions.

It is difficult to accurately predict the extent of a pyroclastic surge but because of their genetic relation to pyroclastic flows, they have a slightly greater lateral extent than a pyroclastic flow. Also, distal pyroclastic surge deposits are commonly poorly preserved in the geologic record and therefore a surge deposit may not necessarily indicate the maximum extent of a former pyroclastic surge. Thus, we are uncertain about the extent of this hazard boundary (fig. 15). Because surges are hot (300 to 800 °C) and gaseous, death or injury from asphyxiation and burning is likely. Because the surge cloud may travel very fast (at least tens of meters per second), pre-eruption evacuation from areas on the volcano flanks, especially major drainages on the volcano, is the only way to eliminate risk from pyroclastic surges.

Lahars, Lahar-Runout Flows and Floods

Most volcanoes in Alaska are mantled with ice and snow and have significant amounts of unconsolidated volcanic debris on their flanking slopes. Because eruptive materials are hot, partial melting of the ice and snowpack can result. As meltwater mixes with available unconsolidated sediment, various types of flowage phenomena may develop. The most common process is debris flow, or more specifically, lahar. A typical lahar is a fast-moving slurry composed of a poorly sorted mixture of boulders, sand, and silt. Commonly, lahars undergo downstream transformation to finer grained, more watery flows, called hyperconcentrated flows or lahar-runout flows. If enough sediment is lost from the lahar during flowage, the lahar may transform into a normal streamflow or flood and consist mostly of water. Flow transformation is a common attribute of *noncohesive lahars*, and their deposits usually contain less than 3 to 5 percent clay (Scott, 1988). Noncohesive lahars commonly form from pyroclastic flows that generate meltwater, which subsequently erodes and transports locally available sediment on the volcano flanks or in stream channels. In contrast, a *cohesive lahar* contains more than 3 to 5 percent clay, and typically does not undergo downstream flow transformation (Vallance and Scott, 1997). Cohesive lahars usually evolve from large volcanic avalanches and are not necessarily related to an eruption.

Pyroclastic flows generated during Holocene eruptions of Akutan Volcano melted snow and ice on the volcano that formed lahars. The lahars flowed down the volcano flanks and into major valleys, reaching the coast in some areas (fig. 16). All major valleys contain at least one lahar deposit of Holocene age. The majority of these deposits are com-

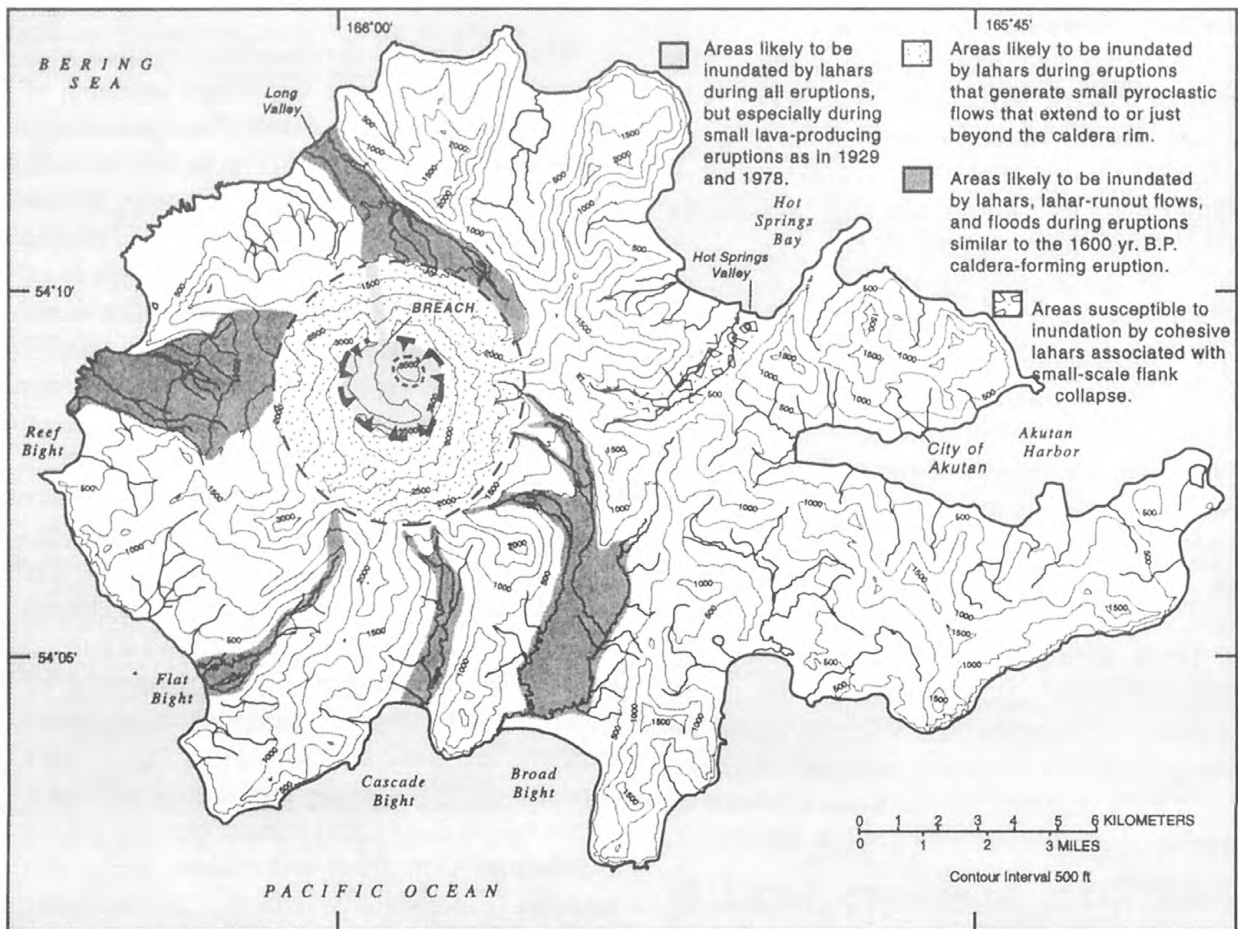


Figure 16. Akutan Island and areas that could be affected by lahars, lahah-runout flows, and floods. Area outlined by stippled zone around the caldera and upstream reaches of individual drainages would be more hazardous during all eruptions relative to areas of higher topography. Degree of hazard generally diminishes in the downstream direction and with elevation above valley bottoms.

posed of angular cobble- and boulder-sized clasts of volcanic rock debris, sand, and silt and are classified as noncohesive lahars because they contain little or no clay.

A cohesive lahar deposit in Hot Springs Valley (fig. 16) containing more than 3 percent clay, and only altered clasts of volcanic rock probably formed from a small-scale flank collapse of altered rock debris in an area of active fumaroles at the head of the valley. The deposit is about 6000 years old and is the only lahar deposit in Hot Springs Valley (Waythomas, in prep.). One other cohesive lahar deposit is present in Long Valley (fig. 17). This deposit also has more than 3 percent clay

and contains altered clasts of volcanic rock. The origin of this deposit is somewhat uncertain, but it may have formed from the avalanche debris that was generated by partial collapse of the caldera rim to form the breach (fig. 17).

Because lahars, lahah-runout flows, and floods move rapidly (meters per second or faster) and can transport boulder-sized clasts, they are typically quite hazardous to life and property. Lahars pose no significant hazard on Akutan Island because the likely flow paths and areas that could be inundated are uninhabited, include no permanent structures or facilities, and are rarely visited by people.

