Preliminary Volcano-Hazard Assessment for Gareloi Volcano, Gareloi Island, Alaska

Scientific Investigations Report 2008-5159

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 the Kamchatkan Volcanic eruptions Response Team.

Cover: Lava flows from a 20th-century eruption drape the south flank of Gareloi's South Peak crater. The white zone on the crater headwall is an extensive fumarole field. Photograph by R.G. McGimsey, August 2003.

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[In pocket]

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SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

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

$$°F=(1.8\times°C)+32$$

Datum

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

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

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Summary of Volcano Hazards at Gareloi Volcano

Gareloi Volcano (178.794˚W and 51.790˚N) is located on Gareloi Island in the Delarof Islands group of the Aleutian Islands, about 2,000 kilometers west-southwest of Anchorage and about 150 kilometers west of Adak, the westernmost community in Alaska (fig. 1). This small (about 8×10 kilometer) volcano has been one of the most active in the Aleutians since its discovery by the Bering expedition in the 1740s, though because of its remote location, observations have been scant and many smaller eruptions may have gone unrecorded. Eruptions of Gareloi commonly produce ash clouds and lava flows. Scars on the flanks of the volcano and debris-avalanche deposits on the adjacent seafloor indicate that the volcano has produced large landslides in the past, possibly causing tsunamis. Such events are infrequent, occurring at most every few thousand years. The primary hazard from Gareloi is airborne clouds of ash that could affect aircraft. In this report, we summarize and describe the major volcanic hazards associated with Gareloi.

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 Gareloi Island would carry ash primarily to the northeast, east, and southeast, but ash could travel in any direction. Airborne ash is hazardous to aircraft because of the detrimental effect on jet engines and airframes. Because of nearby heavily traveled air routes between North America and Asia, ash clouds pose the greatest risk associated with eruptions of Gareloi Volcano.

Ash Fall

Ash clouds produced by explosive eruptions contain particles that will eventually fall to the ground, forming ash fall, or tephra-fall deposits. Fine ash particles may be carried far downwind from the vent, whereas larger (coarser) particles will rain out closer to the source. On Gareloi Island, tephra deposits from Gareloi Volcano are as thick as several tens of centimeters and contain particles several centimeters in diameter. Typical Gareloi eruptions could produce layers of fine ash no more than several millimeters thick in Adak, Alaska, the closest community. Such ash would impact seafood processing, port, and air operations out of Adak, as well as the Missile Defense Agency's nearby sea-based X-band radar facility. Ash in the atmosphere can interfere with radio communications and damage power lines.

Ballistics

Ballistics, or volcanic bombs, are pebble- to boulder-size particles ejected explosively during eruptions. They follow parabolic trajectories carrying them usually only a few kilometers from the vent. At Gareloi, ballistics from previous eruptions are confined mostly to several hundred meters from the two summit craters. Risk from ballistics at Gareloi would be to visitors to the island or passing watercraft.

The Alaska Volcano-Hazard Assessment Series

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

Pyroclastic Flows and Surges

During some explosive eruptions, hot, dense, ground-hugging clouds of gas, ash, and rock flow rapidly from the vent. Called pyroclastic flows, these phenomena kill humans caught in their paths. Related phenomena, pyroclastic surges are fast-moving hot blasts of gas and particles that commonly precede and accompany pyroclastic flows. Flows and surges usually follow topography and travel down gullies and valleys surrounding the volcano. At Gareloi Volcano, deposits from pyroclastic flows and surges that crop out on most flanks of the volcano indicate eruptions have produced flows and surges in the past. Large explosive eruptions could send pyroclastic flows beyond the island's coastline and as far as 5 km over the sea. These phenomena are primarily a proximal hazard but can commonly produce billowing co-ignimbrite ash clouds above the volcano that can drift tens of kilometers downwind.

Lava Flows

Magma that erupts non-explosively during effusive eruptions forms lava flows or piles of lava rubble called domes. Lava flows at Gareloi Volcano are mostly fluid and elongate, and many reach the coastline. Lava flows can bury, bulldoze, and burn anything in their path, but move slowly. They can also shed hot blocks as they form, especially if emplaced on steep slopes. When hot lava interacts with water, snow, or ice, sudden explosions of steam and rock fragments can occur. This scenario is likely if flows from Gareloi reach the coastline.

Rockfalls, Landslides, and Lahars

Rockfalls and small landslides may occur on the steep slopes and crater walls of Gareloi Volcano. Landslides from steep coastal cliffs may form small waves close to the island. These events can be, but are not necessarily, related to volcanic activity and pose localized hazards.

Lahars are mobile, destructive volcanic mudflows consisting of volcanic debris and water. An eruption or increased heat could melt snow and ice to generate water that could mix with debris on Gareloi's steep slopes to form lahars. Because Gareloi Island is uninhabited and there are no permanent buildings, the risk posed by lahars is small.

Volcanic Gases

Volcanic vents can emit hot water vapor and volcanic gases such as carbon dioxide, hydrogen sulfide, and sulfur dioxide. In sufficient concentrations, these gases can be harmful. Some gases are heavier than air and tend to collect in low-lying areas, making descent into volcanic fissures or craters potentially hazardous. Windy conditions in the Aleutian Islands often preclude gas buildup and lessen the hazards from volcanic gases. The North Summit crater of Gareloi Volcano periodically emits volcanic gas, and there is a persistently active fumarole field on the west wall of the South Summit crater. Caution should be used when approaching these areas.

Rare Hazardous Phenomena that Could Accompany Large Eruptions of Gareloi Volcano

Debris Avalanches

Debris avalanches are large, fast-moving masses of rock debris—potentially an entire flank or sector of a volcano—produced by landslides. These avalanches may travel tens of kilometers from their source, including under water. Volcanic eruptions or volcanic or tectonic earthquakes may trigger them. At least two such events have occurred at Gareloi Volcano.

Volcanic Tsunamis

Volcanic tsunamis are destructive waves that can result from the rapid displacement of water generated by a volcanic debris avalanche, landslide, or pyroclastic flow that enters the sea. Debris avalanches preserved in the geologic record at Gareloi likely produced tsunamis, but the magnitudes and effects are not known. These north- and northwestward events would have produced waves that propagated into the Bering Sea but were not likely large enough to impact coastal Alaska. Like the events that produce them, tsunamis are rare. Given Gareloi's remote location, little risk is associated with volcanic tsunamis. Ships in the open sea would be unlikely to notice passage of tsunamis.

Suggestions for Reading this Report

Readers who want a brief overview of volcano hazards at Gareloi Volcano are encouraged to read the summary section and consult plate 1 and the illustrations. Individual sections of this report provide a slightly more comprehensive overview of the various hazards at Gareloi Volcano. A glossary of relevant geologic terms is included at the end of the report. Additional information about Gareloi 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).

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). Frequently active volcanoes can erupt *ash clouds* into the atmosphere threatening the numerous aircraft that travel between North America and Asia each day.

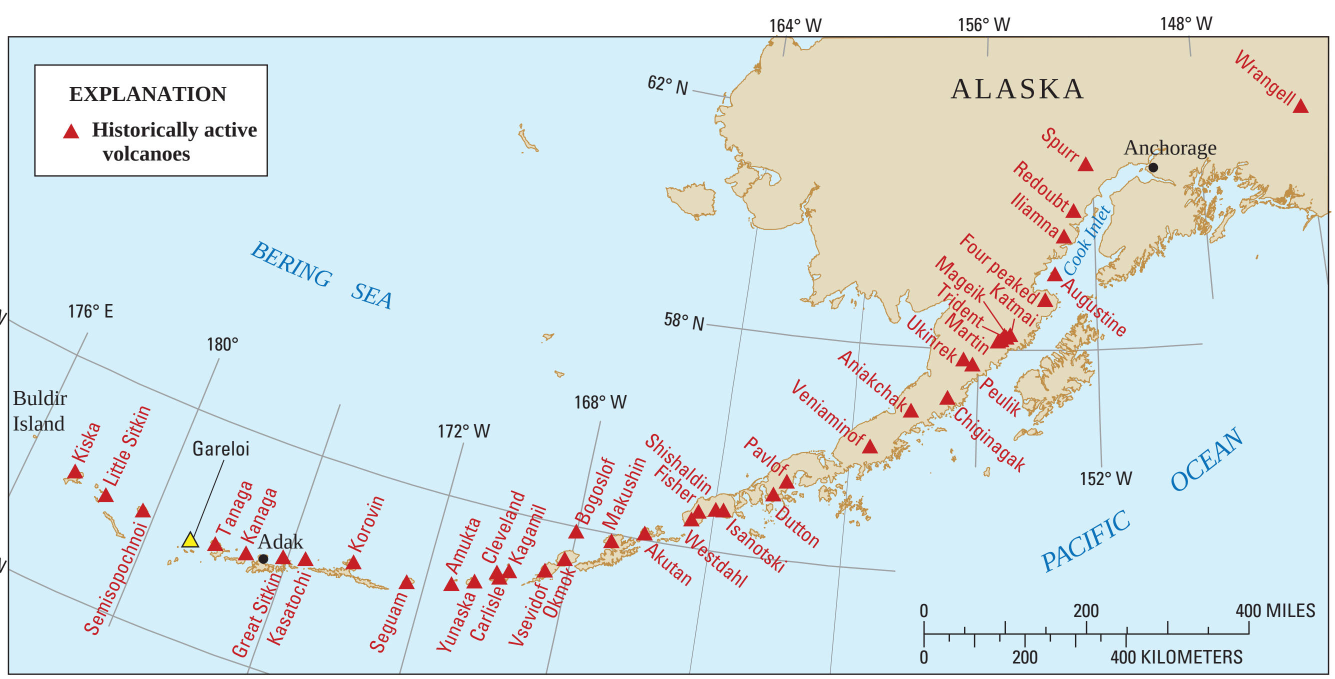
In 2003, U.S. Geological Survey (USGS), Alaska Volcano Observatory (AVO) scientists visited Gareloi Island to begin the first field study of the volcano since reconnaissance fieldwork of the mid-1940s (Coats, 1959). Sixteen reports of eruptive activity since 1760 (table 1) suggest that Gareloi is one of the most active volcanoes in the Aleutians. Many of the reports, however, are limited in their scope. Studies of the volcanic deposits help determine the likelihood and style and frequency of past eruptions from Gareloi Volcano. This geologic record is then used to infer likelihood and style of future eruptions.

In tandem with geologic studies in 2003, a network of six *seismometers* was installed to monitor volcanic activity—five on Gareloi Island and one on Kavalga Island, 22 km to the south. AVO has detected high levels of volcanic seismicity beneath Gareloi from the time the network was installed. Seismic unrest and the history of frequent eruptions make it important to understand the potential *hazards* associated with future eruptions of the volcano.

Table 1. Observations of historical eruptions and volcanic unrest at Gareloi Volcano, Gareloi Island, Alaska.

