U.S. DEPARTMENT OF THE INTERIOR
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Preliminary Volcano-Hazard Assessment for Aniakchak Volcano, Alaska

Open-File Report 00–519

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This report is preliminary and subject to revision
as new data become available

Alaska Volcano Observatory
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The Alaska Volcano Observatory (AVO) was established in 1988 to monitor dangerous volcanoes, issue eruption alerts, assess volcano hazards, and conduct volcano research in Alaska. The cooperating agencies of AVO are the U.S. Geological Survey (USGS), the University of Alaska Fairbanks Geophysical Institute (UAFGI), and the Alaska Division of Geological and Geophysical Surveys (ADGGS). AVO also plays a key role in notification and tracking eruptions on the Kamchatka Peninsula of the Russian Far East as part of a formal working relationship with the Kamchatkan Volcanic Eruptions Response Team.

Cover photograph: Oblique aerial view of Vent Mountain, a 670-meter-high cone that developed within Aniakchak Crater. Vent Mountain has been the source of numerous eruptions of ash, bombs, and lava flows since the formation of the caldera 3,500 years ago. Aniakchak Peak is the high point on the caldera rim. View is toward south. Photograph by author R.G. McGimsey, June 28, 1997.

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

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CONVERSION FACTORS and VERTICAL DATUM

Multiply	by	To obtain
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
cubic meter (m^3)	35.31	cubic foot
cubic kilometer (km^3)	0.2399	cubic mile
meter per second (m/s)	3.281	foot per second
meter per second (m/s)	2.237	mile per hour
kilometer per hour (km/h)	0.6214	mile per hour
cubic meter per second (m^3/s)	35.31	cubic foot per second
meter per square second (m/s^2)	3.281	foot per square second

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

$$°F = (1.8 \times °C) + 32)$$

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

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SUMMARY OF VOLCANO HAZARDS AT ANIAKCHAK VOLCANO

Aniakchak is an active volcano located on the Alaska Peninsula 670 kilometers southwest of Anchorage. The volcano consists of a dramatic, 10-kilometer-diameter, 0.5 to 1.0-kilometer-deep *caldera* that formed during a catastrophic eruption 3,500 years ago. Since then, at least a dozen separate *vents* within the caldera have erupted, often explosively, to produce *lava* flows and widespread *tephra* (*ash*) deposits. The most recent eruption at Aniakchak occurred in 1931 and was one of the largest *explosive eruptions* in Alaska in the last 100 years. Although Aniakchak volcano presently shows no signs of unrest, explosive and nonexplosive eruptions will occur in the future. Awareness of the hazards posed by future eruptions is a key factor in minimizing impact.

• Ash clouds

The main hazard posed by future activity at Aniakchak is volcanic ash—pulverized fragments of rock and volcanic glass less than 2 mm across—ejected high into the atmosphere during explosive eruptions. Prevailing winds in the vicinity of Aniakchak volcano will carry clouds of ash preferentially to the north, northeast, and east, although transport in other directions is possible. Such ash clouds *are a significant hazard to aircraft near the volcano and could damage aircraft even thousands of kilometers downwind from the volcano. Because heavily used regional and North Pacific air routes pass directly over and downwind from the Aniakchak area, the risk to aircraft could be severe in the event of an eruption.*

• Fallout

During an explosive eruption, volcanic ash and coarser debris carried aloft eventually settles to the ground. Right at the vent, the depth of accumulated fallout *may be as great as tens of meters. In general, the thickness and grain size of fallout decreases with distance from the vent. During the 1931 eruption,* pumice *fragments as much as 5 cm across pelted homes in Meshik (former townsite, now part of the community of Port Heiden), about 25 km away, and 20-cm-diameter fragments were reported floating in Bristol Bay. Pumice this large could damage structures or injure people. Based on past Aniakchak eruptions, fallout of sand-sized ash is typically less than a few centimeters thick and may be only a fine dusting at distances of 100 km or more from the volcano. Accumulation of large amounts of ash could collapse buildings in nearby communities, damage vegetation, clog streams, and impact wildlife habitat around Aniakchak for many years. If inhaled, ash can cause respiratory problems. The abrasive ash also can damage mechanical equipment. Sufficient quantities of ash in the atmosphere can interfere with radio communications and damage power lines.*