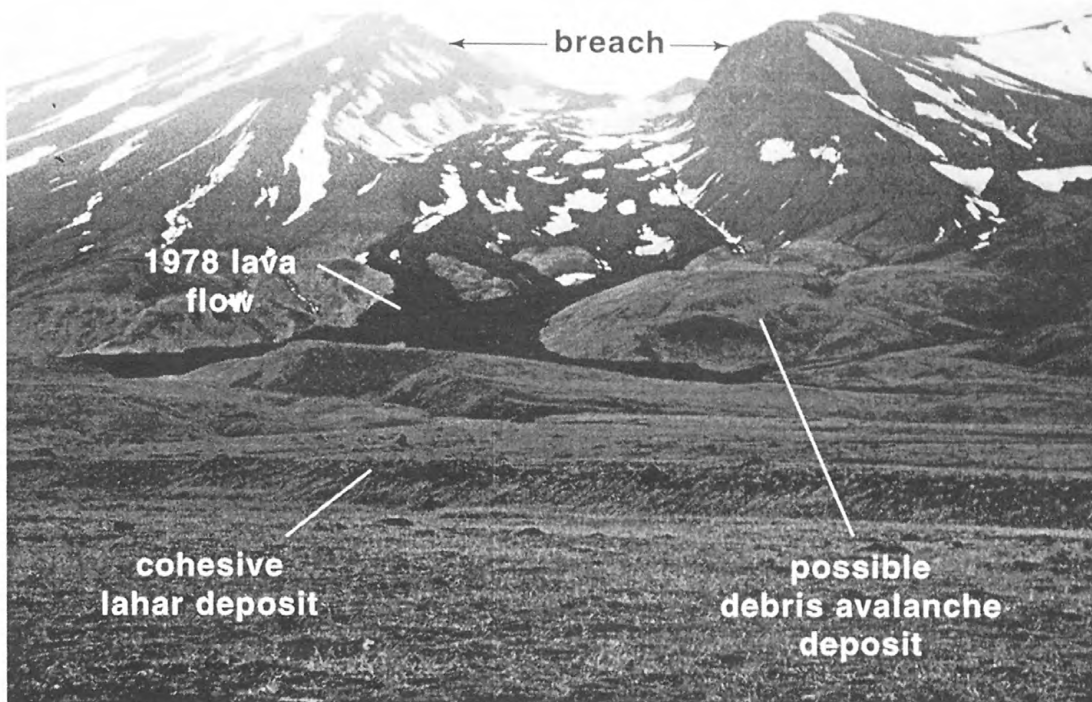


Figure 17. Akutan Volcano and breach through caldera rim on the north side of the volcano. A slightly cohesive lahar deposit in the foreground may have originated from altered, water-saturated rock debris that collapsed to form the breach. The age of the lahar deposit is unknown, but its field appearance suggests a young age, perhaps only a few hundred years.

Lava Flow

Narrow streams and intracaldera pools of molten rock or lava have formed during several historical eruptions of Akutan Volcano. Typical Akutan lava flows are *andesitic* in composition and when molten are relatively sluggish compared to the more fluid Hawaiian type lava flows. Thus, they tend to move slowly downslope, probably not more than a few tens of meters per hour. Lava flows of this type pose little hazard to people who could easily walk from them. Akutan lava flows may develop steep, irregular fronts and are likely to shed blocks and debris downslope, which could be hazardous to anyone near the front of an advancing lava flow.

During future eruptions, lava flows would probably cover the caldera floor before exiting the caldera through the breach on the north side (fig. 18). If lava-producing eruptions persist for long periods of time (months to years), lava could exit the caldera by overtopping the rim. The ensuing flows would probably follow major valleys and tributaries (fig. 18). During future eruptions similar to those of 1978 and 1929, lava flows could pour from the caldera through the breach and down Long Valley (fig. 18). If new vents develop during future eruptions, lava flows could extend beyond the caldera but would probably be confined to valleys or other topographically low areas (fig. 18). Ground cracks formed during the March 1996 seismic swarm were likely caused by the

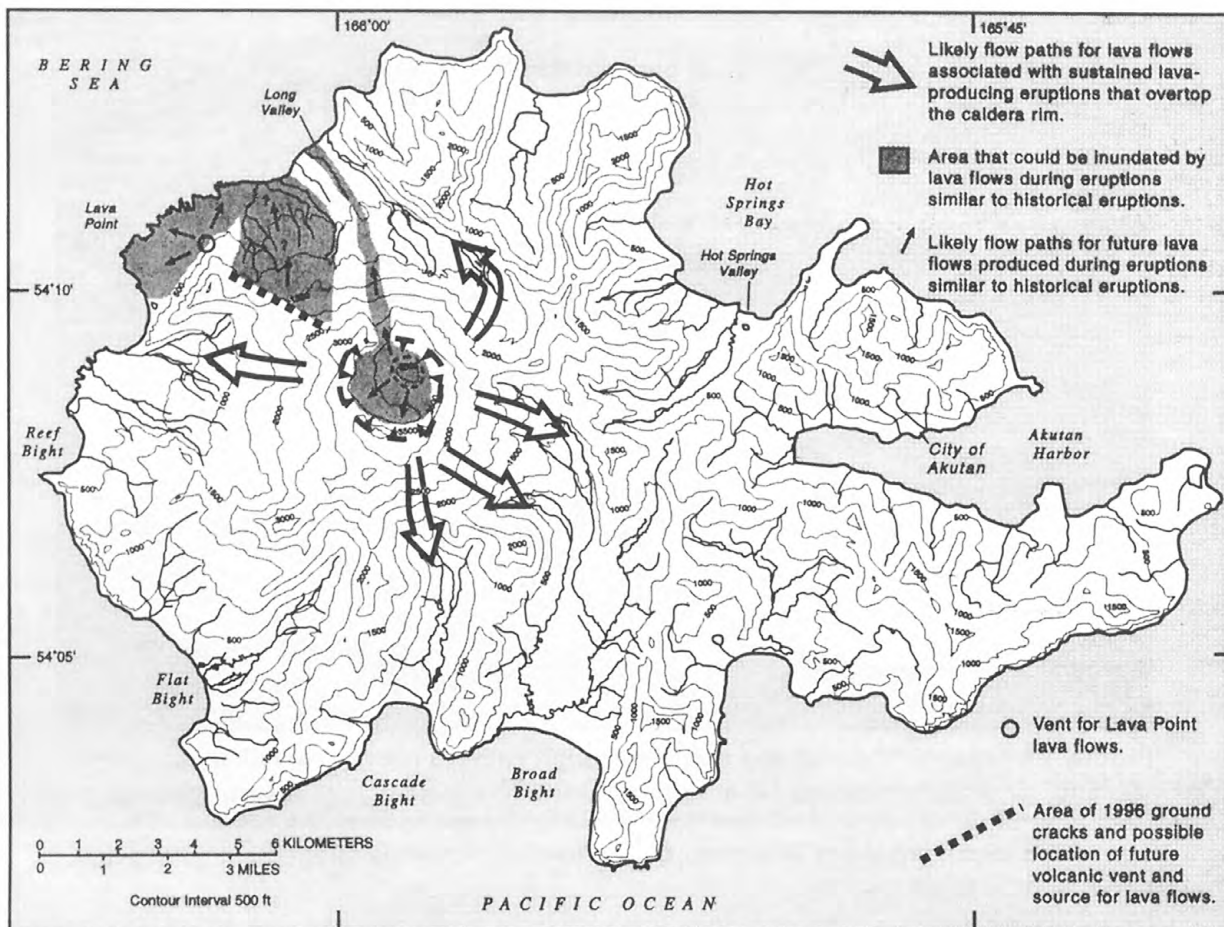


Figure 18. Akutan Island and areas that could be affected by lava flows. Typical eruptions are expected to produce lava flows that extend no farther than the caldera, but may exit the caldera through the breach. Lava flows could extend into the upper parts of major valleys during sustained lava-producing eruptions only if the flows are able to exit the caldera by overtopping the rim or if new breaches develop. The age of eruptive activity in the Lava Point area is not known but the fresh appearance of lava flows in this area indicates that the flows may have formed recently. Future eruptive activity could occur in this area. Should a new vent develop in the area of the 1996 ground cracks, lava flows (if produced) would flow toward the coast along stream valleys or other topographically low areas.

intrusion of magma to within several kilometers of the surface. The area of ground cracks northwest of the caldera could be a site of future eruptive activity including lava flows (fig. 18).