[Information compiled by C. Cameron, Alaska Division of Geological and Geophysical Surveys and Alaska Volcano Observatory; available at www.avo.alaska.edu. m, meter]

Date	Eruptive activity or observation	Reference
1760	"Active", "Smoking"	Grewingk, 1850
1790	"Fire-belching" (questionable)	Grewingk, 1850
1791	"Fire-belching" (questionable)	Grewingk, 1850
1792	"Fire-belching" and "smoking"	Grewingk, 1850
1828–29	"Smoking"	Grewingk, 1850
1873	"Active"	Becker, 1898
1922	"Major explosive eruption"	Coats, 1950
1927	"Fuming"	Jaggar, 1927, 1928
1929	Explosive fissure eruption and lava flows	Coats, 1956
1950	Minor ash and fume (questionable - may have only been steam)	Jones, 1951
1952	Fuming	Jones, 1952
1980	Explosive eruption – ash to 12,200 m ASL	Miller and others, 1998
1982	Explosive eruption – ash to 7,000 – 9,000 m ASL	Miller and others, 1998
1987	Narrow flow on east flank; steaming	Miller and others, 1998
1989	Grayish-black tephra plume 700 m above summit	Reeder, 1992
1996	Minor ash and steam eruption (questionable)	Smithsonian, 1996



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

Figure 1. Location of Gareloi Volcano and Island, in relation to other historically active volcanoes of Alaska (as listed in Miller and others, 1998).

Purpose and Scope

In this report, we describe our current understanding of the hazards associated with Gareloi Volcano. The term ‘hazard’ refers to danger posed by the physical events during an eruption (or less likely, physical phenomena on the volcano not directly associated with an eruption, such as landslides). ’Hazard’ should not be confused with *risk*, which comprises probability of hazard and consequences of events on people, infrastructure, buildings, and economic activity (Blong, 1996). In this preliminary hazard assessment, observations of historical eruptions and interpretation of the geologic and stratigraphic records enable us to make informed statements about the probable nature and magnitude of future volcanic events.

We first describe the physical character of Gareloi Volcano, followed by a brief geologic history. We later present the individual hazards that occur at the volcano.

Physical Setting and Features of Gareloi Volcano

Gareloi (178.794˚W and 51.790˚N) is an 8×10 km volcanic island located in the Delarof group of the Aleutian Islands, about 2,000 km west-southwest of Anchorage, Alaska, and about 150 km west of Adak, Alaska, the westernmost and southernmost community in the State (figs. 1 and 2). This remote island entirely comprises Gareloi Volcano, a steep-sided, 1,573 m-tall *stratovolcano*, one of a curving chain of volcanoes known as the Aleutian volcanic arc (fig. 1).

Gareloi Volcano has the conical shape of a classic *stratocone* (fig. 3). Its two summits, North Peak and South Peak, are separated by about 500 m, and both possess volcanic *craters* (figs. 3, 4, and 5). A small glacier, the southernmost and westernmost in Alaska, sits in the saddle between the two peaks (fig. 4). North Peak is the volcano’s true summit, at

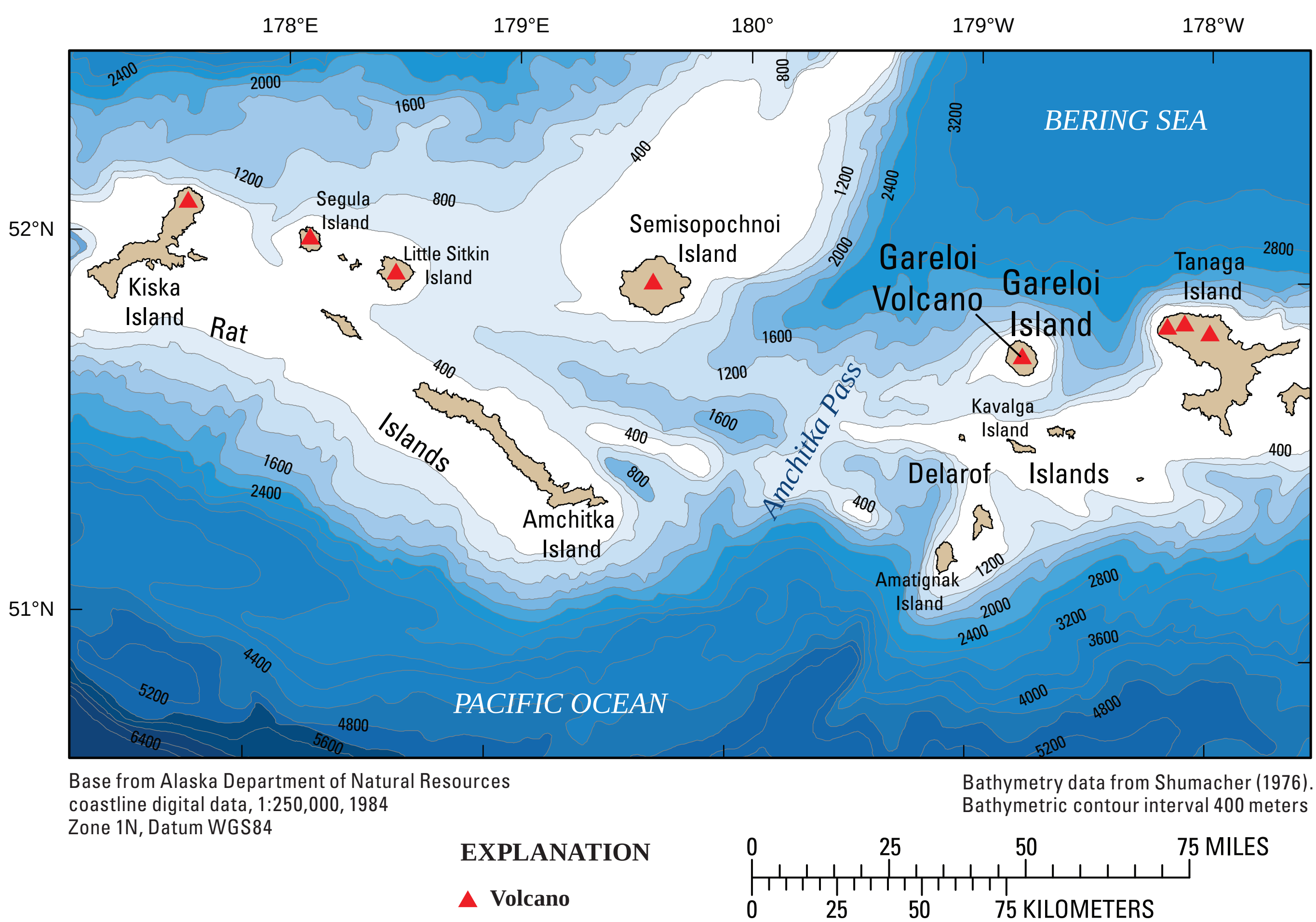


Figure 2. Geographic setting of Gareloi Volcano, Gareloi Island and nearby islands, Alaska.

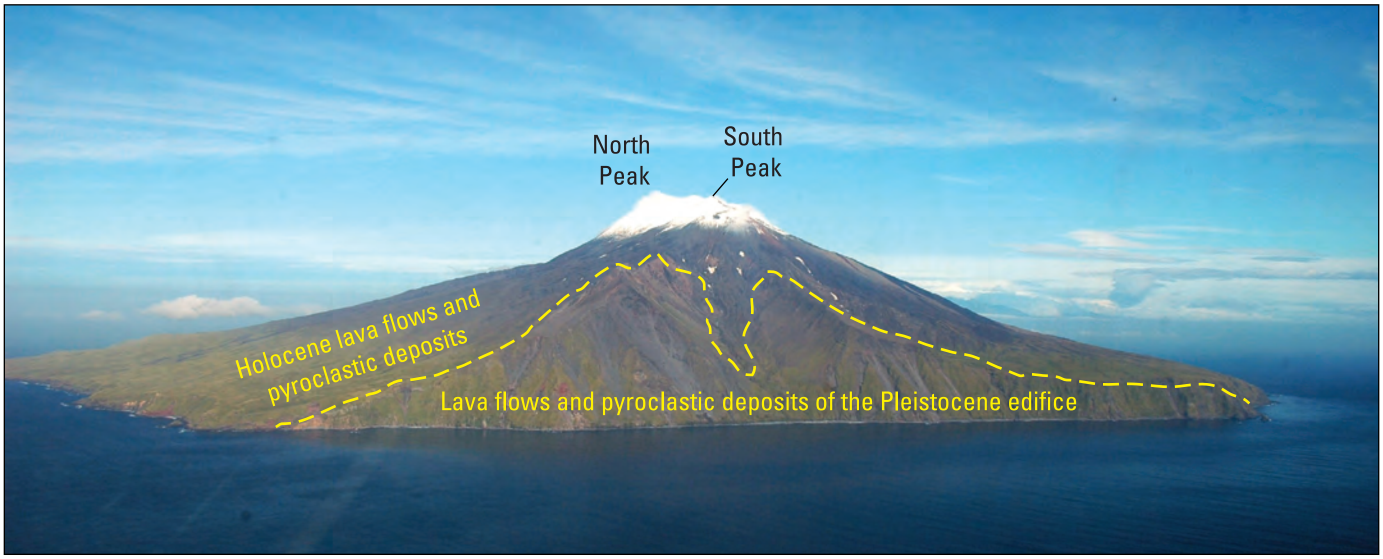


Figure 3. View looking east of Gareloi Island, Alaska. Island is approximately 9 km across in this view. Tanaga Island is partially visible through the clouds along the horizon to the right of Gareloi. Photograph by M.L. Coombs, USGS, October 2005.

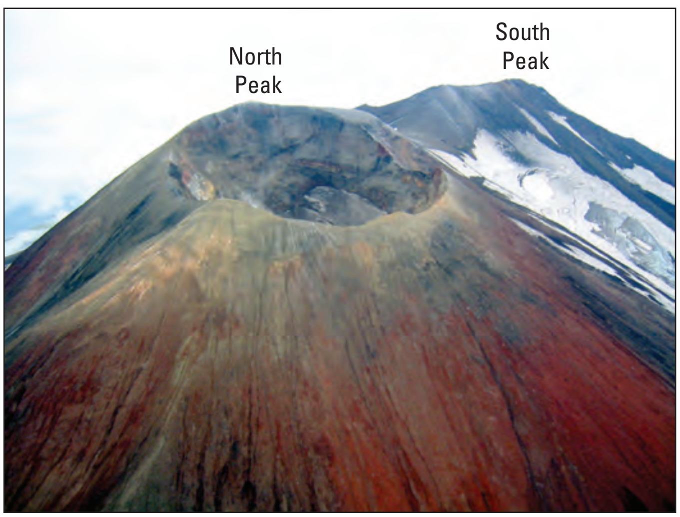


Figure 4. Oblique aerial photograph showing summit of Gareloi Volcano illustrating North Peak crater in foreground and rim of South Peak crater in background. Small glacier is visible on right side of image. North Peak crater is approximately 450 m across. Photograph by M.L. Coombs, USGS, August 2003.

