U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Preliminary Volcano-Hazard Assessment for Kanaga Volcano, Alaska

Open-File Report 02–397

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This report is preliminary and subject to revision as new data become available. It does not conform to U.S. Geological Survey editorial standards or with the North American Stratigraphic Code.

Alaska Volcano Observatory
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The Alaska Volcano Observatory (AVO) was established in 1988 to monitor dangerous volcanoes, issue eruption alerts, assess volcano hazards, and conduct volcano research 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 eruptions on the Kamchatka Peninsula of the Russian Far East as part of a formal working relationship with the Kamchatkan Volcanic Eruptions Response Team.

Cover photograph: South flank of Kanaga Volcano, June 2000. Although Kanaga Volcano does not support glacier ice, it is snow covered most of the year. The small snow-free zone near the summit is an area kept warm by active fumaroles. Photograph by C.F. Waythomas, U.S. Geological Survey.

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By Christopher F. Waythomas, Thomas P. Miller, and Christopher J. Nye

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Alaska Volcano Observatory

Anchorage, Alaska

2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS and VERTICAL DATUM

Multiply	by	To obtain
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
cubic kilometer (km^3)	0.2399	cubic mile
meter per second (m/s)	3.281	foot per second
cubic meter per second (m^3/s)	35.31	cubic foot per second

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the equation

$$°F = (1.8 \times °C) + 32)$$

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada. In the area of this report, datum is mean lower low water.

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SUMMARY OF VOLCANO HAZARDS AT KANAGA VOLCANO

• Ash clouds

Clouds of volcanic ash 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 future eruptions could interfere with air travel, especially during a large, sustained eruption

.• Ash fallout

Ash fallout *from historical and prehistorical eruptions of Kanaga Volcano reached Adak and possibly other nearby islands in the west-central Aleutian Islands. Several millimeters of fine ash were deposited on parts of Adak Island during the 1993-95 eruption. Fine ash may cause respiratory problems in some humans and animals. Heavy ash fall can disrupt many human activities, interfere with power generation, affect visibility, and damage electrical components and equipment. Resuspension of ash by wind could extend the unpleasant effects of ash fallout.*

• Volcanic Bombs (Ballistics)

During most eruptions, pebble-sized and larger fragments of volcanic rock may be explosively ejected from the vent. These particles are called volcanic bombs or ballistics. Impact craters formed by ballistic fallout are common on the flanks of Kanaga Volcano. Ballistic fallout could occur within a few kilometers of the vent and would be hazardous to people, boats, or aircraft near the volcano.

• Lava flows

Streams of molten rock (lava) may extend a few kilometers from the vent. Most lava flows expected at Kanaga Volcano will 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 on the volcano or into the sea could be hazardous to people or boats close to the flow front. Lava flows that reach the sea could generate steam explosions.

• Lahar and lahar-runout flows

Hot volcanic debris interacts with snow and ice to form fast-moving slurries of water, mud, rocks, and sand. These flows, called lahars, are expected to form during most future eruptions of Kanaga Volcano. Lahars will follow streams and drainage ways and could flow to the coastline and into the sea on the north and west sides of the volcano.

THE ALASKA VOLCANO-HAZARD ASSESSMENT SERIES

This report is part of a series of volcano-hazard assessment reports 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. Considered preliminary, these reports are subject to revision as new data become available.

• **Pyroclastic flows and surges**

Hot material expelled from the volcano may travel rapidly down the volcano flanks as flows of volcanic debris called pyroclastic flows and surges. These flows will travel primarily along valleys, gullies, and low-lying topography and are expected to reach the coastline on the north and west sides of the volcano. Historical eruptions did not produce pyroclastic flows and they are not expected to form during most effusive eruptions. They pose little hazard except to people on or near the volcano during an eruption. Pyroclastic flows may extend out over water and could be hazardous to passing ships.

Other hazardous phenomena that may occur but are uncommon during typical eruptions of Kanaga Volcano include the following:

• **Debris avalanches**

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. Debris-avalanche deposits are present on the volcano but are small in volume. Debris avalanches could form during future eruptions of Kanaga Volcano, but they are not likely to be voluminous. Small rockfalls and avalanches could occur along the coastline and could be hazardous to people and boats.

• **Directed blasts**

A directed blast *is a lateral explosion of the volcano caused by rapid release of internal pressure, commonly resulting in a slope failure or landslide. Directed blasts are rare volcanic events. Evidence for a directed blast has not been identified at the Kanaga Volcano.*

• **Volcanic gases**

Some volcanoes emit gases in concentrations that are harmful to humans. The vent area on Kanaga Volcano is a crater-like depression that could collect harmful gases. However, the frequently windy conditions around the volcano will likely prevent the buildup of volcanic gases. Thus, the hazard from volcanic gases is minimal unless one is in or near the crater for prolonged periods of time.

SUGGESTIONS FOR READING THIS REPORT

Readers who want a brief overview of volcano hazards at Kanaga Volcano are encouraged to read the summary section and consult plate 1 and the illustrations. Individual sections of this report provide a slightly more comprehensive overview of the various hazards at Kanaga Volcano. A glossary of relevant geologic terms is included. Additional information about Kanaga Volcano can be obtained by consulting the references cited at the end of this report or by visiting the Alaska Volcano Observatory Web site (URL: <http://www.avo.alaska.edu>).

INTRODUCTION

Kanaga Volcano is a steep-sided, symmetrical, cone-shaped, 1307 meter high, andesitic *stratovolcano* on the north end of Kanaga Island (51°55' N latitude, 177°10' W longitude) in the western Aleutian Islands of Alaska (fig. 1). Kanaga Island is an elongated, low-relief (except for the volcano) island, located about 35 kilometers west of the community of Adak on Adak Island and is part of the Andreanof Islands Group of islands (fig. 2). Kanaga Volcano is one of the 41 historically[1] active volcanoes in Alaska and has erupted numerous times in the past 11,000 years, including at least 10 eruptions in the past 250 years (Miller and others, 1998). The most recent eruption occurred in 1993-95 and caused minor *ash* fall on Adak Island and produced blocky aa *lava* flows that reached the sea on the northwest and west sides of the volcano (Neal and others, 1995).

The summit of the volcano is characterized by a small, circular crater about 200 meters in diameter and 50-70 meters deep. Several active fumaroles are present in the crater and around the crater rim. The flanking slopes of the volcano are steep (20-30 degrees) and consist mainly of blocky, linear to spoon-shaped lava flows that formed during eruptions of late *Holocene* age (about the past 3,000 years). The modern cone sits within a circular caldera structure that formed by large-scale collapse of a preexisting volcano. Evidence for eruptions of this preexisting volcano mainly consists of lava flows exposed along Kanaton Ridge, indicating that this former volcanic center was predominantly *effusive* in character.

In winter (October-April), Kanaga Volcano may be covered by substantial amounts of snow that would be a source of water for *lahars* (volcanic mudflows). In summer, much of the snowpack melts, leaving only a patchy distribution of snow on the volcano. Glacier ice is not present on the volcano or on other parts of Kanaga Island.

Kanaga Island is uninhabited and is part of the Alaska Maritime National Wildlife Refuge, managed by the U.S. Fish and Wildlife Service (http://www.r7.fws.gov/nwr/akmnwr.html). The island is remote and often shrouded by clouds and fog. It can be reached only by boat, helicopter,or amphibious-landing aircraft.

[1] The "historical" period is generally the past 200-300 years and loosely corresponds to the period of written records of volcanic activity in Alaska.

Figure 1. Location of Kanaga Volcano with respect to other active volcanoes in Alaska.

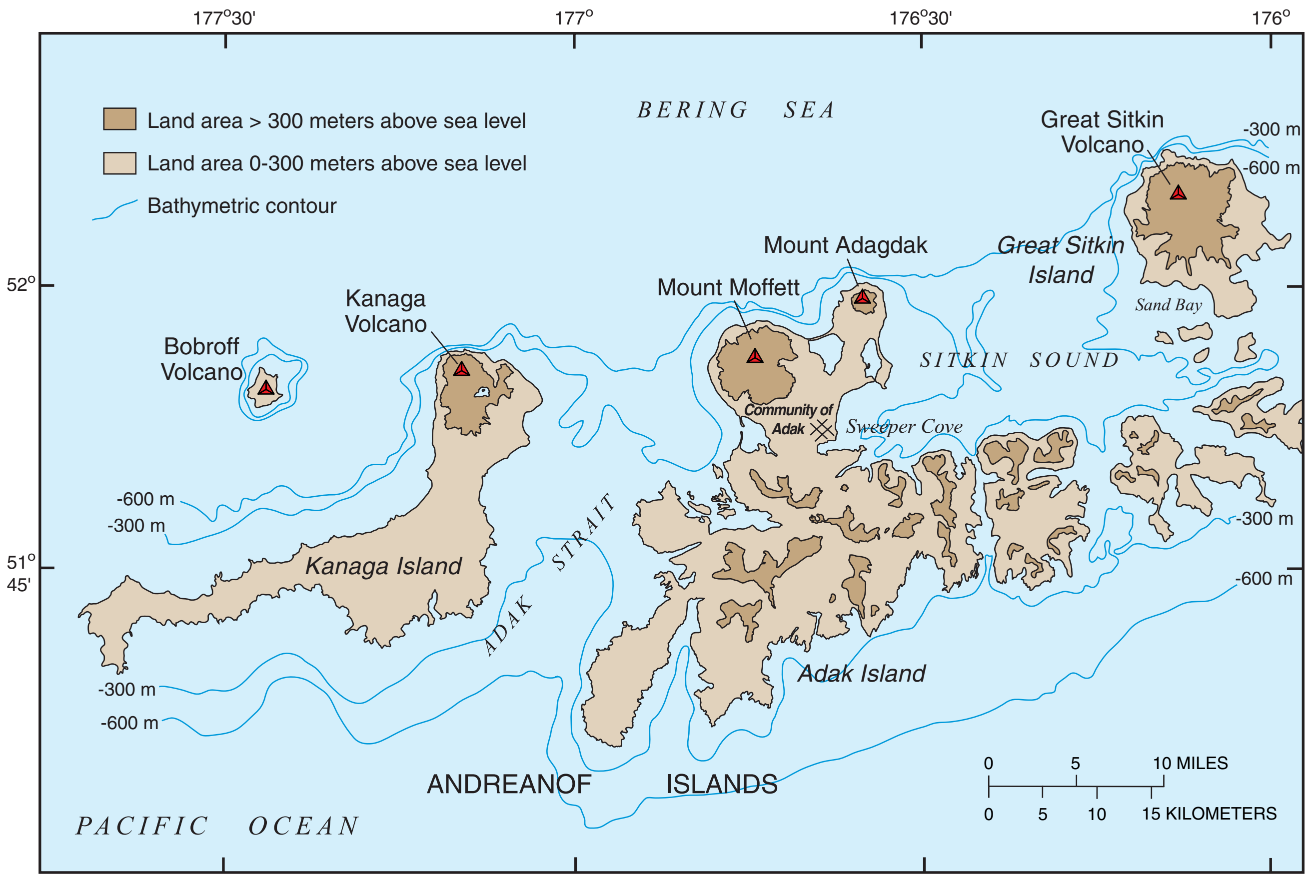


Figure 2. Geographic setting of Kanaga Volcano and nearby islands. Also shown is Adak, the closest community to Kanaga Volcano.