Because Akutan Volcano is snow covered for most of the year and because small lakes are present in the caldera, developing lava

flows are likely to contact either snow or water. Lava-generated meltwater could lead to the development of small lahars as it did in 1929 (Byers and Barth, 1953) and localized explosions could occur where lava traps or envelops snow or water. These types of lava–water interactions pose no hazard unless someone is in the flow path or within a few meters of the lava front.

OTHER HAZARDOUS PHENOMENA

Debris Avalanche

Volcanic *debris avalanches* typically form by structural collapse of the upper part of the volcano. The ensuing avalanche moves rapidly down the volcano flank and forms a bouldery deposit that may extend many kilometers from its source. Typical debris-avalanche deposits have a characteristic hummocky, irregular surface and contain numerous large boulders and blocks. Although some debris avalanches occur during an eruption, large-scale collapse of a volcanic cone may occur during a distinctly non-eruptive period, sometimes as a result of long-term chemical alteration of volcanic rock by hot, acidic ground water. As the interior structure of the volcano becomes weakened, the flank may collapse and produce a debris avalanche. Debris-avalanche deposits that form this way are usually clay rich, and the deposit matrix often contains more than 3-to-5-percent clay. Such an avalanche may evolve into a cohesive lahar (Valance and Scott, 1997).

Debris-avalanche deposits are present at only two locations, near the breach on the north side of the caldera rim and in upper Long Valley (fig. 19). Debris-avalanche deposits below the breach probably formed by structural collapse and avalanche of a small part of the caldera rim thus forming the breach. A cohesive lahar appears to have developed from the avalanche debris; the lahar flowed to the coast and transported large boulders (fig. 20).

Weakening of the caldera rim caused by hydrothermal alteration could result in a future collapse and debris avalanche, which may form a cohesive lahar. The most likely place for collapse to occur is the northeast sector of the caldera rim near the active intracaldera cone (fig. 19). The bedrock in this area exhibits slight hydrothermal alteration, but otherwise does not appear unstable. Should a flank

collapse occur, a debris avalanche would likely be small in volume (100 million cubic meters or less) and probably not extend more than about 2 kilometers from the present caldera margin (fig. 19). If the debris avalanche contains sufficient clay and water, it could transform into a cohesive lahar.

Slope failures mobilizing to cohesive lahars also may develop in upper Hot Springs Valley (fig. 19) as they did about 6000 years ago. A zone of active fumaroles and altered rock debris at the head of the valley is a potential source area for slope failures, and at least one large failure and ensuing lahar have occurred here in about the past 6000 years (Waythomas, in prep.). A zone of altered bedrock in upper Long Valley also may be susceptible to failure and could be a source area for small debris avalanches (fig. 19). A slope failure and debris avalanche from this area could transform into a cohesive lahar.

Volcanic Gases and Geothermal Activity

Gases are emitted by most active volcanoes because *magma* contains dissolved gases and boils off shallow ground water. The most common volcanic gases are water, carbon dioxide, sulfur dioxide, hydrogen sulfide, and carbon monoxide. Volcanic sulfur and halide gases that encounter water form sulfuric acid (H_2SO_4), and minor amounts of hydrochloric acid (HCl) and hydrofluoric acid (HF) occur as aerosols or droplets. Both carbon monoxide and carbon dioxide are colorless and odorless and thus impossible to detect without some kind of monitoring device. Although carbon dioxide is not toxic, it is heavier than air and may displace the available oxygen in confined spaces or low-lying areas causing suffocation. In high concentrations, both hydrogen sulfide and sulfur dioxide may be harmful or toxic to humans and may damage vegetation downwind from the volcano. Acid precipitation may develop from the mixing of snow or rain

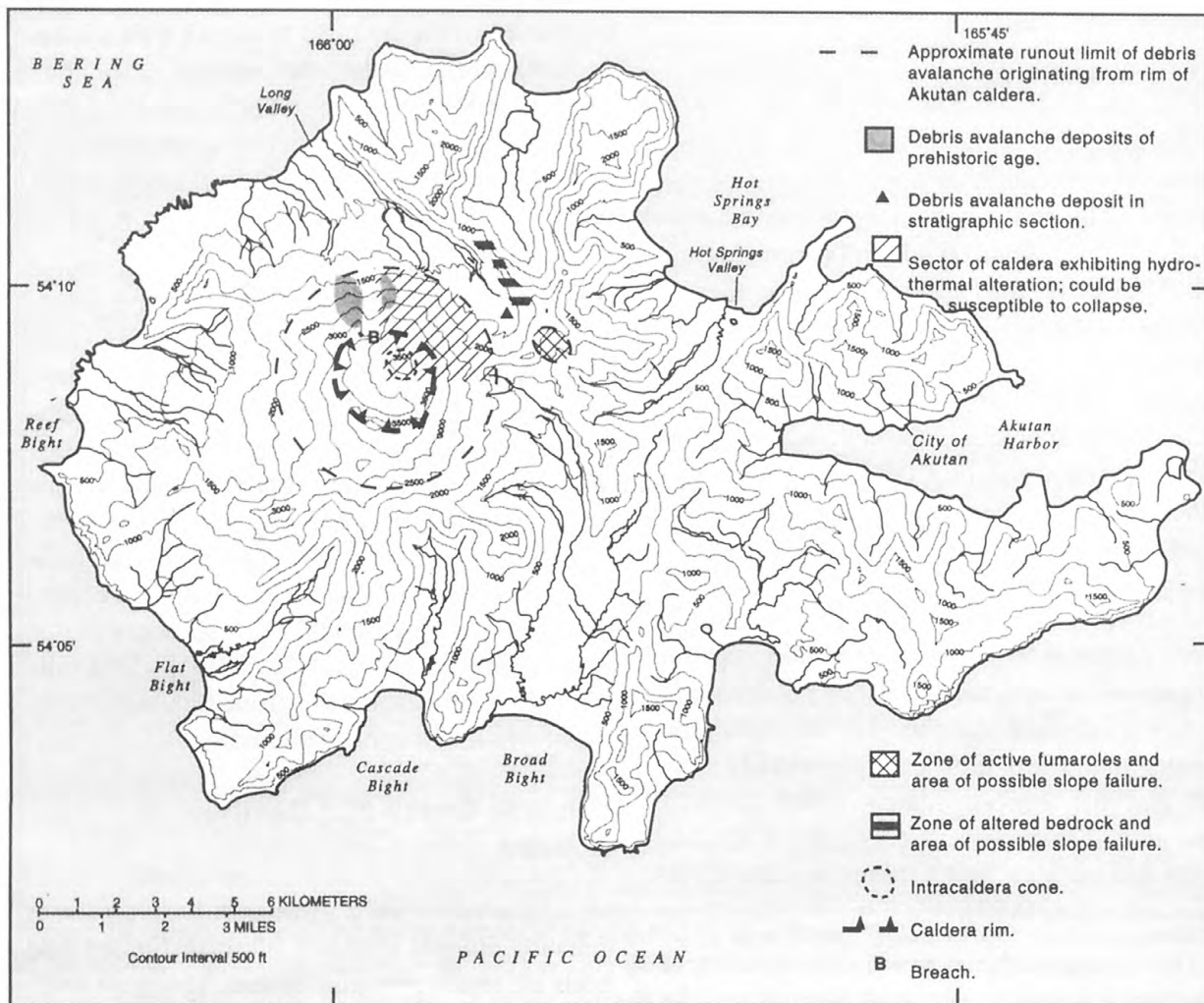


Figure 19. Akutan Island and areas that could be affected by debris avalanche. Debris avalanche deposits have been identified in only two locations indicating that structural collapse of the volcano is relatively uncommon. A small-scale flank collapse probably formed the breach and the avalanche deposit appears to have evolved into a cohesive lahar. Although parts of the caldera rim are hydrothermally altered, it is unlikely that a large-scale collapse of the volcano flank will occur in the future.

with acidic volcanic aerosols, which may cause various types of skin and respiratory irritations and corrosive damage to paint, fabric, and structures. The characteristically strong Aleutian wind tends to disperse volcanic gas which is typically not found near the ground in concentrations hazardous to humans or animals on Akutan Island.