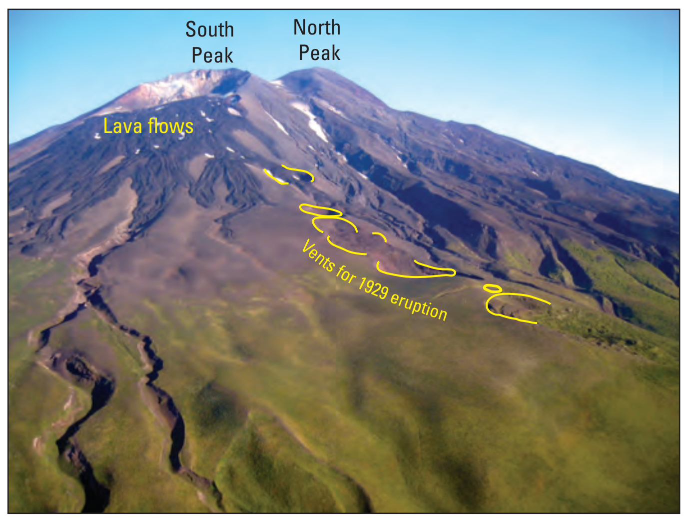


Figure 5. View looking north of Gareloi Volcano, Gareloi Island, Alaska. Photograph by R.G. McGimsey, USGS, August 2003.

1,573 m ASL, and its 300×350-m crater is fully enclosed and roughly 100 m deep (fig. 4). South Peak reaches 1,510 m ASL, and its crater is a 300-m-wide amphitheater formed by the partial collapse of its southern wall (likely during the 1929 eruption). The South Peak crater contains several active *fumaroles* (fig. 5). Visible in the walls of the South Peak crater are thick sequences of young *pyroclastic* deposits erupted from the volcano (fig. 6).

Gareloi 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 treeless, but its lower slopes are covered in thick, low vegetation and are home to large migratory seabird colonies (Jones and others, Alaska Maritime National Wildlife Refuge, unpub. data, 2006). The island is reachable only by boat or helicopter. Because of its roughly circular shape, Gareloi Island does not provide good anchorages. Tanaga Bay on the west coast of Tanaga Island, 50 km to the east, provides the closest protected anchorage (fig. 2).

Figure 6. Rim of South Peak crater of Gareloi Volcano, Gareloi Island, Alaska. Geologist is standing atop thick sequence of young pyroclastic deposits explosively erupted from the South Peak crater vent. Note large ballistic blocks in foreground. Photograph by R.G. McGimsey, USGS, August 2003.

Eruptive Activity of Gareloi Volcano

Historical Eruptions

There have been 16 reports of eruptive activity at Gareloi since 1760 (Miller and others, 1998; table 1). Some of the reports indicate only that the volcano was fuming or steaming; it is unclear whether some of the reports refer to steam or ash. Since 1922, the historical record shows that at least six explosive eruptions of the volcano have occurred. Historical accounts also indicate that Gareloi has exhibited both explosive and effusive eruptive activity, producing ash clouds, ash fall, *pyroclastic flows*, and *lava flows*.

1929 Eruption

The 1929 eruption is the largest historical eruption of Gareloi and also unique in its eruptive style and composition. The most detailed description of the eruption is given by Coats (1959), who summarized the first-hand observations of William H. Dirks, Sr. (Coats, 1959; p. 252):

> "In April of 1929, there was an eruption. A terrible quake… split the mountain from its crater right to the beach. Ashes fell, completely covering their cabins and boats…"

Coats further elaborated on the series of events from observations of the deposits, which were 17 years old when he visited the island and still unmodified either by vegetation or further eruptive activity. According to Coats, the eruption excavated 13 explosion craters, ranging in diameter from 80 to 1,600 m, along a 4.3-km-long, south-southeast trending fissure (figs. 5 and 7). On the basis of work by Coats (1959) and our fieldwork, the eruption began with formation of the current South Peak crater and a possible *directed blast* to the south. Following this, an *explosive eruption* covered the southern half of the island in several meters of *tephra* fall (fig. 8). At this time, the upper craters were excavated. Small pyroclastic-flow deposits are interbedded with tephra-fall deposits, indicating that pyroclastic flows accompanied tephra fall.

During the second half of the eruption, the composition of the juvenile clasts in the fall deposits became more *mafic*; craters formed lower on the flank, and small lava flows effused from them. Sometime after explosive activity ceased, *debris flows* from the summit carried *hydrothermally* altered blocks down the volcano's southern slope.

The eruption's total volume is unknown, as much of the *ejecta* were deposited offshore. Onland pyroclastic deposits represent about 16,000 m^3, and that of lavas is about 2,500 m^3.

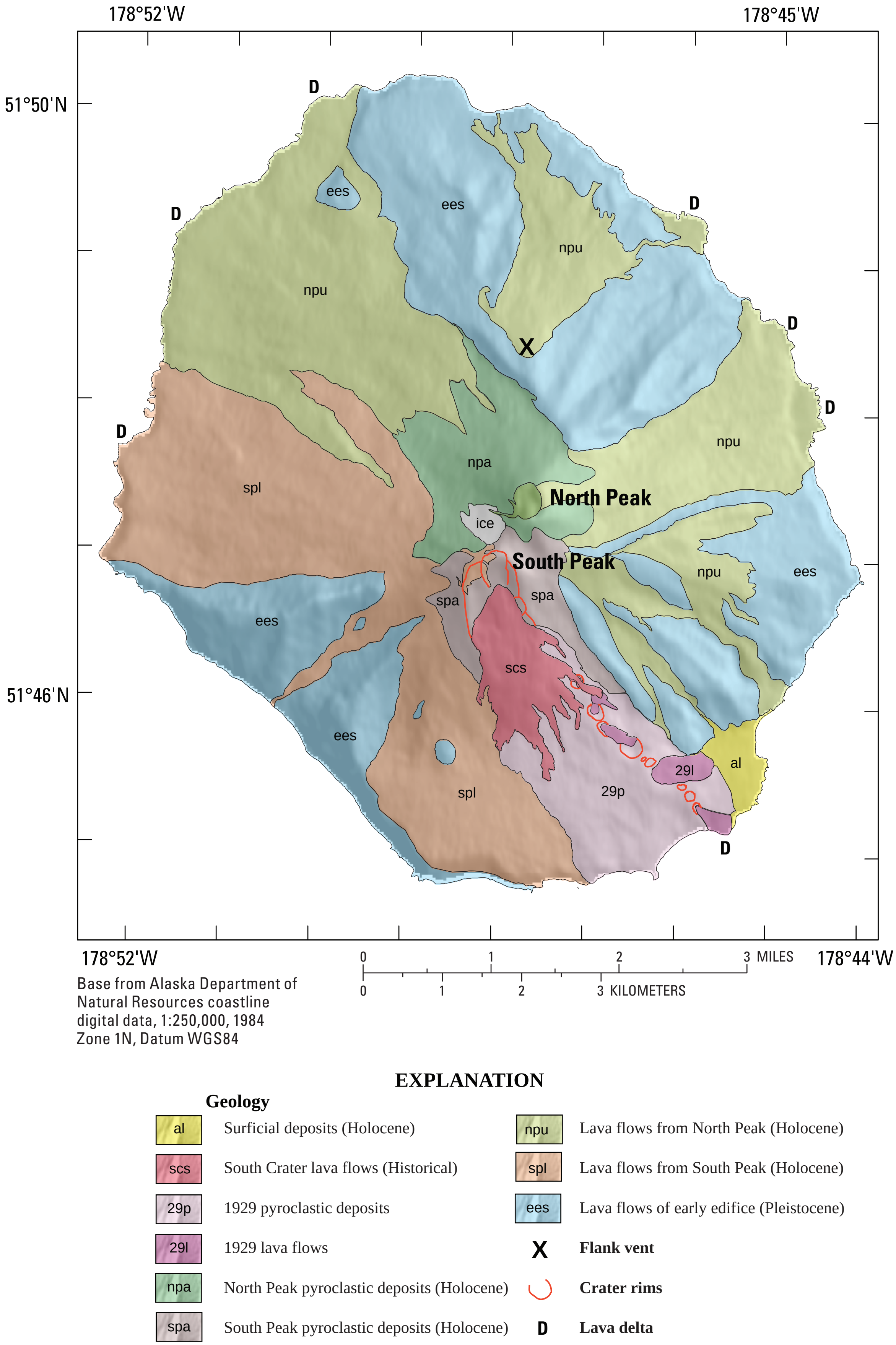


Figure 7. Simplified geologic map of Gareloi Volcano, Gareloi Island, Alaska.

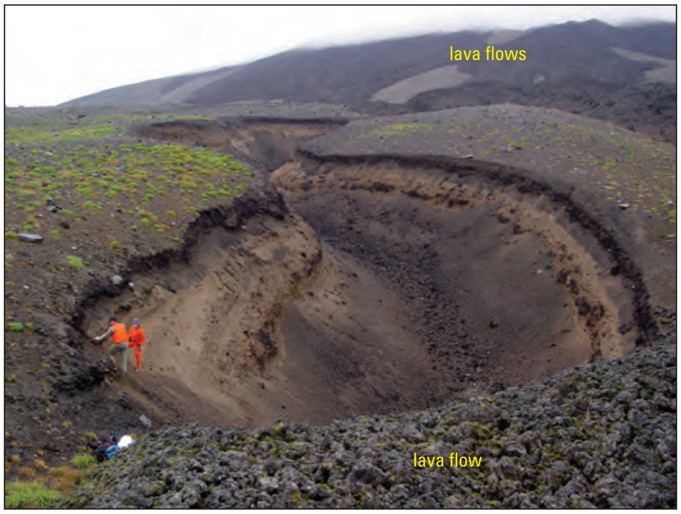


Figure 8. View of gully eroded into thick sequence of tephra deposits formed during 1929 eruption of Gareloi Volcano, Gareloi Island, Alaska. Color variations correlate to different chemical compositions, and pinkish cast is caused by oxidation of more silica-rich layers. Dark rubbly lava flows, erupted sometime between 1946 and 1980, are visible at the top and bottom of photograph. Photograph by R.G. McGimsey, USGS, September 2003.

South Peak Effusive Eruption (Between 1946 and 1980)

One of the most prominent features on Gareloi's south flank is a field of dark, sinuous, overlapping aa lava flows that emanate from the floor of the South Peak crater and extend 800 m down the volcano's southeast flank (figs. 5 and 7). Records do not exist to indicate when these flows were emplaced. They were not present in photographs from 1946 but are visible in images from August 1980. The only reports of activity during this interval were during 1950 and 1952, when minor ash and fume were observed (Jones, 1951; 1952; table 1).