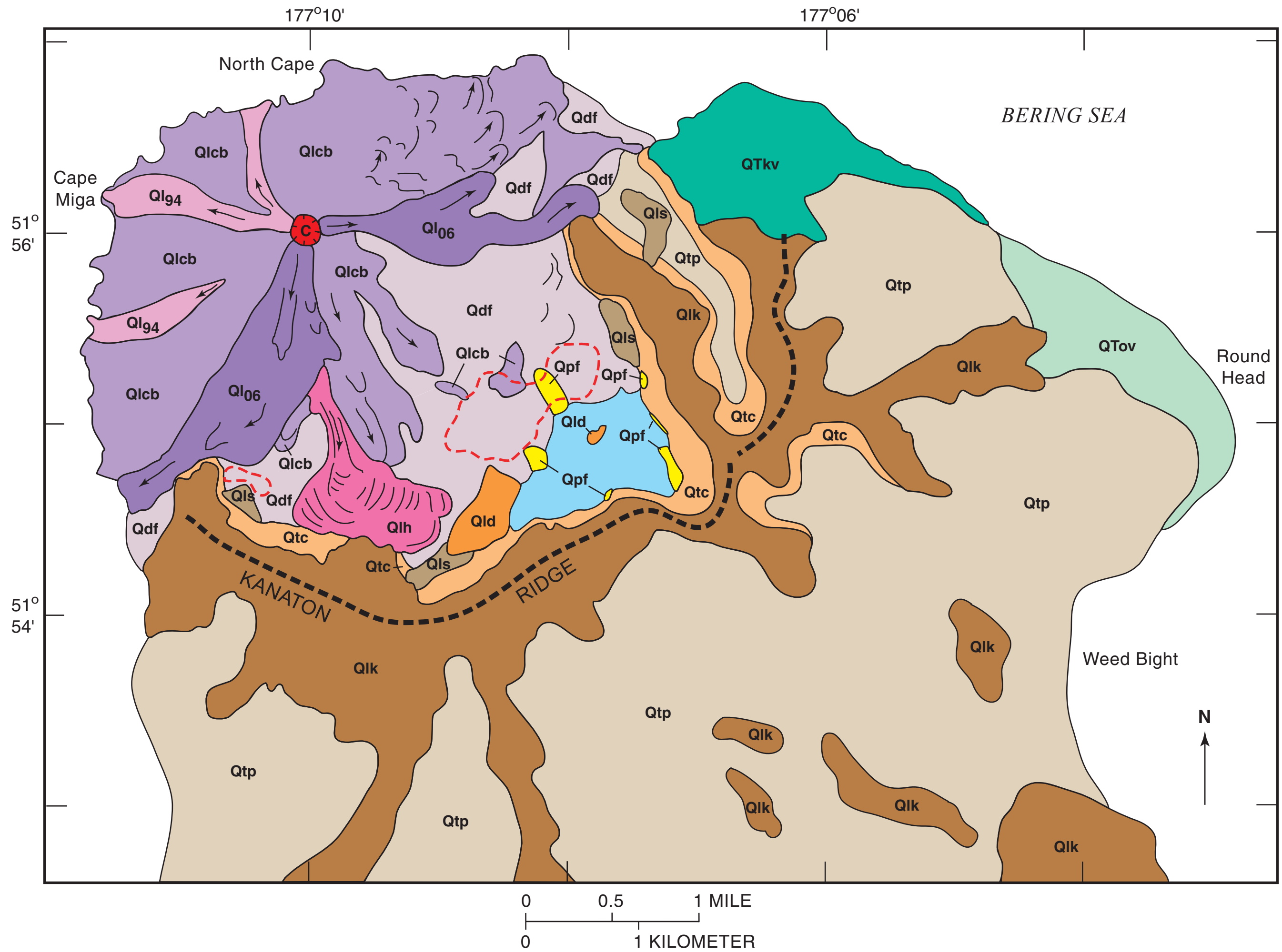
Purpose and Scope

This report summarizes the principal volcano hazards associated with eruptions of Kanaga Volcano. Hazardous volcanic phenomena likely to occur on or near the volcano, as well as distal effects of eruptions, are described. 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 show potentially hazardous areas are included. A glossary of geologic terms is provided at the end of the report. Terms defined in the glossary are italicized at their first appearance in the text.

PREHISTORIC ERUPTIVE ACTIVITY ON NORTHERN KANAGA ISLAND

The modern cone of Kanaga Volcano consists of lava flows composed of *andesite* and basaltic andesite that are unsystematically interbedded with rock avalanche debris, *ash*, and *pyroclastic*-flow and lahar deposits (fig. 3). The modern cone sits within an arcuate-shaped, 6-kilometer-diameter caldera defined by a prominent ridge around the south and east sides of the volcano called Kanaton Ridge (fig. 4; Coats, 1956). The rocks that compose Kanaton Ridge were erupted from ancestral Mount Kanaton and include lava flows, pyroclastic rocks (fig.3), and minor intrusive rocks of late *Tertiary* to *Pleistocene* age (Coats, 1956; Fraser and Barnett, 1959; Brophy, 1990). Basaltic lava flows exposed along the northeastern coast of Kanaga Island formed during eruptions from *vents* on the flanks of the ancestral volcano (Coats, 1956) and from preexisting vents offshore.

The lava flows that compose Kanaton Ridge dip southerly at low angles (less than 15 degrees), implying that most of these rocks were part of a broad, shield-like volcano–Mount Kanaton–whose vent was located near the site of the modern cone. Kanaton Ridge and its associated south-dipping lava flows are



DESCRIPTION OF MAP UNITS

Lava flows of historical eruptions

Ql94 Andesite flows erupted in 1994.

Ql06 Andesite flows erupted in 1906.

Qlh **Lava flow of late Holocene age**—Andesite aa lava flow produced by historical(?) eruption of Kanaga Volcano.

Qlcb **Lava flows of Holocene age**—Lava flows produced by prehistoric and older eruptions of Kanaga Volcano. May include areas of blocky talus and avalanche debris.

Qpf **Pyroclastic-flow deposits of Holocene age**—Pumiceous pyroclastic-flow deposits associated with eruptions from vents on the southeast flank of Kanaga Volcano.

Qld **Lava domes of Holocene(?) age**—Andesite lava domes on the southeast flank of Kanaga Volcano.

Qdf **Lahar and lahar runout deposits of Holocene age**—Poorly sorted, fan-shaped deposits of boulders, gravel, sand, and silt deposited by water-saturated mixtures of volcaniclastic debris during eruptions. May contain juvenile clasts of dacite and andesite.

Qtp **Tephra, soil, and peat deposits of Holocene age**—Blanketing mantle of air-fall tephra, buried soils, and peat, 1-3 meters thick. May include colluvial and beach deposits.

Qls **Landslide deposits (age uncertain)**—Intact to partially disaggregated blocks of andesitic lava derived from Kanaton Ridge.

Qtc **Talus and other colluvial deposits of Holocene age**—Rock rubble, solifluction deposits, and rockfall debris on slopes.

Qlk **Lava flows erupted from Mount Kanaton (Pleistocene and Pliocene?)**—Andesitic, cone-building lava flows of ancestral Kanaton Volcano.

QTkv **Lava flows older than Kanaton Volcano (Quaternary or Tertiary)**—Basaltic lava flows erupted from vents on or near the north coast of Kanaga Island.

QTov **Lava flows erupted from vents offshore of Kanaga Island (Quaternary or Tertiary)**—Basaltic lava flows and breccia associated with no-longer-active vents offshore of Kanaga Island.

C **Crater of Kanaga Volcano**

Pressure ridges and flow fronts of lava flows

Flow path of lava flows

Collapse caldera margin

Field of ballistic impact craters

Figure 3. Generalized geologic map of northern Kanaga Island and Kanaga Volcano.

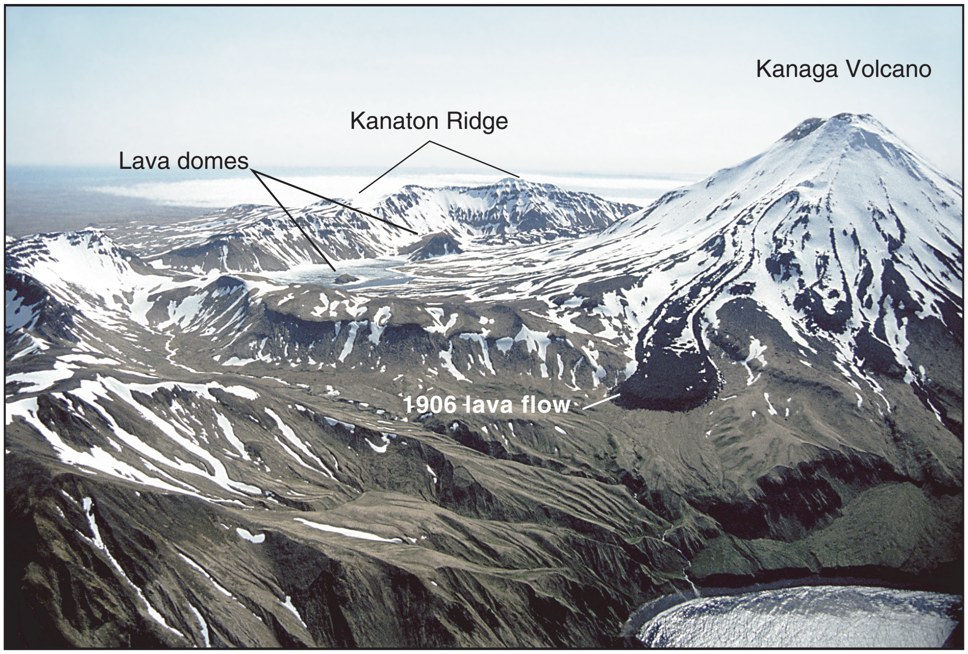


Figure 4. Kanaga Volcano, Kanaton Ridge, the 1906 lava flow, and lava domes south of the volcano. View is to the southwest. Photograph by C.J. Nye, Alaska Division of Geological and Geophyical Surveys, June 2000.

all that remain of this ancestral volcano (fig. 5). The destruction of Mount Kanaton and the formation of the caldera-like escarpment that defines Kanaton Ridge (fig. 6) were thought to have been the result of a major explosive eruption (Coats, 1956; Black, 1980; Miller and others, 1998). Caldera formation at other volcanoes is commonly associated with the generation of voluminous pyroclastic- or ash-flow deposits (Miller and Smith, 1987; Lipman, 2000). Roof collapse over a shallow *magma* chamber tends to produce a circular caldera depression that is typically flanked on all sides by extensive ash-flow deposits. Such deposits extend radially away from the volcano for tens of kilometers and form sheet-like accumulations of ash-flow debris meters to many tens of meters thick. Pyroclastic-flow deposits like this are absent on northern Kanaga Island. Pyroclastic-flow deposits are recognized in only a few locations around the southeast end of the intracaldera lake and at one location outside the caldera. Radiocarbon ages associated with the deposits inside the caldera near the lake indicate that they were erupted within the past 1,000 years. The lack of widespread pyroclastic-flow deposits on the southern slopes of Kanaton Ridge indicates that a major pyroclastic eruption of ancestral Mount Kanaton did not lead to caldera formation as previously thought (Coats, 1956; Black, 1980; Miller and others, 1998) and, therefore, that the caldera structure must have formed by another process. Structural collapse of ocean-island volcanoes has been documented in many areas of the world where a substantial portion of the volcano fails and slides seaward. In the absence of strong evidence for caldera formation associated with a major pyroclastic eruption, it appears likely that sometime prior to the development of Kanaga Volcano, Mount Kanaton collapsed to the northwest and a sizeable piece of the volcano slid into the sea.

Long-range sidescan sonar data (Bering Sea EEZ-Scan Scientific Staff, 1991) from just offshore of northern Kanaga Island indicate areas of irregular, hummocky topography comparable in volume to the size of the avalanche caldera. The hummocky deposits on the sea floor may be debris-avalanche deposits formed by the collapse of ancestral Mount Kanaton. It is not known when the avalanche caldera formed, but recent studies of Kanaga Volcano indicate that the bulk of the modern cone is of Holocene age. Therefore, caldera formation most likely occurred more than 10,000 years ago.

Other aspects of the eruptive history of Kanaga Volcano have been determined by analyzing volcanic ash deposits preserved in areas beyond the volcano. Volcanic activity is generally episodic: long periods of

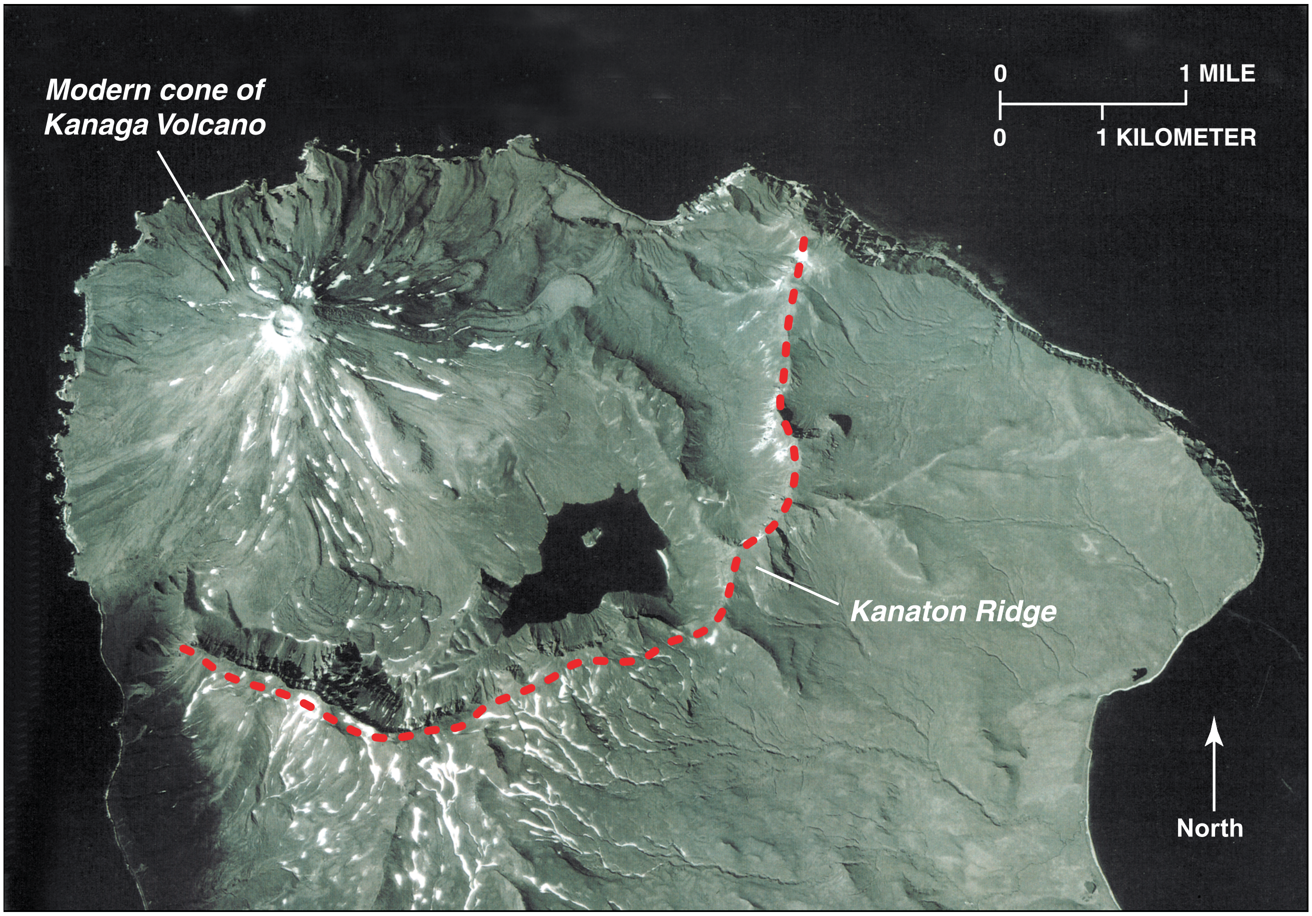


Figure 5. Aerial photograph of northern Kanaga Island showing the modern cone of Kanaga Volcano and Kanaton Ridge.