• Ballistics

Most energetic eruptions launch pebble- to boulder-sized fragments of rock or pumice on explosive, arcuate trajectories from the vent. These projectiles, called ballistics*, can pose a serious hazard to people and structures within several kilometers of the vent. Numerous eruptions at Aniakchak have produced ballistic showers of rock and pumice, mostly confined within a few kilometers of the caldera.*

• Pyroclastic flows and surges

Destroying everything in their path, hot avalanches or hurricane-force blasts of volcanic gas, ash, and rock debris can travel away from an eruption site at speeds in excess of 100 m/s. These phenomena, called pyroclastic flows *and* pyroclastic surges*, have occurred within the caldera at Aniakchak multiple times within the last 3,500 years. Future eruptions may be accompanied by pyroclastic flows and surges within the caldera. In the event of a major eruption, these phenomena may extend outside the caldera.*

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. Considered preliminary, they are subject to revision as new data become available.

• **Lava flows and domes**

When magma *erupts nonexplosively at the Earth's surface, it can form elongate lava flows or mounds of rubble, called* lava domes, *above the vent. The immediate hazard from lava flows is burial. Sudden explosions can occur where lava contacts bodies of water, snow, or ice. In some cases, thick, silica-rich lava flows or domes can form oversteepened, unstable flow fronts that fall apart explosively in a sudden* pyroclastic *avalanche or surge. Quiet effusion of a lava dome can change character and produce explosive tephra columns or ballistics without warning. Aniakchak has been the site of lava-flow and dome eruptions for much of its history, and such eruptions within the caldera are likely in the future.*

• **Lahars and floods**

Hot ejecta *can mix with snow, ice, and surface water to form water floods and* lahars, *which are destructive, fast-moving slurries of water, mud, sand, and boulders. Such flows can sweep rapidly downslope and into drainages leading away from the volcano. The most significant accumulation of perennial snow and ice occurs along the south caldera rim and wall. Mixing of hot ejecta with this snow and ice could form lahars and induce flooding within the caldera and along the Aniakchak River. Hot debris accumulating on the rim or outer flanks of Aniakchak volcano could generate lahars and water flows across the upper slopes of the volcano and in drainages below. Sudden release of impounded water from the large* maar *crater or from Surprise Lake (inside the caldera) could also generate floods along Aniakchak River.*

Other hazardous phenomena that may occur but are uncommon during typical eruptions at Aniakchak include the following:

• **Debris avalanches**

A debris avalanche *is a rapidly moving mass or landslide of incoherent rock, soil, and debris that forms during gravitational failure of a volcano's flank. No geologic evidence for debris avalanches has been discovered at Aniakchak. Furthermore, the lack of a large* stratocone *edifice having steep, outward-facing slopes prone to collapse makes this a very low probability hazard at Aniakchak.*

• **Tsunami and waves in Surprise Lake**

Large debris avalanches or other mass flows that rapidly disturb a body of water may initiate volcanic tsunami. *Although a tsunami in Bristol Bay may have accompanied the caldera-forming eruption of Aniakchak 3,500 years ago, a future eruption of sufficient magnitude to send large volumes of material into the Pacific Ocean or the Bering Sea is highly unlikely. Eruptions within the caldera, large earthquakes beneath the caldera, or landslides may produce waves within Surprise Lake that could inundate the shoreline and cause sudden increases in flow rates in the Aniakchak River.*

• **Volcanic gas and fumaroles**

At present, the Aniakchak volcano does not emit volcanic gas in concentrations harmful to humans. At least one thermal spring near the north shore of Surprise Lake vents carbon dioxide. However, the gas is not present at toxic levels. Should molten rock rise toward the surface or erupt, potentially lethal quantities of carbon dioxide and other gases could be released. A few scattered areas of warm ground are present within Half Cone, but temperatures at the surface are far below boiling and these fumaroles *pose no threat at this time.*

• **Volcanic earthquakes**

Typical earthquakes related to volcanic activity are too small to damage structures in Port Heiden, which is the community nearest the volcano—less than 30 kilometers away (pl. 1). Even minor earthquakes, however, may initiate rockfalls or avalanches within the caldera. Sudden disturbances of Surprise Lake by shallow earthquakes may cause waves that could inundate the shoreline. Tectonic (nonvolcanic) earthquakes pose a far greater seismic risk in this region.