1980 Explosive Eruption

The first reported eruption since 1929 took place in August and September 1980. On August 8, the crew of a Northwest Orient Airlines plane spotted a plume of ash that rose 35,000–40,000 ft ASL (Anchorage *Times*, August 16, 1980, p. A3). David Evans of the USGS reported earthquakes whose epicenters were west of the Adak seismic network on August 8 and 9. Ash fall was not reported at Adak. Cloud cover mostly obscured further observations after August 10, although a photograph of the summit from August 13 shows a light-gray plume rising from the North Peak crater (fig. 9). Evans said, "As far as we know, there was no lava eruption" (Anchorage *Times*, August 16, 1980, p. A3). On August 10, airborne stratospheric sampling detected ash and elevated sulfate concentrations between 54˚N and 60˚N and 150˚W (about 2,000 km away) at an altitude of 63,000 ft ASL (Sedlacek and others, 1981). On the basis of wind direction and NOAA-6 satellite imagery, the plume was a plausible product of the August 8 eruption (Sedlacek and others, 1981). The Smithsonian reported renewed ash emissions to 6 km ASL in September 1980.

1982 Explosive Eruption

On January 14, 1982, a magnitude 3.2–3.3 earthquake was recorded in the vicinity of Gareloi, and on January 15, a 23,000–30,000 ft-high eruption cloud was observed on satellite imagery (Miller and others, 1998).

1987 Flow

On September 4, 1987, a commercial pilot observed a dark, narrow flow-like feature on the steep east flank of the volcano that extended from the North Peak crater rim at 1,500 m altitude down to at least 1,100 m, below which it was obscured by clouds. Steam rose 100 m above the feature and the crater was vigorously steaming (Smithsonian, 1987). A similar feature was observed from afar during field work in 2003 but we were unable to determine whether it was lava or debris flow.

Figure 9. Steam and ash emanating from the North Peak crater of Gareloi Volcano, Gareloi Island, Alaska, August 13, 1980. Photographer unknown.

1989 Explosive Eruption

Evan Klett, of U.S. Fish and Wildlife Service, flying from Shemya Island to Adak aboard a commercial jet on August 17, 1989, observed a gray-black ash plume rising about 2,300 ft above Gareloi's North Peak crater (Reeder, 1992). The plume covered the top of the crater.

1996 Explosive Eruption

On September 27, 1906, the National Weather Service Aviation Weather Unit in Anchorage received a pilot report of a minor eruption of ash and steam from the volcano to 5,000 ft ASL (Smithsonian, 1996). Through early December of that year, AVO had received no further indications of eruptive activity at Gareloi.

Prehistoric Eruptive Activity

All of Gareloi Island is volcanic and seafloor mapping reveals that much of Gareloi Volcano lies below sea level (fig. 10). On the basis of outcrop appearance and erosion, we infer that the oldest rocks exposed on the island formed during the *Pleistocene epoch*. The oldest rocks consist of a deeply dissected stack of lavas and pyroclastic deposits that form wedge-shaped sectors southwest, southeast, and northeast of the volcano (figs. 3 and 7).

In addition to volcanic eruptions, ice and landslides are the two main agents that have shaped Gareloi Island. Glacial ice eroded and smoothed Pleistocene rocks prior to its retreat from this area roughly 10,000 years ago. Since glaciation, landslides occurred on the east and north flanks.

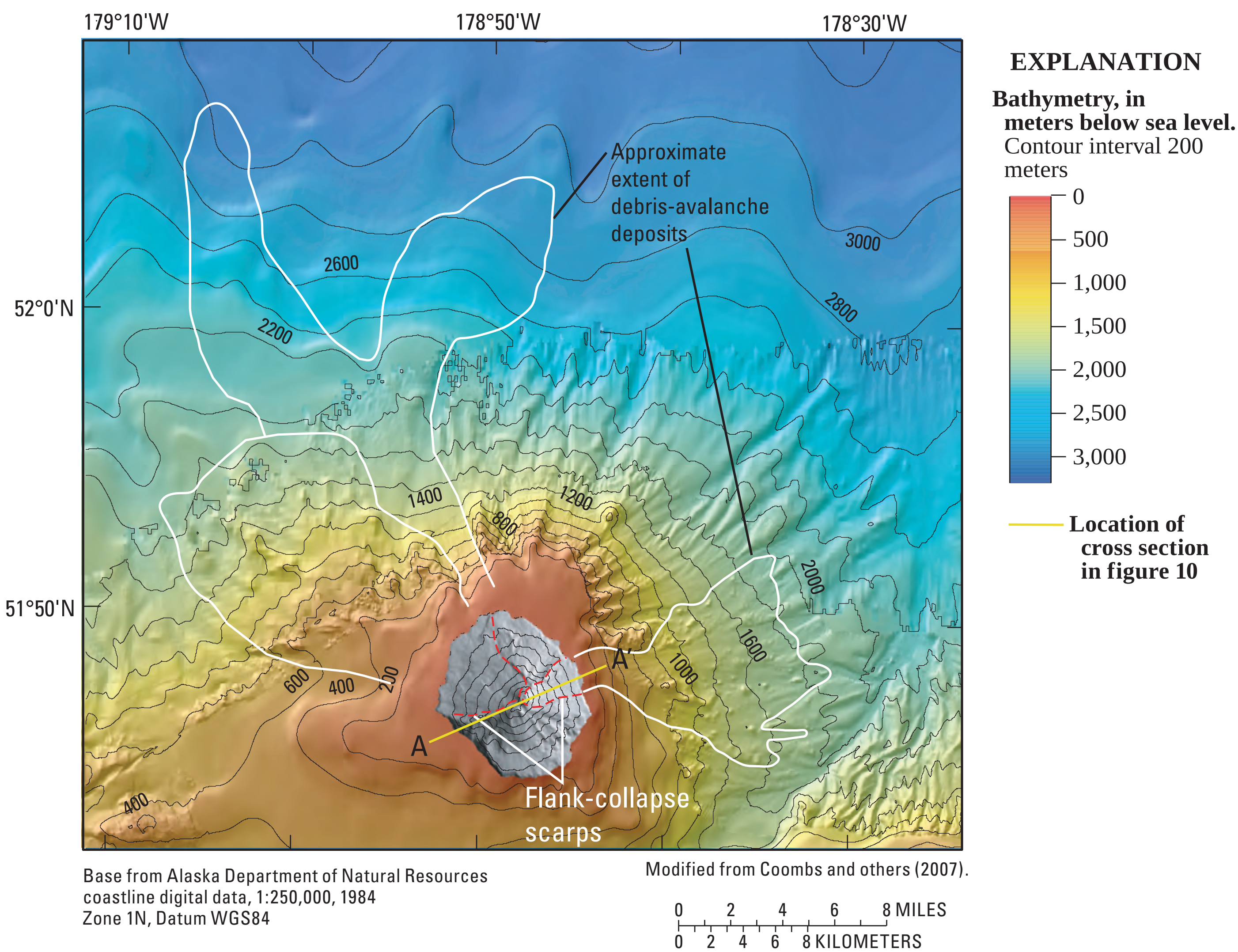


Figure 10. Topography and surrounding seafloor bathymetry, Gareloi Volcano, Gareloi Island, Alaska. Bathymetry combines regional, low-resolution data (smoother areas) and high-resolution data that reveal more detail of the seafloor. Bathymetry and reflectivity (not shown) define extents of debris-avalanche deposits.

The landslides deposited huge volumes of volcanic debris on the seafloor (fig. 10). We discovered no evidence to indicate that eruptions triggered the slope failures. Eruptions of lava flows and pyroclastic deposits have partially filled in the avalanche scars (fig. 11).

In the past few thousand years, many *effusive eruptions* from both North and South Peaks have covered the flanks of the volcano with blocky lava flows. Mapping reveals that multiple lava flows (and most likely accompanying explosive deposits) form during a single eruptive episode. Some flows formed *lava deltas* when they reached the sea (fig. 7). *Magma* erupted at Gareloi tends to be relatively *mafic* in composition, meaning that it erupts as rather thin, elongate lava flows instead of thicker flows and domes, though more *silica*-rich magma erupted in 1929 and formed short, stubby lava lobes.

Recent eruptions have produced blankets of *scoria* that cover the upper flanks of the volcano. Around the summit areas, layers of fine-grained ash and *ballistics* suggest hydrovolcanic activity. Tephras are locally preserved on the volcano's lower flanks but high levels of volcanic activity, severe weather, and exposed terrain have prevented the development of extensive tephra-soil complexes.

Seismicity

Since installation of the six-station seismic network in 2003 (Dixon and others, 2004; fig. 12), hundreds to thousands of earthquakes have been recorded at the volcano daily (Caplan-Auerbach and Prejean, 2005). These events, mostly of very small magnitudes (that is, less than 1), vary in style and depth and are likely related to the volcano's active hydrothermal system. Such activity is unusual for volcanoes, but these earthquakes are ongoing at Gareloi. A lack of corresponding eruptions suggests that this seismicity is "background" or "normal" for Gareloi. On September 2, 2005, seismometers recorded a 70-minute period of volcanic *tremor* (Caplan-Auerbach and Prejean, 2005). Movement of magma or other fluids such as hot water or gas causes tremor, which commonly causes eruptions. Visual observations by author M. Coombs on October 2, 2005, however, revealed no obvious changes that indicate an eruption took place.

Fumarolic Activity

Fumaroles in both South and North Peak craters of Gareloi have been sporadically active. Photographs from 1942 and 1986 show billowing, white steam emanating from the North Peak crater. During 2003 and 2005–07, the bottom of North Peak crater was snow-covered and not steaming, but the western interior wall of the South Peak crater contained a series of active fumaroles (fig. 13).