inactivity are punctuated by periods of rapid deposittion of volcanic sediment or lava flows during eruptions. Vegetation growth and soil development may occur during noneruptive periods, but during eruptions, vegetation and soil may be buried by volcanic deposits, particularly volcanic ash. A stratigraphic sequence of buried soils and vegetation, volcanic deposits, and volcanic ash develops in this manner over many thousands of years. It is possible to determine the eruptive history of the volcano by dating buried soils and plant remains associated with the volcanic deposits. Volcanic rocks can be dated directly using *radiometric dating* techniques such as argon-argon dating. This methodology has been applied at Kanaga Volcano, and recent studies have concentrated on the geologic record of volcanic ash deposition. These results are the basis for deciphering the eruptive history of the volcano during the past 11,000 years.

Coarse-grained pyroclastic-fall deposits are common on the slopes surrounding Kanaton Ridge (fig. 3) and also on nearby Adak Island (Kiriyanov and Miller, 1997) (fig. 2). Pyroclasts in these deposits range in size from several millimeters (coarse ash) to several centimeters (*lapilli*) in diameter. The coarse-grained ash and lapilli beds on northern Kanaga Island were undoubtedly produced by explosive eruptions of Kanaga Volcano as it evolved during the Holocene epoch. Recent studies of the geology of Kanaga Volcano and radiocarbon dating of buried soils associated with prominent pyroclastic-fall deposits indicate that the volcano has erupted explosively many times during the past 11,000 years (fig. 7). Pyroclastic-fall deposits composed of pebble-sized *pumiceous* lapilli are common in many locations on northern Kanaga Island. These deposits record major explosive eruptions associated with extensive ash *fallout*, localized *pyroclastic flows*, lahars, and *lava* flows. At least four such eruptions have occurred in the past 11,000 years, and the most recent explosive event occurred about 500 years ago (fig. 7). Small, short lived eruptions, similar to the 1993-95 eruption, also occurred many times in the past, and these generally produced thin, fine-grained,

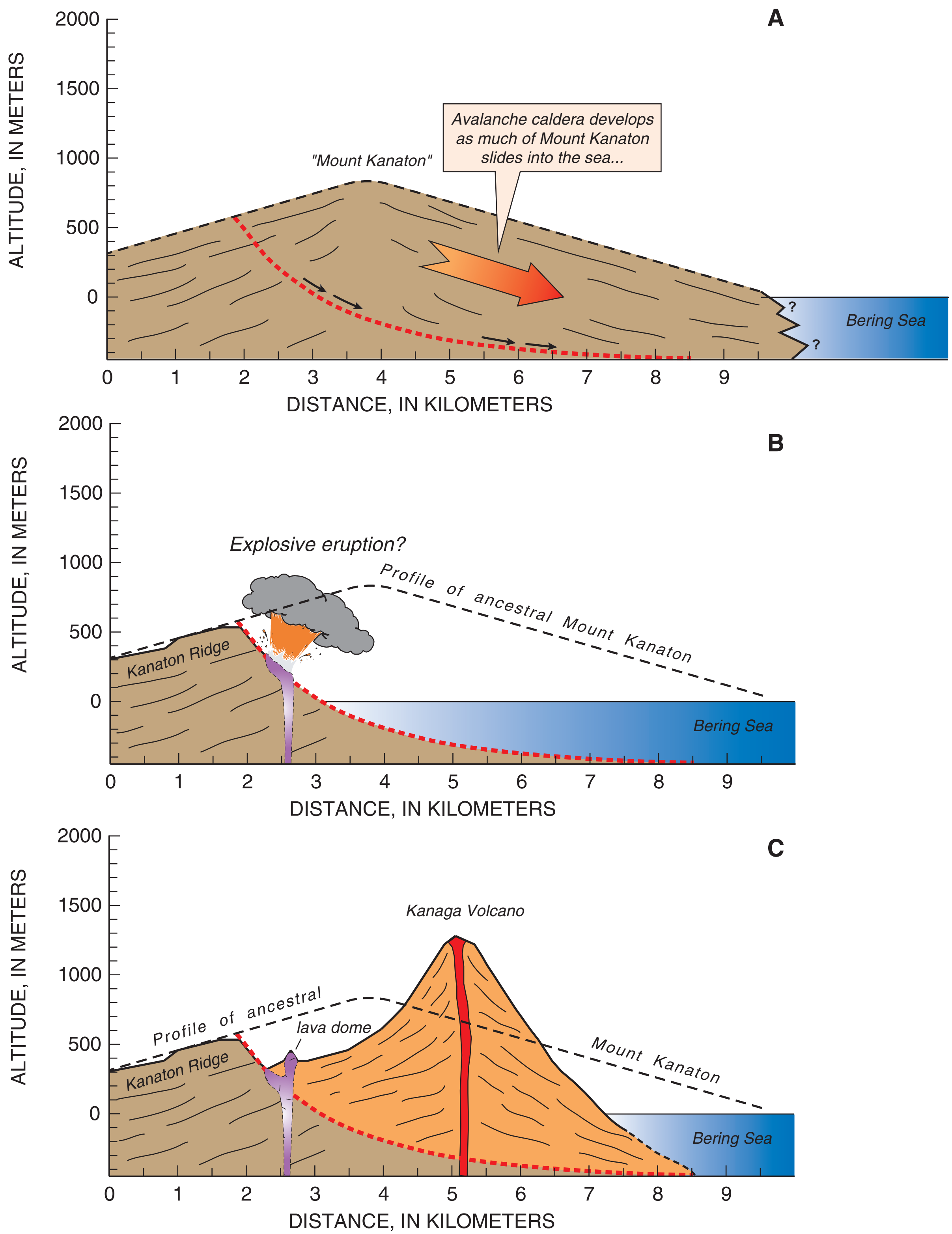


Figure 6. Interpretation of the evolution of Mount Kanaton and Kanaga Volcano. A) Resconstruction of ancestral Mount Kanaton, showing geologic conditions at the time of a northwestward flank collapse of the volcano. B) Possible post-collapse eruption. C) The modern cone of Kanaga Volcano develops in the collapse scrap of Mount Kanaton. A lava dome complex on the distal south flank of the volcano may have been an active vent since the destruction of former Mount Kanaton.

localized volcanic ash deposits, small pyroclastic flows and lahars on the flanks of the volcano, and lava flows (fig. 7). Stratigraphic profiles of volcanic ash from various locations on northern Kanaga Island also contain a number of silt-sized, thin-bedded ash layers. Many of these deposits were formed by minor, short-lived eruptions of Kanaga Volcano, but some of the ash beds could be fallout from other volcanoes west of Kanaga Island (fig. 1).

HISTORICAL ERUPTIONS

Recurrent, small-scale, ash-and-lava-producing eruptions have characterized the eruptive behavior of Kanaga Volcano during the past 200 years. "Smoke" was reported above the island in 1790, 1791, 1827, and 1829; some or all of these accounts may refer to steam produced by fumaroles on the upper part of the cone (Coats, 1956). Activity of an unspecified nature was noticed in 1763, 1768, 1786 (Grewingk, 1850; cited in Petroff, 1884), and 1933 (Coats, 1956). The most significant historical volcanic event observed on Kanaga was a series of lava flows erupted in 1906 (Coats, 1956) and possibly earlier, in 1904 (Jaggar, 1927). A trapper living on the island in 1906 experienced several earthquakes and witnessed lava pouring down both the east and west sides of the cone. Coats (1956) interpreted these flows to be the ones now present on the northeast and southwest slopes of the volcano (fig. 3). Another flow, on the northeast flank of the volcano, may have formed during a poorly documented eruption in 1904.

The most recent eruption began in mid-1993 and continued intermittently throughout most of 1995 (Neal and others, 1995). The eruption was characterized by steam and ash plumes rising as high as 7.5 kilometers above sea level and drifting a few tens of kilometers downwind (mainly east) from the volcano. The exact start of the eruption is not known, although pilot reports indicated a distinct increase in steam emissions from the summit crater by April 1993. By early January 1994, short-lived explosive bursts that produced ash plumes rising as high as 1 kilometer above the summit were reported by pilots and residents of Adak Island. At least two significant ash-plumes were observed during 1994, on February 21 and August 18. The February 21 eruption generated an ash plume that rose to about 7.5 kilometers above sea level, and the August 18 eruption sent a plume to about 4.5 kilometers above sea level. Light ash fall (a few millimeters or less) was reported on parts of Adak Island on August 20, especially on the northwest side of the island near Mount Moffett and on the community of Adak. Air traffic was disrupted on August 22 because of continued low-level eruptive activity and cloudy conditions that, together, prevented visual approaches to the Adak airfield. During the eruption, lava was extruded from vents in the summit crater. The lava overflowed the crater and formed blocky aa lava flows that streamed down the north and northwest sides of the volcano. The lava flows reached the sea in at least two places where they produced minor steam explosions. Piles of incandescent debris accumulated on the crater rim and occasionally collapsed and flowed down the north flank of the volcano, sometimes reaching the sea and also producing minor steam explosions. Strong sulfur odors coincident with westerly winds were reported on occasion by people on Adak.

HAZARDOUS PHENOMENA ASSOCIATED WITH ERUPTIONS

A volcano hazard (fig.8) is any volcanic phenomenon that is potentially threatening to life or property. In general, hazards associated with volcanic eruptions are grouped as proximal or distal relative to the areas most likely to be affected by specific volcanic phenomena as a function of distance from the vent. The classification of hazardous phenomena as proximal or distal is an approximate classification because the extent of a particular hazard is, in part, related to the size of the eruption. Thus, a large eruption may cause some phenomena to affect areas well beyond the volcano, whereas during a smaller eruption, the same phenomena may only affect areas in the immediate vicinity of the volcano.

