Preliminary Volcano-Hazard Assessment for the Tanaga Volcanic Cluster, Tanaga Island, Alaska

Scientific Investigations Report 2007-5094

U.S. Department of the Interior
U.S. Geological Survey

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 th Kamchatkan Volcanic Eruptions Response Team.

Cover: View of Sajaka, Tanaga, and East Tanaga volcanoes (from left to right) as seen looking west from the summit of Takawangha volcano. These volcanoes compose the Tanaga volcanic cluster on the northern half of Tanaga Island. (Photograph taken on September 16, 2003, by author M.L. Coombs.*)*

Preliminary Volcano-Hazard Assessment for the Tanaga Volcanic Cluster, Tanaga Island, Alaska

By Michelle L. Coombs, Robert G. McGimsey, and Brandon L. Browne

Scientific Investigations Report 2007–5094

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Coombs, M.L., McGimsey, R.G., and Browne, B.L., 2007, Preliminary volcano-hazard assessment for the Tanaga Volcanic Cluster, Tanaga Island, Alaska: U.S. Geological Survey Scientific Investigations Report 2007-5094, 36 p.

Contents

Summary of Volcano Hazards at Tanaga Volcanic Cluster....1
Volcanic Ash Clouds....1
Volcanic Ash Fallout....1
Ballistics....2
Pyroclastic Flows and Surges....2
Lava Flows....2
Lahars....2
Rockfalls and Landslides....2
Volcanic Gases....2
Rare Hazardous Phenomena that Could Accompany Large Eruptions of the Tanaga Volcanic Cluster....3
Debris Avalanches....3
Directed Blasts....3
Volcanic Tsunamis....3
Introduction....5
Purpose and Scope....5
Physical Setting and Features of Tanaga Volcanic Cluster....6
Sajaka....8
Tanaga....8
Takawangha....8
Eruptive Activity of Tanaga Volcanic Cluster....12
Historical Volcanic Activity....12
Seismicity....12
Fumarolic Activity and Thermal Springs....12
Prehistoric Eruptive Activity....12
Earliest Eruptive History....13
Eruptive History of the Modern Volcanoes....16
Volcano Hazards at Tanaga Volcanic Cluster....16
Volcanic Ash Clouds....18
Volcanic Ash Fallout and Volcanic Bombs (Ballistics)....19
Pyroclastic Flows and Surges....20
Lava Flows....21
Lahars and Floods....21
Debris Avalanches, Rockfalls, and Landslides....24
Directed Blasts....26
Tsunamis....26
Volcanic Gases....26
Event Frequency and Risk at Tanaga Volcanic Cluster....27
Hazard Warning and Mitigation....28
What's in a Name?....29
References Cited....31
Glossary....33

Plates

[In pocket]

Plate 1. Preliminary volcano-hazard assessment for the Tanaga volcanic cluster, Alaska.

Figures

Figure 1. Map showing location of the Tanaga volcanic cluster, Tanaga Island, in relation to other active volcanoes of the Aleutian volcanic arc, Alaska 5
Figure 2. Map showing geographic setting of Tanaga volcanic cluster, Tanaga Island and nearby islands, Alaska 6
Figure 3. Shaded relief map showing location of the Tanaga volcanic cluster on Tanaga Island, Alaska 7
Figure 4. Photograph showing view of the Tanaga volcanic cluster, looking north, Tanaga Island, Alaska 8
Figure 5. Map showing geology of the Tanaga volcanic cluster, showing eruptive products from each volcano, Tanaga Island, Alaska 9
Figure 6. Aerial photographs showing Sajaka volcano edifice, Tanaga Island, Alaska 10
Figure 7. Aerial photographs showing Tanaga volcano edifice, Tanaga Island, Alaska 11
Figure 8. Photographs showing Takawangha volcano summit, Tanaga Island, Alaska 11
Figure 9. Map showing locations of radio-telemetered seismic stations on Tanaga Island, Alaska 13
Figure 10. Chart outlining eruptive history of the Tanaga volcanic cluster, Tanaga Island, Alaska 14
Figure 11. Schematic cross sections of Tanaga volcanic cluster, Tanaga Island, Alaska from the Pleistocene epoch to present. 15
Figure 12. Diagram showing hazardous phenomena associated with stratovolcanoes 17
Figure 13. Map showing areas of potential ashfall during a moderate eruption of a Tanaga cluster volcano, Tanaga Island, Alaska 19
Figure 14. Map showing approximate extent of proximal hazard zones from ashfall and ballistics near the Tanaga volcanic cluster, Tanaga Island, Alaska 20
Figure 15. Map showing approximate areas likely to be affected by pyroclastic flows and surges originating at the active vents of the Tanaga volcanic cluster, Tanaga Island, Alaska 22
Figure 16. Map showing areas that may be inundated by lava flows during a Tanaga volcanic cluster eruption, Tanaga Island, Alaska 23
Figure 17. Map showing areas that could be swept by lahars and floods, Tanaga Island, Alaska 24
Figure 18. Map showing areas that could be affected by debris avalanches and rockfalls, Tanaga Island, Alaska 25
Figure 19. Map showing areas that could be affected by directed blasts near Tanaga Island, Alaska 27
Figure 20. Map showing principal North Pacific air routes in relation to the Tanaga volcanic cluster, Tanaga Island, Alaska 28
Figure 21. Example of hypothetical information release from the Alaska Volcano Observatory during volcanic unrest at the Tanaga volcanic cluster, Tanaga Island, Alaska 30

Tables

Table 1. Historical eruptions and volcanic unrest of Tanaga volcanic cluster, Tanaga Island, Alaska 12
Table 2. Summary of volcanic hazards at the Tanaga volcanic cluster, Tanaga Island, Alaska 18
Table 3. Volcanic-alert levels used by volcano observatories in the United States 29
Table 4. Aviation level-of-concern color codes 29

Conversion Factors and Datum

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch
kilometer (km)	3,281	foot
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
	Area	
cubic meter (m^3)	35.31	cubic mile
cubic kilometer (km^3)	0.2399	cubic mile
square kilometer (km^2)	0.3861	square mile
	Flow rate	
meter per second (m/s)	3.281	foot per second

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F= (1.8×°C) +32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

This page is intentionally left blank.

Preliminary Volcano-Hazard Assessment for the Tanaga Volcanic Cluster, Tanaga Island, Alaska

By Michelle L. Coombs, Robert G. McGimsey, and Brandon L. Browne

Summary of Volcano Hazards at Tanaga Volcanic Cluster

The Tanaga volcanic cluster lies on the northwest part of Tanaga Island, about 100 kilometers west of Adak, Alaska, and 2,025 kilometers southwest of Anchorage, Alaska. The cluster consists of three volcanoes—from west to east, they are Sajaka, Tanaga, and Takawangha. All three volcanoes have erupted in the last 1,000 years, producing *lava flows* and *tephra* (ash) deposits. A much less frequent, but potentially more hazardous phenomenon, is volcanic edifice collapse into the sea, which likely happens only on a timescale of every few thousands of years, at most. Parts of the volcanic bedrock near Takawangha have been altered by *hydrothermal* activity and are prone to slope failure, but such events only present a local hazard. Given the volcanic cluster's remote location, the primary hazard from the Tanaga volcanoes is airborne *ash* that could affect aircraft. In this report, we summarize the major volcanic hazards associated with the Tanaga volcanic cluster.

Volcanic Ash Clouds

During *explosive eruptions*, clouds of ash—pulverized volcanic rock less than 2 mm across—can rise into the atmosphere and travel hundreds to thousands of kilometers downwind of the volcano. The prevailing winds around Tanaga Island would carry ash primarily to the east, but ash could travel in any direction. Airborne ash is hazardous to aircraft because of the detrimental effect on jet engines. Because heavily traveled air routes between North America and Asia overlie the volcano, *ash clouds* probably are the most hazardous phenomena associated with eruptions of the Tanaga volcanic cluster.

Volcanic Ash Fallout

Ash clouds produced by explosive eruptions contain ash particles that will fall to the ground, forming *fallout*, or tephra deposits. Fine ash particles may be carried far downwind from the *vent*, whereas larger (coarser) particles will rain out closer to the source. On Tanaga Island, tephra deposits from the Tanaga volcanic cluster are up to several tens of centimeters thick and contain particles several centimeters in diameter. Heavy ash fall can collapse buildings, harm mechanical equipment, damage vegetation, clog streams, and effect wildlife, although typical Tanaga eruptions would produce tephras of fine ash only several millimeters thick in Adak, Alaska, the closest community. Ash in the atmosphere can interfere with radio communications and damage power lines. Ash fall downwind of Tanaga may affect airport and fishing port operations.

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.

Ballistics

Ballistics, or volcanic bombs, are pebble- to boulder-size particles ejected explosively during eruptions. They follow arcuate trajectories carrying them only a few kilometers from the vent. Ballistics pose a substantial hazard to individuals, equipment, and property within their range. At Tanaga, ballistics from previous eruptions are confined mostly to several hundred meters from the individual vents.

Pyroclastic Flows and Surges

During some explosive eruptions, hot, dense, ground-hugging clouds of steam, ash, and rock flow rapidly from the vent. Called *pyroclastic flows*, these phenomena are hazardous to those caught in their path. Related phenomena, *pyroclastic surges* are hot blasts of gas and particles, typically preceding and accompanying pyroclastic flows. Flows and surges typically expected from these volcanoes usually follow topography and travel down gullies and valleys surrounding the volcano, but surges can be energetic enough to surmount ridges and hills. At the Tanaga volcanic cluster, deposits from pyroclastic flows and surges are confined to the upper flanks of the volcanic cones, indicating eruptions have produced relatively small flows and surges in the past.

Lava Flows

Magma that erupts non-explosively during *effusive eruptions* forms lava flows or piles of rubble called lava domes. Magmas at the Tanaga volcanic cluster tend to form elongated lava flows, and many reach the coastline. Immediate hazards from lava flows are burial and hot blocks shed from the distal portions of flows, especially if they are emplaced on steep slopes. When hot lava interacts with water, snow, or ice, however, sudden explosions can occur. This scenario is likely if flows from Tanaga, Sajaka, and East Tanaga reach the coastline, or if lava flows from the summit of Takawangha erupt through snow or ice. The Tanaga volcanic cluster has been a prodigious producer of lava flows, and eruptions of lava flows are likely in the future.

Lahars

Lahars are volcanic mudflows consisting of a mixture of volcanic debris and water. The steep, debris-laden slopes of the Tanaga volcanic cluster are potential sources for lahars. However, no sufficient standing water sources are near the summits of any of the volcanoes, therefore, an eruption or increased heat flow would be necessary to melt snow and ice to generate water for a lahar. Because Tanaga Island is uninhabited and there are no permanent buildings, the hazard posed by lahars is small. Lahars would only affect the flanks of the volcanoes and surrounding stream drainages. Topography constrains this hazard area to the northwest sector of the island.

Rockfalls and Landslides

Rockfalls and small landslides may occur on the steep slopes of the Tanaga volcanic cluster and surrounding ridges. These events can be, but are not necessarily, related to volcanic activity and pose only localized hazards to people in their path.

Volcanic Gases

Volcanic vents can emit hot steam and *volcanic gases* such as carbon dioxide, hydrogen sulfide, and sulfur dioxide. In sufficient concentrations, these gases can be harmful to humans. Some gases are heavier than air and tend to collect in low-lying areas, making descent into volcanic fissures, *craters*, or caves potentially hazardous. Lava flows and pyroclastic flows also can emit hazardous amounts of gas. Windy conditions in the Aleutian Islands can preclude gas buildup and lessen the hazards from volcanic gases. The only continuously active *fumarole* is on the northwest coast of Tanaga Island, but during increased volcanic activity, gas emission is likely from one or more of the volcanic vents.

Suggestions for Reading this Report

Readers who want a brief overview of volcano hazards at the Tanaga volcanic cluster 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 the Tanaga volcanic cluster. A glossary of relevant geologic terms is included at the end of the report. Additional information about the Tanaga volcanic cluster can be obtained by consulting the references cited at the end of this report or by visiting the Alaska Volcano Observatory wet site (URL: http://www.avo.alaska.edu).

Rare Hazardous Phenomena that Could Accompany Large Eruptions of the Tanaga Volcanic Cluster

Debris Avalanches

Debris avalanches are large, fast-moving masses of rock debris—potentially an entire flank of a volcano—produced by landslides. These avalanches may travel tens of kilometers from their source, including under water. They may be triggered by a volcanic eruption, a volcanic or tectonic earthquake, or they may have no obvious cause other than gravitational sliding. The resulting deposits can be hundreds of meters thick and often remove large parts of the volcanic edifice. Roughly 200,000 years ago, a massive debris avalanche sent the northwestern part of Tanaga Island sliding into the sea. About 3,000 years ago, the western half of Sajaka volcano was destroyed in a smaller debris avalanche accompanied by a volcanic eruption. Such an event occurs probably once every few thousand years, at most.

Directed Blasts

A *directed blast* is a sudden, violent volcanic explosion that occurs when a shallow body of magma is depressurized—for example, by a debris avalanche uncapping the magmatic system. Directed blasts produce high-velocity pyroclastic surges that radiate laterally from the affected side of the volcano. In the Tanaga volcanic cluster, only Sajaka appears to have experienced a directed blast, about 3,000 years ago. During this event, the west flank of Sajaka slid into the sea, depressurizing magma under the volcano that erupted explosively. Almost all *ejecta* from the eruption were directed over the water, and only small outcrops are preserved on land. Future directed blasts at the Tanaga volcanic cluster could happen at any of the volcanoes. Because directed blasts commonly are initiated by debris avalanches, potential blasts will be directed away from flanks most likely to fail. Such events are likely to occur no more than every several thousand years or more.

Volcanic Tsunamis

Destructive waves called volcanic *tsunami* can result from the rapid displacement of water generated by a large volcanic debris avalanche, landslide, or pyroclastic flow that enters the sea. Both debris avalanches preserved in the geologic record at Tanaga likely produced tsunamis, but the magnitudes and effects are not known. These north and northwestern directed events would have produced waves that propagated into the Bering Sea. Like the debris avalanches that produce them, these events are rare. Given Tanaga's remote location, the main hazard would be to ships close to the island.

This page is intentionally left blank.

Introduction

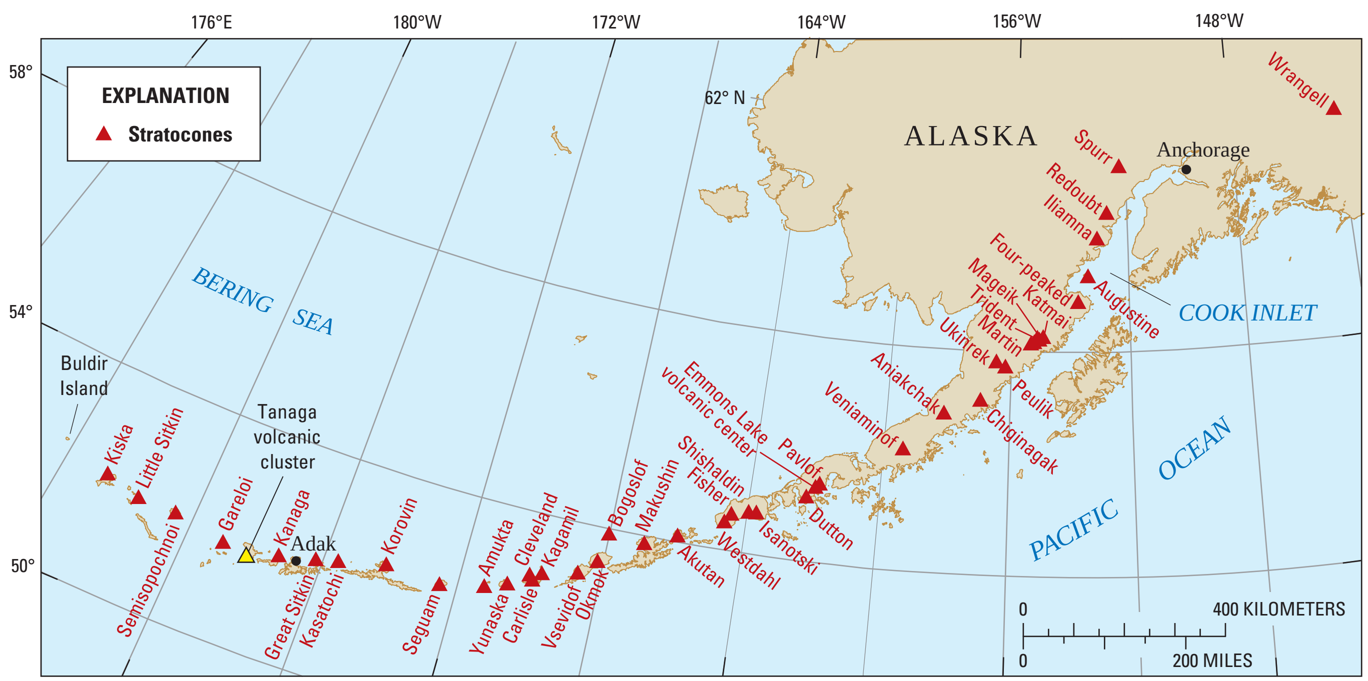
The Aleutian volcanic arc stretches about 2,500 km from Buldir Island in the west to Cook Inlet in the east, and contains about 40 historically active volcanoes, many on uninhabited islands (fig. 1). Eruptions from these frequently active volcanoes can send ash clouds into the atmosphere causing hazardous conditions for the numerous aircraft that travel between North American and Asia.

In 2003, Alaska Volcano Observatory (AVO) scientists visited Tanaga Island to begin the first field studies of the volcanoes on the northern part of the island. Little was known about the geology of the island because only a few days of reconnaissance fieldwork was done in the mid-1940s. Reports of volcanic activity on the island are sparse and do not provide the location of the vent(s) for the eruptions. Therefore, studies of the volcanic deposits are important to determine the likelihood and style of future eruptions from the Tanaga volcanic cluster.

In tandem with geologic studies in 2003, a network of six *seismometers* was installed on the island. From the time of installation through late summer 2005, the island remained seismically and volcanically quiet. Then, beginning in October 2005 and continuing for 2 months, a *seismic swarm* of volcanic earthquakes was detected below the Tanaga volcanic cluster. Although this swarm did not culminate in an eruption, the event illustrated that the volcanoes of Tanaga Island remain potentially active, and highlighted the importance of understanding the hazards associated with future eruptions.