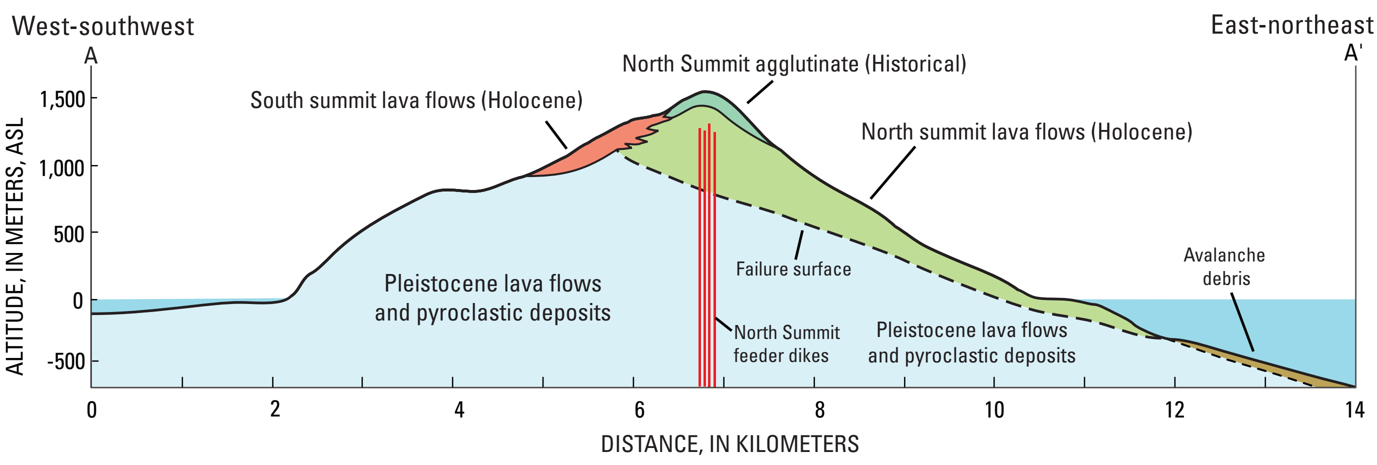
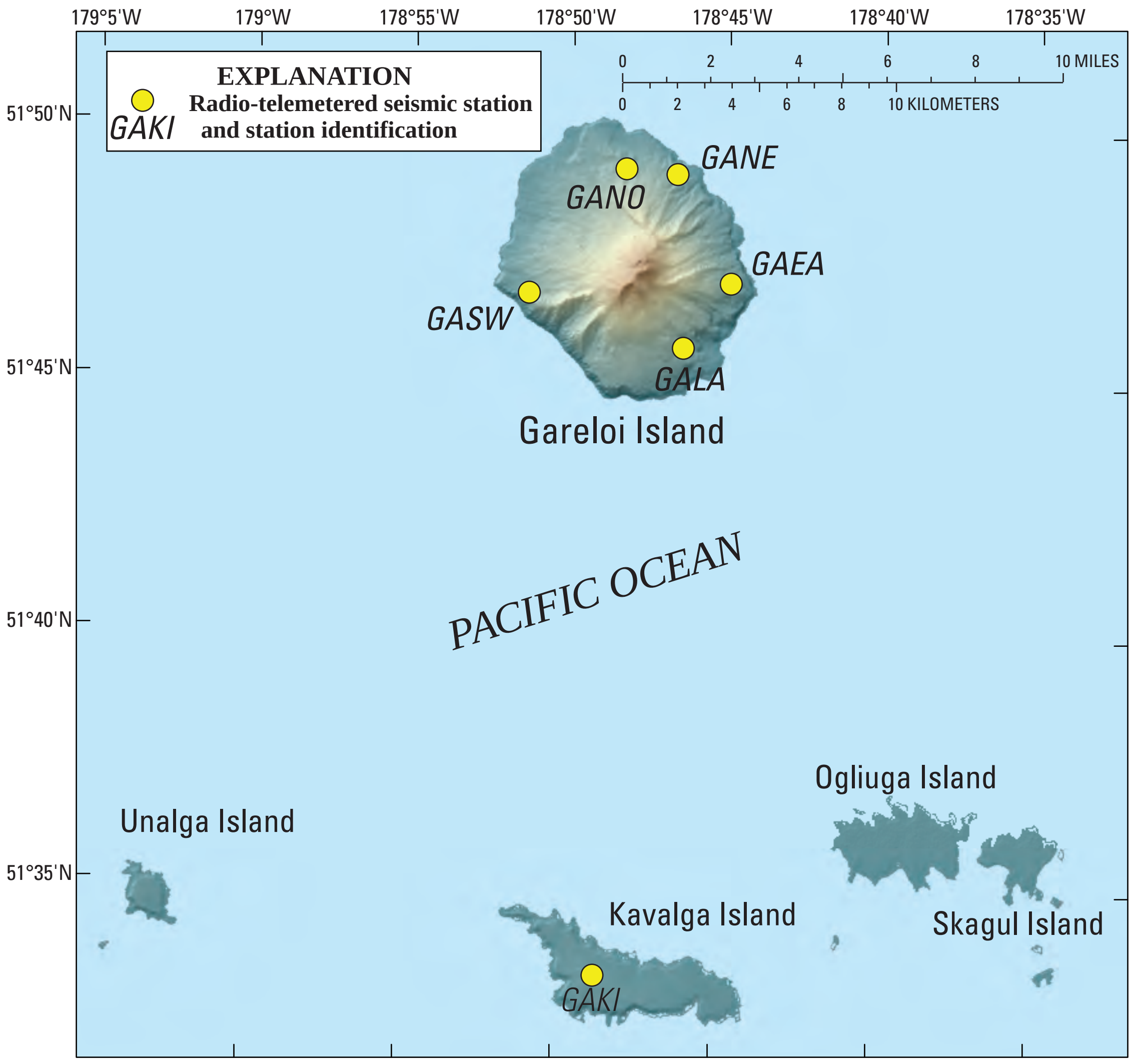


Figure 11. Cross section of Gareloi Volcano, Gareloi Island, Alaska. Location of cross section shown in figure 9.



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

Figure 12. Locations of radio-telemetered seismic stations on Gareloi and Kavalga Islands, Alaska. Data are radio-telemetered to Adak, Alaska, and then sent via telephone to the Alaska Volcano Observatory in Anchorage.

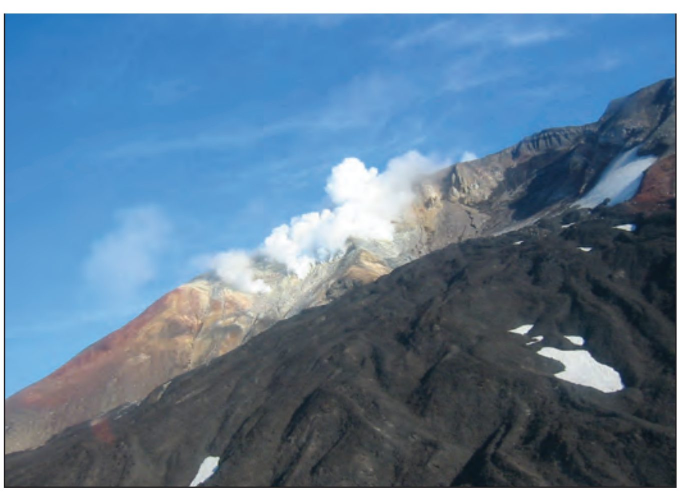


Figure 13. Oblique aerial photograph showing fumarole field on west wall of South Peak crater, Gareloi Volcano, Gareloi Island, Alaska. Note yellow discoloration that indicates sulfur precipitation and hydrothermal alteration. Visible white plume is predominantly condensed steam. Dark lava flows are visible in the foreground. Fumarole field is about 300 meters across. Photograph by M.L. Coombs, USGS, September 2003.

Volcano Hazards at Gareloi Volcano

A *volcano hazard* is a volcano-related process that potentially threatens life or property (fig. 14). These hazards are often, but not always, associated with eruptive activity. Events at other volcanoes can augment our understanding of hazards associated with Gareloi Volcano.

The severity of hazards associated with Gareloi Volcano may be proximal or distal (table 2; pl. 1). Proximal hazards are those affecting only an area within a few tens of kilometers of the active *vent*. These hazards could result in death or injury to anyone in this area for two main reasons. First, there may be little warning, and second, volcanic phenomena are more energetic closer to the vent. In contrast, distal hazards pose less risk because there is usually sufficient time to provide warnings, and the eruptive phenomena are less energetic and therefore less dangerous far from the active vent. Some phenomena, such as ash clouds and ash fall, can pose serious hazards locally and regionally.

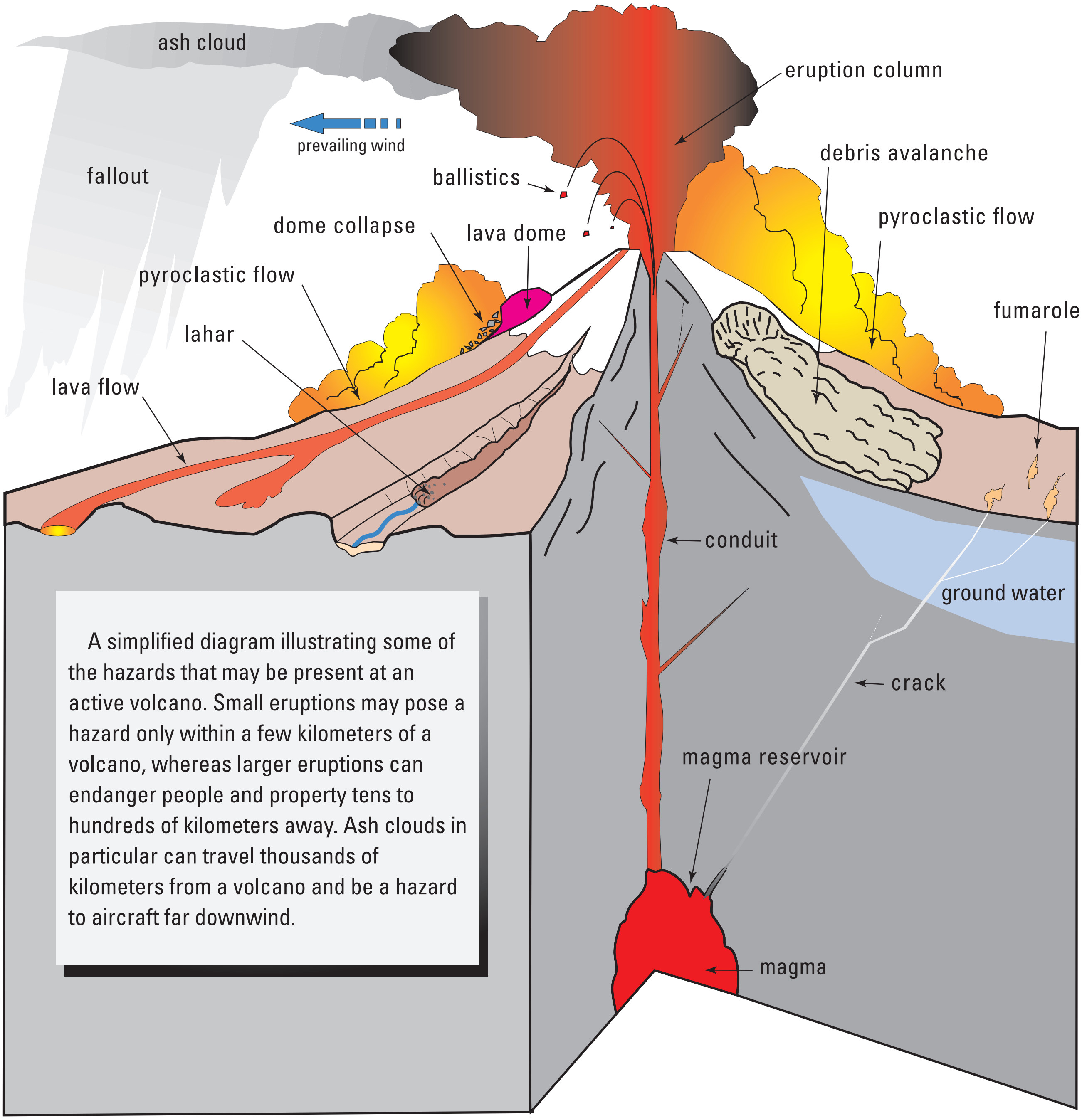
Geographic boundaries of hazard zones presented in this report should be considered approximate. We consider this evaluation of hazards preliminary because our geologic studies of Gareloi Volcano are limited by deposit preservation, remote location, and challenging logistics. In addition, although deposits from previous eruptions provide guides to future eruptive styles, a volcano may erupt in an unexpected way. The size and duration of an eruption will affect the area at risk, with larger eruptions potentially affecting larger areas. Environmental conditions, such as wind speed and direction, can affect hazards associated with eruptions. Even with modern instrumentation and monitoring techniques, the size, style, and duration of an eruption are difficult to predict.