Proximal hazards are those phenomena that occur in the immediate vicinity of the volcano, typically within a few tens of kilometers of the active vent. The proximal hazard zone boundary can be approximated by the ratio of the volcano summit height (H) to the runout length (L) of on-ground hazardous phenomena such as pyroclastic flows, *debris avalanches*, and lahars. Typical H/L values for volcanoes like Kanaga range from 0.1 to 0.3, and this zone includes all of northern Kanaga Island. People, structures, and boats within the proximal hazard zone may be at risk during

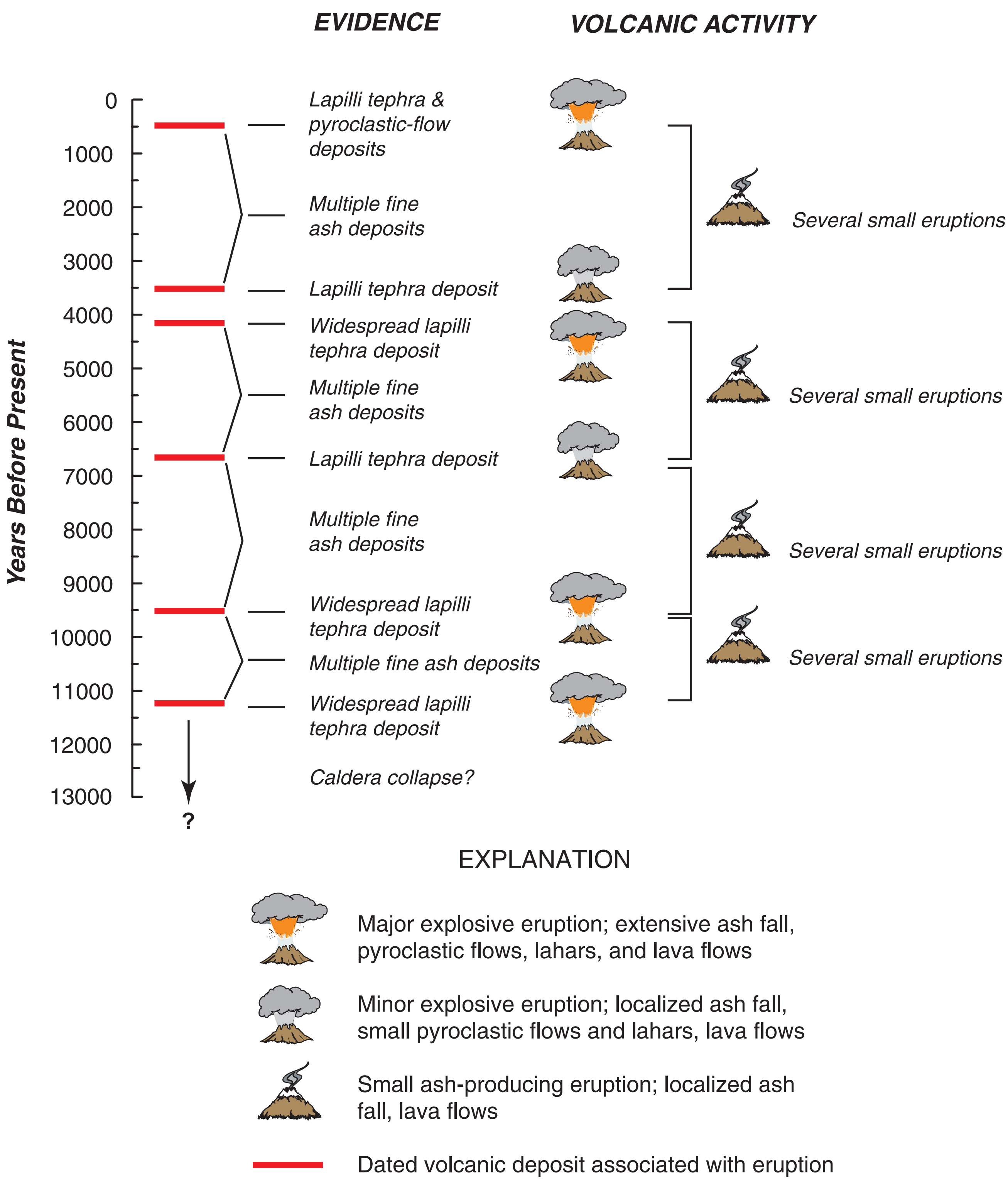


Figure 7. Eruptive history of Kanaga Volcano as determined from radiocarbon dating of volcanic ash beds found on Kanaga Island. Historical eruptions not shown.

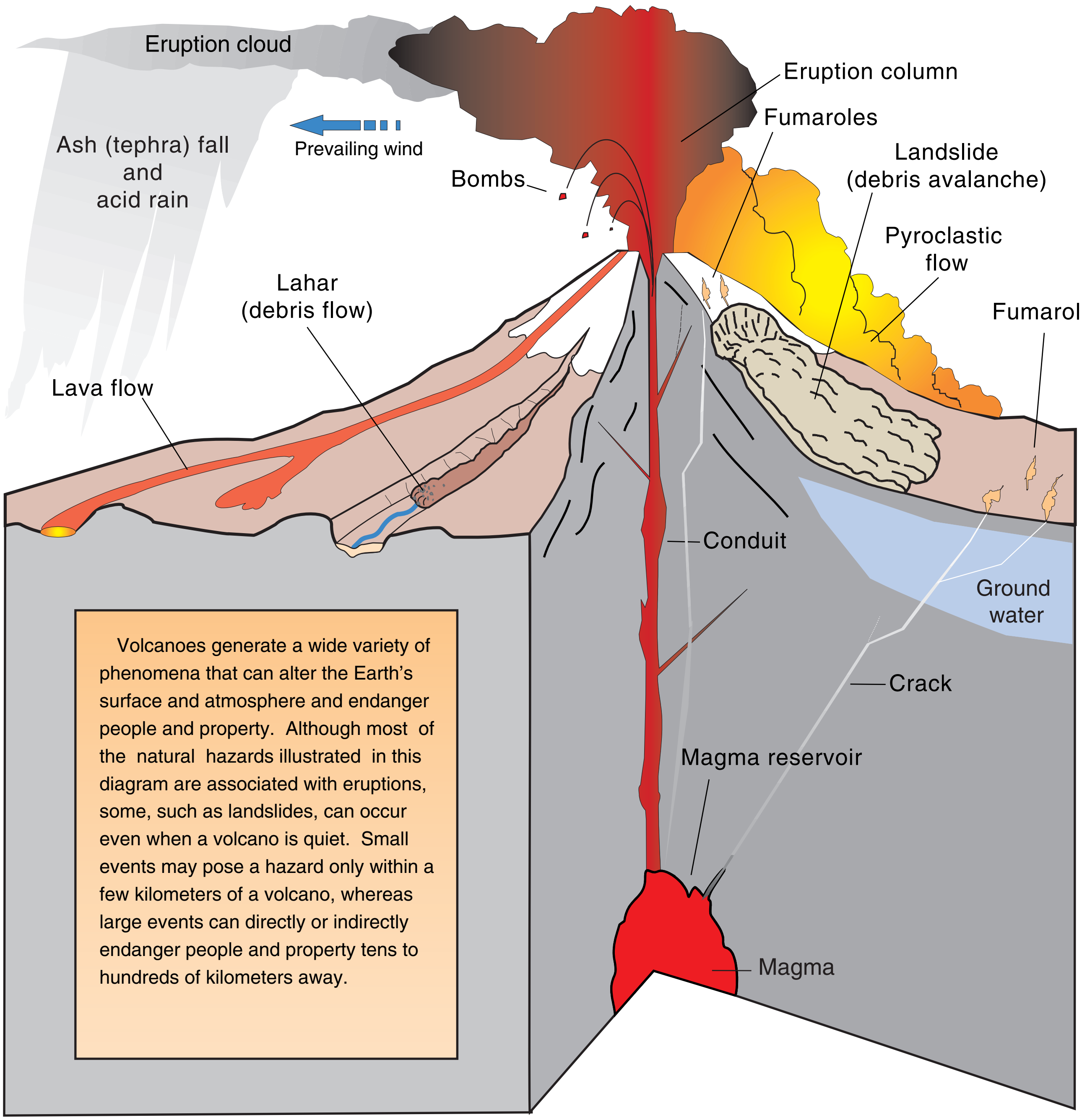


Figure 8. Hazards associated with eruptions of stratovolcanoes (modified from Myers and others, 1997).

all eruptions and anyone in this zone would have little or no time to escape from the area once an eruption commenced.

Distal hazards pose less risk to people because there is usually adequate time for warning and evacuation. This group of hazards affects people and structures that are more than about 10 to 30 kilometers from the volcano. Volcanic ash, either in explosive *eruption columns* or ash clouds that drift far away from the volcano, can be both a proximal and a distal hazard, especially to aircraft. Fallout of volcanic ash also can be a proximal and a distal hazard.

Deposits and features formed by various volcanic phenomena are shown on the geologic map of Kanaga

Volcano (fig. 3). The processes that produced these deposits and features on the modern cone were generally confined to the flanks of the volcano. Only volcanic-ash clouds, ash fallout, pyroclastic flows and surges, and unusually large-volume debris avalanches that could initiate tsunamis are most likely to affect areas more than a few kilometers from Kanaga Volcano.

VOLCANIC HAZARDS

Ash Clouds

Study of pyroclastic-fall deposits on northern Kanaga Island indicates that explosive eruptions of Kanaga Volcano have occurred numerous times during the past 11,000 years. Although pyroclastic-fall deposits from Kanaga Volcano have not been positively identified on the islands to the east, the explosive eruptions recorded by these deposits on Kanaga Island likely produced significant quantities of volcanic ash that rose upward into the atmosphere (fig. 8) and drifted away from the volcano with the wind (fig. 9). Fine ash particles in an explosively generated *eruption cloud* may remain in the atmosphere for days to weeks and can be transported many thousands of kilometers beyond the volcano, depending on the side of the eruption. Volcanic ash clouds area a potential hazard to all aircraft downwind from the volcano (Casadevall, 1994).

Eruptions of Kanaga Volcano in 1993-95 produced small ash clouds (fig. 10) that reached altitudes up to about 7.5 kilometers above sea level. These ash clouds drifted mainly northeast and east of the volcano but could not be systematically tracked in satellite images then available to the Alaska Volcano Observatory. The ash clouds did not result in ash-aircraft encounters, although air traffic in the vicinity of Adak Island was disrupted on August 22, 1994 (Neal and others, 1995).

Future eruptions of Kanaga Volcano are likely to be similar to the 1993-95 eruption, and small ash clouds rising several kilometers above the volcano and possibly drifting tens of kilometers downwind should be expected. Eruptions more energetic than the 1993-95 events could produce voluminous ash clouds that could rise 10 to 20 kilometers above sea level and extend downwind for tens to hundreds of kilometers beyond the volcano.

Ash Fallout and Volcanic Bombs (Ballistics)

Drifting ash clouds are usually associated with a steady rain or fallout of volcanic ash over areas immediately downwind from the volcano. Accumulations of millimeters to centimeters are common, although thicker amounts of *tephra* fallout may occur during large eruptions, especially in areas close to the volcano. Few people have ever been killed directly by falling ash, although the weight of a thick ash fall could cause structures to collapse, and inhaling fine ash particles is a health hazard that can be life threatening to some people with respiratory problems. Sometimes a “mud rain” results if airborne volcanic ash mixes with falling rain or snow.

Ash clouds from the 1993-95 eruption of Kanaga Volcano deposited small amounts of fine ash over areas north and east of the volcano, but most of the ash was deposited on the flanks of the volcano and other parts of northern Kanaga Island. Small amounts of fine ash (1-2 millimeters) were deposited on parts of northern Adak Island, including the community of Adak. Subsequent periods of rain and drizzle removed the light ash fall within a few days, and AVO received no reports of any adverse effects associated with the ash fall. Ash fall from future eruptions of Kanaga Volcano could be a public health concern if greater amounts of ash fall on the community of Adak. Depending on the wind conditions at the time of an eruption, ash particles could remain suspended in the air over Adak or be periodically resuspended from accumulations on the ground by high winds. This could significantly diminish air quality for days to weeks after the eruption.

Wind direction and speed control the movement of an ash plume and influence ash fallout. The areas most likely to receive ash fall are those in the zone of prevailing winds (fig. 9). The strongest and most consistent winds aloft in the vicinity of Kanaga Volcano are westerly, which would generally cause deposition of volcanic ash east of the volcano (fig. 9). The thickness of ash fallout would decrease in a downwind direction, but it is impossible to predict how much ash would be produced during an individual eruption, although any amount of ash fall could be disruptive to communities in the zone of fallout.

Figure 9. Prevailing winds and ash fallout from Kanaga Volcano.

It is common during explosive eruptions, and especially those involving water, that blocks and bombs of volcanic rock debris are ejected from the vent as ballistic projectiles. Usually, ballistic fallout occurs in areas near the vent but, in extreme cases, bombs may travel long distances, sometimes 10 kilometers or more from the vent. Typically, the zone of ballistic fallout is within a few kilometers of the vent, and people or low-flying aircraft would be at risk only within this zone.

Ejection of ballistic particles has occurred during recent eruptions of Kanaga Volcano, and all the flanks of the volcano show impact craters produced by bomb fallout (fig. 11). Most of the impact craters are 2 to 3 kilometers from the summit crater and range up to 10 meters in diameter.

Lava Flows

Streams of molten rock, or lava, are likely to form during a future eruption of Kanaga Volcano. Most of Kanaga Volcano is composed of lava flows (figs. 3 and 12), mainly of andesitic composition. Typical lava flows on Kanaga Volcano are linear accumulations of blocky aa lava that extend from the summit of the volcano for several kilometers and, in some areas, terminate in the sea (fig. 12). Future eruptions would probably generate lava flows similar to those preserved on the volcano. The lava flows are expected to move slowly downslope, probably not more than a few tens of meters per hour, although the flow speed would depend on the viscosity of the lava. The typical Kanaga lava flow could be hazardous to people near the flow front because it sometimes sheds hot blocks and debris downslope. Lava flows that reach snow, ice,

Figure 10. Kanaga Volcano in eruption, 1994, with ash cloud drifting eastward. View is of the southeast flank of the volcano. Photograph by J. Meehan, U.S. Fish and Wildlife Service, 1994.