During any eruption, the emission rate and concentration of volcanic gases will be high near the vent but diminishing downwind. However, during an eruption of Akutan Volcano, the hazard from volcanic gases is unlikely to be greater than that posed by other volcanic phenomena. During non-eruptive periods, emission of volcanic gases may pose a



Figure 20. Large boulders on surface of cohesive lahar deposit near the mouth of Long Valley. The boulders were transported by a lahar that may have evolved from an avalanche of the caldera rim. The boulders are composed of agglutinate, a type of volcanic rock that forms by the accumulation of spatter from the vent.

health concern to someone actually in the caldera or near an active vent; however, the frequent windy conditions over the summit of Akutan Volcano preclude localized buildup of volcanic gas. During periods of little or no wind, volcanic gas could accumulate in the caldera or in the areas around active vents. At these times it may be unsafe to enter the caldera or approach an active vent but generally, the hazard from volcanic gas inside the caldera is minimal.

Volcanic gas also is emitted from a small active fumarole field in the upper part of Hot Springs Valley (fig. 21). The fumarole field consists of zones of steaming ground, boiling acidic springs, and small pressurized steam vents (Motyka and Nye, 1988). The principal gas emitted from the fumarole field is carbon dioxide but minor amounts of hydrogen sulfide, methane, and nitrogen also are present (Motyka and Nye, 1988). The gases from the

fumarole field are rapidly dispersed by wind and generally pose no hazard to people in upper Hot Springs Valley. However, if the gas emission rate were to increase significantly at times of little wind, carbon dioxide gas could collect in topographically low areas of upper Hot Springs Valley. Because it is more dense than air, carbon dioxide gas would displace air from low areas in the upper part of the valley and could pose a suffocation hazard for people and animals. Spring water from the fumarole field is acidic ($\text{pH} = 2.6$ on July 9 1981; Motyka and Nye, 1988) and could be harmful to people or animals if ingested or if there is prolonged contact with the skin.

Numerous thermal springs are present in Hot Springs Valley near the mouth of the main tributary flowing into the bay (fig. 21). The temperature of the spring water ranged from 26 to 85 °C when measured in 1981 and 1983 and was as high as 100 °C in 1996 (Motyka

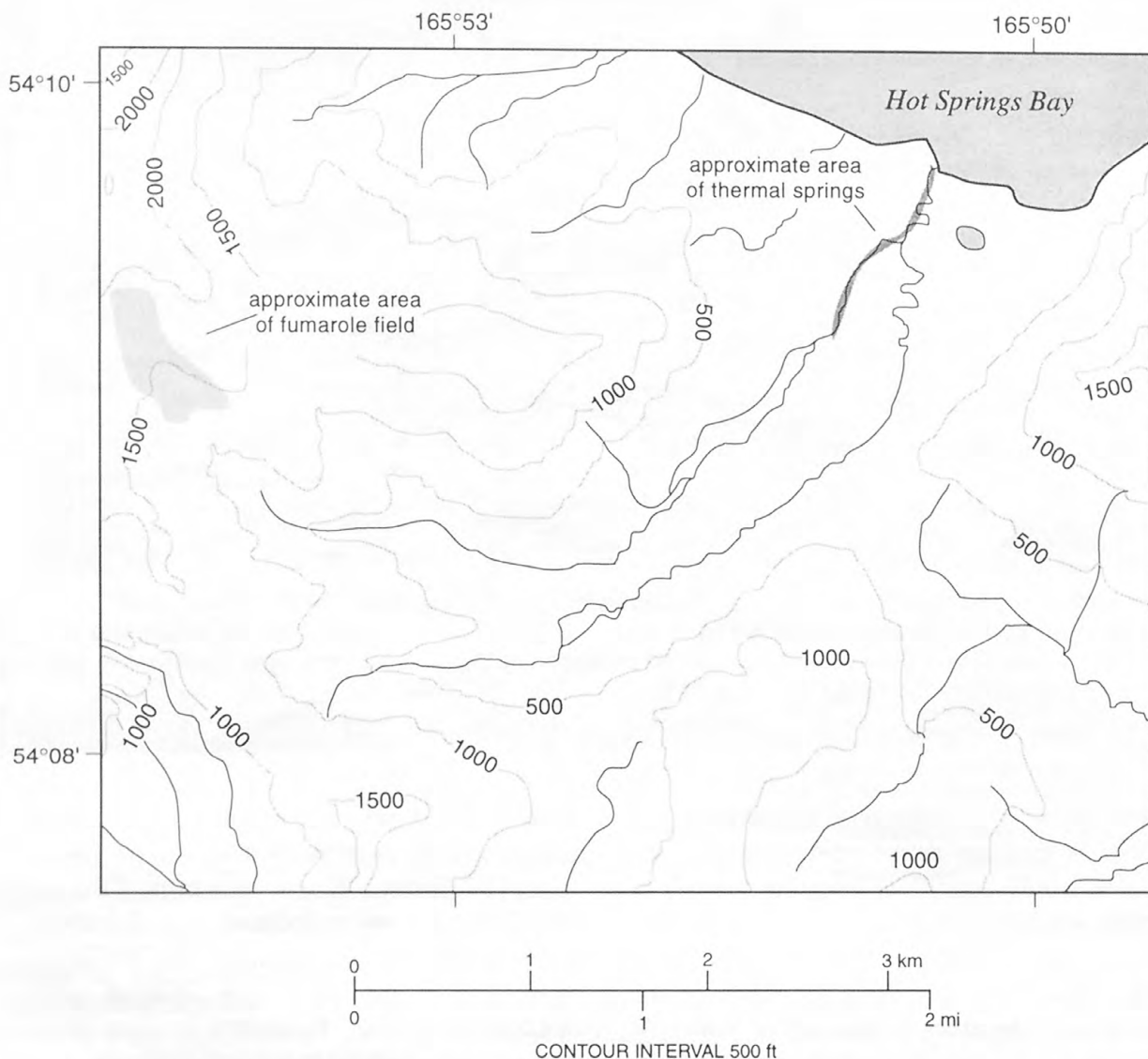


Figure 21. Hot Springs Valley showing location of fumarole field and thermal springs.

and Nye, 1988; R.B. Symonds, USGS, unpublished data). The spring water is moderately enriched in sodium chloride, silica, and bicarbonate; the pH of the water ranges from about 6.5 to 8.4 (Motyka and Nye, 1988). These conditions pose no hazard at present, but the temperature and chemical composition of the springs may change rapidly and prolonged exposure to the hot alkaline waters could be harmful to humans.