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

Table 2. Types of phenomena and degree of hazard posed at Gareloi Volcano, Gareloi Island, Alaska.

[See fig. 12 and text for schematic representation and description of these processes. >, greater than]

Type of hazard	Severity of hazard: Proximal (Gareloi Island and immediately offshore)	Severity of hazard: Distal (>10 km from Gareloi Island)	Severity of hazard: Airborne	Comments
Ash clouds	Substantial	Substantial to slight	Substantial	Severe hazard to aircraft even hundreds or thousands of kilometers downwind.
Ash fall	Substantial	Substantial to none	Substantial	Significant hazard to anyone around volcano including passing ships and to nearby communities. Minor hazard or nuisance in distant communities.
Ballistics	Substantial	None	None	Significant hazard to anyone on or around volcano during explosive eruptions.
Pyroclastic flows and surges	Substantial	None	Slight	Significant hazard to anyone on or near the volcano during explosive eruptions. Possible hazard to over flying aircraft during large eruptions.
Lava flows	Substantial	None	None	Significant hazard to anyone near flows; attendant pyroclastic flows, ash fall, or ballistics increase the area potentially affected. Collapse of lava deltas at shoreline may cause local waves hazardous to ships.
Lahars	Substantial	None	None	Significant hazard limited to volcano's flanks and drainages.
Rockfalls and landslides	Substantial	None	None	Persistent hazard to anyone near steep slopes or coastal cliffs on the island.
Volcanic gases	Moderate	None	Slight	Significant hazard during periods of strong degassing from fumaroles or vents.
Debris avalanches	Substantial	Moderate	Slight	Significant hazard to anyone around volcano during event, especially in low-lying areas. Larger debris avalanches would extend offshore.
Volcanic tsunamis	Substantial	Substantial	None	Very low-probability but significant hazard during large debris avalanche or eruption that produces large pyroclastic flows that enter the sea; would affect areas on nearby islands, shipping routes, and the Bering Sea coastline.



Modified from Meyers and others (1997)

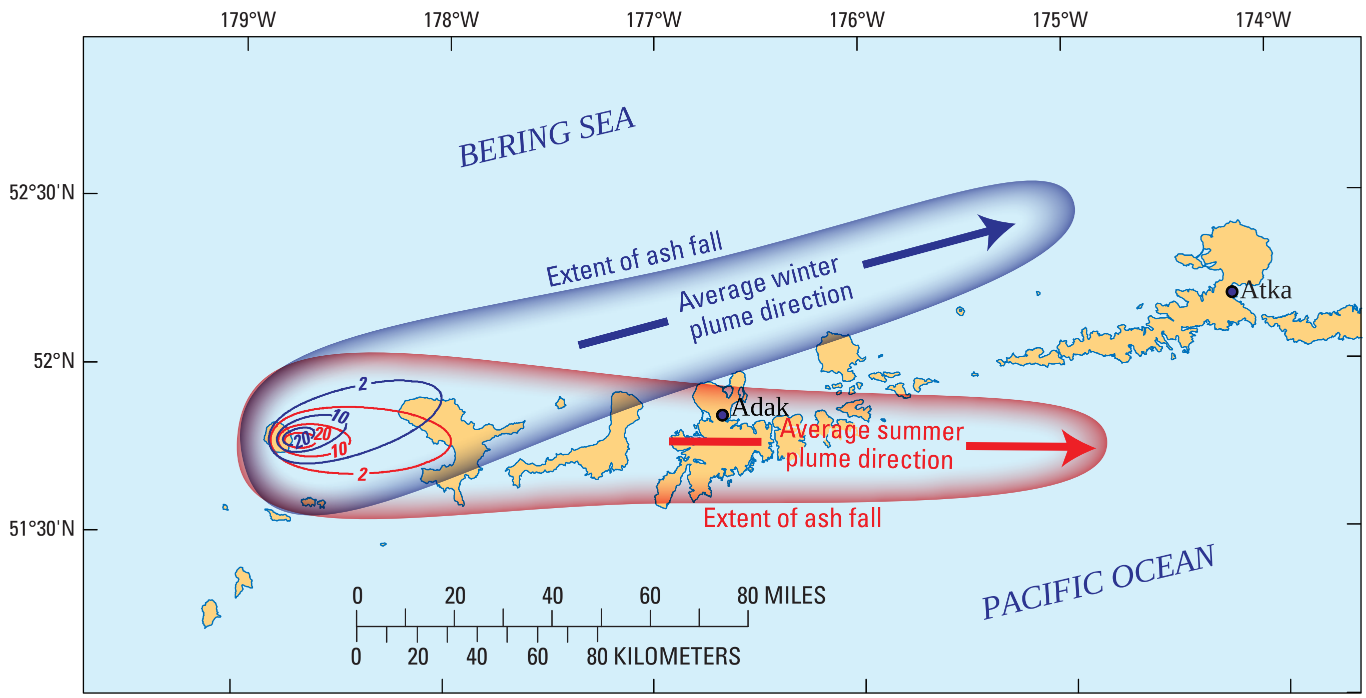
Figure 14. Hazardous phenomena associated with stratovolcanoes.

Ash Clouds

An explosive eruption of Gareloi Volcano will inject large quantities of ash and gas into the atmosphere and form an ash cloud or eruption cloud. These clouds may rise to as many as 15,000 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 varies with altitude, the ash cloud may spread in different directions. Ash clouds from Gareloi will most commonly move eastward, the prevailing wind direction (fig. 15). Eruption clouds are hazardous to aircraft that fly through them, because volcanic ash interferes with engine operation, damages electronics, and abrades exposed surfaces (Casadevall, 1994).

Historically, Gareloi eruptions have produced ash clouds that reached as high as 12,000 m ASL, and similar eruptions can be expected in the future. Satellite observations and ash-cloud trajectory modeling are the most effective tool for monitoring the clouds and mitigating hazard to aircraft and communities downwind.

A *phreatic eruption* is an eruption that occurs when hot, hydrothermally heated ground water transforms to steam, becomes pressurized, and expands explosively at the surface. Phreatic eruptions can produce ash, though typically the ash clouds are smaller in volume and height reached compared to magmatic explosive eruptions. Given the hydrothermal activity and near-vent deposits at Gareloi, small phreatic eruptions may be common there.



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

Figure 15. Areas of potential ash fall during a moderate eruption of Gareloi Volcano, Gareloi Island, Alaska. Ash fall during an actual eruption will depend on wind direction and total volume erupted and may deviate from these examples. Hypothetical ash-fall contours, in millimeters, are generated using the ASHFALL model (Hurst, 1994). Two sets of wind data are shown—red highlights potential ash fall assuming average summer winds, and blue highlights potential ash fall assuming average winter winds. Summer (May through October) and winter (November through April) averages derived from National Center for Environmental Prediction (NCEP) long-term monthly wind data for 1968–96 (Kalnay and others, 1996). Such data are available from 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 ash-fall 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 Gareloi Volcano.

Ash Fall and Volcanic Bombs (Ballistics)

Volcanic ejecta moving downwind in an ash cloud settle out and fall to the ground and form a blanketing layer of ash. Generally, the thickness and grain size of ash fall decreases away from the volcanic vent. The windspeed, direction, and height of the ash cloud will strongly affect how much ash fall is deposited, and where. Within several kilometers of the vent, ash fall may be many meters thick and contain clasts more than 1 meter in diameter. For example, the 1929 eruption produced several meters of ash fall on the island's south flank (fig. 8). Far from vent, the fall may be less than a millimeter thick and consist of very fine ash (fig. 15).

Volcanic ash poses several hazards. Fine ash (less than 1 micron—0.001 mm—in diameter) 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 navigation (for example, GPS), and ash falling on power lines and transformers can cause electrical outages. Prevailing winds would carry future ash from eruptions of Gareloi eastward, possibly toward communities of Adak, Alaska (150 km east) and Atka, Alaska (320 km east; fig. 15). Ash fall at Adak would likely be less than 2 mm (less than 0.1 in.) from a typical eruption of Gareloi, with little more than a dusting at Atka. Ash fall within several kilometers of the vent, however, could accumulate to several centimeters (fig. 16).

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 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 extremely hazardous to anyone or anything in their path.

At Gareloi Volcano, pyroclastic flows likely would form by collapse of *eruption columns*. The dense part of an eruption column can collapse and fall back toward the volcano during explosive eruptions. 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. Because of Gareloi's steep slope and small area, pyroclastic flows from either the north or south crater could sweep down most flanks, reach the coastline, and flow into and over the sea (fig. 16).

Pyroclastic flows and surges also may form during directed blasts—sudden, violent, laterally directed volcanic explosions that occurs when a shallow body of magma is depressurized quickly (Valentine and Fisher, 2000). Large landslides or sector collapses off the flanks of volcanoes are the main process that produces directed blasts (Siebert and others, 1987). Pyroclastic flows and surges that form during these blasts radiate out from the affected side of the volcano. Large directed blasts are extremely rare and highly unlikely to occur at Gareloi. A small directed blast may have occurred at the onset of the volcano's eruption in 1929, sending a pyroclastic surge over the volcano's south flank.

If an explosive eruption were to occur when the volcano was covered with snow, pyroclastic flows would melt the snow and could form hot *lahars* that would flow down the flanks (see section, "Lahars").

The runout distance of pyroclastic flows is estimated using the ratio between the fall height, H (typically the height of the summit), and the runout length, L. Typical ratios for observed pyroclastic flows elsewhere are 0.2–0.3 (Hayashi and Self, 1992; Hoblitt and others, 1995). Thus at Gareloi, pyroclastic flows and surges could travel about 7 km from vents (fig. 16).

When large pyroclastic flows reach a coastline, 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 section "Tsunamis"). No evidence on Gareloi Island indicates that such large pyroclastic flows occurred in the last 10,000 years, therefore they would be an unusual phenomenon at this volcano.