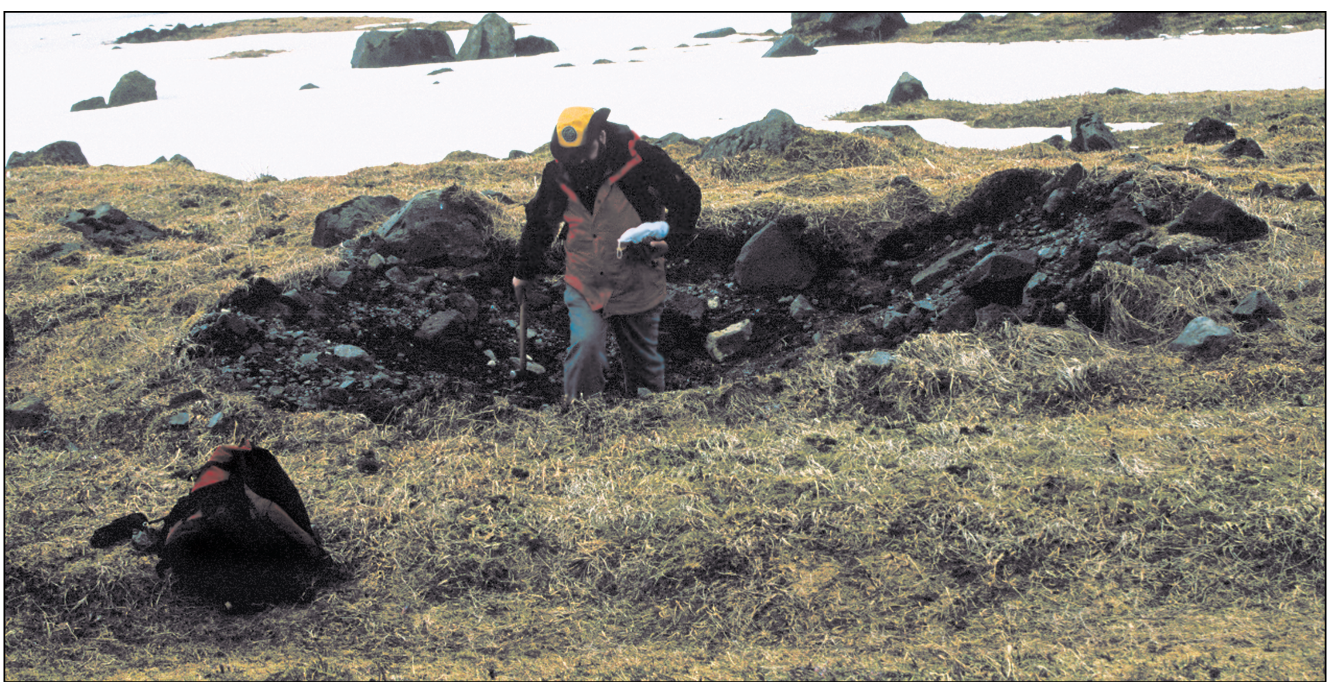


Figure 11. Impact crater formed by ballistic projectile during the 1993-95 eruption of Kanaga Volcano. Photograph by C.F. Waythomas, U.S. Geological Survey, 2000.

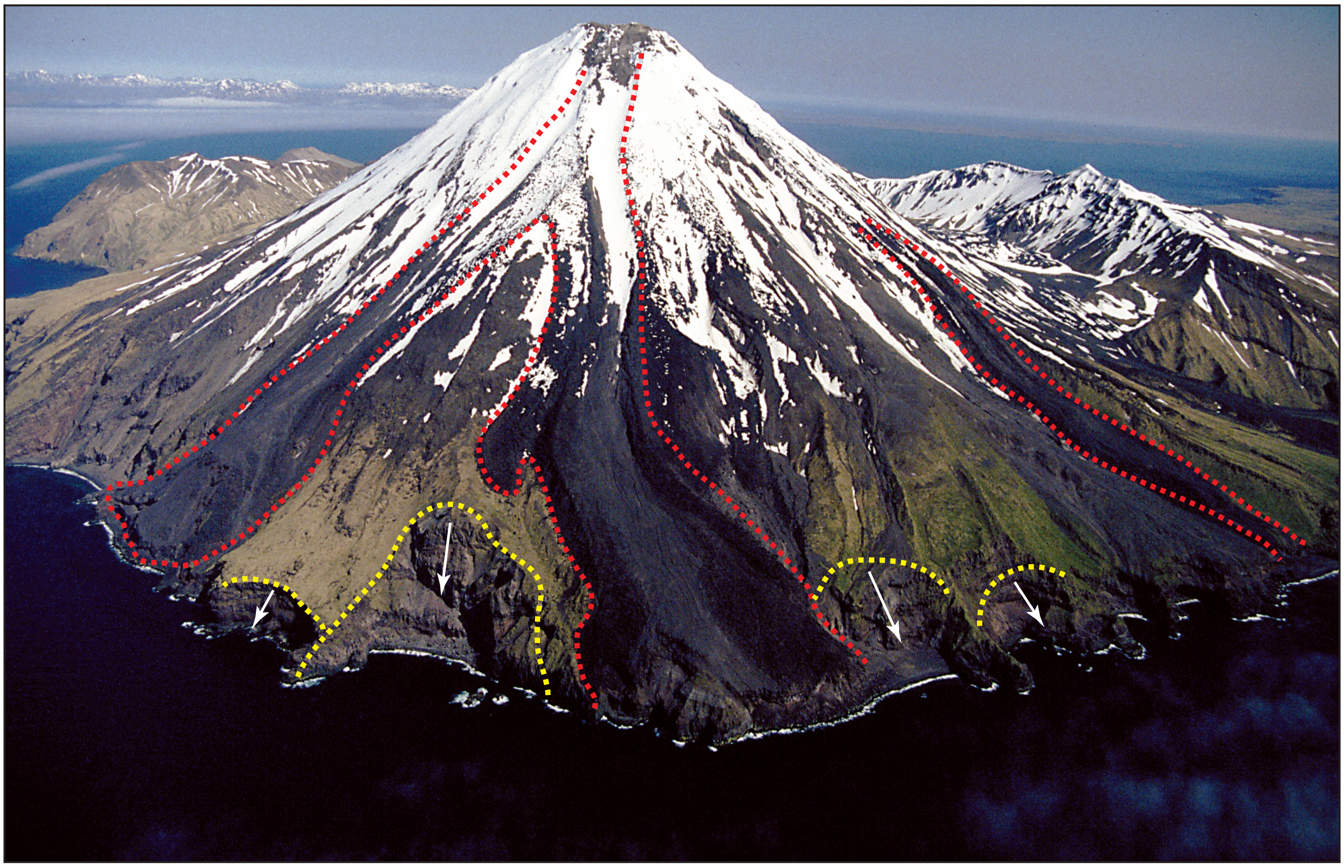


Figure 12. Northwest flank of Kanaga Volcano showing lava flows (outlined in red) erupted during the 1993-95 eruption. Collapse scars produced by small-scale rock avalanches are outlined in yellow. Arrows indicate direction of avalanche movement. Photograph by C.J. Nye, Alaska Division of Geological and Geophysical Surveys, 2000.

or the ocean may initiate minor steam explosions. If lava flows pour into the sea for an extended period of time, unstable lava deltas may develop. These are prone to collapse and could generate local waves capable of swamping small boats or inundating the coastline in the vicinity of the lava delta.

Lahars, Lahar-Runout Flows, and Floods

Most of the volcanoes in Alaska support glaciers or are snow covered most of the year. During typical eruptions, hot pyroclastic debris expelled from the volcano interacts dynamically with the snowpack or glacier cover and causes rapid, extensive melting and water production. As meltwater mixes with available unconsolidated volcanic debris, various types of mass flows may occur on the volcano flanks and in stream channels and drainages downstream from the volcano. Volcanic mass flows that form from the interaction of pyroclastic flows with snow and ice are called lahars (fig. 8). Lahars consist of a poorly sorted mixture of boulders, sand, silt, and water that has the consistency of wet concrete. As a lahar flows downstream, it typically transforms into finer grained, watery flow, called hyperconcentrated flow or lahar-runout flow. If enough sediment is lost from a lahar during flowage, the lahar may transform into a normal streamflow or flood and consist mostly of water.

Kanaga Volcano is typically snow covered almost year round, so eruptions in any season could produce lahars. Even in summer, parts of the cone can remain snow covered. Lahars produced by the 1993-95 eruption affected only the south flank of the volcano (fig. 13), but all flanks of the volcano are susceptible to inundation by lahars. The 1993-95 lahar deposits contain abundant cobble- to boulder-sized clasts of prismatically fractured, dark-grey, juvenile andesite; these materials indicate that the lahar flows were probably still hot when they reached the lower southeast flank of the volcano. Lahars produced during eruptions of Kanaga Volcano would be restricted to the flanks of the volcano, and they could enter the sea if flows descend the north side where they could initiate local waves upon impact with the sea. Kanaton Ridge would prevent lahars from reaching other parts of northern Kanaga Island.

Because lahars, lahar-runout flows, and floods can move rapidly, can be several meters deep, and can transport boulder- and block-sized particles, they would be hazardous to anyone in the flow path. Lahars are not a serious hazard on Kanaga Island unless someone is on or near the volcano during an eruption.

Debris Avalanches

Volcanic rock or debris avalanches (fig. 8) 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, unsorted gravel deposit many kilometers from the source that may exhibit a characteristic hummocky, irregular surface and cover a broad area. Most debris-avalanche deposits extend up the slopes of the volcano to an arcuate- or horseshoe-shaped scar at or near the volcano summit that marks the zone of collapse and origin of the avalanche. Many large debris avalanches (greater than 1 cubic kilometer in volume) occur during eruptions (Siebert, 1996) but, it is possible for large-scale collapse of a volcanic cone to occur during a distinctly noneruptive period, sometimes as a result of long-term chemical alteration of volcanic rock in the *edifice* by hot, acidic ground water that weakens the edifice.

Prior to the development of the modern cone of Kanaga Volcano, a portion of the preexisting volcano-Mount Kanaton-collapsed and slid into the Bering Sea (fig. 6). An area of irregular, hummocky topography is present on the sea floor north of Kanaga Island (fig. 14), and this feature could be the debris-avalanche deposit that formed when ancestral Mount Kanaton foundered into the sea. It is not known what caused this major collapse of Mount Kanaton.

A large-scale collapse, similar to the one that destroyed ancestral Mount Kanaton, is rare and unlikely to occur for many thousands of years. The cone-shaped edifice of Kanaga Volcano is not obviously unstable, and alteration of rocks on the volcano has not been observed. A major collapse of the cone is unlikely unless an unusual amount of magma begins rising through the crust toward the surface beneath the cone and causes obvious surface displacement. Thus, the hazard from debris avalanches is minor unless conditions at the volcano change significantly, and this is not expected.

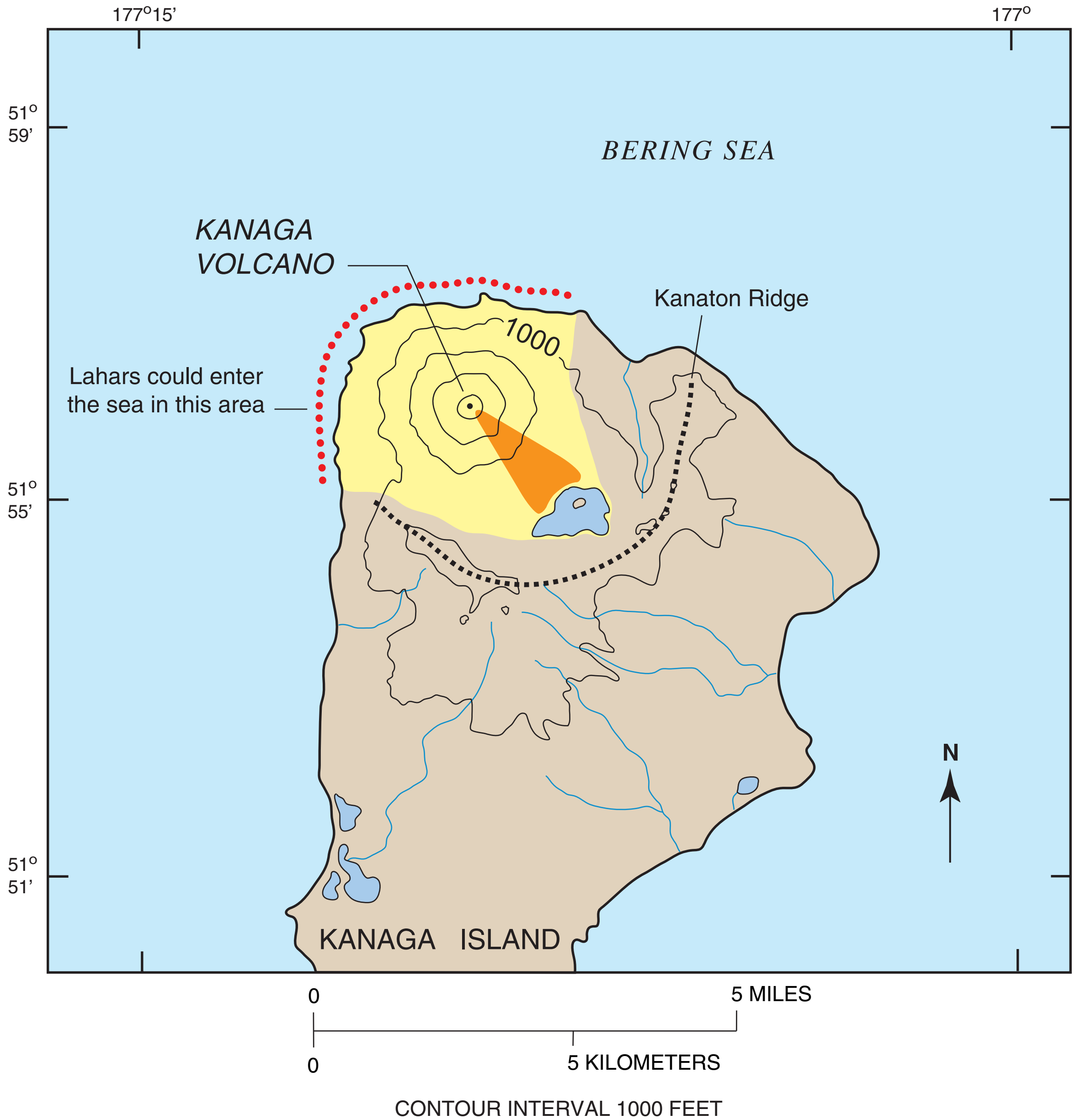
Although a large-scale collapse of Kanaga Volcano is not considered likely, all flanks of Kanaga Volcano are susceptible to being swept by small-scale rockfalls and minor debris avalanches (fig. 15). Most likely are small debris avalanches formed by the collapse of lava-flow fronts and thick piles of spatter that accumulate on the crater rim. Localized rockfall avalanches from lava flows exposed along the northern coast of Kanaga Island are likely (fig. 12). These events could be hazardous to people or boats near the site of the avalanche, and localized waves could be generated.