Tsunamis

Volcanoes situated near or on the coastline are potentially capable of initiating *tsunamis*. According to a synthesis of tsunamis associated with, or caused by, volcanic activity (Latter, 1981), 22 percent were caused by volcanic earthquakes, 20 percent were caused by pyroclastic flows entering the water, 19 percent were caused by submarine explosions, 12 per-

cent were caused by volcanic debris avalanches (both hot and cold), 9 percent were caused by caldera collapse, 7 percent were caused by pyroclastic surges, about 10 percent were caused by lahars and air waves from explosions, and 1 percent were caused by lava avalanching into the sea (Latter, 1981, p. 470). Evidence for volcanic tsunamis caused by these processes has not been found on Akutan Island. It is unlikely that future eruptions of Akutan Volcano will initiate volcanic tsunamis.

Lahars formed during prehistoric eruptions of Akutan Volcano have been sufficiently mobile to flow several kilometers and reach the sea. Lahars that reached the coast in Long Valley were probably slow moving and likely flowed passively into the Bering Sea not initiating even a small tsunami. Lahar deposits of Holocene age are present in other valleys that head on the caldera, but none are exposed at the coast, indicating that large volume lahars were probably never discharged into the sea and it is unlikely that tsunamis were ever generated by these lahars.

Voluminous pyroclastic flows entering the sea at high speed could initiate tsunamis (Simkin and Fiske, 1983; Waythomas and Neal, 1997) but there is no evidence for large-volume pyroclastic flows being generated during eruptions of Akutan Volcano (Richter and others, 1998; Waythomas, in prep.). Thus, pyroclastic flows are not considered a viable mechanism for tsunami generation at Akutan Volcano.

Akutan is at much greater risk from tsunamis associated with large regional *tectonic* earthquakes (Lockwood and others, 1990). In 1946, several homes on the eastern shore of Akutan Island were washed off their foundations by the same tsunami that destroyed the Scotch Cap lighthouse on nearby Unimak Island (Lander, 1996).

Rockfall

The volcanic bedrock that makes up Akutan Island is susceptible to gravitational collapse forming large rockfalls that are especially prominent along the coastline. Steep, nearly vertical sea cliffs composed of fractured and broken volcanic bedrock render some areas along the coast at risk from rockfall (fig. 22). Most of the known rockfall deposits are relatively small (less than about 750,000 cubic meters), but could be hazardous regardless of size. A very large rockfall into one of Akutan Island's many restricted, deep-water bays or coves could initiate a local tsunami that could be hazardous to small boats or people in close proximity.

EVENT FREQUENCY AND RISK AT AKUTAN VOLCANO

Moderately explosive, short-duration, strombolian-style eruptions of Akutan Volcano should be anticipated in the future, probably within a decade or less. Such eruptions will probably continue for days to weeks, and be characterized by emission of fine ash, lava flow, and small pyroclastic flows. The primary hazard during a future eruption likely will be drifting clouds of volcanic ash, which could rise 3 kilometers or more above sea level and drift downwind. It is not possible to determine the characteristics of the ash clouds before an eruption occurs, except that they are likely to be similar to those of previous eruptions. All aircraft, boats and ships, some facilities, and living things, including humans, downwind from the volcano are at risk from effects of volcanic ash clouds and fallout. Ash clouds from Akutan Volcano could move into the flight paths of jet aircraft using the airfield at Dutch Harbor on Unalaska Island (fig. 1), as well as aircraft approaching or departing Aku-

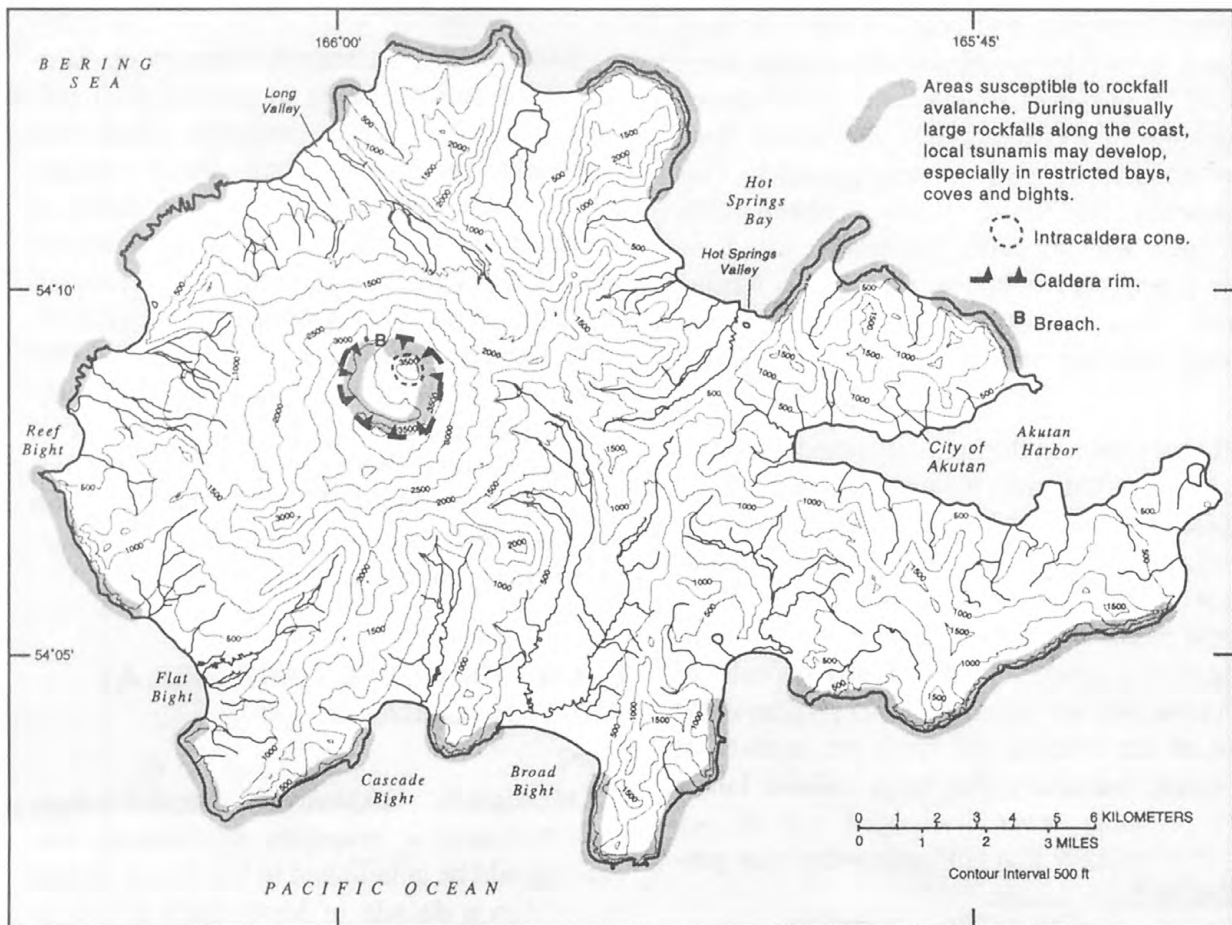


Figure 22. Akutan Island and areas that could be affected by rockfall avalanches.

tan Island. The number of dangerous clouds of volcanic ash and the amount of ashfall produced during an eruption can not be estimated with certainty. Signs of volcanic unrest may precede an eruption and permit reasonable estimates of the likelihood of volcanic ash emission once an eruptive phase is detected.

In general, historical eruptions of Akutan Volcano have been similar in style. Typically, bursts of ash and steam form diffuse ash clouds that may rise several thousand meters above the volcano. Ash fallout is generally confined to the area around the vent, but could occur over Akutan Harbor if the eruption is large enough and the winds are strong. When lava flows are produced, they flow out over the caldera floor, occasionally exiting the caldera

through the breach. The most likely sites of future activity are the intracaldera cone and possibly the north and northwest flanks. Depending on the size of the eruption and the position of a new vent, other flanks could be affected as well.