Purpose and Scope

In this report, we describe our current understanding of the *hazard*s associated with the Tanaga volcanic cluster. The term 'hazard' refers to the physical events produced by an eruption (or less likely, physical phenomena on the volcanoes not directly associated with an eruption, such as landslides).



Base from Alaska Department of Natural Resources
coastline digital data, 1:250,000, 1984
Albers Equal-Area Conic projection

Figure 1. Location of the Tanaga volcanic cluster, Tanaga Island, in relation to other active volcanoes of the Aleutian volcanic arc, Alaska.

'Hazard' should not be confused with *risk*, which includes consideration of the consequences of events on people, infrastructure, buildings, and economic activity (Blong, 1996). In this hazard report, as in others, we use observations of historical eruptions and interpretation of the geologic and stratigraphic records to understand past volcanic events. This enables us to make informed statements about the probable nature and magnitude of future volcanic events, and therefore volcanic hazards.

A description is provided of the physical character of the volcanoes, followed by the geologic history of the Tanaga volcanic cluster. Finally, details are provided about individual hazards that may occur at the volcanoes. Photographs, maps, and other figures accompany the text to highlight the extent of possible hazards.

Physical Setting and Features of Tanaga Volcanic Cluster

Tanaga Island is a 529 km^2 land mass in the Andreanof Island group about 100 km west of Adak, Alaska, and 2,025 km southwest of Anchorage, Alaska (figs. 1 and 2). The volcanoes of the Tanaga volcanic cluster are part of a curving chain of volcanoes known as the Aleutian *volcanic arc*. The Aleutian volcanic arc is one of the most active volcanic regions in the world stretching from Buldir Island in the west to Cook Inlet in the east (fig. 1). Most volcanoes in the western part of the arc are isolated with only one volcano on an island. The Tanaga volcanic cluster, however, includes three active volcanic *edifices*— Sajaka, Tanaga, and Takawangha— within a small area on one island (figs. 3 and 4).

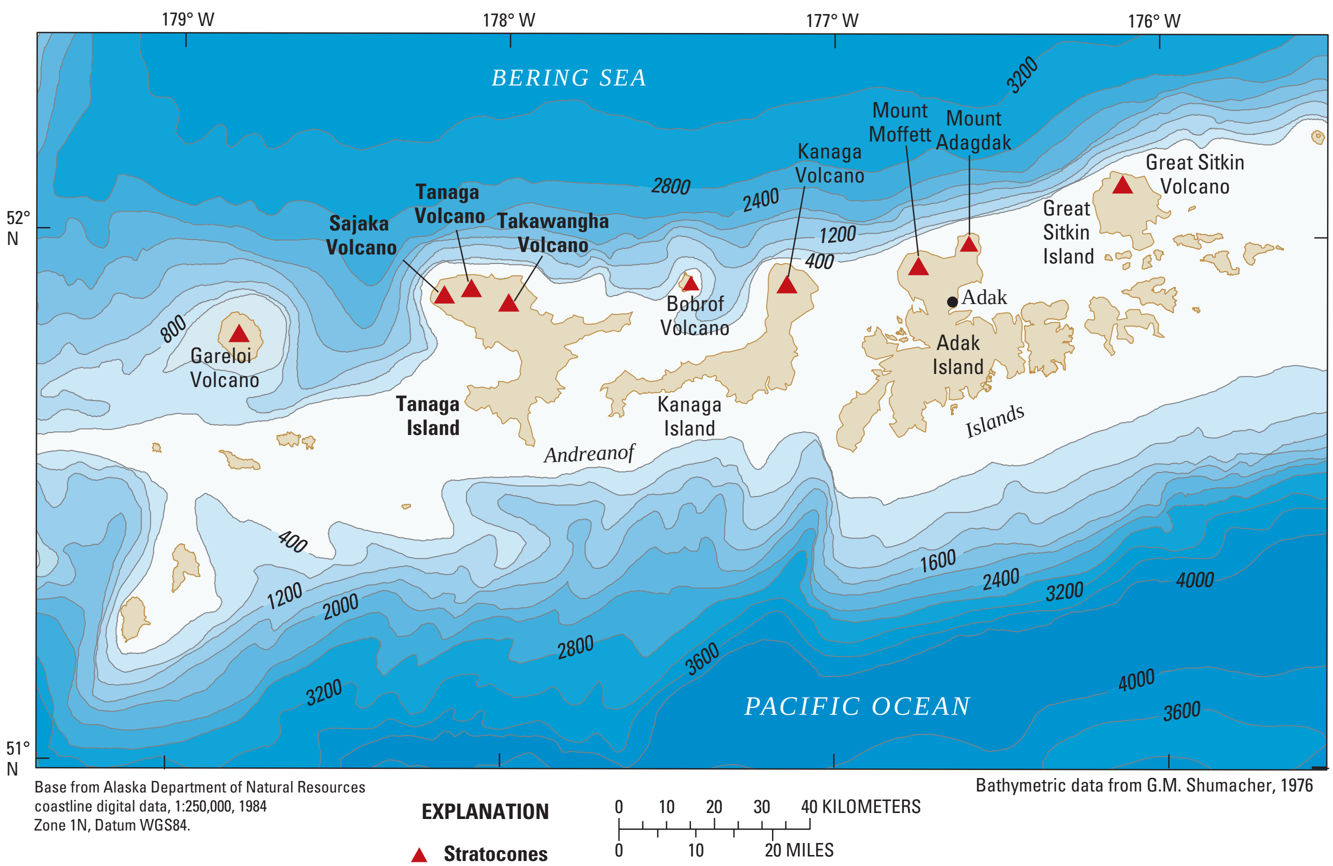
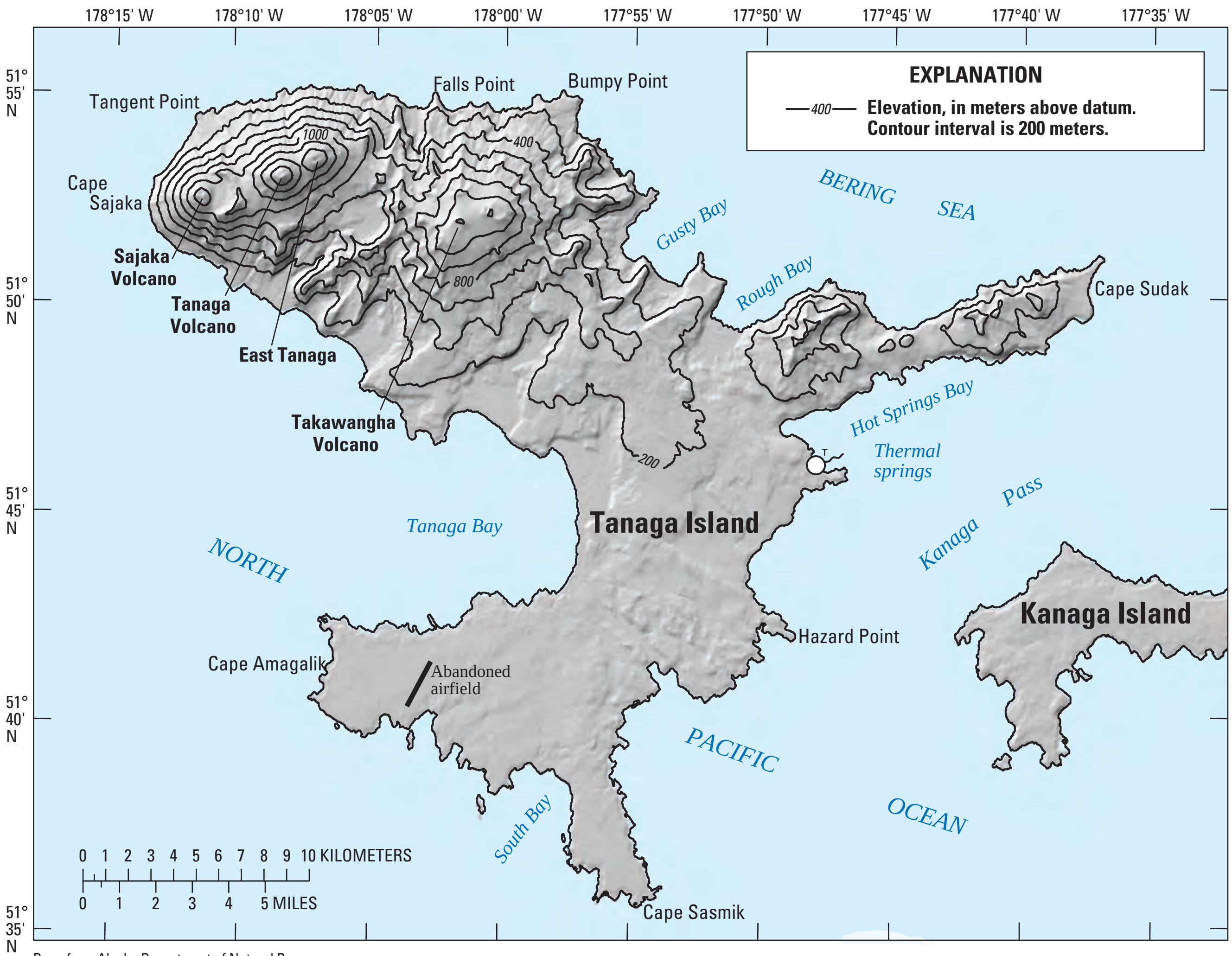


Figure 2. Geographic setting of Tanaga volcanic cluster, Tanaga Island and nearby islands, Alaska. Bathymetric contour interval is 400 meters.

The island consists of three distinct topographic terrains—the low-lying southern half, the finger-shaped northeastern highland terminating at Cape Sudak, and the ruggedly mountainous northwest sector (fig. 3). The Tanaga volcanic cluster is in the third sector. The Tanaga volcanoes rest on older volcanic basement rock ranging from *Pleistocene* to *Tertiary* in age (fig. 5).

Tanaga Island is uninhabited and is part of the Alaska Maritime National Wildlife Refuge managed by the U.S. Fish and Wildlife Service. The island is remote and reachable only by boat or helicopter. Tanaga Bay on the west coast of the island, and Gusty Bay, Hot Springs Bay, and Rough Bay to the east all provide adequate anchorages (fig. 3). An airstrip, built by the U.S. Navy during World War II, lies on Cape Amagalik at the southwestern tip of the island but is no longer usable.

In this report, we focus on the three volcanoes on the island that have been active in the Holocene and summarize the prominent physical characteristics of each.



Base from Alaska Department of Natural Resources coastline digital data, 1:250,000, 1984
Zone 1N, Datum WGS84.

Figure 3. Location of the Tanaga volcanic cluster on Tanaga Island, Alaska. Topographic contour interval is 200 meters.

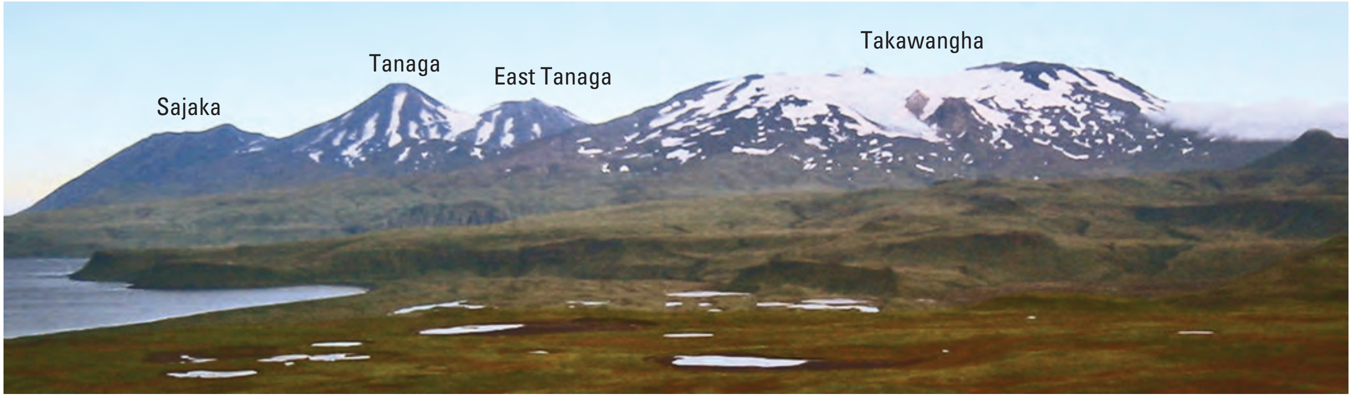


Figure 4. View of the Tanaga volcanic cluster, looking north, Tanaga Island, Alaska. Relief of volcano summits with respect to the foreground area is about 1,500 m. Cape Sajaka is at the far left of the image. Photograph by M.L. Coombs, U.S. Geological Survey, August 2003.

Sajaka

Sajaka volcano (altitude 1,354 m) is named for Cape Sajaka, on the extreme northwest of Tanaga Island (figs. 3 and 4). Sajaka's edifice is compound. The older edifice ("Sajaka One") to the east was partially destroyed during a debris avalanche into the sea in the last few thousand years. A new cone ("Sajaka Two") has grown in the breach (fig. 5**;** fig. 6*A*). Sajaka Two (altitude 1,312 m) consists of steeply dipping, interbedded *scoria* beds and thin, *spatter*-fed lava flows. This new cone is steep sided with slopes reaching precipitously to the shoreline to form Cape Sajaka. Three shallow explosion craters pock its summit (fig. 6*B*). The saddle, formed as Sajaka Two has grown alongside Sajaka One, supports a small glacier (figs. 5 and 6*A*).

Tanaga

Tanaga volcano (altitude 1,806 m) has the steep, regular slopes of a classic *stratovolcano* (figs. 7*A* and *B*). A small crater sits atop its summit (fig. 5). Lava from Tanaga has flowed from the summit several kilometers down the north and south flanks, reaching both coasts. Another series of thick, prominent lava flows wrap around the east side of a ridge of older rock and fill a glaciated valley (figs. 5 and fig. 7*A*). Small patches of permanent snow or ice persist high on the Tanaga cone even during summer when the rest of the edifice is mostly snow-free.

On the northeast shoulder of Tanaga is a smaller (altitude 1,584-m) more subdued peak informally named East Tanaga. This cone has a 650-m-wide crater at its summit and two more ice-filled craters on its northeast flank. These craters form a line that includes the crater atop Tanaga (fig. 7*B*). East Tanaga's north slopes are similar to those of Tanaga, with lava that flowed steeply to the coast. Lava that flowed down the volcano's south flank has settled in a glacially carved basin. Overlapping of lava flows from the two cones indicate the cones have been active during approximately the same period. The upper flanks of both volcanoes are blanketed in coarse debris (ash, scoria, etc.).

Takawangha

Takawangha volcano (altitude 1,449-m) is a stratovolcano that lies across a steep, rocky divide east of Sajaka and Tanaga (figs. 3 and 4). The edifice is much broader than the other cones of the Tanaga volcanic cluster, and much of its bulk consists of older basement rock beneath the Takawangha lava (fig. 5). Unlike the other Tanaga volcanic cluster volcanoes, Takawangha is composed of both *glaciated* and unglaciated lava, indicating a longer history than the other two volcanoes in the cluster, dating into the Pleistocene. The summit is mostly ice-covered, except for five young craters that have erupted ash and lava flows in the last few thousand years (fig. 8). Parts of Takawangha's edifice are altered hydrothermally, as indicated by orange-yellow outcrops, mostly of older rocks, on its flanks.

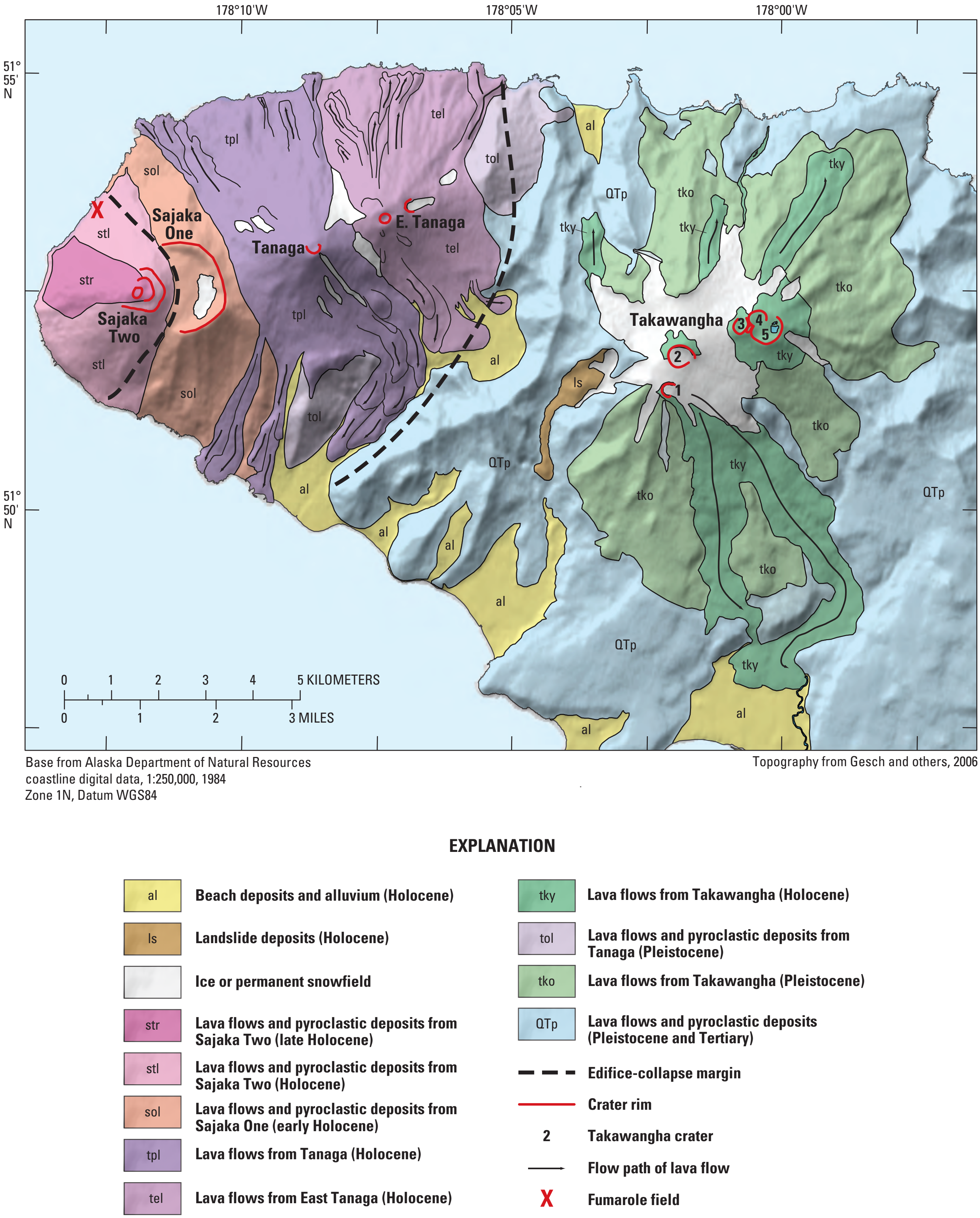


Figure 5. Geology of the Tanaga volcanic cluster, showing eruptive products from each volcano, Tanaga Island, Alaska. Solid lines in a single-colored map unit delineate individual flows or units.