Pyroclastic Flows and Surges

A pyroclastic flow is a hot, dry mixture of volcanic rock debris and gas (mostly air) that flows rapidly downslope (fig. 8). A *pyroclastic surge* is similar to and often occurs with a pyroclastic flow but is more dilute and contains fewer and smaller particles. A pyroclastic surge moves more rapidly than a pyroclastic flow and may not be confined by topography and, therefore, may climb up and over ridges. Pyroclastic flows will generally follow topographically low areas such as stream valleys and gullies. Because they are hot (several hundred degrees Celsius) and fast moving, both pyroclastic flows and surges could be lethal to anyone on or near Kanaga Volcano during an eruption.

During explosive eruptions characterized by high, vertical eruption columns, the dense portion of the eruption column would collapse and fall back toward the volcano, forming a fast-moving pyroclastic flow. Pyroclastic flows that form by eruption column collapse can sweep all sides of the volcano and are likely to follow topographically low areas like river valleys.

Pyroclastic flows at Kanaga Volcano also may form by collapse of recently extruded *lava domes*. Lava domes are plug-like masses of molten rock that are slowly extruded from the vent during an eruption. As the domes are extruded, their outer margins often



EXPLANATION

- Areas that could be inundated by lahars, lahar-runout flows, and floods during eruptions of all sizes, but especially during explosive eruptions. Extent of inundation depends on the volume of the snowpack and the duration and style of the eruption.
- Area inundated by hot lahars during the 1993-95 eruption.

Figure 13. Areas that could be inundated by lahars, lahar-runout flows, and floods generated by eruptions of Kanaga Volcano.

become oversteepened and unstable. This leads to failure of the lava dome by gravitational collapse and results in the release of hot, pressurized gas and rock debris from inside the cooling lava dome, forming a pyroclastic flow.

Pyroclastic flows generated by dome collapse usually affect only a specific sector of the volcano and typically do not have the broad areal extent common to pyroclastic flows initiated by eruption column collapse. Lava domes are present on the southeast flank of Kanaga Volcano inside the caldera near the lake (fig. 3). The age of the lava domes is not known, but their location and fresh appearance indicate that they could have formed within the past 11,000 years. Pyroclastic flows initiated by lava dome collapse form a distinctive deposit called a *block-and-ash-flow* deposit, and these deposits usually contain a significant amount of dense, juvenile material within a matrix of fine, ash-rich volcanic debris. During recent studies of the volcano, no block-and-ash-flow deposits were discovered. This indicates that, although lava domes did form at Kanaga Volcano, they may not have collapsed to form pyroclastic flows. During future eruptions, lava domes could develop on the flanks of the volcano, and they may initiate pyroclastic flows if they collapse. These flows likely would be small, confined to the caldera and may travel only a few kilometers from their source.

Hot lahar deposits on the southeast flank of Kanaga Volcano indicate that small-volume pyroclastic flows were probably generated during the 1993-95 eruption. These flows were probably produced by collapse of still-hot ejecta avalanching from the crater rim onto the snow-covered south flank, which initiated lahars (fig. 13).

Pumice-rich pyroclastic-flow deposits are rare on Kanaga Island and are known only along the southeast sector of the caldera near the lake and at one locality outside the caldera (fig. 16). The source of the pyroclastic-flow deposits is not known.

Pyroclastic flows and surges from most eruptions would be expected to reach at least several kilometers beyond the vent and could travel in almost any direction (fig. 16). The runout distance of pyroclastic flows is estimated by determining the ratio of the fall height (H) (usually assumed to be the volcano summit) to the runout distance (L) of known flows. Typical H/L values are between 0.2 and 0.3 (Hayashi and Self, 1992; Hoblitt and others, 1995). These values give runout distances on land of about 4 to 6 kilometers for pyroclastic flows erupted from the summit of Kanaga Volcano.

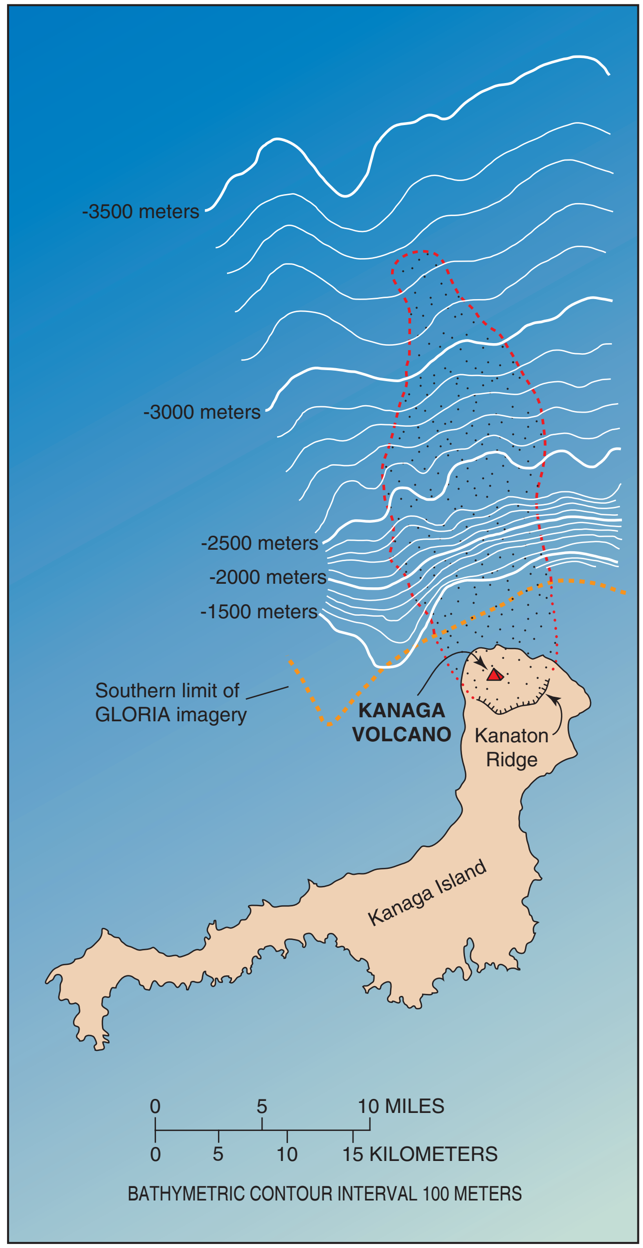
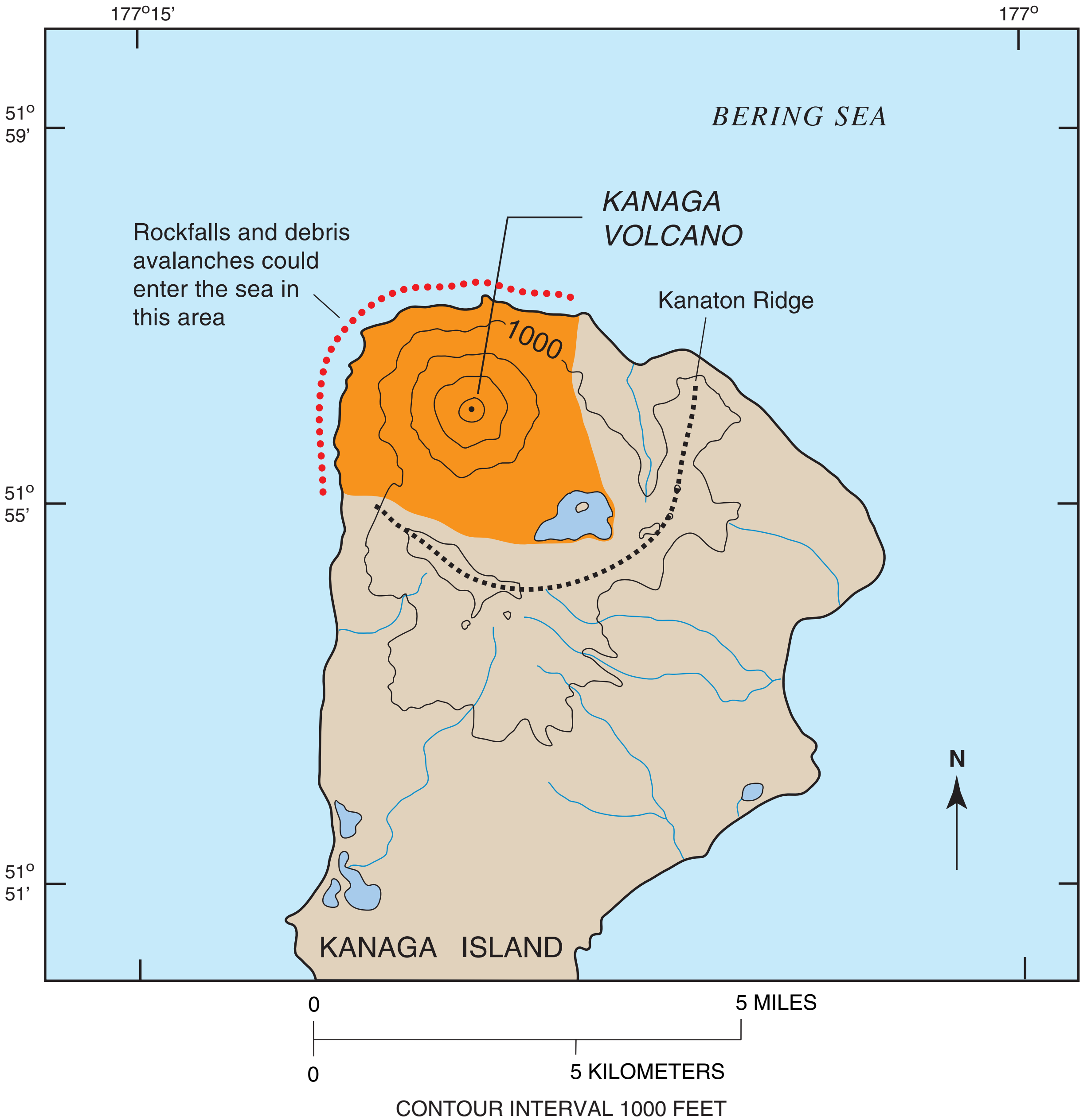