Volcanic bombs lofted eastward during a large caldera-forming eruption could be as big as 10 centimeters in diameter and would be hazardous to humans and property. More likely is fallout of fine (silt-sized) ash, which could occur during eruptions similar to those that have happened at Akutan Volcano this century. Because most of Akutan Island is uninhabited and has little recreational use, only the Akutan Harbor area is at risk from tephra fallout.

Pyroclastic flows and lava could produce lahars and floods in major valleys that head on the caldera. Inundation by lahars and floods would probably be restricted to areas inside the caldera or downvalley from the breach. More extensive inundation could happen during an eruption similar to the caldera-forming eruption or if pyroclastic flows reached the snow-covered upper flanks of the volcano beyond the crater rim. Lahars produced by the interaction of pyroclastic flows with snow could inundate areas on the volcano flanks and valleys down-slope.

The caldera of Akutan Volcano was formed during a large eruption about 1600 years ago. Available data indicate that this could have been the largest eruption in the last 8000 years and possibly the last 10,000 years (Waythomas, in prep.). An older caldera may have formed 8000 to 10,000 years ago, but additional field studies and data are needed to confirm this. The presence of two caldera structures indicates that large caldera-forming eruptions are a repeatable process at Akutan Volcano but eruptions of this scale happen infrequently. In the immediate future, the probability of an eruption equivalent to or larger than the 1600 year old caldera-forming eruption is low. In the Aleutian Arc, such eruptions occur every few thousand years or more, which indicates that a major eruption of Akutan Volcano in the near future is unlikely.

Recent study of the geology and eruptive history of the volcano indicates that all historical eruptions have been from vents inside the caldera. A small eruptive center at Lava Point was probably not active in historical time, but could be a site of future eruptions. The zone of ground cracks northwest of the caldera (fig. 10) may be a place where new flank vents could develop. We are uncertain how likely it is for new vents to develop in this area during future eruptive activity.

Since about 1790, there have been 27 reports of eruptive activity at Akutan Volcano

(Miller and others, in prep.; Simkin and Siebert, 1994; Byers and Barth, 1953) indicating an average frequency of eruptive activity every 5-6 years. Because volcanoes do not erupt at regular intervals, this estimate is only a rough approximation of future eruptive activity. However, Akutan Volcano is the second-most historically active volcano in the Aleutian Arc and shows no signs of decreasing activity. The volcano will erupt again, probably as it has over the last century.

VOLCANO MONITORING AND ERUPTION RESPONSE

One of the primary roles of the Alaska Volcano Observatory (AVO) is to communicate timely warnings of volcanic unrest and potential eruptions (Eichelberger and others, 1995, p. 4). During the March 1996 seismic episode, the AVO was able to respond by installing a temporary network of seismic monitoring instruments and performing satellite observations. This information was used to develop a comprehensive assessment of the likelihood of an eruption and enable rapid warning if an eruption occurred.

The AVO monitors Akutan Volcano with a real-time seismic network (fig. 23) equipped with an alarm system that is triggered by elevated levels of earthquake activity that may indicate volcanic unrest. A permanent network of six radio-telemetered seismometers sends real-time radio signals to AVO offices in Anchorage and Fairbanks. A multi-station network of benchmarks, precisely located on the volcano with global positioning satellite technology, can be reoccupied to monitor small-scale changes in the shape of the volcano that may accompany volcanic unrest. When volcanic unrest is detected, other monitoring techniques, such as satellite observations, measurement of volcanic gas flux, and remote observation with real-time video or time-lapse cameras may be used (weather permitting) to

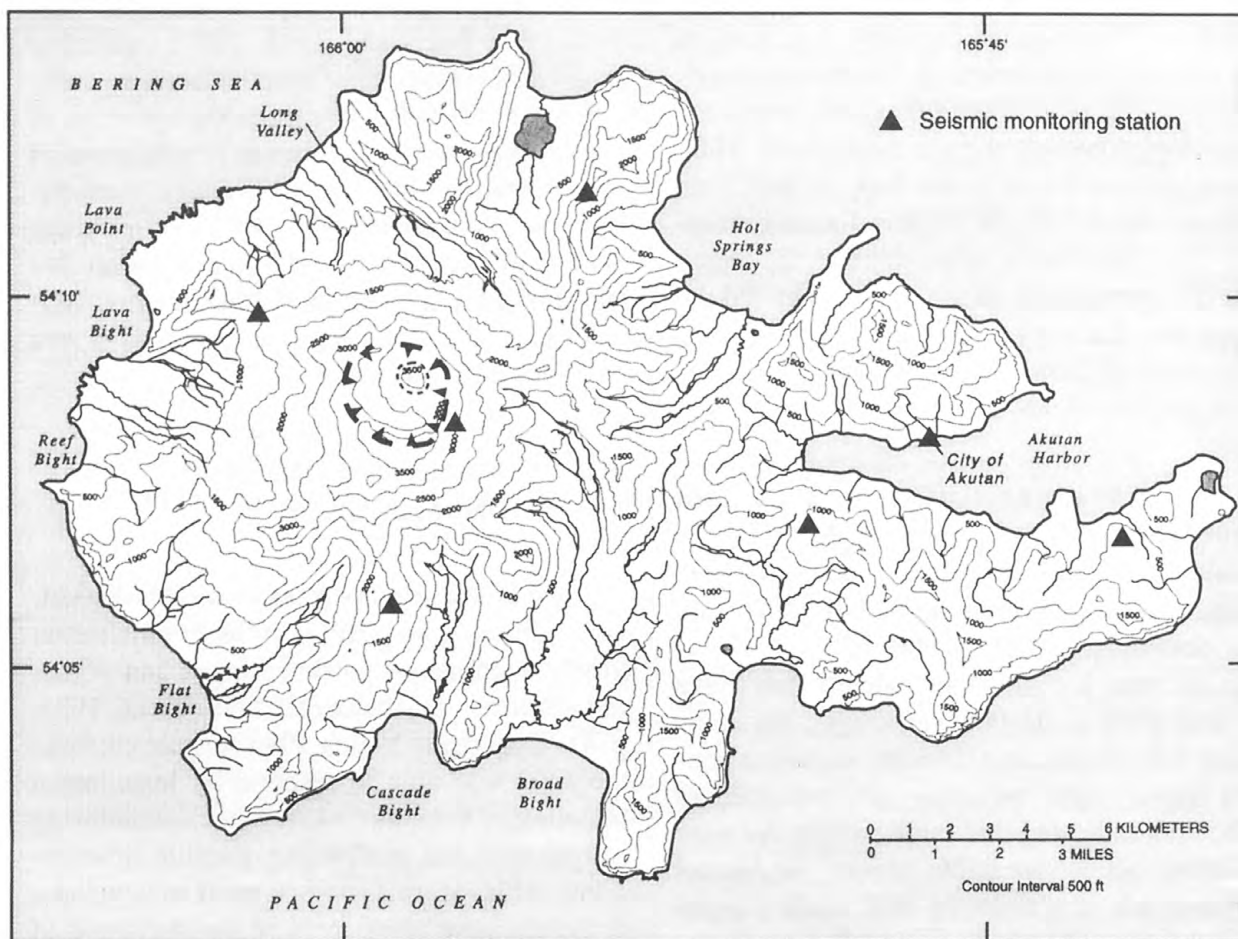


Figure 23. Location of seismic monitoring stations on Akutan Island. With this network, it is possible to obtain real-time data on earthquakes beneath the volcano.

enhance our ability to accurately assess the characteristics and likely progression of volcanic activity.

The AVO distributes by fax and electronic mail, a weekly update of volcanic activity that summarizes the status of the 16 seismically instrumented historically active volcanoes along the Aleutian Arc. During periods of unrest or volcanic crises, updates are issued more frequently to report significant changes in activity. Recipients of these updates include the Federal Aviation Administration, the National Weather Service, the Alaska Division of Emergency Services, local military bases, the Governor's office, various State offices, television and radio stations, news wire ser-

vices, air carriers, and others. Updates also are distributed by electronic mail to various volcano information networks.