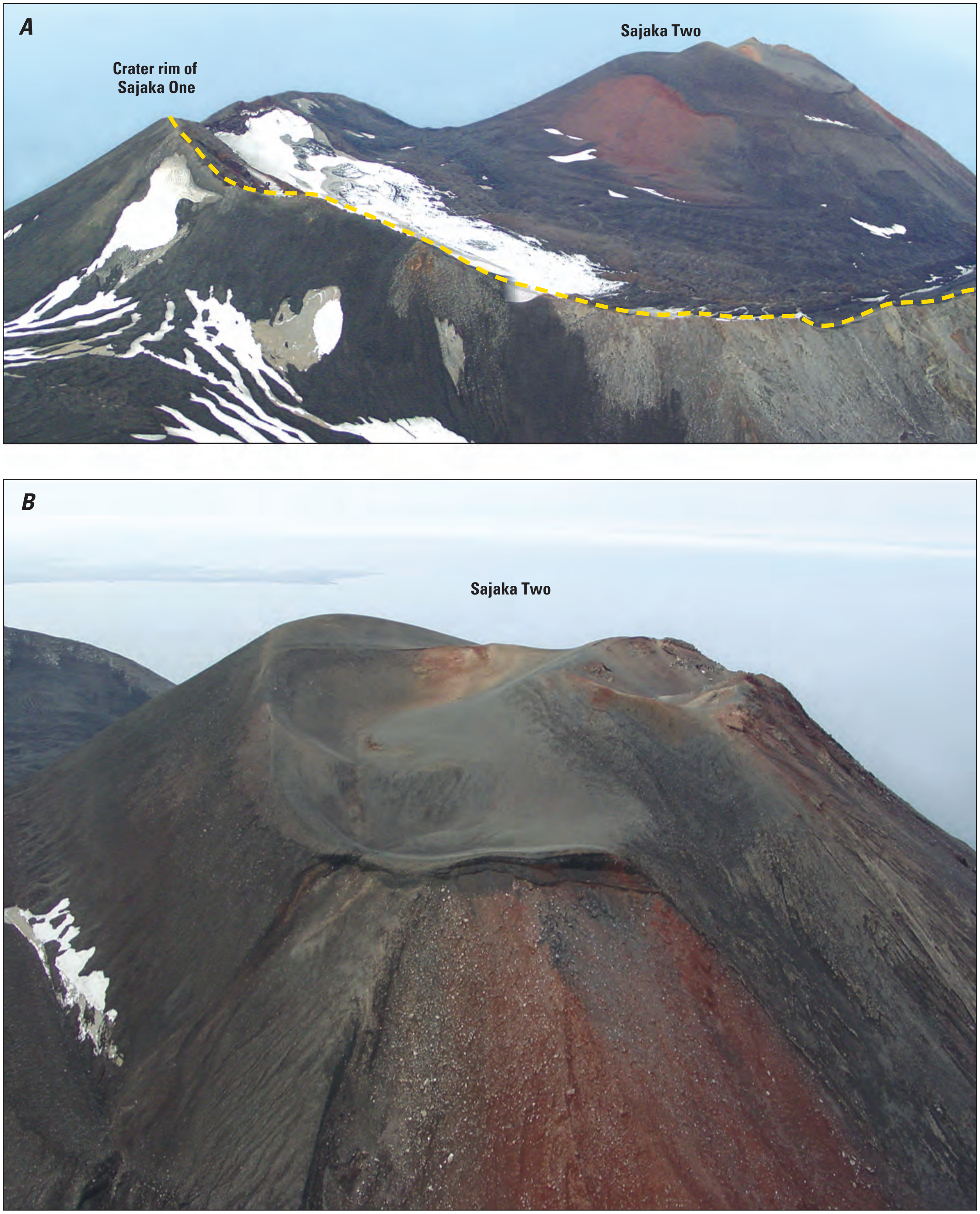


Figure 6. Sajaka volcano edifice, Tanaga Island, Alaska. *(A)* View of Sajaka volcano summit, looking southwest; the older rim of Sajaka One wraps around the new cone of Sajaka Two. A small glacier sits in the saddle between Sajaka One and Sajaka Two. *(B)* View of craters atop Sajaka Two, looking southeast. Photographs by R.G. McGimsey, U.S. Geological Survey, August 2003.

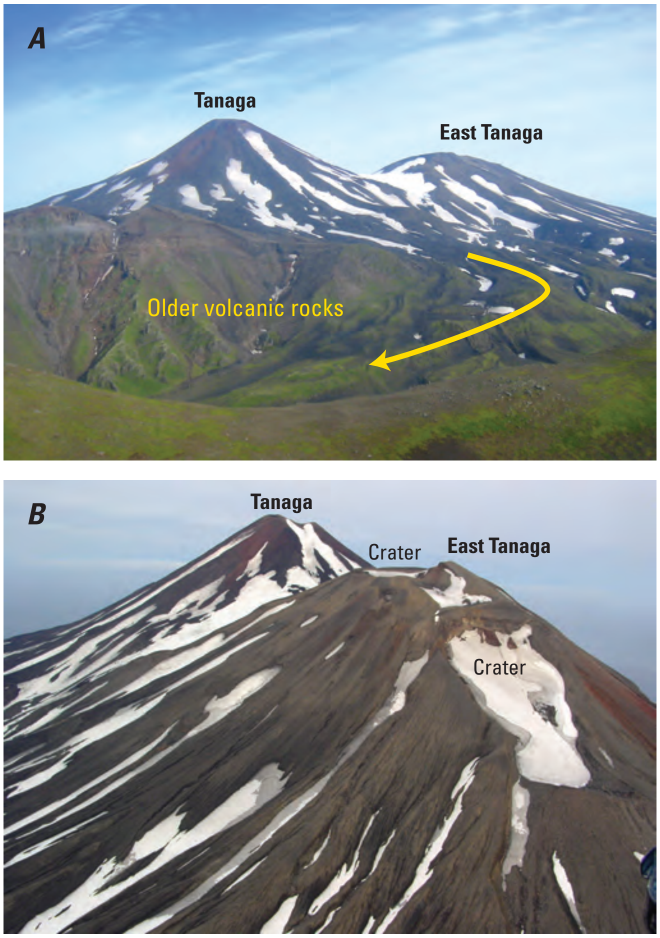


Figure 7. Tanaga volcano edifice, Tanaga Island, Alaska. *(A)* View of Tanaga and East Tanaga vents, looking northwest. Arrow shows direction of a series of thick lava flows from Tanaga wrapped around a ridge of older rock. *(B)* View of Tanaga and East Tanaga vents, looking west. Two craters are visible on East Tanaga. Photographs by R.G. McGimsey, U.S. Geological Survey, August 2003.

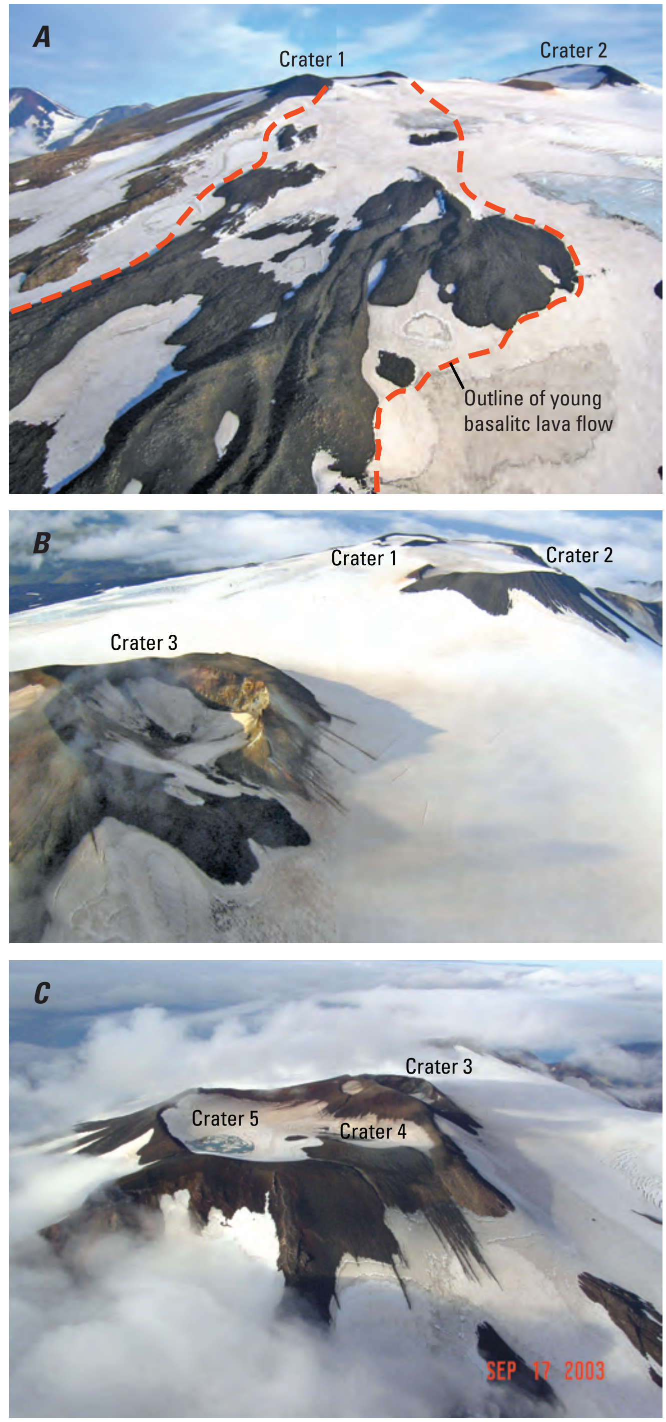


Figure 8. Takawangha volcano summit, Tanaga Island, Alaska. Crater numbers correspond to those shown in figure 5. (*A*) View of craters 1 and 2 showing a young basaltic lava flow from crater 1, looking north. Crater 1 is covered partly by glacial ice. (*B*) View of craters 1, 2, and 3, looking southwest. (*C*) View of craters 3, 4, and 5, looking west. Photographs (*A*) and (*B*) by M.L. Coombs, U.S. Geological Survey, August 2003. Photograph (*C*) by R.G. McGimsey, U.S. Geological Survey, September 2003.

Eruptive Activity of Tanaga Volcanic Cluster

Historical Volcanic Activity

Information about historical volcanic activity of the Tanaga Island volcanoes is sparse because of the remote location. Five episodes of possible eruptive activity have been recorded since sailors began traveling by the island in the mid-1700s (table 1). The first episode was from 1763 to 1770 when the volcano was described as "constantly active" (Grewingk, 1850). Observations of "smoking" were reported on June 9, 1791, and during 1829 (Grewingk, 1850). These accounts likely refer to steam produced by fumaroles at the summit of one or more ov the volcanic cones. The last reported volcanic activity on the island was in 1914 when a lava flow was observed (Coats, 1950). No report specifies a particular peak as the vent.

Seismicity

In August 2003, AVO personnel installed a network of six seismic instruments on northern Tanaga Island (fig. 9). From that time through September 2005, Tanaga Island was quiet seismically, with only a few earthquakes detected each year. Beginning in early October 2005 and continuing through November 2005, a swarm of *volcano-tectonic earthquakes* was detected below the northern half of the island (Dixon and others, 2006). These earthquakes were between 15 and 0 km below sea level, and likely reflected new magma movement (or at least volcanic gas) into the shallow crust beneath the Tanaga volcanic cluster. The magnitude of the largest of these earthquakes was 3.0 or less. Such swarms are common beneath some Aleutian volcanoes and often do not result in eruptions. Another type of seismic signal unique to volcanoes, called *tremor*, was recorded beneath the island during this time. This signal typically is associated with fluid movement (likely water, gas, or magma). No eruption occurred, and in late 2005, the seismic activity quieted to background levels.

Table 1. Historical eruptions and volcanic unrest of Tanaga volcanic cluster, Tanaga Island, Alaska.

[Observations do not specify a vent and activity could have occurred at any center in the cluster]

Date	Activity	References
1763–70	"Constantly active"	Grewingk, 1850
June 9, 1791	"Smoking"	Grewingk, 1850
1829	"Smoking"	Grewingk, 1850
1914	Lava flow	Coats, 1950
2005	Seismic swarm, edifice inflation	Dixon and others, 2006

Fumarolic Activity and Thermal Springs

Fumaroles are openings, cracks, or vents that emit steam and volcanic gas. During field work in 2003, no active fumaroles were observed at the summits of any of the Tanaga volcanic cluster vents. The only fumarolic activity on the island, spotted from aboard ship, was on the northwest flank of Sajaka Two near shoreline (fig. 5). The temperature and composition of the gases emitted there are unknown. Blocks of native sulfur near one of Takawangha's vents indicate gases have been emitted there in the recent past. Historical reports of "smoking" from the Tanaga volcanic cluster may have been made during periods of increased fumarolic activity at one or more of the volcanoes.

A small thermal spring is on the east coast of the island in aptly named Hot Springs Bay (fig. 3). The spring contains few mineral encrustations and its temperature is below boiling.

Prehistoric Eruptive Activity

Because of the sparse historical record of volcanic activity at Tanaga, using the geologic record is vital to understanding the eruptive style, scale, and frequency of prehistoric eruptions in the area and to help scientists better understand future volcanic activity and hazards. Our geologic work on Tanaga Island has established an eruptive history for each volcano in the Tanaga volcanic cluster (fig. 10). Geologic mapping reveals the distribution of volcanic deposits (such as lava flows or debris-avalanche deposits) from each volcano. By combining mapping with *radiometric dating* of lava flows, we can assign ages to the eruptive centers and determine broad periods of activity. In this report, we present the first such ages for lava flows of the Tanaga volcanic cluster. These ages are the first results from an ongoing study (A. Calvert, written commun., 2005). Because of errors inherent to the technique, we cannot resolve ages for lava flows more accurately than a few thousand years.

In addition to mapping the exposed rock types of the volcanoes, we also use the stratigraphy of unconsolidated ash, *pumice*, and scoria layers to learn more about younger eruptive events. Because these deposits are more prone to erosion (especially by glaciers) than lava flows and other hard rocks, explosive eruptions generally are poorly represented in the geologic record. Such deposits typically are interbedded with soils and peat layers that were deposited after the last glaciation. Radiometric dating of organic horizons can provide precise ages of these unconsolidated deposits (ranging from tens to hundreds of years). Thus, our understanding of the explosive histories of the volcanoes is skewed toward postglacial, or *Holocene*, time.

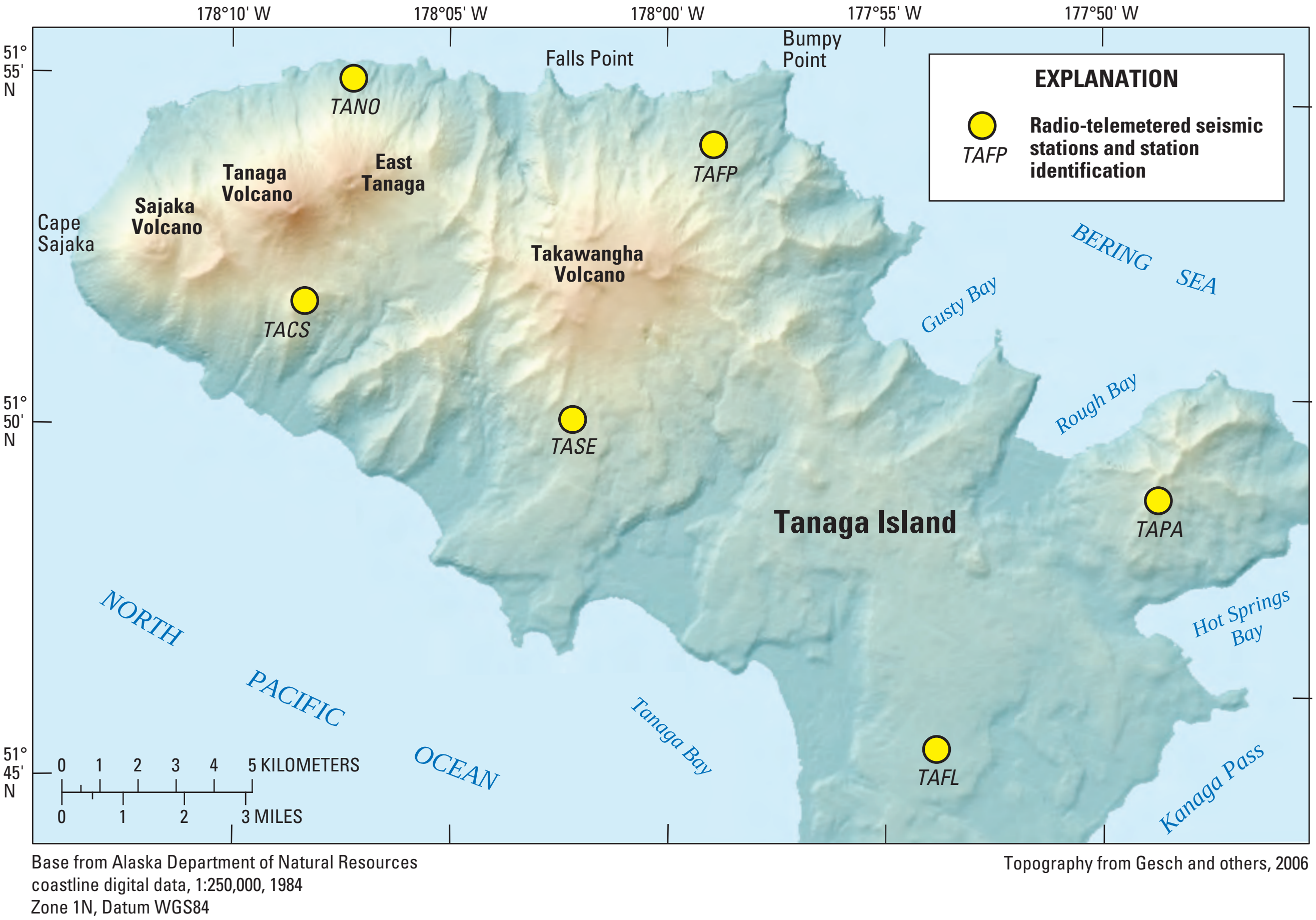


Figure 9. Locations of radio-telemetered seismic stations on Tanaga Island, Alaska. Data are radio-telemetered to Adak, Alaska, and then sent by telephone circuit to the Alaska Volcano Observatory in Anchorage.