Lava Flows

When magma (particularly mafic magma) erupts quietly or non-explosively (effusively) at the Earth's surface, the lava can flow downslope in streams, fans, or lobes. Such *lava flows* accompany many eruptions at Gareloi and compose most of its *edifice*. The flows typically have pronounced lateral levees and steep fronts that can shed hot debris as they advance. By analogy with similar flows observed elsewhere, such lava flows would travel slowly, no more than tens of meters an hour. Lava that reaches the coastline may build out into the water, forming lava deltas (fig. 7). These are unstable structures that can collapse into the sea with little or no warning, generating localized waves (tsunami).

Because of Gareloi's fairly symmetrical shape, lava flows could occur over most of the volcano (and island). Any given flow, however, will likely only affect a few square kilometers and be less than a kilometer wide and several kilometers long. Historical activity and geologic mapping show that multiple flow lobes are often erupted during a single eruptive episode that can last months or perhaps years. Where ravines or valleys are present, lava flows will follow these topographically low areas. During the *Holocene epoch*, lava flows have erupted from North Peak, South Peak, and an apparent flank vent north of North Peak. Future eruptions could involve these or new vents anywhere on the island.

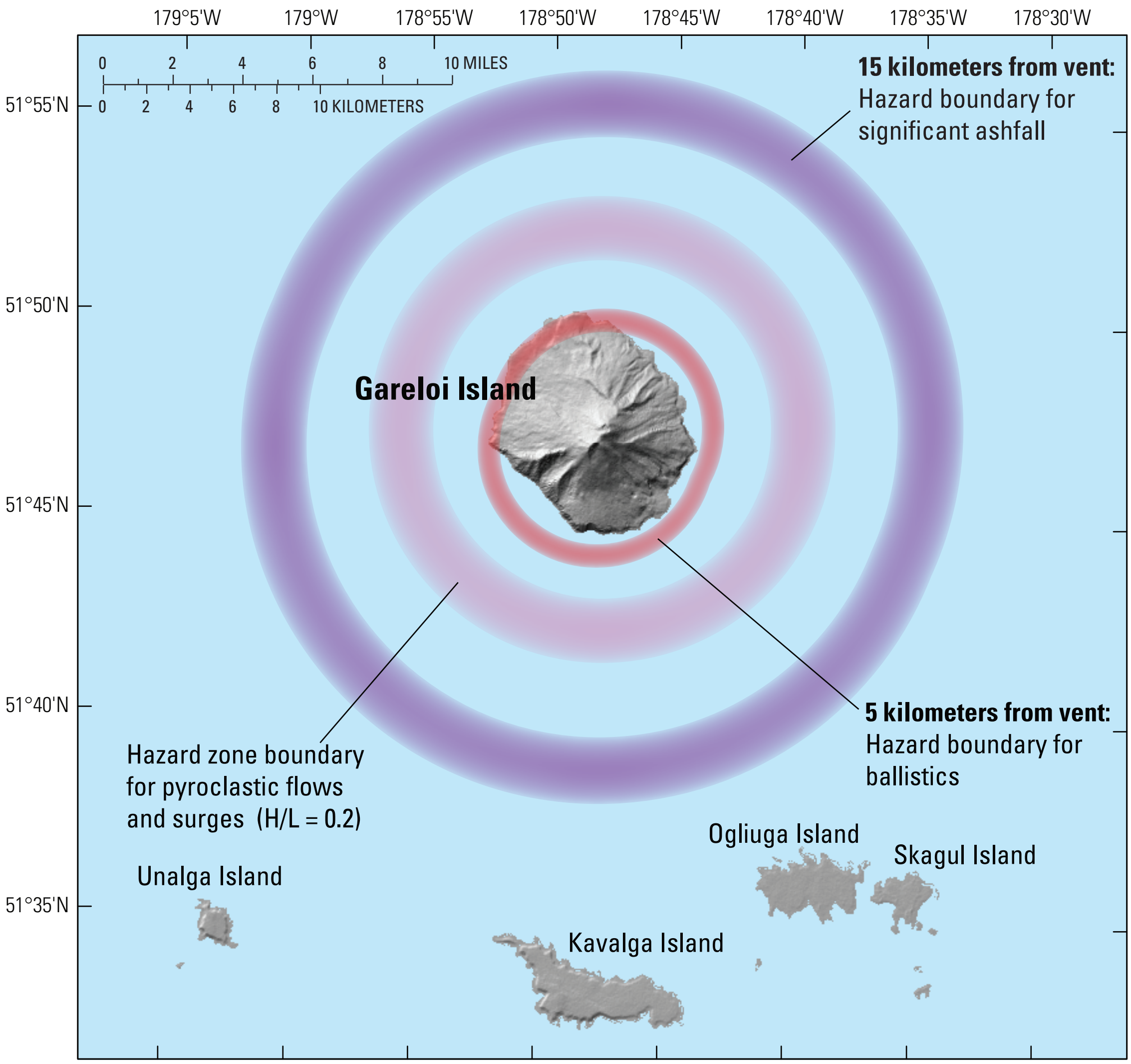


Figure 16. Approximate extent of proximal hazard zones from ash fall, ballistics, and pyroclastic flows and surges near Gareloi Volcano, Gareloi Island, Alaska. Ballistics large enough to harm humans likely will be restricted to within 5 kilometers of the potentially active vent. For typical eruptions, tephra accumulations of several centimeters, or more, likely will be restricted to within 15 kilometers of the active vent. Pyroclastic flows and surges form energetic eruptions may reach all coastlines of Gareloi and travel short distances over the water. Pyroclastic flows and surges that originate from collapse of a tall eruptive column may travel farther than these boundaries indicate, though we observed no geologic evidence for such large flows occurring in the past. In addition to ash fall from eruption clouds, some explosive eruptions can launch blocks of dense rock or pumice, called ballistics, on arcuate trajectories from the vent. Ballistics generally do not travel beyond 5 kilometers from the vent (Blong, 1996). These can travel in any direction from the vent and pose a serious hazard to people within their range (fig.16). Recent activity has scattered ballistic blocks over the summit region of the volcano.

Lahars

Lahars are volcanic mudflows that consist of some combination of volcanic debris and water. They also are 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 travel at speeds as fast as 20 m/s in steep channels and 5-10 m/s down gentler slopes (Blong, 1984). Lahars will inundate everything in their path and can leave several meters or more of sediment behind.

All slopes of Gareloi Volcano are potential sources for lahars. Several thin, localized lahar deposits occur on the volcano's flanks. Because Gareloi Island is uninhabited and there are no permanent structures, the risks posed by lahars are small. Lahars would usually be confined to the flanks of the volcano, and if they entered the sea would not travel far or cause tsunamis.

Debris Avalanches, Rockfalls, and Landslides

Because of the rapid growth and interbedded layers of fragmental and more coherent rocks, stratovolcanoes tend to be unstable, steep-sided constructions. Mass wasting of volcanoes can range widely in size. Rockfalls and small landslides on steep slopes and surrounding ridges may be independent of volcanism and will only affect areas directly downslope from source. *Debris avalanches* form when a substantial part of a volcanic edifice collapses. These avalanches can move quickly and can travel more than 10 times their vertical drop (Siebert, 1996). Worldwide, documented have volumes as great as several cubic kilometers (Siebert, 1984).

Two significant debris avalanches that have occurred at Gareloi incised into the edifice and spread debris on the sea floor. Frequently active volcanoes such as Gareloi produce thin, interbedded lava and pyroclastic flows and these volcanoes often have landslides that remove relatively thin sections of a flank (though still perhaps many hundreds of meters thick). A future failure could occur on any flank of the volcano.

Tsunamis

Tsunamis are waves or wave trains produced by sudden displacement of seawater. Volcanic landslides, avalanches, and flows that sometimes occur during eruptions can generate tsunamis when they suddenly enter the sea (for example, Waythomas and Neal, 1998; Ward and Day, 2003). The geologic record shows no evidence of eruptions from Gareloi Volcano large enough to produce a tsunami, but landslides and subsequent debris avalanches may have. The magnitude of tsunamis generated during these events is unknown. Gareloi's remote location and the relatively small volumes (several cubic kilometers, at most) of the landslides, however, mean that significant waves would likely only reach neighboring islands and would not be felt along distant coastlines.

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 hydrogen chloride. 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 of special concern because it is heavier than air and collects in low areas. In high enough concentrations, carbon dioxide can quickly asphyxiate people and animals and kill vegetation. Most gas that is emitted from volcanoes, however, will rapidly dissipate into the atmosphere and pose little threat to people more than several kilometers from the active vent.

During recent visits to Gareloi, the fumarole field in the South Peak crater vigorously emitted gas, and steaming has been observed in the past from North Peak crater. An increase in gas or steam flux at either vent could presage an impending eruption. Commonly, "volcanic unrest" includes episodic steaming that does not lead to eruption.

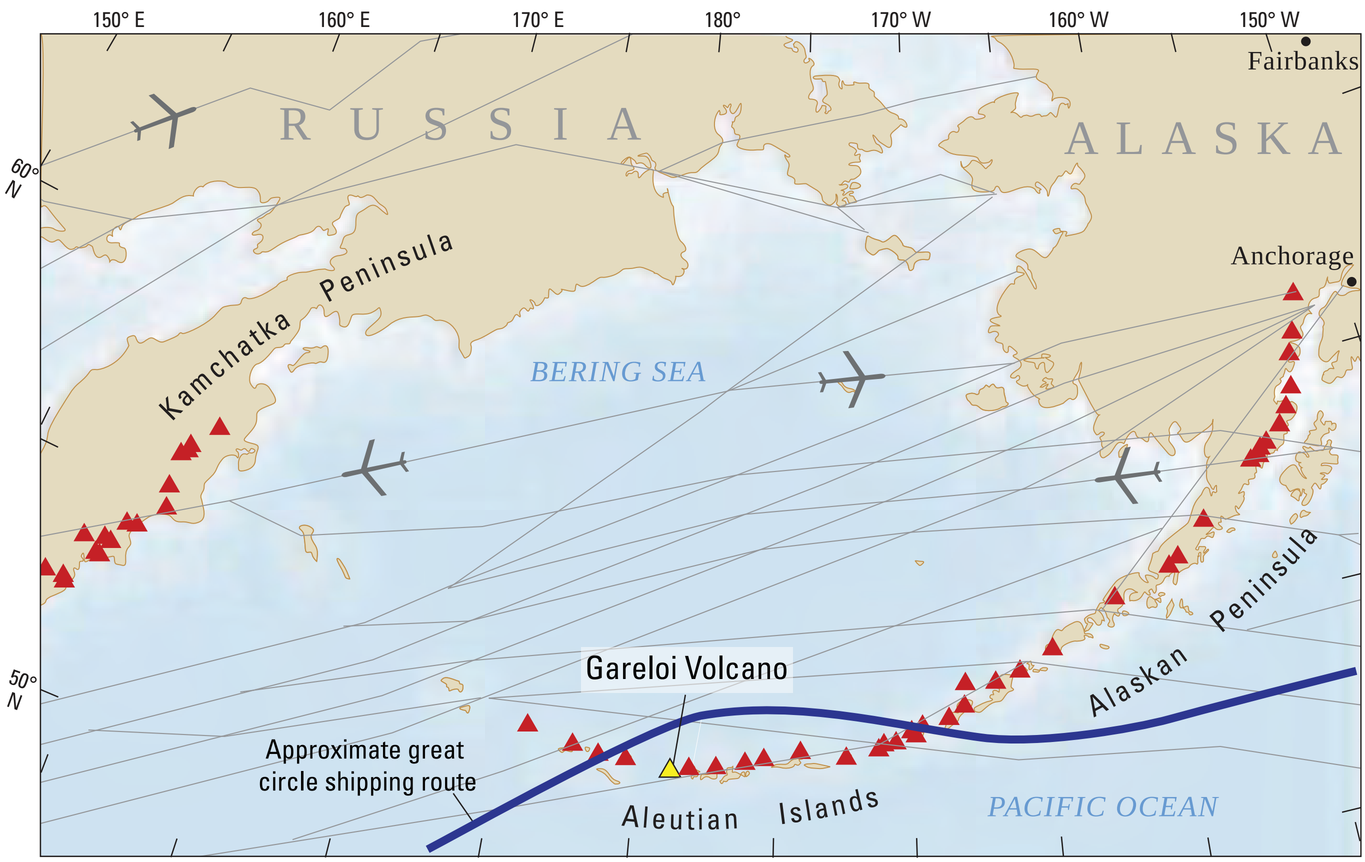
Event Frequency and Risk at Gareloi Volcano