A "level of concern color code" (fig. 24) developed by AVO during the 1989-90 eruption of Redoubt Volcano (Brantley, 1990) provides efficient and simple information about the status of volcanic unrest and conveys the AVO's interpretation of that activity or unrest in terms of the potential for an eruption and its likely effects. In the advent of a volcanic crisis, various Federal, State, and local officials are contacted by telephone, advised of the situation, and the level of concern color code is established while an update is being prepared. This approach was used successfully during

LEVEL OF CONCERN COLOR CODE

To more concisely describe our level of concern about possible or ongoing eruptive activity at an Alaskan volcano, the Alaska Volcano Observatory (AVO) uses the following color-coded classification system. Definitions of the colors reflect AVO's interpretations of the behavior of the volcano. Definitions are listed below followed by general descriptions of typical activity associated with each color.

<i>Color</i>	<i>Intensity of Unrest at Volcano</i>	<i>Forecast</i>
GREEN	Volcano is in quiet, "dormant" state.	No eruption anticipated.
YELLOW	Small earthquakes detected locally and (or) increased levels of volcanic gas emissions.	An eruption is possible in the next few weeks and may occur with little or no additional warning.
ORANGE	Increased number of local earthquakes. Extrusion of a lava dome or lava flows (non-explosive eruption) may be occurring.	Explosive eruption is possible within a few days and may occur with little or no warning. Ash plume(s) not expected to reach 25,000 feet above sea level.
RED	Strong earthquake activity detected even at distant monitoring stations. Explosive eruption may be in progress.	Major explosive eruption expected within 24 hours. Large ash plume(s) expected to reach at least 25,000 feet above sea level.

Figure 24. Alaska Volcano Observatory's level of concern color code. This code is used in the weekly AVO update of volcanic unrest and provides a rapid summary of the degree of volcanic activity at any unrestful or erupting volcano. Updates are distributed to government agencies, the media, airlines, and the public.

recent periods of volcanic unrest, such as the 1996 Akutan seismic crisis, the 1989-90 eruptions of Redoubt Volcano, and the 1992 eruptions of Mount Spurr Volcano, and the 1996-97 eruption of Pavlof Volcano.

Minimizing the risks posed by eruptions of Akutan Volcano is possible through adequate warning and education about potential hazards, such as drifting ash clouds and fallout, and by avoiding development or utilization of areas most likely to be affected by future eruptions (plate 1). If for some reason, development is unavoidable in hazardous areas, engineering measures may be employed to minimize or prevent undesirable consequences.

Knowledge of potential hazards is required to assess the risk associated with a specific location on or near the volcano and to assess

whether or not movement to another location would be safer. Low-lying terrain along streams and gullies that extend toward the summit are subject to pyroclastic flow and surge, lahars, floods, and lava flows. Should a major eruption appear imminent, access closer than about 10 kilometers from the volcano could be impossible and the risks to human life great. However, even during eruptions, similar in size and style to historical eruptions, significant hazards still exist from airborne debris, especially in areas close to or downwind from the volcano. Small planes and helicopters seeking a view of an eruption could be at risk from intermittent and unpredictable ejection of ballistic projectiles (volcanic bombs) or sudden changes in the travel direction of the eruption plume.

People and facilities located farther away from the volcano may have additional time to prepare for the adverse effects of an eruption; however, an emergency plan should be developed and ready prior to the onset of an eruption. The planning for volcanic emergencies is similar to that for other emergencies, such as flooding or extreme weather. The sources of emergency information are often the same and the usual interruption of essential services may result. Thus, planning for interruptions in electrical service, transportation (especially air travel), and outdoor activities is appropriate for volcanic emergencies.

REFERENCES CITED

- Alaska Sportsman, 1949, From Barrow to Ketchikan: p. 18.
- Blong, R.J., 1984, Volcanic hazards—A sourcebook on the effects of eruptions: Sydney, Academic Press, 424 p.
- Brantley, S.R., ed., 1990, The eruption of Redoubt Volcano, Alaska, December 14, 1989—August 31, 1990: U.S. Geological Survey Circular 1061, 33 p.
- Byers, F.M., Jr., and Barth, T.F.W., 1953, Volcanic activity on Akun and Akutan Island: 7th Pacific Science Conference Proceedings, New Zealand, v. 2, p. 382-397.
- Carey, S., Sigurdsson, H., Mandeville, C., and Bronto, S., 1996, Pyroclastic flows and surges over water: An example from the 1883 Krakatau eruption: Bulletin of Volcanology, v. 57, p. 493-511.
- Casadevall, T.J., ed., 1994, Volcanic ash and aviation safety: Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety: U.S. Geological Survey Bulletin 2047, 450 p.
- Eichelberger, J.C., Keith, T.E.C., Miller, T.P., and Nye, C.J., 1995, The 1992 eruptions of Crater Peak Vent, Mount Spurr Volcano, Alaska. Chronology and summary, in Keith, T.E.C., ed., The 1992 eruptions of Crater Peak Vent, Mount Spurr Volcano, Alaska: U.S. Geological Survey Bulletin 2139, p. 1-18.
- Finch, R.H., 1935, Akutan Volcano: Zeitschrift für Vulkanologie, Bd. XVI, p. 155-160.
- Lander, J.F., 1996, Tsunamis affecting Alaska 1737-1996: National Geophysical Data Center Key to Geophysical Research Documentation No. 31, 195 p.
- Latter, J.H., 1981, Tsunamis of volcanic origin: Summary of causes with particular reference to Krakatoa, 1883: Bulletin of Volcanology, v. 44, p. 467-490.
- Lockwood, M., Elms, J.D., Lockridge, P.A., Moore, G.W., Nishenko, S.P., Simkin, T., and Newhall, C.G., 1990, Natural hazards map of the Circum-Pacific region; Pacific Basin sheet: U.S. Geological Survey Circum-Pacific Map Series, CP-31.
- McGimsey, R.G., Neal, C.A., and Doukas, M.P., 1995, 1992 volcanic activity in Alaska: Summary of events and response of the Alaska Volcano Observatory: U.S. Geological Survey Open-File Report 95-83, 26 p.
- Miller, T.P., McGimsey, R.G., Richter, D.H., Yount, M.E., Nye, C.J., and Dumoulin, J. Catalog of active volcanoes in Alaska. U.S. Geological Survey Open-File Report, in prep.
- Motyka, R.J., and Nye, C.J., (eds.), 1988, A geological, geochemical, and geophysical survey of the geothermal resources at Hot Springs Bay Valley, Akutan Island, Alaska: Alaska Division of Geological and Geophysical Surveys, Report of Investigations 88-3, 115 p.
- Myers, B., Brantley, S.R., Stauffer, P., and Hendley, J.W., II, 1997, What are volcano hazards?: U.S. Geological Survey Fact Sheet FS 002-97.
- Reeder, J.W., 1983, Preliminary dating of the caldera forming Holocene volcanic events for the eastern Aleutian Islands: Geological Society of America Abstracts with Program, v. 15, p. 668.
- Richter, D.H., Waythomas, C.F., McGimsey, R.G., and Stelling, P.L., 1998, Geologic map of Akutan Island, Alaska: U.S. Geological Survey Open-File Report 98-135, 22 p. + plate
- Scott, K.M., 1988, Origins, behavior, and sedimentology of lahars and lahar-runout flows in the Toutle-Cowlitz River System: U.S. Geological Survey Professional Paper 1447-A, 74 p.
- Simkin, T., and Fiske, R.D., 1983, Krakatau 1883—The volcanic eruption and its effects: Washington, Smithsonian Institution Press, 464 p.
- Simkin, T., and Siebert, L., 1994, Volcanoes of the world: Tucson, Geoscience Press, 349 p.