Earliest Eruptive History

The geologic history of Tanaga Island is marked by long-lived volcanism. The basement the young Tanaga cones rest on is composed of volcanic and *sedimentary* rocks from the *Pleistocene epoch*. The bedrock on other parts of the island consists of volcanic rocks from the *Tertiary* period (Coats, 1984). Preliminary radiometric dating results indicate the oldest rocks that underlie the northern part of the island are roughly 250,000 years old and mark the beginning of the relatively continuous volcanic record of the Tanaga volcanic cluster.

Because of erosion and cover by younger rocks, little is known about the volcano or volcanoes that produced the earliest lava flows and fragmental rocks on the northwest part of the island. The edifice was once much larger than it is today and probably was centered between Tanaga and Takawangha. A broadly crescent-shaped scarp, concave to the west, separates the Takawangha and Tanaga edifices. This ridge is thought to be the residual rim of an amphitheatre that formed as the older volcanic edifice partially collapsed, as a debris avalanche, into the sea (fig. 11). On the basis of radiometric dates of lava flows on either side of the collapse scar, this event occurred between 240,000 and 118,000 years ago. Similar collapses have been recognized for other Aleutian volcanoes that sit on the north edge of the underwater Aleutian ridge (Coombs and others, 2007). Although many volcanic collapses of this kind are accompanied by eruptions, no widespread eruptive deposit has been correlated to the Tanaga collapse. This information indicates either such a deposit has been erased by erosion, or the collapse was caused by gravitational instability of the growing volcano, until the volcano finally gave way and fell into the sea.

After this collapse, another volcano grew near where Tanaga is today. This volcano was active between 118,000 and 40,000 years ago based on dating of lavas. The older volcano remnants are deeply eroded and underlie modern day Tanaga and East Tanaga cones.

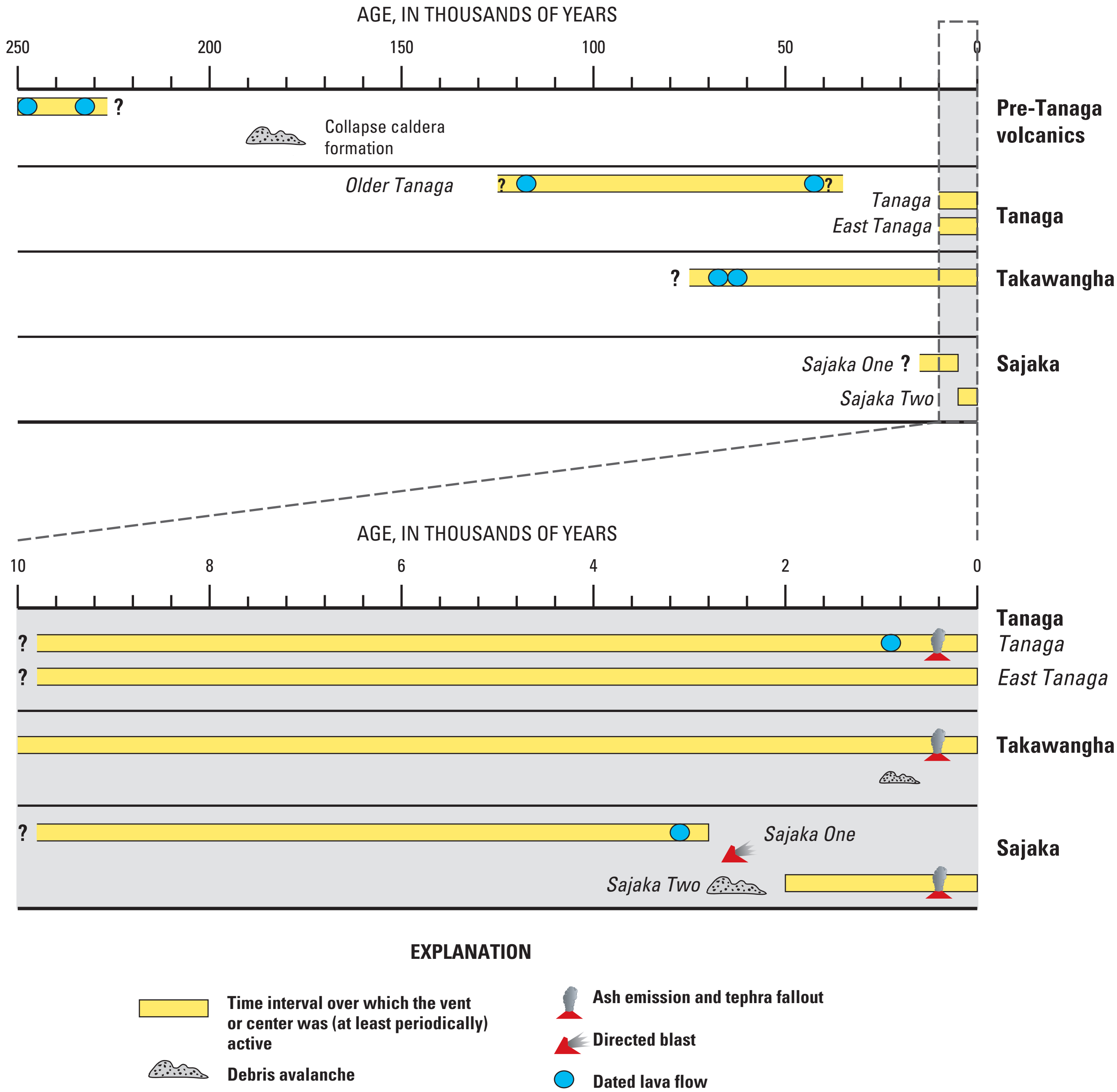


Figure 10. Eruptive history of the Tanaga volcanic cluster, Tanaga Island, Alaska. Top panel summarizes the eruptive history beginning 250,000 years ago, most notably showing the catastrophic collapse caldera and debris avalanche around 200,000 years ago. Bottom panel summarizes eruptive activity during the last 10,000 years (the Holocene epoch). All Tanaga volcanic cluster volcanoes have been active during this period. A directed blast and accompanying debris avalanche mark the transition from Sajaka One to Sajaka Two, several thousand years ago.

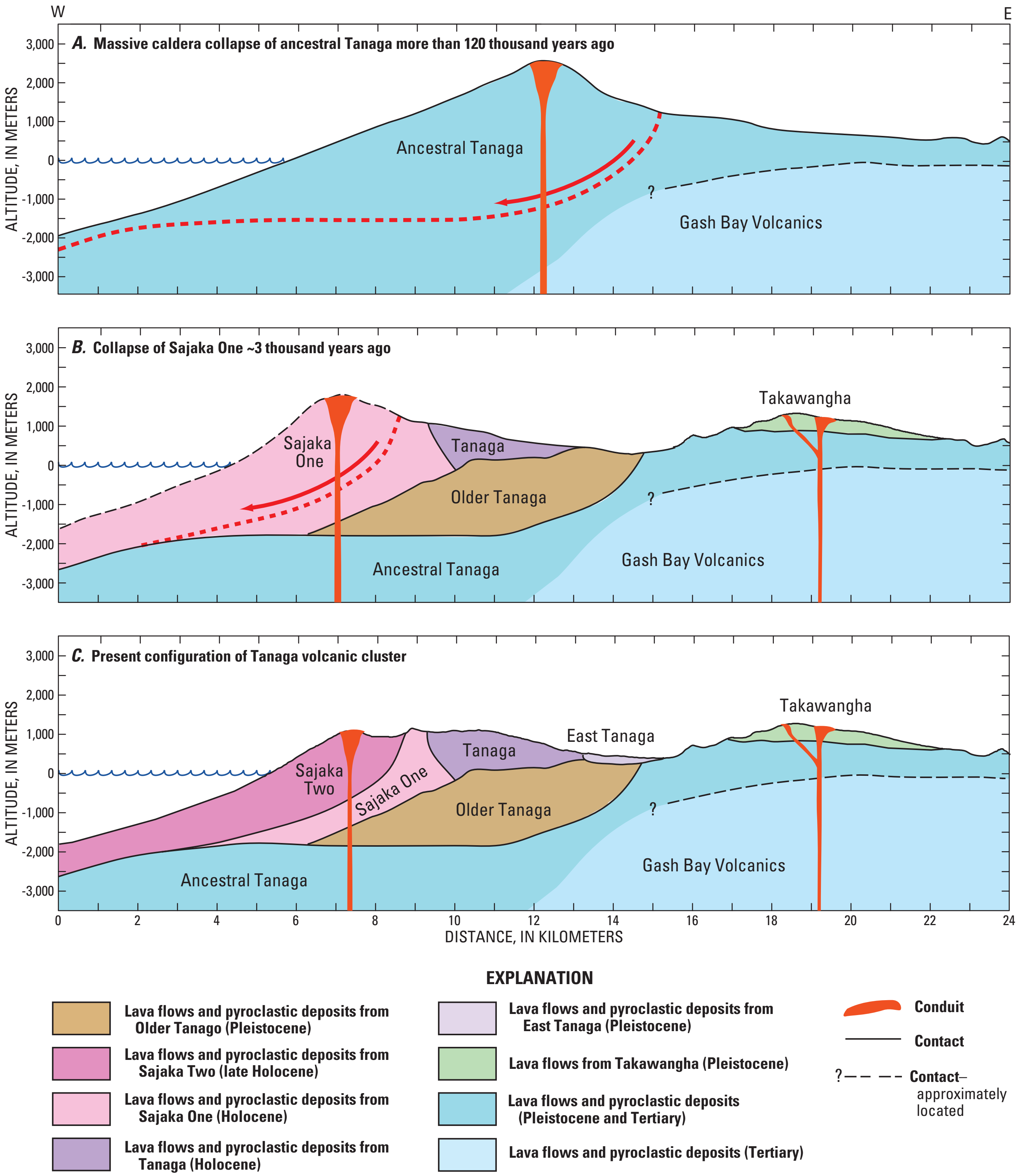


Figure 11. Tanaga volcanic cluster, Tanaga Island, Alaska from the Pleistocene epoch to present. *(A)* Ancestral edifice configuration and inferred failure surface for the catastrophic edifice collapse that predated the modern Tanaga volcanoes. *(B)* Sajaka One edifice configuration and inferred failure surface for a flank collapse that occurred about 3,000 years ago. *(C)* Current volcano configurations, with Sajaka, Tanaga, and East Tanaga growing within the scar left by the ancient edifice collapse, and Takawangha growing on top of relatively high, older basement rocks. Because of the cross section line placement, summits of Tanaga and East Tanaga are not shown in the cross section.

Eruptive History of the Modern Volcanoes

All active volcanoes on Tanaga Island erupt magma with low *silica* content—specifically, *basalts* and *basaltic andesites*, also known as *mafic* magmas. Mafic magmas have lower viscosities than magmas containing higher silica (such as *rhyolite*). Because of this characteristic, mafic magmas often erupt less explosively than more silicic magmas. Typical deposits of mafic volcanoes are lava flows, *agglutinated* spatter deposits, and localized tephras; therefore, it is not surprising that the Tanaga volcanoes tend to produce these deposits.

Of the currently active stratovolcanoes on Tanaga Island, **Takawangha** is the oldest, having been active for the last 60,000 years, based on radiometric dating of its lava flows. Many of these flows were eroded and smoothed by the glacial ice that covered the highlands of the island until retreat of ice at the end of the last glaciation. The timing of this retreat is not well constrained for the Aleutians, but was likely around 10,000 years ago. The edifice—broad and high—is made of Takawangha lava flows sitting like a veneer on an upland of older volcanic rock, which gives Takawangha its apparent bulk. Holocene eruptions of Takawangha volcano primarily produced blocky lava flows that effuse from shallow craters at the summit, with minor, localized tephra deposits.

Tanaga and **East Tanaga** cones are much younger than Takawangha, having Holocene age cone-building lava. Tanaga and East Tanaga cones share similar shapes and eruptive styles, having mostly erupted blocky lava flows. Most explosive deposits from the two cones are confined to areas close to the vent. One exception is a few-hundred-year-old tephra layer at several sites around the northern part of the island. This tephra probably erupted from East Tanaga and is as much as several centimeters thick close to the volcano.

Sajaka's eruptive history can be broken into two parts. **Sajaka One** started to grow several thousand years ago, forming a cone likely to have been similar to those of Tanaga and East Tanaga. The eastern half of the Sajaka One edifice is still intact, but the western half is missing (fig. 11). A new, younger cone (**Sajaka Two**) has grown in the scar. The removal of Sajaka One's western half probably was caused by a landslide. Recent bathymetric mapping of the seafloor west of Sajaka revealed a debris field with several large blocks in the areas within the failure scarp of Sajaka One (Coombs and others, 2007). On land, no debris-avalanche deposit has been recognized, but outcrops of a pyroclastic-flow deposit were detected on top of Sajaka One lava. The presence of the pyroclastic-flow deposit indicates the collapse may have been accompanied by an explosive eruption, or possibly a lateral blast (Siebert, 1984). The lower part of the Sajaka One amphitheatre is obscured by the new Sajaka Two cone; however, the upper reach of the Sajaka One edifice is truncated by a 1.5-km-diameter crater that resembles those at Bezymianny, Russia, and Mount St. Helens, Washington, other volcanoes that have experienced lateral blasts (fig. 6). The age of the Sajaka One collapse is thought to be a few thousand years ago, because lava from beneath the pyroclastic-flow deposit and from the Sajaka Two cone yield radiometric ages of 5,000 years to present.

Eruptions from Sajaka Two usually produce thin, runny lava flows, many of which may be fed by spatter that erupts from the vent, coalesces, and begins to flow down the volcano's steep slopes. These thin lava flows are interbedded with scoria layers, forming deposits common at volcanoes that have a *Strombolian* eruptive style.

Volcano Hazards at Tanaga Volcanic Cluster

A volcano hazard is a volcano-related process that potentially threatens life or property (fig. 12). These hazards often, but not always, are associated with eruptive activity. Studying other volcanoes sharing similar processes augments our understanding of hazards associated with the Tanaga volcanic cluster. We can add our knowledge of this particular group of volcanoes to this basic understanding to assess the specific hazards posed by eruptive activity at Tanaga.

Hazards associated with the Tanaga volcanic cluster may be local or regional (table 2). Local hazards are those only affecting an area within a few tens of kilometers of the active vents. These hazards could result in death or injury to anyone in this area for two main reasons. First, there may be little warning prior to local hazards, and second, volcanic events usually are more energetic closer to the vent. In contrast, regional or distal hazards pose less of a risk because there is sufficient time to provide warnings, and the processes associated with an eruption are less energetic away from the active vent. Some phenomena, such as ash clouds and ash fallout, pose serious hazards locally and regionally.

Our geologic studies of the Tanaga volcanic cluster are preliminary, primarily because of the remote location and challenging logistics of the area. In addition, although deposits from previous eruptions can be used as a generally reliable guide to the eruptive styles expected in the future, volcanoes may erupt in different and unexpected ways. The size and duration of an eruption will also affect the total at-risk area for various hazards, with larger eruptions potentially affecting larger areas. Environmental conditions, such as wind speed and snowpack depth, can affect hazards associated with eruptions. For all these reasons, the geographic boundaries of hazard zones presented in this report should be considered approximate. Even with modern instrumentation and monitoring techniques, the size and duration of an eruption are difficult to predict.

This report describes the types of hazards posed by the Tanaga volcanic cluster in general order of importance, with the most severe hazards described first.