Historic observations indicate that Gareloi Volcano will erupt in the future. Over the past 250 years of historical observations, there have been 16 reports of activity at Gareloi. Several of these are unclear, leaving 11 reports of activity that appear to correlate with ash-producing eruptions. Because some of the observations possibly can be lumped into periods of continuous activity, the reports of activity suggest that Gareloi has an episode of volcanism every 20–50 years.

The timing or magnitude of the next eruption of Gareloi can not be predicted with certainty. However, on the basis of past eruptions, any future eruption likely would be mafic in composition, and produce ash plumes and fall, and possibly lava and pyroclastic flows. Ash plumes are likely to be tens of thousands of feet high, and are likely to impact airspace above the volcano and hundreds of kilometers downwind. Ash fall will likely be less than a few millimeters on the communities of Adak and Atka, and heavy only within several kilometers of the volcano. Lava and pyroclastic flows would not travel far past the current coastline of the uninhabited island.

Three primary groups are at risk from volcanic activity at Gareloi. First, airborne ash would be hazardous to overflying aircraft, either flying to or from Adak or flying the North America-Asia air routes (fig. 17). About 80,000 aircraft travel over the Aleutians every year and as many as 30,000 passengers per day (Schaefer and Nye, 2008). Secondly, ash fall would impact the community of Adak, 150 km to the east. With approximately 80 year-round residents, Adak also is home to a deepwater port, seafood processing facilities, and the largest airport in the Aleutians. In addition, a sea-based X-Band radar facility lies offshore of Adak. This infrastructure could be adversely affected by ash fall from Gareloi. Finally, passing ships or fishing vessels are at risk from ash fall, and also from proximal hazards if they pass close to the island. About 3,100 vessels travel the northern great circle route between the contiguous United States and Asia every year (Nuka Research and Planning Group, 2006). This route passes just north of Gareloi and other central Aleutian volcanoes (fig. 17).

Proximal hazards restricted to Gareloi Island likely will pose little or no risk because of the absence of residents or property. Anyone planning to visit Gareloi Island should obtain up-to-date information regarding volcanic activity.



Base modified from Neal and others (1987)

Figure 17. Principal North Pacific air routes and great circle shipping route in relation to Gareloi Volcano, Gareloi Island, Alaska.

Hazard Warning and Mitigation

Most volcanic eruptions follow weeks to months of precursory seismic activity in the form of earthquakes and volcanic seismic signals called tremor. Movement of fluids and the breaking of rock as magma moves toward the surface cause these precursory signals. Since 2003, a network of six seismic instruments around Gareloi Volcano transmits seismic data in real-time to AVO offices in Anchorage and Fairbanks (fig. 12). This network is the primary means of monitoring volcanic unrest at Gareloi.

Daily satellite images indicate hot areas on Alaskan volcanoes or ash in the atmosphere. If unrest were detected at Gareloi, satellite-based thermal and SO_2 sensors could gather information about possible volcanic activity. Airborne or ground-based volcanic gas measurements and ground deformation and thermal change surveys would likely be limited because of Gareloi's remote location.

Because of inclement weather and the remoteness of Aleutian volcanoes such as Gareloi, AVO relies on the observations of pilots, mariners, or others nearby. Reports of anomalous steaming, fumarolic activity, new deposits, or possible ash clouds prompt AVO personnel to further investigate.

AVO communicates warnings of volcanic unrest or potential eruptions to agencies and the public. In addition, AVO summarizes the status of Alaskan volcanoes each week. Updates and summaries are sent to the Federal Aviation Administration, National Weather Service, Alaska Department of Homeland Security and Emergency Services, the Governor's office, State offices, military bases and airports, the U.S. Coast Guard, air carriers, television and radio stations, and wire services. During times of volcanic unrest, AVO disseminates information releases to the same groups. Weekly updates, daily status reports, and information releases are sent to volcano information networks and posted on the AVO website (www.avo.alaska.edu).

To summarize the status of Alaska's 30 monitored volcanoes, AVO uses a two-tiered alert-level system now shared by all five of the USGS Volcano Observatories. The volcano alert system uses a set of general terms to describe the level of activity: **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 telephone calls directly to pertinent government agencies (fig. 18).

Table 3. Volcano alert levels used by USGS Volcano Observatories.

[See Gardner and Guffanti (2006) for more information]

Alert Levels	
NORMAL	Volcano is in typical background, noneruptive state *Or, after a change from a higher level,* Volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level, *Or, after a change from a higher level,* Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential for eruption, timeframe uncertain, **OR** Eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

A second component of the warning system, aviation color codes (**GREEN, YELLOW, ORANGE, and RED**) also are used to provide information about volcanic-ash hazards to aviators (table 4). The two systems often change in parallel 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 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 Gareloi, AVO's monitoring efforts would increase. Volcanic activity notifications would be dispatched as new information became available and would detail the current level of unrest, the likelihood of an eruption, and the possible outcomes of such an event.

Table 4. Aviation color code used by USGS Volcano Observatories.

Level of Concern Codes for Aviation	
GREEN	Volcano is in typical background, non-eruptive state *Or, after a change from a higher level,* volcanic activity has ceased and volcano has returned to non-eruptive background 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 or escalating unrest with increased likelihood of eruption, timeframe uncertain. **OR** eruption is underway with no or minor volcanic-ash emissions.
RED	Eruption is forecast to be imminent with significant emission of ash into the atmosphere likely. **OR** eruption is underway or suspected with significant emission of volcanic ash into the atmosphere.

AVO/USGS Volcanic Activity Notice

Volcano: Gareloi (CAVW #1101-07-)

Current Volcano Alert Level: WATCH
Previous Volcano Alert Level: Advisory

Current Aviation Color Code: ORANGE
Previous Aviation Color Code: Yellow

Issued: Tuesday, June 10, 2008, 4:25 PM AKDT (20080610/0025Z)
Source: Alaska Volcano Observatory
Notice Number: 2008/A5
Location: N 51 deg 47 min W 178 deg 47 min
Elevation: 5161 ft (1573 m)
Area: Aleutians Alaska

Volcanic Activity Summary: An increase in seismicity and the presence of a strong thermal anomaly at the volcano suggest that an explosive eruption is likely within the next few days. Such an eruption would likely produce ash clouds to 40,000 ft asl and may result in light ash fall on Adak and Atka.

Recent Observations:
[Monitoring report] This morning at 9:30 AKDT, the number of earthquakes recorded beneath Gareloi Island began to increase dramatically, and the seismicity continues at this time. Satellite imagery shows a thermal anomaly near the volcano's summit.

Hazard Analysis:
[General hazards] Seismicity indicates that magma is moving beneath the volcano. An explosive eruption is possible within the next few days.
[Ash cloud] Light ash fall may occur in the communities of Adak and Atka.
[Ash fall] An eruption could produce ash clouds to 40,000 ft asl.

Remarks: Please see http://www.avo.alaska.edu/activity/Gareloi.php for more information.

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

Steve McNutt, Coordinating Scientist, UAF
steve@giseis.alaska.edu (907) 474-7131

Next Notice: A new VAN will be issued if conditions change significantly or alert levels are modified. While a VAN is in effect, regularly scheduled updates are posted at http://www.avo.alaska.edu

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 18. Example of hypothetical volcanic activity notification from the Alaska Volcano Observatory during volcanic unrest at Gareloi Volcano, Gareloi Island, Alaska.

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Glossary

Ash Fine fragments (less than 2 mm across) of 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.

Ash fall *Ash* that falls to Earth from an *eruption cloud*. See also *tephra*.

Ballistic Fragments ejected explosively from a volcanic *vent* on parabolic trajectories, much like cannonballs. Also called volcanic bombs. Ballistic fragments seldom land farther than a few kilometers from the volcano; concurrently erupted *ash clouds* go much farther.

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

Debris avalanche Rapidly sliding 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 landslide or slope failure that rapidly depressurizes a shallow magma body or hydrothermal system. Typically travels rapidly away from the volcano at a low angle and may overtop ridges or other topographic barriers. Ejecta are carried away form the volcano in much the same way as *pyroclastic surges*.

Edifice Upper constructional 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 (e.g., tephra).

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

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 as they cool.

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

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

Hydrothermal Related 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 intact flows. On steep submarine slopes, these layers of debris are unstable and can collapse suddenly 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.

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

Phreatic eruption An eruption primarily involving steam explosions depressurization of hot ground water.

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

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 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.

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.

Seismometer An instrument that can detect earth motions such as earthquakes. Around volcanoes, a network of seismometers can detect seismic (earthquake) activity possibly associated with volcanic activity.

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.

Stratocone See stratovolcano.

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.

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 *ash fall*, but technically includes *pyroclastic-flow* material as well.

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

Ttsunami Sea waves or wave trains typically initiated by sudden displacements of the sea floor during earthquakes or landslides. 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 and Alaska Peninsula lie along the Aleutian volcanic arc.

Volcano hazard Potentially destructive volcanic processes in a given period of time.

For more information concerning the research in this report, contact the
Director, Alaska Science Center
U.S. Geological Survey
4210 University Drive
Anchorage, Alaska 99508
http://alaska.usgs.gov

USGS Coombs and others— **Preliminary Volcano-Hazard Assessment for Gareloi Volcano, Gareloi Island, Alaska**—Scientific Investigations Report 2008–5159