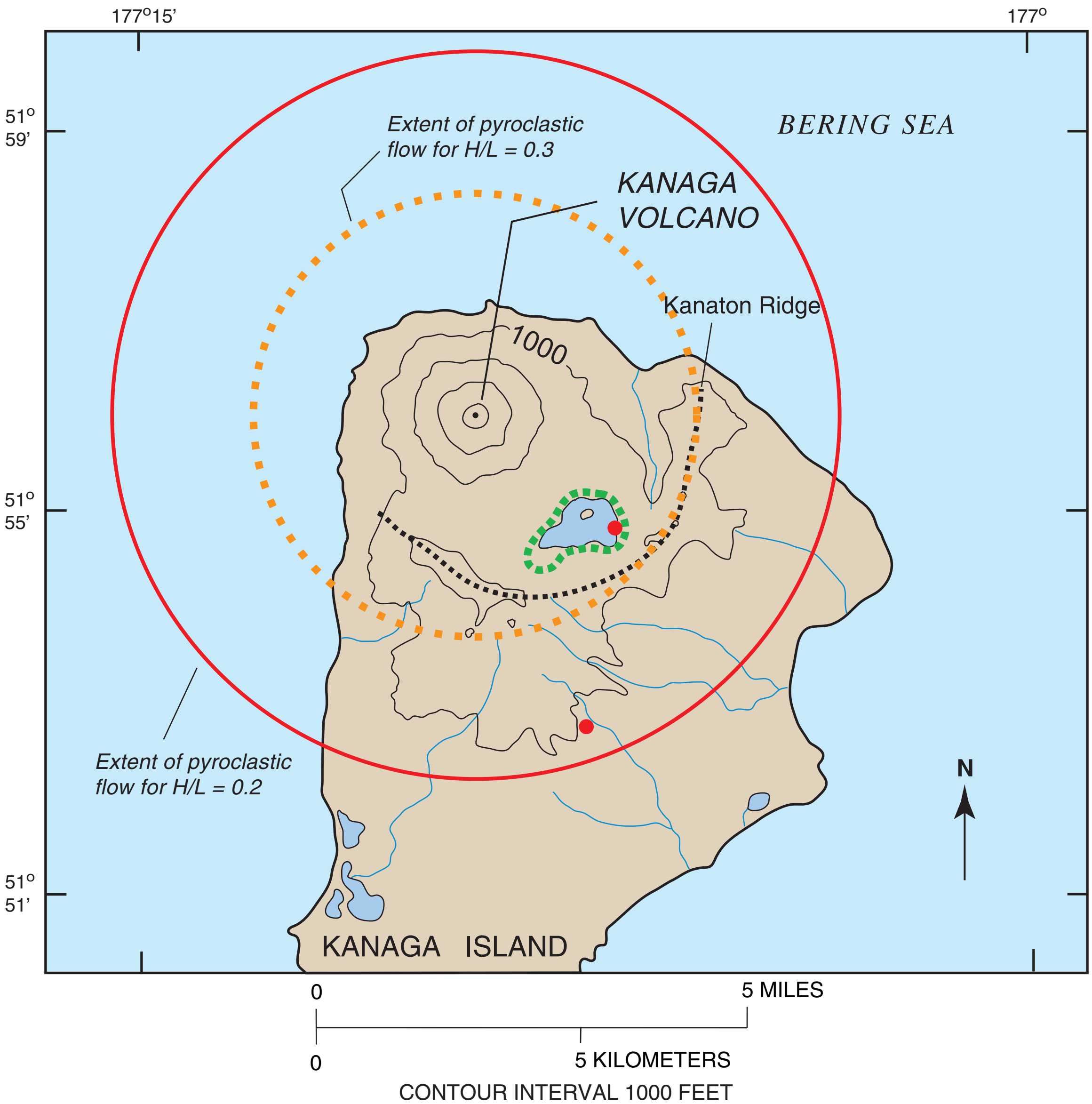
Figure 14. Approximate area of irregular topography on the sea floor north of Kanaga Island. The area outlined in red could be a debris-avalanche deposit that formed when ancestral Mount Kanation collapsed and slid into the sea. Bathymetric data from Bering Sea EEZ-Scan Scientific Staff, 1991.



EXPLANATION

Areas that could be affected by small debris and rockfall avalanches. Most likely are small-scale collapses of lava-flow fronts and spatter piles on the rim of the crater.

Figure 15. Areas that could be affected by small-volume debris and rockfall avalanches.



EXPLANATION

Areas that could be affected by pyroclastic flows produced by small to moderate eruptions from the volcano summit. Hazard boundaries correspond to *H*/*L* = 0.3 (orange dashed line) and *H*/*L* = 0.2 (red solid line).

Known pyroclastic-flow deposits; ages of these deposits not known, but most likely of Holocene age.

Cluster of andesite lava domes and possible vent area and source of pyroclastic flows and surges.

Figure 16. Areas that could be affected by pyroclastic flows and surges produced by small- to moderate-sized eruptions. The hazard zone boundary corresponds to a fall height (*H*) to runout length (*L*) ratio of 0.3. Eruptions producing pyroclastic flows more extensive than this boundary are possible but not likely.

Pyroclastic flows and surges directed north or west from the summit of Kanaga Volcano would soon encounter water and may travel a greater distance than they do on land. Voluminous pyroclastic flows that enter the sea may initiate tsunamis (Waythomas and Neal, 1998), but this is not likely to happen during typical effusive eruptions of Kanaga Volcano similar to those that have occurred historically.

It is difficult to accurately predict the extent of a pyroclastic surge. They are commonly associated with pyroclastic flows and have a slightly greater lateral extent. The location of the hazard boundary for pyroclastic surge is uncertain and is not shown on figure 16 or plate 1. The boundary is approximated by the hazard boundary for pyroclastic flow, although a pyroclastic surge would be expected to extend beyond this boundary, perhaps by several kilometers or more. Pyroclastic surges composed of dilute clouds of pulverized rock also may be hot (300 to 800°C); therefore, death or injury from asphyxiation and burning is likely. Because the surge cloud may travel very fast (at least tens of meters per second), may detach itself from the pyroclastic flow, and may surmount topographic barriers, pre-eruption evacuation of the area near the volcano is the only way to eliminate risk from pyroclastic surges.

Directed Blasts

A *directed blast* is a large-scale, lateral volcanic explosion caused by a major landslide or slope failure that uncaps the internal vent system of the volcano. This causes a sudden drop in pressure of a shallow *magma* body or hydrothermal system and leads to a blast-like explosion. Such an event is rare in the history of a volcano. Although geologic evidence indicates that at least one major slope failure has occurred at Kanaga Volcano, evidence for a directed blast has not been discovered. Tephra deposits found on Adak Island to the east may have been produced during a large eruption associated with flank collapse on Mount Kanaton but, to date, blast deposits have not be recognized on Kanaga Island. Kanaga Volcano continues to construct a steep cone that is unbutressed and open to the sea on the northwest. If a flank collapse were to occur, it is most likely to happen on this side of the volcano and could bring about a northwest-directed blast. This does not mean that a directed blast will occur if the northwest or any other flank of the volcano collapses.The hazard-zone boundary showing the area most likely to be affected by a directed blast (fig. 17) is based on data from the 1980 eruption of Mount St. Helens. The directed blast associated with the 1980 Mount St. Helens eruption is one of the largest known historical directed blast events and, thus, is a “worst case” example. If a directed blast were to occur from Kanaga Volcano, it could affect a broad area, possibly a 180° sector from the vent. A directed blast can happen during the onset of a large eruption; thus, there may be little time for warning or evacuation once the eruption is imminent. Living things in the path of a directed blast would be killed or destroyed by impact, burning, abrasion, burial, and heat.

Volcanic Gases

Gases are emitted by most active volcanoes because magma contains dissolved gas and boils off shallow ground water that is typically present in the edifice of the volcano. The most common volcanic gases are water vapor, carbon dioxide, carbon monoxide, sulfur dioxide, and hydrogen sulfide. Volcanic sulfur and halide gases that combine with water in volcanic plumes can form large amounts of sulfuric acid (H_2SO_4) and minor amounts of hydrochloric acid (HCI) and hydrofluoric acid (HF) as aerosols or droplets. In high concentrations, carbon dioxide, hydrogen sulfide, and sulfur dioxide may be harmful or toxic to humans and animals and may affect areas immediately downwind from the volcano. Acid precipitation may develop from the mixing of snow or rain with acidic volcanic aerosols, which may cause various types of skin and respiratory irritations and cause corrosive damage to materials. Wind tends to disperse volcanic gas, it is typically not found near the ground in concentrations hazardous to humans or animals more than about 10 kilometers from the volcano. During large eruptions, significant volumes of gas can travel high in the atmosphere downwind from the volcano for days and over distances of thousands of kilometers.

During the 1993-95 eruptions of Kanaga Volcano, people on Adak Island reported smelling sulfur. Gas emission from Kanaga Volcano is normal, and the hazard from volcanic gases is unlikely to be greater than that posed by other volcanic phenomena. At times, a white steam plume ascends rapidly from the summit of the volcano and could be mistaken for an eruption cloud. Gases may become trapped within the

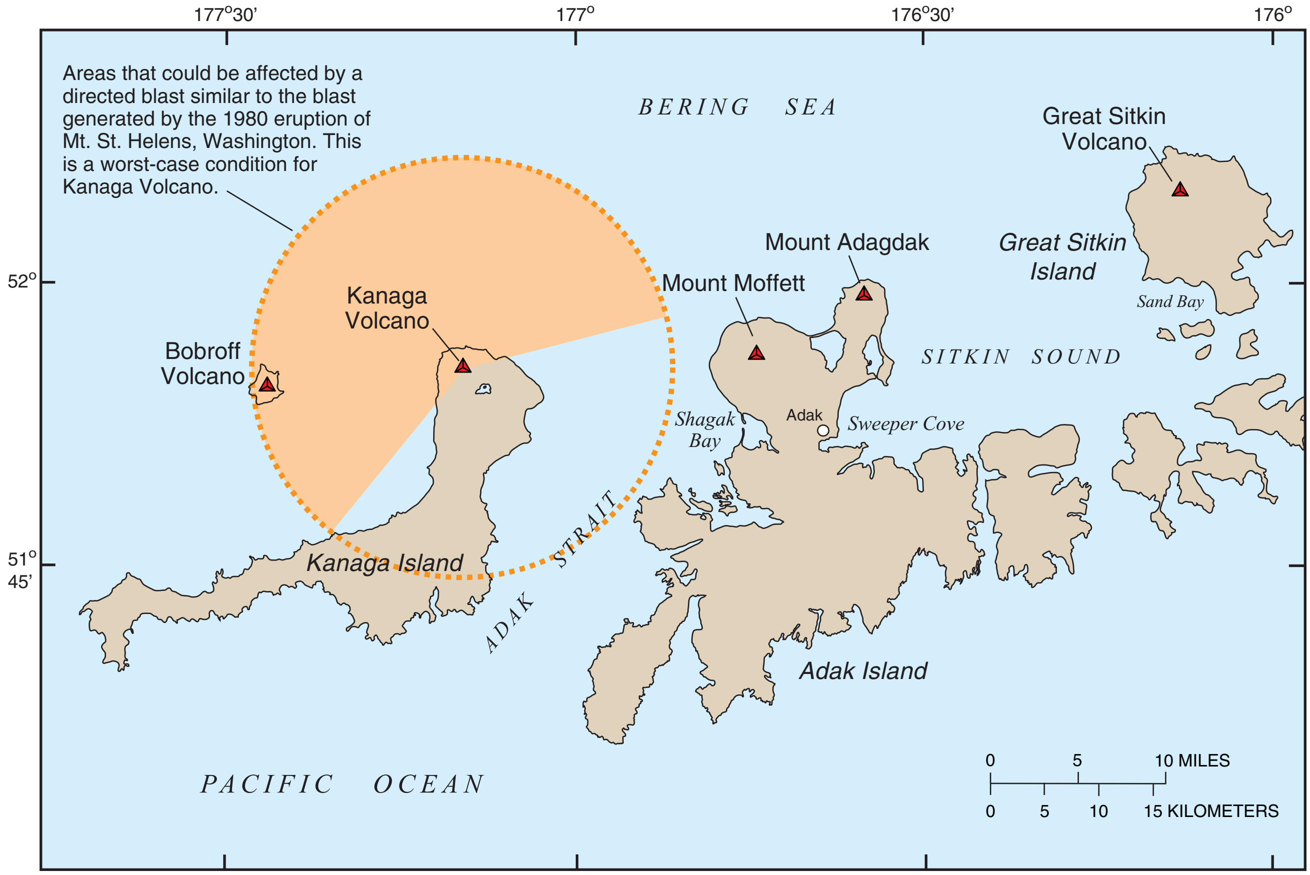


Figure 17. Areas that could be affected by a directed blast. Shaded zone indicates area most likely to be affected by a directed blast associated with a north-directed failure of the volcano. Directed blasts are rare events and not expected to occur at Kanaga Volcano unless conditions at the volcano change significantly.

summit crater if the air is calm and could be hazardous to anyone in the crater at that time. However, frequent windy conditions at Kanaga Volcano usually inhibit localized buildup of volcanic gas. Therefore, the hazard from volcanic gases is minor. A small area of hot springs is located along an unnamed drainage about 1.2 kilometers west of Weed Bight on the east side of Kanaga Island (fig. 3). The temperature and composition of the spring water are not known. Thermal and chemical conditions at hot springs may change rapidly and, thus, may pose a hazard to humans without warning.