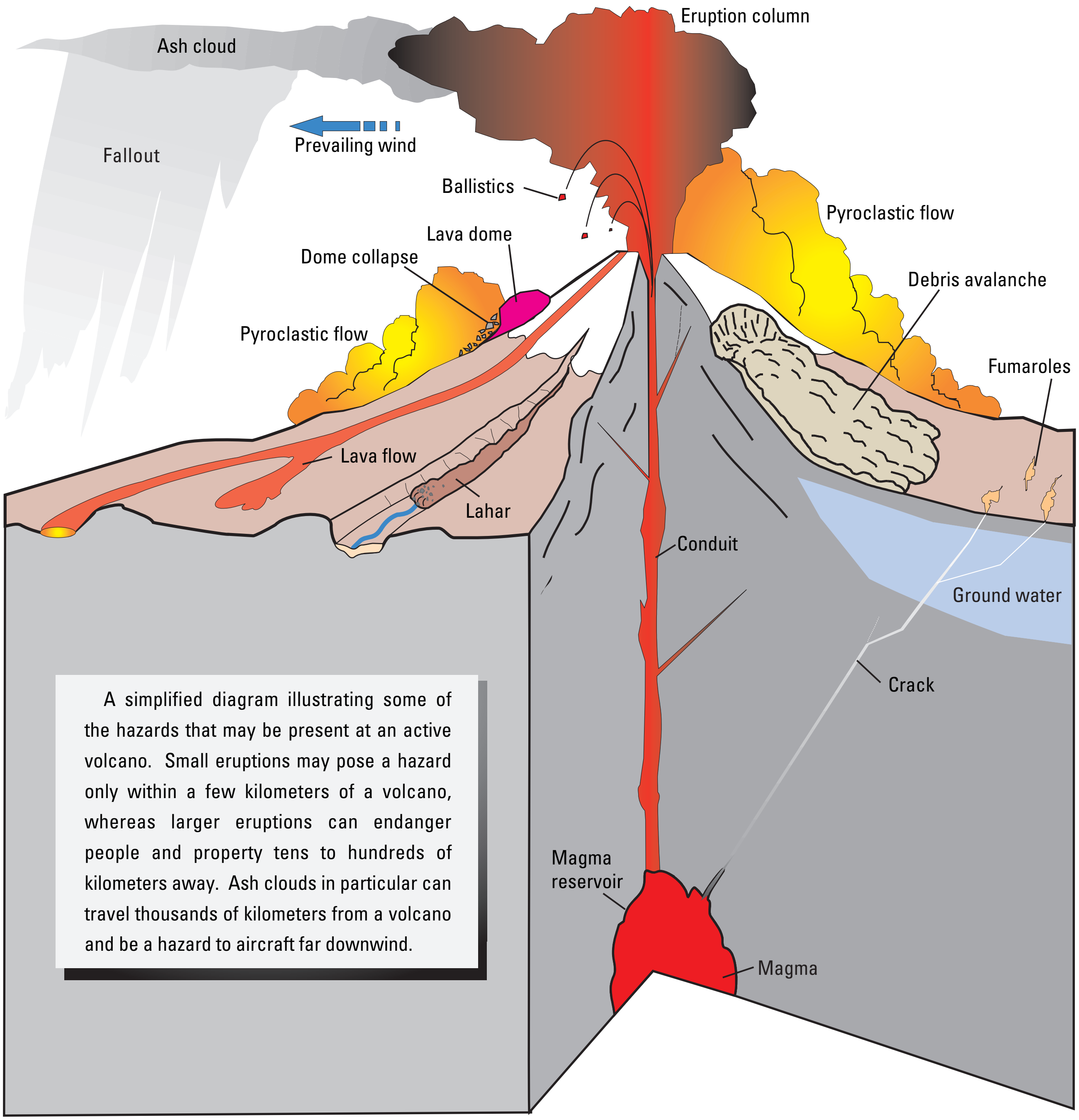


Figure 12. Hazardous phenomena associated with stratovolcanoes. (Modified from Meyers and others, 1997.)

Table 2. Summary of volcanic hazards at the Tanaga volcanic cluster, Tanaga Island, Alaska.

[See figure 12 and text for schematic representation and description of these processes. **Degree affected:** “Proximal” refers to northern Tanaga Island. “Distal” refers to areas offshore and the southern portion of Tanaga Island. “Overhead” refers to the area above the volcano (for example, for aircraft flying overhead)]

Type of hazard	Degree affected			Comments
	Proximal	Distal	Overhead	
Ash clouds	Major	Major to slight	Major	Severe hazard to aircraft even hundreds or thousands of kilometers downwind.
Fallout	Major	Major to nil	Major	Significant hazard to anyone around volcano and to nearby communities. Minor hazard or nuisance in distant communities.
Ballistics	Major	Nil	Nil	Significant hazard to anyone on or around volcano during explosive eruptions.
Pyroclastic flows and surges	Major	Nil	Slight	Significant hazard to anyone on or near the volcano during explosive eruptions. Possible hazard to overflying aircraft during large eruptions.
Lava flows	Major	Nil	Nil	Significant hazard to anyone near flows; attendant pyroclastic flows, fallout, or ballistics increase the area potentially affected.
Lahars	Major	Nil	Nil	Significant hazard limited to drainages downstream from erupting vent.
Rockfalls and landslides	Major	Nil	Nil	Persistent hazard to anyone near steep slopes especially those that are hydrothermally altered.
Volcanic gases	Major	Nil	Slight	Significant hazard during periods of strong degassing from fumaroles or vents.
Debris avalanches	Major	Major	Slight	Significant hazard to anyone around volcano during an event, especially in low-lying areas. Larger debris avalanches would extend offshore.
Directed blasts	Major	Major	Major	Very low-probability but significant hazard especially in the path of a directed blast; attendant pyroclastic flows, fallout, and debris avalanche would increase affected area.
Volcanic tsunamis	Major	Major	Nil	Very low-probability but significant hazard during a large debris avalanche or eruption that produces large pyroclastic flows that enter the sea; could occur off the north or west shore of the island, affecting areas on nearby islands, shipping routes, and the Bering Sea.

Volcanic Ash Clouds

During an explosive eruption of any of the Tanaga volcanic cluster volcanoes, large quantities of ash likely will be ejected into the atmosphere forming an ash cloud or eruption cloud propelled by fast-moving, expanding volcanic gases. These clouds may rise to several thousand meters above sea level, can remain aloft for hours to days, and may drift hundreds to thousands of kilometers beyond the volcano with the prevailing wind. If wind direction is stratified by altitude, parts of the cloud may travel in different directions. Winds in this part of the Aleutians are generally from the west, therefore, most ash clouds will be carried to the east (fig. 13). Eruption clouds can be hazardous if encountered by aircraft (Casadevall, 1994).

Commonly, eruptions of Tanaga volcanic cluster volcanoes will produce ash clouds that only rise to several kilometers above the volcano, but larger eruptions could produce clouds that reach higher altitudes. Satellite observations are the most effective tool for monitoring the clouds and mitigating hazard, such as by diversion of air traffic.

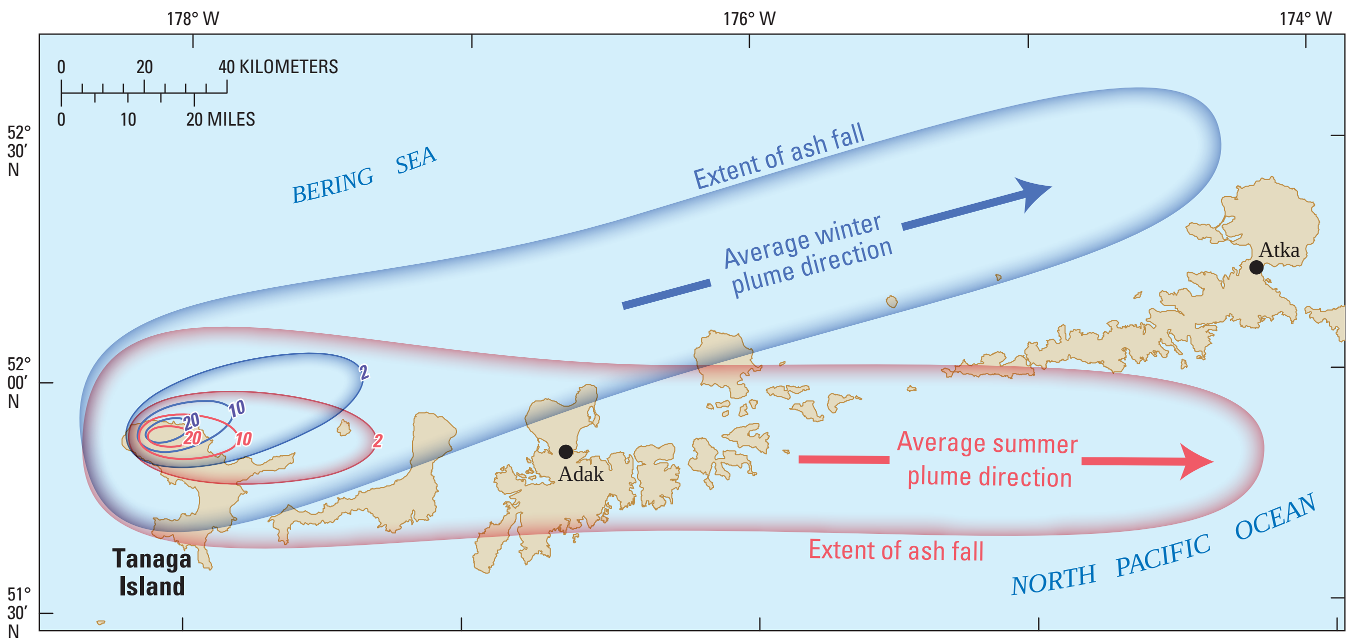
A *phreatic eruption* is an eruption that occurs when hot, hydrothermally heated ground water transforms to steam, becomes pressurized, and may release explosively at the surface. Phreatic eruptions can produce ash, though typically not in the volume produced during magmatic explosive eruptions.

Volcanic Ash Fallout and Volcanic Bombs (Ballistics)

Volcanic ejecta moving downwind in an ash cloud settles out and falls to the ground forming a blanketing layer of ash, or tephra. Generally, the thickness and grain size of fallout decreases away from the volcanic vent. The windspeed and height of the ash cloud will strongly affect how much fallout is deposited, and where. Close to the vent, fallout may be many meters thick and contain clasts more than 1 m in diameter. Far from vent, the fallout may be less than 1 mm thick and consist of very fine ash.

Volcanic ash poses several hazards. Fine ash can cause respiratory problems if inhaled, and can irritate the eyes. Ash is abrasive and will damage mechanical equipment such as vehicles. Ash suspended in the atmosphere can hamper radio communications, and ash falling on power lines can cause electrical outages. Despite its fine grain size, ash is heavy and becomes heavier if wet, therefore, substantial accumulations of ash (especially wet) can cause roofs to collapse. Given prevailing wind conditions in the Aleutians, future fallout from eruptions of Tanaga volcanic cluster likely will carry ash to the east, causing possible fallout on the communities of Adak, Alaska (100 km east) and Atka, Alaska (265 km east (fig. 13). During a typical eruption, the fallout at Adak likely would be less than 2 mm (less than 0.1 in.), with little more than a dusting at Atka. Fallout within several kilometers of the vent, however, could accumulate to several centimeters (figs. 13 and 14).

In addition to fallout from eruption clouds, some explosive eruptions can launch blocks of rock or pumice, called ballistics, on arcuate trajectories from the vent. These can travel in any direction from the vent and pose a serious hazard to people within a few kilometers (fig. 14). Ballistics generally do not travel beyond 5 km from the vent (Blong, 1996).



Base from Alaska Department of Natural Resources coastline digital data, 1:250,000, 1984
Zone 1N, Datum WGS84

Figure 13. Areas of potential ashfall during a moderate eruption of a Tanaga cluster volcano, Tanaga Island, Alaska. Ashfall during an actual eruption will depend on wind direction and size of the eruption, and may deviate from these examples. Hypothetical ashfall contours, in millimeters, are generated using the ASHFALL model (Hurst, 1994). Two sets of wind data are shown: red highlights potential ashfall assuming average summer winds, and blue highlights potential ashfall assuming average winter winds. Summer (May through October) and winter (November through April) means were calculated using National Center for Environmental Prediction (NCEP) reanalysis long-term monthly wind data for 1968–96 (Kalnay and others, 1996). These data were provided by the National Oceanic and Atmospheric Administration/Office of Oceanic and Atmospheric Research/Earth Science Research Laboratory Physical Sciences Division, Boulder, Colorado, USA, at http://www.cdc.noaa.gov/. In the ashfall simulation, the eruption cloud is assumed to reach 12 kilometers (about 40,000 feet) above sea level and consist of 10 million cubic meters of ash. These values conceivably are typical for a moderate explosive eruption from the Tanaga volcanic cluster.

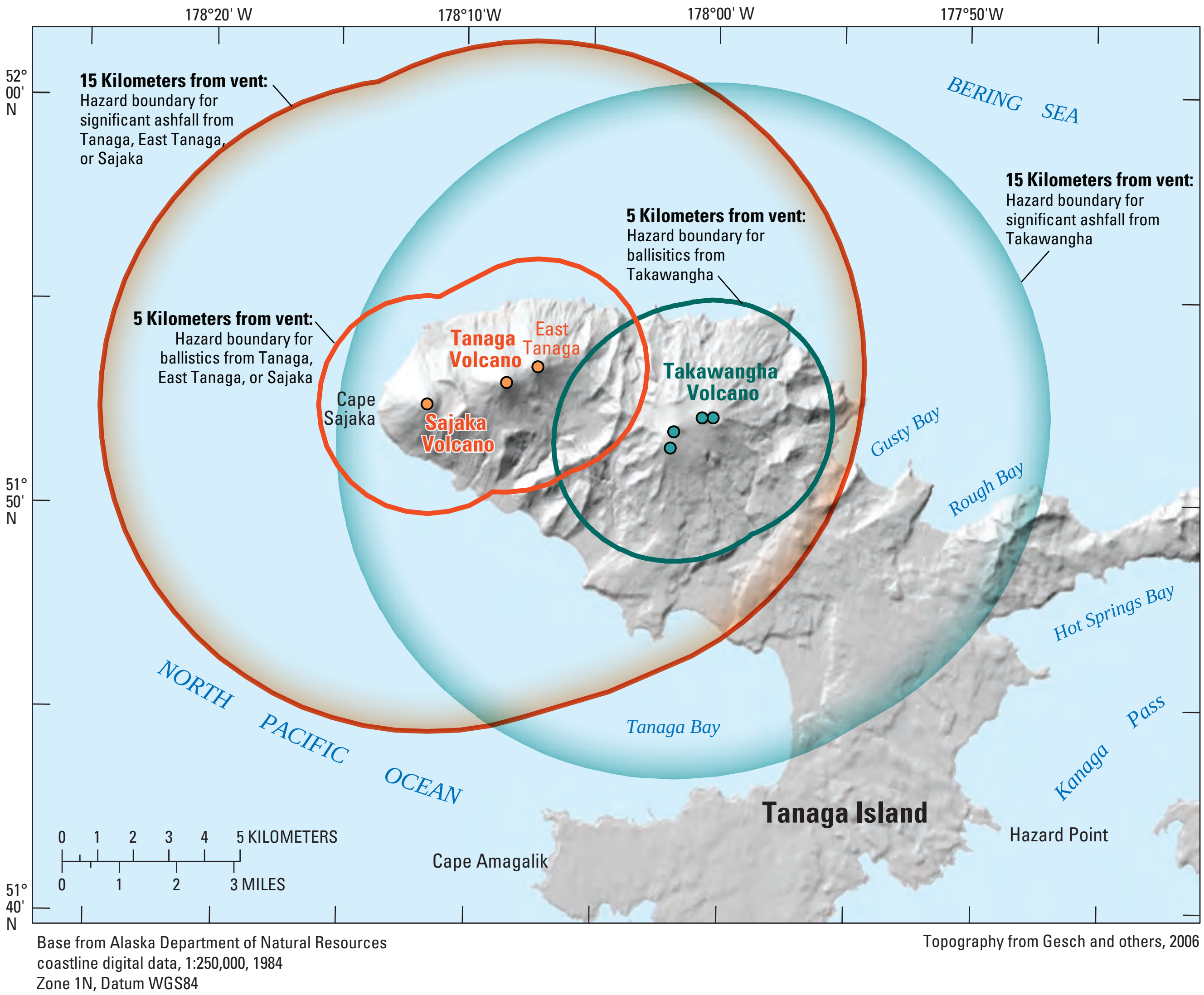


Figure 14. Approximate extent of proximal hazard zones from ashfall and ballistics near the Tanaga volcanic cluster, Tanaga Island, Alaska. Ballistics large enough to cause harm to humans likely will be restricted to within 5 kilometers of the potentially active vents. For typical eruptions, tephra accumulations of several centimeters, or more, likely will be restricted to within 15 kilometers of the active vent.

Pyroclastic Flows and Surges

Pyroclastic flows are hot dry mixtures of ash, rock, and gas that flow rapidly downslope. Pyroclastic surges are similar phenomena that are less dense, contain smaller particles, and are less confined by topography. Pyroclastic flows generally follow topography and will travel down stream valleys and gullies, and often are blocked by topographic barriers such as ridges. Both phenomena are fast-moving and can reach temperatures of several hundred degrees Celsius. Either would be hazardous to anyone near the volcanoes that produced flows or surges.

At the Tanaga volcanic cluster, pyroclastic flows likely would form by collapse of an eruptive column. The dense part of an *eruption column* can collapse and fall back toward the volcano. Parts of this cloud would then race down the slopes of the volcano, forming one or more pyroclastic flows. Pyroclastic flows that form this way can sweep over any part of the volcano flanks. Lower on the flanks, the flows likely will be channeled into river valleys, stream channels, or gullies. Pyroclastic flows from Tanaga, East Tanaga, or Sajaka likely would reach and flow into the sea.

If an explosive eruption and column collapse were to occur when the erupting volcano was covered with snow, the pyroclastic flow would melt the snow and could form hot lahars that would flow down the flanks (see Lahars section of this report).

Observed pyroclastic flow deposits are rare on Tanaga Island and all are within several kilometers of the suspected vent. The runout distance of pyroclastic flows that flow over land is estimated using the ratio between the fall height, H (typically the height of the summit), and the runout length, L. Typical ratios for pyroclastic flows elsewhere are 0.2–0.3 (Hayashi and Self, 1992; Hoblitt and others, 1995). Using these ratios yields runout distances of 4–9 km for the summits of Sajaka Two, Tanaga, East Tanaga, and Takawangha (fig.15). This is only an approximation, and actual pyroclastic flows may vary from this range if they are particularly sluggish or energetic.

When large pyroclastic flows enter the sea, parts of them can travel for many kilometers over water, as occurred at Krakatoa in 1883 (Carey and others, 1996). Pyroclastic flows entering the sea, if large enough, also can generate tsunamis (see Tsunami section of this report). No evidence on Tanaga Island indicates that such large flows occurred in about the last 10,000 years.

Whereas pyroclastic flow deposits are rare in the recent geologic record of the Tanaga volcanic cluster, outcrops of Pleistocene pyroclastic-flow deposits many meters thick underlie Takawangha volcano. These deposits probably formed during a large explosive eruption. Such an eruption would produce pyroclastic flows that might travel many kilometers from their source, including substantial distances over water. Events of this magnitude could happen once every several hundred thousand years at the Tanaga volcanic cluster.