Vallance, J.W., and Scott, K.M., 1997, The Osceola mudflow from Mount Rainier: Sedimentology and hazard implications of a huge clay-rich debris flow: Geological Society of America Bulletin, v. 109, p. 143-163.

Waythomas, C.F., and Neal, C.A., 1997, Tsunami generation during the 3500 yr B.P. caldera-forming eruption of Aniakchak Volcano: Eos, Transactions of the American Geophysical Union, v. 78, no. 46, p. F816.

Waythomas, C.F., in prep., Late Holocene caldera formation and stratigraphic framework of Holocene volcanoclastic deposits, Akutan Volcano, east-central Aleutian Islands, Alaska.

GLOSSARY

Aa. A Hawaiian term for lava flows that have a rough, jagged surface.

Andesite. A fine-grained volcanic rock made up of feldspars and ferromagnesian minerals; typically has a silica content of 54 to about 62 percent.

Ash. Fine fragments (less than 2 millimeters across) of lava or rock formed in an explosive volcanic eruption.

Caldera. A large crater formed by collapse or subsidence of the ground surface following a great eruption. During a typical caldera-forming eruption, the magma chamber is partially emptied and large amounts of ash and pyroclastic debris are extruded.

Cohesive lahar. A type of volcanic debris flow that contains more than 3-5 percent clay in the deposit matrix. Such lahars are thought to form from volcanic debris avalanches. Cohesive lahars are very mobile and may flow long distances (several tens of kilometers or more).

Debris avalanche. Rapidly moving, dry flows of disaggregated rock debris, sand, and silt. Volcanic debris avalanches commonly form by some type of structural collapse of the volcano, usually the steep front of the cooled lava dome, or other parts of the upper edifice. A large portion of the volcano may become unstable, break away from the volcanic massif, and become an avalanche. A debris avalanche may be triggered by an eruption or earthquake. Debris avalanches move at velocities ranging from a few tens of meters per second to more than 100 meters per second and behave like complex granular flows or slide flows. Commonly they are quite voluminous (greater than 10 cubic kilometers) and may run out

considerable distances (up to 85 kilometers) from their source. The resulting debris-avalanche deposit usually exhibits hummocky surface morphology.

Dike. A tabular igneous intrusion that cuts across the host bedrock.

Eruption cloud. Cloud of gas, ash, and other fragments that forms during an explosive volcanic eruption and travels long distances with the prevailing winds.

Eruption column. The vertical portion of the eruption cloud that rises above a volcanic vent.

Fallout. A general term for debris that falls to the earth from an eruption cloud.

Fumarole. A small volcanic vent from which gases and vapors are emitted.

Holocene. A geologic time designation for the last 10,000 years of Earth history.

Hypocenter. The point within the Earth that is the center of an earthquake. The initial point of rupture during an earthquake.

Lahar. An Indonesian term for a debris flow containing angular clasts of volcanic material. For the purposes of this report, a lahar is any type of sediment-water mixture originating on or from the volcano. Most lahars move rapidly down the slopes of a volcano as channelized flows and deliver large amounts of sediment to the rivers and streams that drain the volcano. The flow velocity of some lahars may be as high as 20 to 40 meters per second and sediment concentrations of greater than 750,000 parts per million are not uncommon. Large volume lahars can travel great distances if they have an appreciable clay content (greater than 3 to 5 percent), remain confined to a stream channel, and do not significantly gain sediment while losing water. Thus, they may affect areas many tens to hundreds of kilometers downstream from a volcano.

Lapilli. Ejected rock or pumice fragments between 2 and 64 millimeters in diameter.

Lava. Molten rock that reaches the Earth's surface.

Lava dome. A steep-sided mass of viscous and commonly blocky lava extruded from a vent; typically has a rounded top and roughly circular outline.

Magma. Molten rock beneath the Earth's surface.

Noncohesive lahar. A type of volcanic debris flow that contains less than 3-5 percent clay in the deposit matrix. Such lahars form when meltwater produced by the interaction of pyroclastic flows and snow or ice picks up locally available sediment on the flanks

of a volcano, or in stream channels developed on the volcano. Noncohesive lahars usually evolve downstream into watery sediment-laden flows called hyperconcentrated flows, or floods.

Pleistocene. A geologic time designation for the period of Earth history from about 1.6 million years ago to about 10,000 years ago.

Pyroclastic flow. A dense, hot, chaotic avalanche of rock fragments, gas, and ash that travels rapidly away from an explosive eruption column, down the flanks of the volcano (synonymous with “ash flow”). Pyroclastic flows move at speeds ranging from 10 to several hundred meters per second and are typically at temperatures between 300 and 800 °C (Blong, 1984). Pyroclastic flows form either by collapse of the eruption column, or by failure of the front of a cooling lava dome. Once these flows are initiated, they may travel distances of several kilometers or more and easily override topographic obstacles in the flow path. A person could not outrun an advancing pyroclastic flow.

Pyroclastic surge. A low-density, turbulent flow of fine-grained volcanic rock debris and hot gas. Pyroclastic surges differ from pyroclastic flows in that they are less dense and tend to travel as a low, ground-hugging, but highly mobile cloud that can surmount topographic barriers. Surges often affect areas beyond the limits of pyroclastic flows.

Radiometric age. An age estimate in years for rocks and other geologic materials determined by measuring the amount of a radioactive element such as carbon-14, or a radioactive element and its decay product such as potassium-40/argon-40.

Scarp. A low concave cliff or series of cliffs that marks the detachment zone of a landslide or slope failure.

Scoria. A cinder-like volcanic rock, usually dark brown, red-brown, or black in color.

Seismic swarm. A series of earthquakes, occurring in a limited area over a relatively short period of time.

Stratovolcano (also called a stratocone or composite cone). A steep-sided volcano, usually conical in

shape, built of lava flows and fragmental deposits from explosive eruptions.

Strombolian. An eruption style characterized by pulse-like explosive bursts and low-level emission of ash and pyroclastic debris. Usually each burst lasts for only a few seconds, and sustained eruption columns generally do not develop.

Tectonic. Refers to earthquakes generated by faulting rather than by volcanic activity.

Tephra. Any type of rock fragment that is forcibly ejected from the volcano during an eruption. Tephra may be fine-grained dust or “ash” (0.0625 to 2 millimeter diameter—silt to sand sized), coarser “lapilli” (2 to 64 millimeter diameter—sand to pebble sized), or consist of large blocks or bombs (greater than 64 millimeter—cobble to boulder sized). When tephra is airborne, the coarsest fraction will be deposited close to the volcano, but the fine fraction may be transported long distances and can stay suspended in the atmosphere for many months. Tephra particles are typically sharp, angular, and abrasive, and are composed of volcanic glass, mineral, and rock fragments.

Tsunami. Widely spaced, fast-moving ocean wave(s) most commonly initiated by sudden displacements of the sea floor during earthquakes or submarine landslides. Volcanic eruptions can also cause tsunamis if unconsolidated volcanic sediment flows rapidly or falls into the water as in a catastrophic slope failure from a steep-sided volcanic cone or edifice, or if explosive eruptions occur at or near sea level. Tsunamis are capable of inundating significant portions of the coastline, especially if the wave energy is focused by narrowing of inlets and bays.

Vent. An opening in the Earth's surface through which magma erupts or volcanic gases are emitted.

Volcaniclastic. A volcanic rock or unconsolidated deposit composed of pre-existing fragments, particles or clasts of volcanic origin.

NOTE:

This plate was printed on a color ink-jet
plotter. The ink will run if the plate gets
wet.

USGS LIBRARY - RESTON



3 1818 00265879 5