EVENT FREQUENCY AND RISK AT KANAGA VOLCANO

Additional eruptions of Kanaga Volcano will occur, but the timing of the next eruption is uncertain. The primary hazards during a future eruption will be clouds of volcanic ash, ash fall, ballistic fallout, pyroclastic flows, and lahars. Because Kanaga Island is uninhabited and no permanent structures or facilities are present, only the community of Adak on Adak Island is at risk from future eruptions. During any future eruption, ash could fall on the community of Adak and several millimeters of ash could accumulate downwind from the volcano on parts of Adak Island.

Should a sustained explosive eruption occur, clouds of volcanic ash would be generated that could drift hundreds and possibly thousands of kilometers downwind. All aircraft, some facilities, and living things—including humans—downwind from the volcano would be at risk from effects of volcanic-ash clouds and ash fallout. Ash clouds from Kanaga Volcano could rise to altitudes of 15 kilometers or more and move into the flight paths of aircraft using the Adak airfield or flying North Pacific air routes (fig. 18). The frequency at which dangerous clouds of volcanic ash are produced and the amount of ash fall cannot be estimated with certainty. Volcanic deposits on Kanaga Island indicate that at least 6 major explosive eruptions and more than 10 small, ash-producing eruptions have occurred in the past 11,000 years (fig. 7). All these events likely would have produced significant volumes of ash and extensive ash clouds.

Signs of volcanic unrest, such as elevated levels of earthquake activity, a change in emission rate and volume of volcanic gas, or an increase in ground temperature at or near the vent, usually precede an eruption. These signs will permit reasonable estimates of the likelihood of volcanic ash emission once an eruptive phase is detected. However, it is not possible to determine the characteristics of an ash cloud before an eruption occurs, except that it is likely to be similar to those generated by historical eruptions of Kanaga Volcano and other similar Aleutian arc volcanoes.

HAZARD WARNING AND MITIGATION

Eruptions at most Aleutian arc volcanoes monitored with seismic instruments have been preceded by weeks to months of precursory earthquake activity which gives some degree of warning prior to an eruption. Some eruptions also are preceded by at least several weeks of increased gas emission from the summit area. When volcanic unrest is detected, other monitoring techniques, such as satellite observations, measurement of volcanic-gas flux, remote observation with real-time video or time-lapse cameras, and geodetic surveying, are used to develop a comprehensive assessment of the likelihood of an eruption.

The AVO monitors Kanaga Volcano with a real-time seismic network. A network of six radio-telemetered seismometers sends real-time data to the AVO offices in Anchorage and Fairbanks. Satellite images of the volcano are analyzed twice daily.

One of the primary roles of the AVO is to communicate timely warnings of volcanic unrest and potential eruptions (Eichelberger and others, 1995, p. 4). The AVO distributes by fax and electronic mail a weekly update of volcanic activity that summarizes the status of the currently monitored volcanoes and some historically active but unmonitored volcanoes along the Aleutian volcanic arc. During periods of unrest or volcanic crises, updates are issued more frequently to advise the public of significant changes in activity. Recipients of these updates include the Federal Aviation Administration, air carriers, 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 services, and others. Updates also are distributed by electronic mail to various volcano information networks and are posted on the AVO World Wide Web site (URL: <http://www.avo.alaska.edu>).

During the 1989–90 eruptions of Redoubt Volcano, the AVO developed a "level-of-concern color code" (Brantley, 1990; table 1). This code provides efficient and simple information about the status of volcanic activity or 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 event of a volcanic crisis, various Federal, State, and local officials are contacted by telephone and advised of the situation, and the level-of-concern color code is established while an update is being prepared. This approach has been used successfully during recent eruptions at monitored volcanoes such as Redoubt Volcano (1989–90), Crater Peak (1992), Pavlof Volcano (1996), and Shishaldin Volcano (1999).

Minimizing the risks posed by eruptions of Kanaga Volcano is possible through 1) understanding potential hazards, 2) adequate warning of eruptive activity, and 3) preparing for an eruption. Areas within about 10-20 kilometers of the volcano are at greatest risk. Knowledge of potential hazards is required to assess the risk associated with a specific location on or near the volcano and to assess whether movement to another location would be safer. During an eruption,

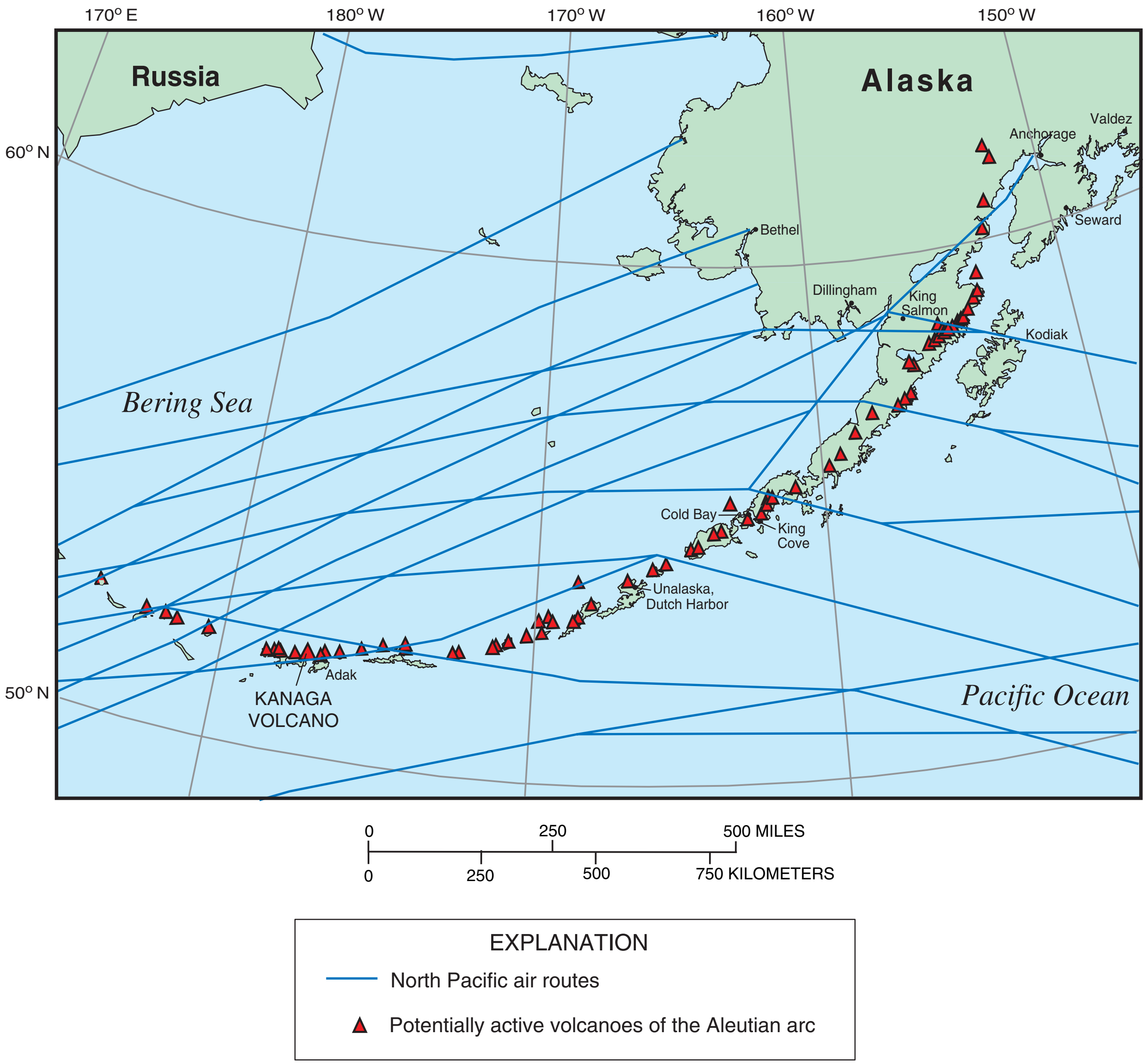


Figure 18. North Pacific air routes in relation to Kanaga Volcano and potentially active volcanoes of the Aleutian volcanic arc.

all areas within about 20 kilometers of the volcano, as well as all areas downwind from the summit, are subject to tephra and ballistic fallout. All flanks of the volcano are subject to pyroclastic flows and surges, lahars, lava flows, and rock avalanches. During an eruption, access closer than about 10 kilometers from the volcano could be impossible and the risks to human life great. Small planes, helicopters, and boats could be at risk from intermittent and unpredictable discharge of ballistic projectiles, pyroclastic flows, or sudden changes in the travel direction of the eruption plume.

Table 1. Alaska Volcano Observatory Level-of-Concern color code

Color	Intensity of unrest at volcano	Forecast
GREEN	Volcano is in quiet, "dormant" state.	No eruption anticipated.
YELLOW	Small earthquakes detected locally and (or) increased levels of volcanic-gas emissions.	Eruption is possible in next few weeks and may occur with little or no additional warning.
ORANGE	Increased numbers of local earthquakes. Extrusion of lava dome or lava flows (nonexplosive 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 7,600 meters (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 7,600 meters (25,000 feet) above sea level.

People located farther away from the volcano may have additional time to prepare for the adverse effects of an eruption; however, an emergency plan developed and ready prior to the onset of an eruption is useful. 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.

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GLOSSARY

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

Ash. Fine fragments (less than 2 millimeters across) of volcanic rock formed in an explosive volcanic eruption. Ash particles are typically sharp, angular, and abrasive, and are composed of volcanic glass, mineral, and rock fragments.

Block-and-ash flow. A pyroclastic flow that contains blocks of primary volcanic rock in coarse, ashy matrix. Block-and-ash flows usually form from a collapsing lava dome.

Debris avalanche. Rapidly moving, dry flows of disaggregated rock debris, sand, and silt. Volcanic debris avalanches often form by some type of structural collapse of the volcano, usually the steep front of the cooled lava dome, or other parts of 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. Often 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.

Directed blast. Large-scale volcanic explosions caused by a major landslide or slope failure that results in rapid drop in the pressure of the intruding magma or hydrothermal system near the surface of the volcanic edifice. The 1980 eruption of Mount St. Helens was triggered by massive slope failure, and subsequent laterally directed blast affected a 180° sector north of volcano and extended for several tens of kilometers outward. A directed blast typically travels away from the volcano at a low angle and may not be deflected by ridges or other topographic barriers. Rock debris propelled by directed blast moves much faster than typical landslides and rockfalls. For example, at Mount St. Helens, initial velocity of directed blast cloud was about 600 kilometers per hour and decreased to about 100 kilometers per hour at a distance 25 kilometers from volcano.

Edifice. The upper part of the volcanic cone, including the vent and summit areas.

Effusive. A nonexplosive eruption characterized by the production of lava flows.

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 Earth's surface from an eruption cloud.

Holocene. An epoch of Earth's history that began 10 thousand years ago and includes the present.

Lahar. An Indonesian term for a wet 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 (Blong, 1984), 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 2 to 64 millimeters in diameter.

Lava. Molten rock that reaches Earth's surface.

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

Magma. Molten rock beneath Earth's surface.

Pleistocene epoch. The period of Earth history between 1.8 million and 10 thousand years before present. Pleistocene age refers to geologic deposits formed during the Pleistocene epoch.

Pumice. Highly vesicular, silica-rich, volcanic ejecta; due to its extremely low density, it often floats on water. Pumiceous refers to volcanic ejecta that is slightly more dense and less vesicular than pumice.

Pyroclastic. General term applied to volcanic products or processes that involve explosive ejection and fragmentation of erupting material.

Pyroclastic flow. A dense, hot, chaotic avalanche of rock fragments, gas, and ash that travels rapidly away from an explosive eruption column, often 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 of 300 to 800°C (Blong, 1984). Pyroclastic flows form either by collapse of eruption column or by failure of the front of 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 low, ground-hugging, but highly mobile cloud that can surmount topographic barriers. Surges often affect areas beyond the limits of pyroclastic flows.

Quaternary. A period of Earth's history that began about 1.8 million years ago and includes the present. The Quaternary period is subdivided into the Pleistocene and Holocene epochs.

Radiometric dating. A technique for determining the age of formation of volcanic rocks based on measuring the amounts of radiogenic isotopes that decay at known rates.

Stratovolcano. A steep-sided volcano, usually conical in shape, built of lava flows and fragmental deposits from explosive eruptions. Also called a stratocone or composite cone.

Tephra. Any type of rock fragment that is ejected forcibly from the volcano during eruption. Tephra may be fine-grained dust or "ash" (0.0625 to 2 millimeters in diameter, or silt to sand sized); coarser lapilli (2 to 64 millimeters in diameter, or sand to pebble sized); or consist of large blocks or bombs (greater than 64 millimeters, or cobble to boulder sized). When tephra is airborne, the coarsest fraction will be deposited close to volcano, but fine fraction may be transported long distances and can stay suspended in atmosphere for many months.

Tertiary. A period of Earth's history beginning about 66.4 million years ago and ending about 1.8 million years ago.

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

Waythomas and Nye—Preliminary VOLCANO-HAZARD ASSESSMENT FOR Kanaga VOLCANO, Alaska—U.S. Geological Survey Open-File Report 02–397