Lava Flows

When magma (particularly mafic magma) erupts effusively at the earth's surface, the lava can flow downslope in streams, fans, or lobes. *Lava flows* accompany most eruptions of the Tanaga volcanic cluster. The edifices of Tanaga, East Tanaga, and Takawangha are composed mostly of lava flows. These flows typically have pronounced lateral levees and steep fronts that can shed debris as they advance. Based on analogy with similar flows observed elsewhere, such lava flows would travel slowly, no more than tens of meters an hour. Lava that flows over snow, ice, streams, or into the ocean may initiate steam explosions. Lava that reaches the ocean may build out into the water, forming *lava deltas*. These are unstable structures that can collapse into the sea with little or no warning.

Sajaka also produces lava flows, but they typically form in a slightly different fashion. Instead of effusing from a summit vent, some Sajaka lava flows are "headless" meaning they did not flow from a vent. Instead, they form when magma leaves the vent explosively, forming spatter, that falls back to the ground close to vent and accumulates into a deposit called agglutinate. Agglutinate, if still hot and fluid enough, can flow downslope forming lava flows. This is common for mafic magmas that tend to be hot and fluid when they erupt, but agglutinate flows are generally thinner and do not travel as far from source.

Lava flows from the Tanaga volcanic cluster could occur over wide areas of the volcanic edifice (fig. 16). Any given flow, however, will likely only affect a few square kilometers and be less than a kilometer wide and several kilometers long. Lava flows will follow topographically low areas, such as ravines or valleys.

Lahars and Floods

Lahars are volcanic mudflows that consist of some combination of volcanic debris and water. They are also referred to as *debris flows*. Snow- and ice-covered volcanoes are prone to the generation of lahars because volcanic debris mixes with water that has formed from melting of snow and ice during eruptions. Lahars can carry sediment that ranges in size from clay to boulders. They can be water-rich to water-poor and travel many kilometers from their source, generally along existing valleys. They travel at speeds as fast as 20 m/s in steep channels and 5-10 m/s second down gentler slopes (Blong, 1984). Lahars will inundate everything in their path and can leave several meters or more of sediment behind. After large eruptions, lahars may occur for years as unconsolidated debris is remobilized by rain or meltwater.

All slopes of the Tanaga volcanic cluster are potential sources for lahars. Only thin, localized lahar deposits were observed on the volcanoes' flanks. Because no large water sources are near any of the volcano summits, either increased *heat flow* or an eruption during the winter months, especially one that emplaced pyroclastic flows on snow, would be necessary to melt snow and ice to provide water for generating lahars. Therefore, substantial lahars on Tanaga would require volcanic unrest and because of the large snow and ice field atop Takawangha, lahars most likely would be generated during such unrest.

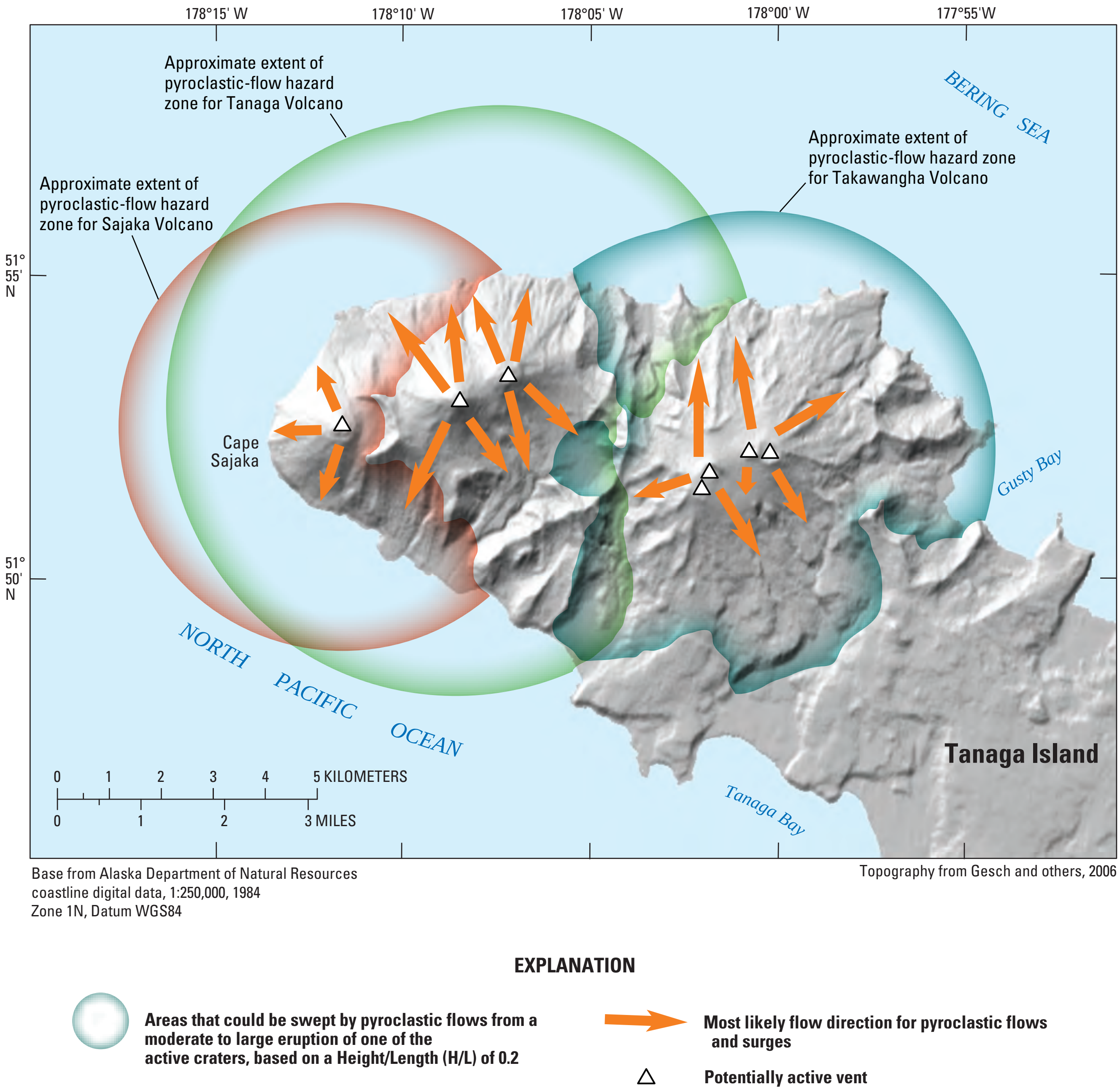


Figure 15. Approximate areas likely to be affected by pyroclastic flows and surges originating at the active vents of the Tanaga volcanic cluster, Tanaga Island, Alaska. Shaded regions show volcano height/runout distance of 0.2, indicating the likely maximum extent of flows and surges from the vents. Pyroclastic flows and surges that originate from collapse of a tall eruptive column may travel farther than these boundaries indicate.

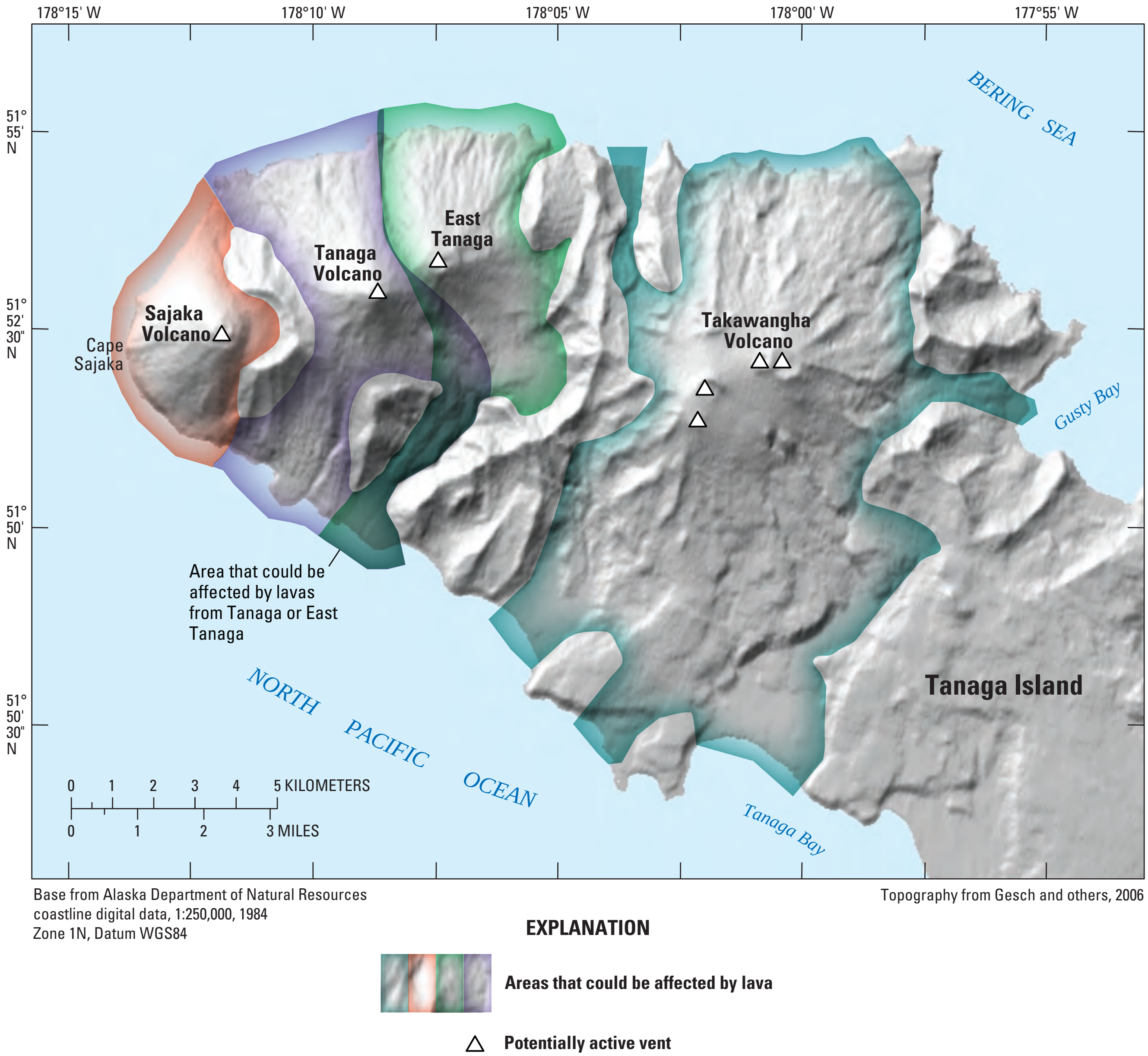
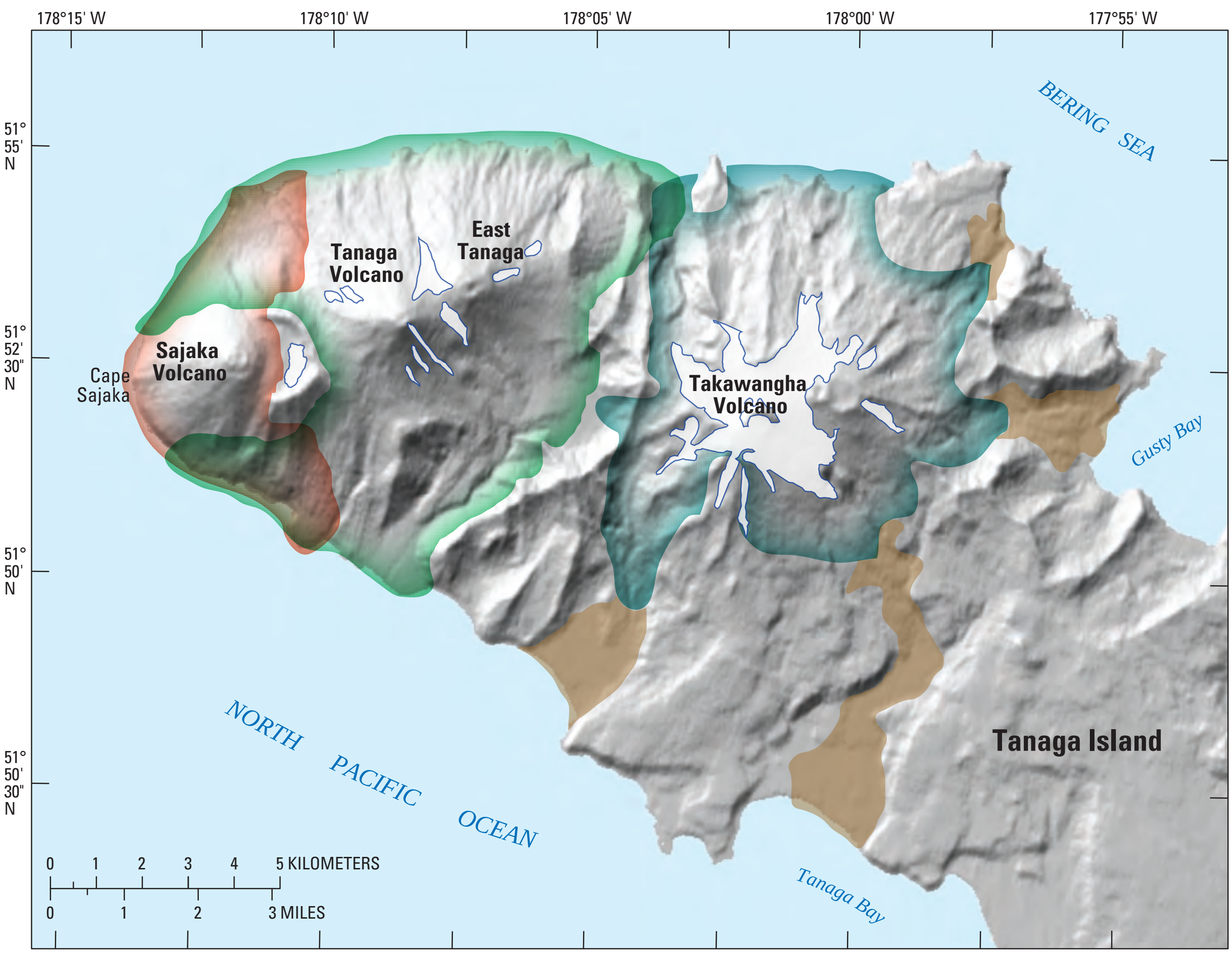


Figure 16. Areas that may be inundated by lava flows during a Tanaga volcanic cluster eruption, Tanaga Island, Alaska. Areas are colored according to vent.

Because Tanaga Island is uninhabited and there are no permanent structures, the risks posed by lahars are small. Lahars would be confined to the flanks of the volcanoes and surrounding stream drainages. The island topography would constrain lahar hazards to the northwest sector of the island (fig. 17). People and property on the southern and northeast sectors of the island would not be at risk from lahars or floods from the Tanaga volcanic cluster.

Debris Avalanches, Rockfalls, and Landslides

Because of the rapid growth and interbedded layers of fragmental and more coherent rocks, stratovolcanoes tend to be unstable constructions. Mass wasting of volcanoes can range widely in size. Rockfalls and small landslides on steep slopes and surrounding ridges often are not associated with volcanic activity. These events will only affect the area directly downslope from the fall or at most a couple of kilometers from the source. Figure 18 shows where rockfalls are most likely to occur in the Tanaga volcanic cluster.



Base from Alaska Department of Natural Resources coastline digital data, 1:250,000, 1984
Zone 1N, Datum WGS84

Topography from Gesch and others, 2006

EXPLANATION

Proximal hazard zone (H/L = 0.3) for individual volcanoes. Within this zone, pyroclastic flows, surges, and debris avalanches could generate lahars. For Sajaka and Tanaga, the proximal hazard zones reach the coastline. [H = fall height of pyroclastic flows; L = runout length.]

Areas that could be inundated by lahars from Takawangha Volcano outside of the proximal hazard zone

Glaciers and persistent snowfields

Figure 17. Areas that could be swept by lahars and floods, Tanaga Island, Alaska. Lahars could affect anywhere within the proximal hazard zones. Drainages around Takawangha Volcano generated within the proximal hazard zone could be inundated by lahars of 500 million cubic meters. Lahar inundation zones estimated by methods described by Iverson and others (1998) and Schilling (1998). Glaciers and persistent snowfields are shown in white.

Debris avalanches form when a substantial part of a volcanic edifice collapses. They can move quickly and can travel more than 10 times the vertical drop (Siebert, 1996). Documented deposits include volumes as great as several cubic kilometers (Siebert, 1984). A large debris avalanche between 240,000 and 118,000 years ago destroyed much of the northern half of Tanaga Island. A smaller debris avalanche, about 3,000 years ago, carried the western half of Sajaka volcano into the sea.

The likelihood of rockfalls, landslides, and debris avalanches increase at a volcano weakened by hydrothermal activity. Hot fluids percolating through a volcanic edifice can alter the rocks creating clays and other weaker mineral phases. An area west of Takawangha has a large concentration of altered rocks, increasing instability (fig. 18) and the likelihood of slope failure. The landslide deposit shown in figure 5 originates from one of these hydrothermally altered areas, and the clasts within the deposit show evidence for hydrothermal alteration.

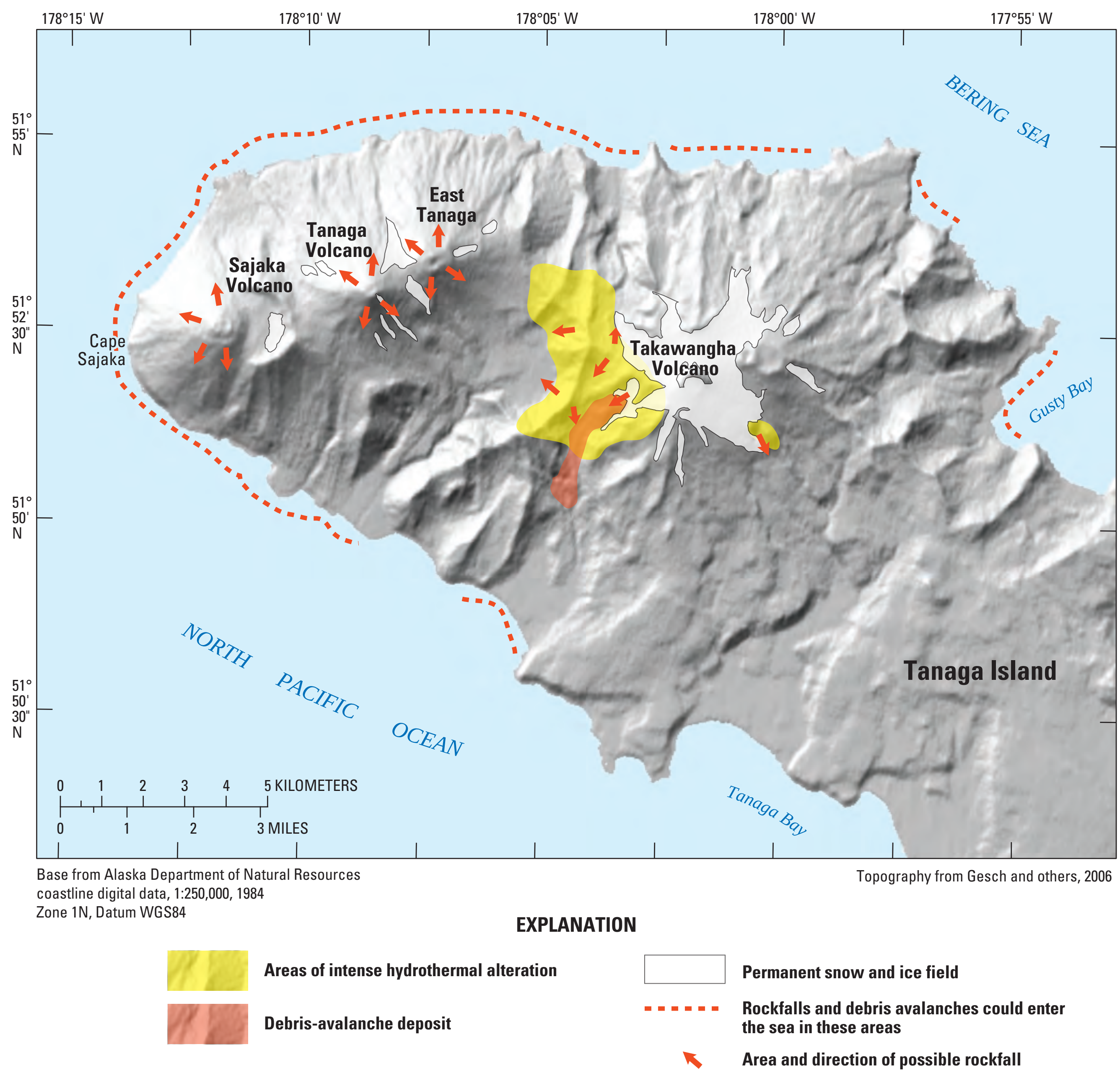


Figure 18. Areas that could be affected by debris avalanches and rockfalls, Tanaga Island, Alaska.

Directed Blasts

A directed blast is a sudden, violent, laterally directed volcanic explosion that occurs when a shallow body of magma is depressurized quickly (Valentine and Fisher, 2000). Large landslides off the flanks of volcanoes are the main process that produces directed blasts (Siebert and others, 1987). This sequence of events was recognized first as the “opening salvo” of the spectacular May 18, 1980, eruption of Mount St. Helens volcano in Washington (Lipman and others, 1981). Directed blasts produce high-velocity pyroclastic flows and surges that radiate out from the affected side of the volcano. Small, shallow landslides on the flanks of volcanoes are typically not accompanied by directed blasts because they do not incise deeply enough to intersect stored magma.

Directed blasts are not common at most volcanoes. Only Sajaka, in the Tanaga volcanic cluster, shows evidence for a directed blast. About 3,000 years ago, the west flank of Sajaka slid into the sea, leaving a large scar in the edifice. Pyroclastic-flow deposits on this scar, and below lava flows from Sajaka Two, indicate the landslide may have depressurized magma under the volcano that erupted explosively. Most ejecta from the eruption probably were directed out over the water, and only small outcrops of the pyroclastic flow deposit remain on land, further indicating the blast traveled laterally to the west, and not vertically.

Future directed blasts at Tanaga volcanic cluster could happen at any of the volcanoes. Any such blast would be preceded by a large landslide, and the blast would be directed away from flanks susceptible to failure. Figure 19 shows the area likely to be affected by a directed blast of Sajaka, Tanaga, or East Tanaga. The zone boundary is based on the area affected by the 1980 blast at Mount St. Helens (Lipman and others, 1981) and is likely a worst-case scenario.

Because of the Tanaga volcanic cluster configuration, future similar events likely would be directed to the north and (or) northwest. The frequency of future directed blasts is considered low.

Tsunamis

Tsunamis are waves or wave trains produced by sudden displacement of seawater. Although tsunamis can be caused by large earthquakes, tsunamis also can be generated by landslides (Ward and Day, 2003) or volcanic eruptions (for example, Waythomas and Neal, 1998) when voluminous pyroclastic flows or debris suddenly enter the sea. The geologic record shows no evidence of eruptions from the Tanaga volcanic cluster large enough to produce a tsunami, but two past non-eruption events may have. The first was the debris avalanche that occurred sometime before 118,000 years ago, and the second was the landslide on Sajaka around 3,000 years ago. During both events, sufficient quantities of volcanic debris catastrophically entered the ocean (several cubic kilometers) and large waves could have resulted. The magnitude and effects of tsunamis generated during these events is not known.

Volcanic Gases

Rising magma is driven to the earth’s surface by volcanic gas emitted in large quantities during an eruption. In addition, as magma rises, the accompanying volcanic gas can separate and arrive at the earth’s surface first—even if the magma itself fails to erupt. The main component of volcanic gas is water vapor (steam), with subordinate amounts of carbon dioxide, sulfur dioxide, hydrogen sulfide, and other minor gases such as chlorine. Gases escape into the atmosphere at vents (holes) or surface cracks called fumaroles.

Most of the non-steam components of volcanic gas are caustic and can affect eyes and respiration, and can corrode metals. Carbon dioxide is a special concern because it is heavier than air and collects in low areas. In great enough concentrations, carbon dioxide can quickly asphyxiate people and animals and kill vegetation. Most gas that is emitted from volcanoes, however, will rapidly dissipate and pose little threat to people more than several kilometers from the active vent.

During recent visits to the Tanaga volcanic cluster only minor gas venting was observed, and that was from the single active fumarole on the northwest coast of the Sajaka Two cone (fig. 5). The gas composition and temperature has not been measured. However, altered rocks and occurrences of native sulfur (precipitated from gas) at the summits of Sajaka Two, Tanaga, East Tanaga, and Takawangha indicate that all these volcanoes likely have emitted gas in the past, and that any of them could emit gas again in the future. Steam increasing at any of the vents could be a warning of an impending eruption; however, this does not mean that an eruption is imminent. Commonly, “volcanic unrest” can include an episode of steaming that does not lead to eruption. However, the onset of, or increase in, steam and gas emission would prompt close monitoring.

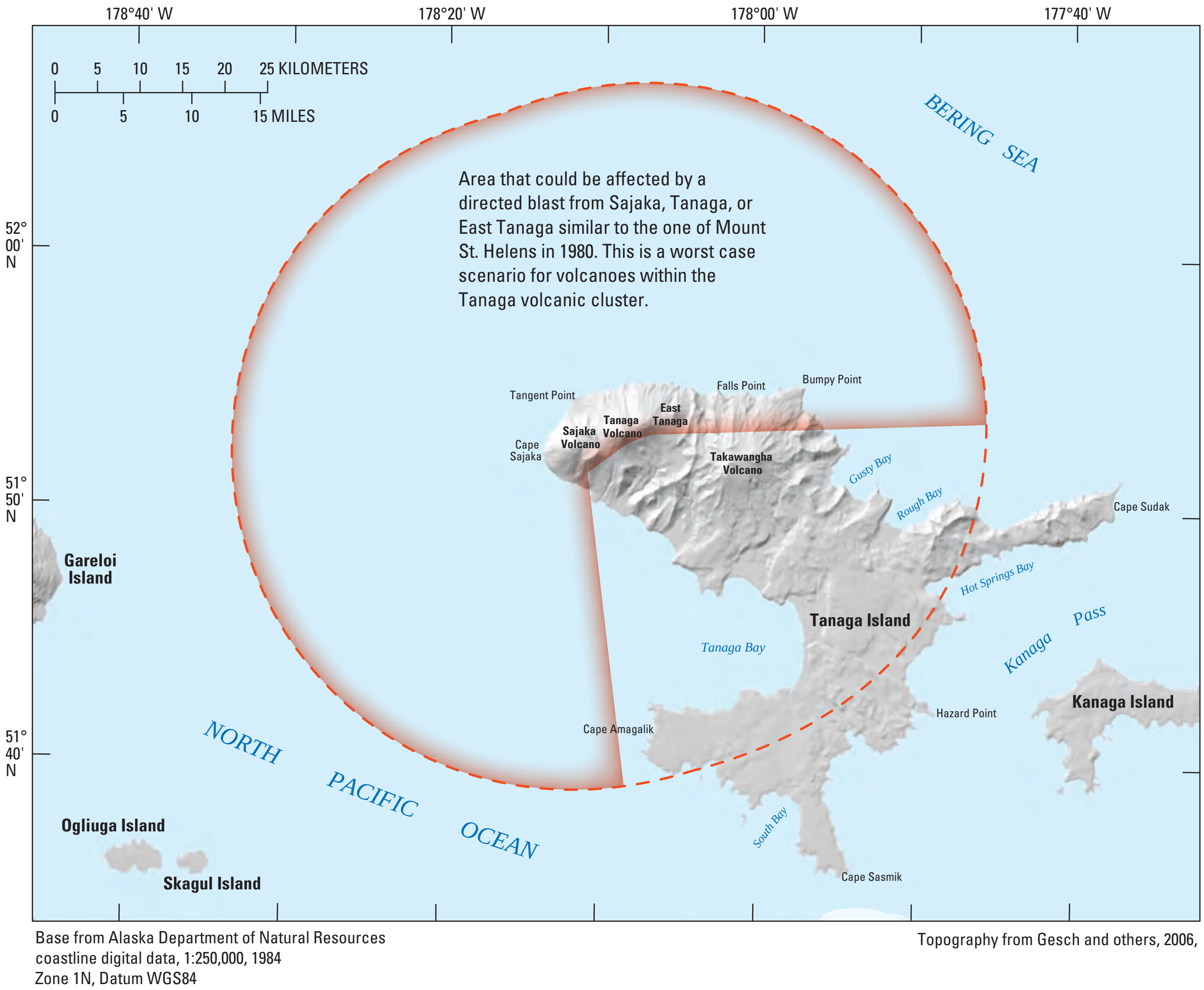


Figure 19. Areas that could be affected by directed blasts near Tanaga Island, Alaska.

Event Frequency and Risk at Tanaga Volcanic Cluster

Future eruptions are expected within the Tanaga volcanic cluster. Study of previous eruption deposits shows that at least seven eruptions have occurred during the last 900 years, indicating a simple recurrence interval of about 130 years. Because evidence for smaller eruptions likely has been removed by erosion, the recurrence interval may be shorter, which is consistent with historical reports that indicate volcanic activity has occurred four times in the last 220 years.

We cannot predict with certainty the timing or magnitude of the next eruption on Tanaga. However, based on past eruptions, any future eruption likely would be mafic in composition, small to moderate in size, and produce lava flow(s) and possibly small pyroclastic flows and ash plumes.

Because Tanaga Island is uninhabited, the greatest risks posed by future eruptions are to the community of Adak, Alaska (100 km to the east), aircraft flying over, and boats and ships passing by or anchoring around the island. Should a sustained explosive eruption occur, clouds of volcanic ash would rise into the atmosphere and drift hundreds of kilometers downwind. Ash clouds could rise to more than 15,000 m into the atmosphere and adversely effect aircraft flying to or from Adak, or, aircraft flying the North America–Asia air routes (fig. 20).

Localized hazards restricted to Tanaga Island likely will pose little or no risk because of the absence of residents or property. Anyone planning to visit Tanaga Island should check with the AVO to receive up-to-date information regarding volcanic activity at the Tanaga volcanic cluster.

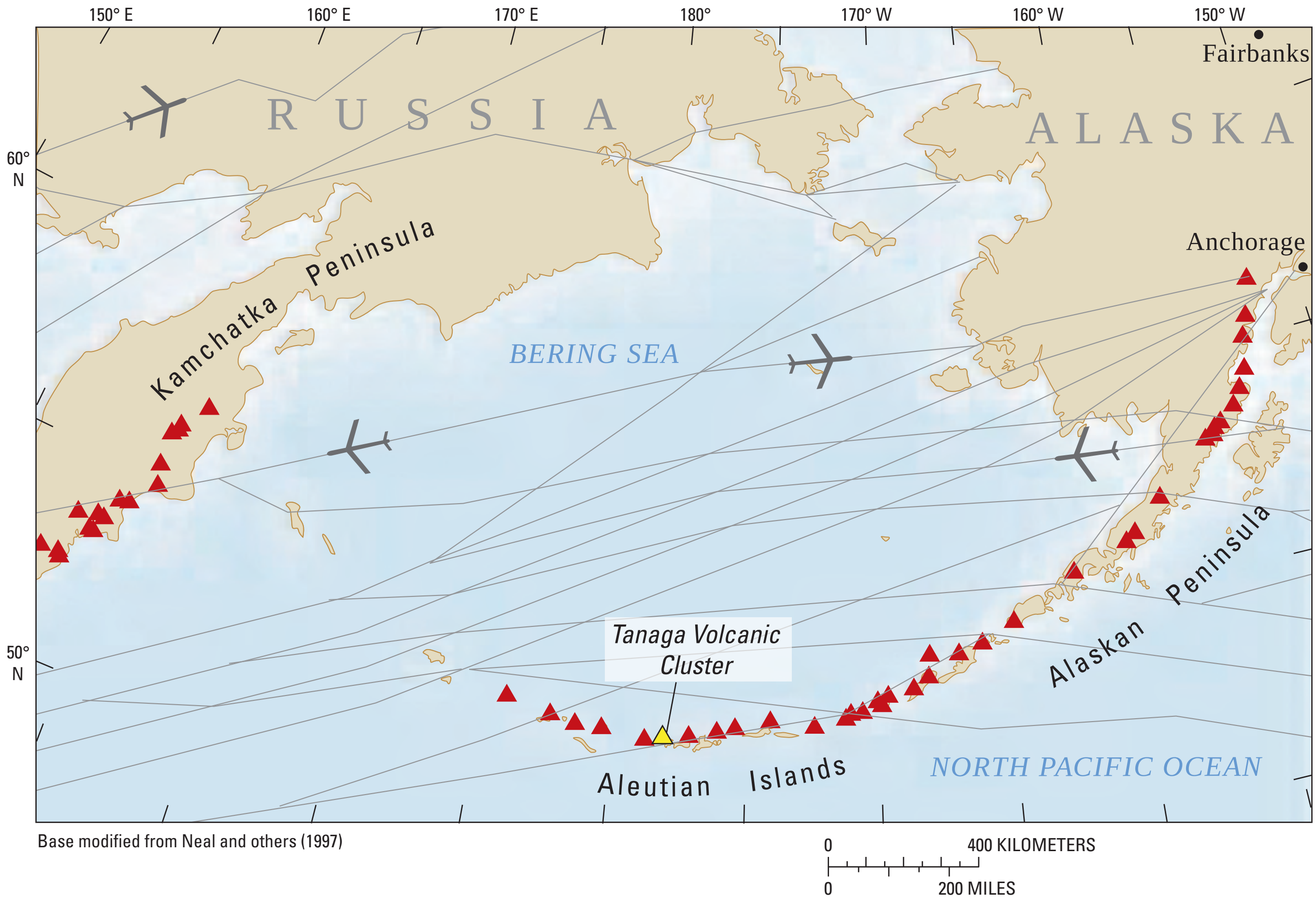


Figure 20. Principal North Pacific air routes in relation to the Tanaga volcanic cluster, Tanaga Island, Alaska.

Hazard Warning and Mitigation

Most volcanic eruptions at Aleutian volcanoes are preceded by weeks to months of precursory seismic activity in the form of earthquakes and volcanic seismic signals called tremor. Magma and gas movement and the breaking of rock as magma seeks a path to the surface, cause these precursory signals. Since 2003, AVO has maintained a network of six seismic instruments on Tanaga Island that transmit seismic data in real-time to our offices in Anchorage and Fairbanks (fig. 9). This network is the primary means of monitoring volcanic unrest at the Tanaga volcanic cluster.

In addition to seismic monitoring, daily satellite images are examined to look for hot areas on the volcanoes or ash in the atmosphere. Airborne or ground-based volcanic gas measurements, thermal water chemistry, and ground deformation and thermal change surveys also provide information about volcanic activity. These techniques commonly are employed when seismic and satellite data indicate unrest may be in progress.

Given the frequent inclement weather and the remoteness of many Aleutian volcanoes, including the Tanaga volcanic cluster, AVO relies on the observations of pilots, mariners, or others nearby. Reports of steaming, fumarolic activity, new deposits, or possible ash clouds prompt further investigation by AVO personnel.

One of the most important roles of AVO is to communicate warnings of volcanic unrest or potential eruptions. Each week, AVO details the status of Alaskan volcanoes using fax and e-mail distribution. This information is sent to the Federal Aviation Administration, National Weather Service, Alaska Department of Emergency Services, Governor's office, various state offices, military bases and airports, air carriers, television and radio stations, various wire services, and others. During times of volcanic unrest, information releases are disseminated and several organizations receive daily updates. Weekly updates, daily status reports, and information releases are sent to various volcano information networks and posted on the AVO website (http://www.avo.alaska.edu).

To summarize information about the status of Alaska's 30 monitored volcanoes, AVO uses an alert-level system shared by all five of the United States volcano observatories. The system uses a set of general terms: **Normal, Advisory, Watch**, and **Warning** (table 3). During a volcanic crisis, the volcanic-alert levels can be used quickly and simply to communicate changes in volcanic activity to agencies and the public. Changes to the alert level of a particular volcano are accompanied by an information release and phone calls directly to pertinent government agencies. Figure 21 shows a hypothetical information release that might accompany increasing unrest at Tanaga as the alert level changed from advisory to watch.

Table 3. Volcanic-alert levels used by volcano observatories in the United States.

NORMAL	**Typical background activity of a volcano in a non-eruptive state** *or, after a change from a higher level:* Volcanic activity considered to have ceased, and volcano reverted to its normal, non-eruptive state.
ADVISORY	**Elevated unrest above known background activity** *or, after a change from a higher level:* Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Heightened/escalating unrest with increased potential for eruptive activity (timeframe variable) OR a minor eruption underway that poses limited hazards.
WARNING	Highly hazardous eruption underway or imminent.

As part of the alert-level system, color codes (**Green, Yellow, Orange, Red**) also are used to provide information about volcanic-ash hazards to aviators (table 4). The two systems often act in tandem as unrest escalates (for example, at the first signs of unrest, the alert level would go from Normal to Advisory, and the aviation color code from Green to Yellow). The alert level pertains to total unrest at the volcano, whereas the aviation color code applies specifically to hazards to aircraft due to ash clouds.

If such elevated volcanic unrest were detected at Tanaga, AVO's monitoring efforts would increase. Twenty-four-hour staffing likely would begin and other means of monitoring likely would be used. Information releases would be dispatched as new information became available, detailing the current level of unrest, the likelihood of an eruption, and the possible outcomes of such an event.

What's in a Name?

For volcano monitoring purposes, we consider the Tanaga volcanic cluster as a single entity. This is because of the proximity—or clustering—of the vents and their remote

Table 4. Aviation level-of-concern color codes.

GREEN	**Volcano is in normal, non-eruptive state,** *or, after a change from a higher level:* **Volcanic activity considered to have ceased and volcano reverted to its normal, non-eruptive state**.
YELLOW	**Volcano is exhibiting signs of elevated unrest above known background levels,** *or, after a change from a higher level:* **Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.**
ORANGE	**Volcano is exhibiting heightened unrest with increased likelihood of eruption**, *or,* **Volcanic eruption underway with no or minor ash emission**.
RED	**Eruption is forecast to be imminent with significant emission of ash into the atmosphere likely,** *or,* **Eruption is underway with significant emission of ash into the atmosphere**.

location. Monitoring of the cluster is primarily through the seismic network, and secondarily from satellite imagery (which can be hampered by cloudy weather). Although AVO's seismic network can usually spatially resolve which vent is seismically active, during a large eruption distinguishing which vent is erupting might not be possible. The most immediate hazard associated with volcanic activity would be airborne ash affecting aircraft flying near an eruption. In this case, which volcano in the cluster is producing ash does not matter.

Weekly updates and information releases for Tanaga, therefore, will refer simply to "Tanaga" as a proxy for the Tanaga volcanic cluster. When possible, accompanying text will provide all information available regarding details of the activity, and indicate which vent most likely shows signs of volcanic unrest. This is important from a hazards standpoint, because, for example, based on previous activity an eruption of Sajaka would likely be a different style than an eruption of Tanaga.

ALASKA VOLCANO OBSERVATORY

INFORMATION RELEASE
Friday, October 7, 2006 1:20 PM AKDT (2120 UTC)

TANAGA VOLCANO (CAVW#1101-08-)
51.885°N 178.1458°W, Summit Elevation 5925 ft (1806 m)
Current Volcanic Activity Alert Level: **WATCH**
Previous Volcanic Activity Alert Level: Advisory
Current Level of Concern Color Code: **ORANGE**
Previous Level of Concern Color Code: Yellow

This morning at 9:30 AKDT, the number of earthquakes recorded beneath Tanaga Island began to increase dramatically. Most of the events are located beneath Takawangha volcano, the easternmost vent in the Tanaga cluster of volcanoes. The nature of the earthquakes suggests that magma is moving beneath the volcano. The seismicity continues at this time, and the likelihood of an eruption has significantly increased. We are elevating the Volcanic Activity Alert Level to **WATCH**, indicating that an explosive eruption is possible within the next few days.

As of yet, AVO has received no pilot or ground-based reports of visible changes at the volcano, and satellite imagery does not show any thermal changes.

VOLCANO INFORMATION ON THE INTERNET: http://www.avo.alaska.edu
RECORDING ON THE STATUS OF ALASKA'S VOLCANOES (907) 786-7478

CONTACT INFORMATION:
Tom Murray, Scientist-in-Charge, USGS
tlmurray@usgs.gov (907) 786-7497

John Eichelberger, Coordinating Scientist, UAF-GI
eich@gi.alaska.edu (907) 474-5530

The Alaska Volcano Observatory is a cooperative program of the U.S. Geological Survey, the University of Alaska Fairbanks Geophysical Institute, and the Alaska Division of Geological and Geophysical Surveys.

Figure 21. Hypothetical information release from the Alaska Volcano Observatory during volcanic unrest at the Tanaga volcanic cluster, Tanaga Island, Alaska.

References Cited

Blong, R., 1984, Volcanic hazards: a sourcebook on the effects of eruptions: Sydney, Australia, Academic Press, 424 p.

Blong, R., 1996, Volcanic hazards risk assessment, *in* Scarpa, R., and Tilling, R., eds., Monitoring and mitigation of volcano hazards: Berlin-Heidelberg, Springer-Verlag, p. 675-698.

Carey, S.N., 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, Seattle, Wash., July 1991: U.S. Geological Survey Bulletin 2047, 450 p.

Coats, R.R., 1950, Volcanic activity in the Aleutian Arc: U.S. Geological Survey Bulletin B 0974-B p. 35-49, 1 sheet.

Coats, R.R., and Marsh, B.D., 1984, Reconnaissance geology and petrology of northern Tanaga, Aleutian Islands, Alaska: Geological Society of America, Abstracts with Programs, v.16, no. 6, p. 474.

Coombs, M.L., White, S.M., and Scholl, D.W., 2007, Massive edifice failure at Aleutian Arc volcanoes: Earth and Planetary Science Letters, v. 256, p. 403-418.

Dixon, J.P., Stihler, S.D., Power, J.A., Tytgat, G., Estes, S., and McNutt, S.R., 2006, Catalog of earthquake hypocenters at Alaskan volcanoes: January 1 through December 31, 2005: U.S. Geological Survey Open-File Report 2006-1264, p. 78.

Gesch, D.B, Muller, J.-P., Farr, T.G., 2006, Foreword: The Shuttle Radar Topography Mission - Data validation and applications: Photogrammetric Engineering and Remote Sensing, v. 72, no. 3, p. 233-235.

Grewingk, C., 1850 [2003], Grewingk's geology of Alaska and the Northwest Coast of America, Marvin W. Falk, ed., translation by Fritz Jaensch: Fairbanks, Alaska, University of Alaska Press, 242 p.

Hayashi, J., and Self, S., 1992, A comparison of pyroclastic flow and debris avalanche mobility: Journal of Geophysical Research, v. 97, p. 9063-9071.

Hoblitt, R., Walder, J., Dreidger, C., Scott, K., Pringle, P., and Vallance, J., 1995, Volcano hazards from Mount Rainier, Washington: U.S. Geological Survey Open-File Report 95-273, 10 p.

Hurst, A.W., 1994, ASHFALL - A computer program for estimating volcanic ash fallout: Report and users guide: Institute of Geological and Nuclear Sciences Science Report 94/23, 22 p.

Iverson, R.M., Schilling, S.P., and Vallance, J.W., 1998, Objective delineation of lahar-inundation zones: Geological Society of America Bulletin, v. 110, p. 972-984.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Leetmaa, A., Reynolds, B., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Jenne, R., and Joseph, D., 1996, The NCEP/NCAR 40-year reanalysis project: Bulletin of the American Meteorological Society, v. 77, p. 437-470.

Lipman, P.W., Mullineaux, D.R., and Ray, D., eds., 1981, The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, 844 p., 1 pl.

Meyers, B., Brantley, S.R., Stauffer, P., and Hendley, J.W., III, 1997, What are volcano hazards?: U.S. Geological Survey Fact Sheet 002-97, 2 p.

Neal, C.A., Casadevall, T.J., Miller, T.P., Hendley, J.W., III, and Stauffer, P., 1997, Volcanic Ash— Danger to aircraft in the North Pacific: U.S. Geological Survey Fact Sheet 030-97, 2 p.

Schilling, S.P., 1998, LAHARZ: GIS programs for automated mapping of lahar-inundation hazard zones: U.S. Geological Survey Open-File Report 98-638, 80 p.

Siebert, L., 1984, Large volcanic debris avalanches; characteristics of source areas, deposits, and associated eruptions: Journal of Volcanology and Geothermal Research, v. 22, p. 163-197.

Siebert, L., 1996, Hazards of large volcanic debris avalanches and associated eruptive phenomena, *in* Scarpa, R., and Tilling, R.I., eds., Monitoring and mitigation of volcano hazards: Berlin, Springer, p. 541-572.

Siebert, L., Glicken, H., and Ui, T., 1987, Volcanic hazards from Bezymianny- and Bandai-type eruptions: Bulletin of Volcanology, v. 49, p. 435-459.

Shumacher, G.M., 1976, Bathymetric map of the Aleutian Trench and Bearing Sea: U.S. Geological Survey Open-File Report 76-821, 2 maps.

Valentine, G.A., and Fisher, R.V., 2000, Pyroclastic surges and blasts, *in* Sigurdsson, H., Houghton, B., McNutt, S.R., Rymer, H., and Stix, J., eds., Encyclopedia of volcanoes: San Diego, Academic Press, p. 571-580.

Ward, S., and Day, S., 2003, Ritter Island Volcano—lateral collapse and the tsunami of 1888: Geophysical Journal International, v. 154, p. 891-902.

Waythomas, C.F., and Neal, C.A., 1998, Tsunami generation by pyroclastic flow during the 3500-year B.P. caldera-forming eruption of Aniakchak Volcano, Alaska: Bulletin of Volcanology, v. 60, no. 2, p. 110-124.

This page is intentionally left blank.

Glossary

Agglutinate: Fragments of volcanic rock, generally near-vent fallout, welded together by their own heat.

Andesite: Volcanic rock with a bulk composition of about 57 to 63 percent silica.

Ash: Fine fragments (less than 2 mm across) of volcanic rock formed in an explosive volcanic eruption.

Ash cloud: Cloud of gas, steam, ash, dust, and coarser fragments formed during an explosive volcanic eruption and commonly blown long distances downwind. Also called an eruption cloud.

Ballistic: Fragments ejected explosively from a volcanic vent on an arcuate trajectory, much like a cannonball. Ballistic fragments seldom land farther than a few kilometers from the volcano; concurrently erupted ash clouds go much further. Also called a volcanic bomb.

Basalt: Volcanic rock with a bulk composition of about 45 to 53 percent silica. Basaltic lava is more fluid than andesitic or dacitic lava, which contains more silica.

Basaltic andesite: Volcanic rock with a bulk composition of about 53–57 percent silica. Basaltic andesite lava is more fluid than lava containing more silica.

Crater: Bowl-shaped, funnel-shaped, or cylindrical depression, commonly near the top of a volcano, and commonly less than 2 km across. Craters are formed by volcanic explosions and typically involve buildup of crater-rimming deposits rather than subsidence of the floor.

Debris avalanche: Rapidly moving slide masses of rock debris, sand, and silt commonly formed by structural collapse of a volcano. Debris avalanches can travel considerable distances from their source, and the resulting deposits are characterized by a hummocky surface.

Debris flow: Rapidly flowing mixture of water, mud, and rock debris. A volcano-derived debris flow is commonly called a lahar. Parts of debris avalanches can transform into debris flows by mixing intimately with the water in overrun rivers or lakes.

Directed blast: Severe volcanic explosion, directed laterally, caused by a major landslide or slope failure that rapidly depressurizes a shallow magma body or hydrothermal system. Typically travels away from the volcano at a low angle and may not be deflected by ridges or other topographic barriers. Ejecta are carried away form the volcano in much the same way as pyroclastic surges.

Edifice: Upper part of a volcanic cone, including the vent, summit area, and typically steep flanks. This is in contrast to deposits originating at the volcano and traveling far from the cone.

Effusive eruption: An eruption producing mainly lava flows and domes (in contrast to an explosive eruption).

Eruption column: Ascending, vertical part of the mass of erupting debris and volcanic gas rising directly above a volcanic vent. Once high in the atmosphere, columns can spread laterally into plumes or umbrella clouds.

Ejecta: General term for anything thrown into the air from a volcano during an eruption.

Explosive eruption: An energetic eruption producing mainly ash, pumice, and fragmental ballistic debris (in contrast to an effusive eruption).

Fallout: A general term for all ash and debris that falls to Earth from an eruption cloud. See tephra.

Fumarole: A small opening, crack, or vent from which hot gases are emitted. Commonly on the floor of a volcanic crater, but may be on a volcano's flanks. Short-lived fumaroles also issue from hot lava flows and pyroclastic deposits during their period of cooling.

Glaciated: Rock outcrops extensively smoothed and eroded by glaciers. Such rocks are thought to be older than the last major glaciation, about 10,000 years ago. (The actual withdrawal of major Pleistocene ice sheets varied by location and latitude, from well before to a few thousand years after 10,000 years before present.)

Hazard: Probability of a given area being affected by potentially destructive volcanic processes in a given period of time.

Heat flow: Heat that is transmitted from the hot interior of Earth to the surface in a specified time across a specified area.

Holocene epoch: Period of earth's history from 10,000 years ago to the present.

Hydrothermal: Refers to the heating of ground water by magma.

Lahar: A mixture of water and volcanic debris that moves rapidly downstream. Consistency can range from that of muddy dishwater to that of wet cement, depending on the ratio of water to debris. Compare to debris flow.

Lava: Molten rock that reaches the Earth's surface and maintains its integrity as a fluid or viscous mass, rather than exploding into fragments. Compare to magma.

Lava delta: Lava entering the sea can build a wide fan-shaped area of new land called a lava delta, usually built on sloping layers of loose lava fragments and flows. On steep submarine slopes, these layers of debris are unstable and can lead to the sudden collapse of lava deltas into the sea.

Lava flow: A usually elongate outpouring of molten rock onto the earth's surface, or the solidified deposit that results.

Mafic magma: Magma containing lower amounts of silica, generally less viscous and less gas rich than silicic magma. Tends to erupt effusively as lava flows. Includes andesites (53–63 percent SiO_2) and basalts (45–53 percent SiO_2).

Magma: Molten rock beneath the Earth's surface. Compare to lava.

Phreatic eruption: An eruption primarily involving steam explosions from ground water flashed by the heat of subsurface magma.

Pleistocene epoch: The period of earth's history between 1.6 million and 10,000 years before present.

Pumice: Highly vesicular volcanic ejecta, essentially magma frothed up by escaping gases and solidified during eruptive cooling.

Pyroclastic: General term applied to volcanic products or processes involving explosive ejection and fragmentation of erupting material. The Greek roots of the word mean "fire" and "broken."

Pyroclastic flow: A hot (typically more than 800°C), chaotic mixture of rock fragments, gas, and ash that travels rapidly (many meters per second) away from a volcanic vent. Pyroclastic flows are formed from an explosive eruption column containing a large proportion of fine ash and pumice, also called ash flows.

Pyroclastic surge: A turbulent hurricane of volcanic ash, rock debris, and hot gas. Pyroclastic surges are low density, turbulent types of pyroclastic flows typically accompanying explosive eruptions.

Radiometric dating: A technique for determining the age of formation of rock or soil based on measuring the amounts of radiogenic isotopes that decay at known rates.

Rhyolite: Volcanic rock with more than 72 percent silica. Rhyolitic lava is viscous and tends to form thick blocky lava flows or steep-sided piles of lava called lava domes. Rhyolite magmas tend to erupt explosively, commonly producing abundant ash and pumice.

Risk: The possibility of a loss, such as life or property, in an area subject to hazard(s).

Scoria: Vesicular volcanic ejecta, essentially magma frothed up by escaping gases. A textural variant of pumice, scoria typically is less vesicular, denser, and commonly andesitic or basaltic.

Sedimentary: A rock type formed by deposition and compaction of sediments. Volcaniclastic rocks are sedimentary rocks where the primary sediment source is volcanic.

Seismometer: A shallow buried instrument that can detect earth motions. Around volcanoes, a network of seismometers can detect seismic activity possibly associated with volcanic activity.

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

Silica: Predominant molecular constituent (SiO_2) of volcanic rocks and magmas tending to polymerize into molecular chains, increasing the viscosity of the magma. Basaltic magma, relatively low in silica, is fairly fluid, but with increasing silica content, magmas becomes progressively more viscous. The greater difficulty for dissolved gas to escape from magma that is more viscous makes higher silica magmas generally more explosive.

Spatter: An accumulation of fluid ejecta, coating the surface around a volcanic vent.

Stratovolcano: A steep-sided volcano, commonly conical in shape with only one central vent; built of lava flows and fragmental deposits from many periods of eruptive activity. Also called a stratocone or composite cone.

Strombolian: Type of volcanic eruption characterized by pulsating jets or fountains of lava from a central crater or cone.

Tephra: Any type and size of rock fragment forcibly ejected from the volcano traveling an airborne path during an eruption (ash, bombs, scoria, cinders, etc.). Generally synonymous with fallout, but may be used loosely to include pyroclastic-flow material as well.

Tertiary: Period of geologic time from about 65 to about 2 million years ago.

Tremor: Low amplitude, continuous earthquake activity commonly associated with magma movement.

Tsunami: Sea waves or wave trains typically initiated by sudden displacements of the sea floor during earthquakes. Collapse of oceanic volcanoes can initiate some tsunamis.

Vent: Any opening at the Earth's surface allowing magma to erupt or volcanic gases to be emitted.

Volcanic arc: A chain of volcanoes above a subduction zone, where an oceanic crustal plate moves underneath another crustal plate. The volcanoes of the Aleutian Islands lie along the Aleutian volcanic arc.

Volcanic gases: Water vapor (steam), carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and several other gases in minor quantities all exsolve from magma rising through the crust. These gases are emitted during volcanic eruptions and between eruptions from vents called fumaroles.

Volcano-tectonic earthquakes: Generally small seismic events caused by the breakage of rock due to movement of magma, gases, or fluids beneath a volcano.

This page is intentionally left blank.

For more information concerning the research in this report, contact the
Director, Alaska Science Center
U.S. Geological Survey
4230 University Dr., Suite 201
Anchorage, Alaska 99508-4650
http://alaska.usgs.gov

USGS

Coombs and others

Preliminary Volcano-Hazard Assessment for the Tanaga Volcanic Cluster, Tanaga Island, Alaska

SIR 2007–5094