• **Rockfalls**

The steep caldera walls and slopes of Vent Mountain, Half Cone, and other bedrock landforms inside the caldera are prone to sudden rockfalls and other debris slides that may or may not be associated with volcanic activity.

SUGGESTIONS FOR READING THIS REPORT

Readers who want a brief overview of volcano hazards at Aniakchak volcano can read the summary section and consult plate 1. The remainder of the report provides a more comprehensive treatment of volcano hazards at Aniakchak volcano, discusses mitigation strategies, and lists sources of additional information. Selected terms are defined in a glossary at the end of the report.

INTRODUCTION

Aniakchak volcano (fig. 1, pl. 1) is one of more than 40 active volcanoes in Alaska (Miller and others, 1998). Remote and seldom visited, the volcano has been the source of many violent, explosive eruptions in the last 1,000 years, most recently in 1931, when Aniakchak erupted intermittently for nearly two months and deposited volcanic ash as far away as Holy Cross, 600 km to the north. Geologic evidence collected during recent work at Aniakchak suggests that additional eruptions similar to those in 1931 are to be expected.

Today, Aniakchak is a 10-km-wide, 0.5- to 1.0-km-deep, circular caldera (pl. 1). The highest point on the rim of the caldera is almost 1,350 m above sea level, and the lowest point on the caldera floor is about 335 m above sea level. Exposed in the steep walls of the caldera are parts of an older Aniakchak volcano, including numerous lava flows, and fossil-bearing sedimentary rocks many millions of years old. A small (about 1-km^2), debris-mantled glacier extends from the inside south caldera wall. Surprise Lake (maximum depth, 19.5 m; area, 2.75 km^2) in the northeastern part of the caldera flows out of the caldera through The Gates as the Aniakchak River.

The volcano's cumulative history of eruptions, partially recorded in deposits that surround the volcano, is the best indicator of the probable style and frequency of future activity. This report describes the range of hazardous phenomena that could be associated with future eruptions at Aniakchak as well as from other volcanic processes active during periods between eruptions. In addition, we present a map that illustrates the approximate areas most likely to be affected by these phenomena, discuss the current state of volcano monitoring at Aniakchak, and describe existing plans for response to volcanic unrest.

LOCATION OF ANIAKCHAK VOLCANO

Aniakchak volcano is part of the Aleutian volcanic arc that stretches across southern Alaska and the Aleutian Island chain (fig.1). Because, on average, several eruptions occur every year in Alaska (Simkin and Siebert, 1994; Miller and others, 1998), it is one of the most active volcanic regions of the world. Aniakchak is located on the Alaska Peninsula 670 km southwest of Anchorage within Aniakchak National Monument and Preserve (fig. 2). This land is managed by the National Park Service, is relatively remote, and is

Figure 1. Location of Aniakchak volcano in Aleutian arc and with respect to other historically active volcanoes, which are those that have had documented eruptions, earthquake swarms, or vigorous steaming episodes since the mid-1700's (Miller and others, 1998).

visited by few backcountry users, most of whom arrive by float-equipped or wheeled aircraft. Recreational activities in and around Aniakchak volcano and the Aniakchak River include backpacking, camping, fishing, hunting, and rafting. Subsistence use of the area includes hunting, fishing, trapping, and plant collection within Aniakchak National Monument and Preserve and on adjacent lands (Morseth, 1998). The Bristol Bay salmon fishery to the west of Aniakchak volcano is one of the most productive fisheries in the world.

Communities near the Aniakchak National Monument and Preserve include Port Heiden (about 25 km west of the volcano); Chignik, Chignik Lagoon, and Chignik Lake (about 65 km, 68 km, and 75 km south-southwest, respectively); and Pilot Point and Ugashik (each about 75 km northeast). As of this writing, five seasonal hunting and fishing lodges are within about 50 km of the volcano. At any one time, other temporary camps associated with these commercial ventures may be scattered about the monument and preserve as well as on adjacent State, village corporation, and Alaska Peninsula National Wildlife Refuge lands (J.L. Hummel, National Park Service, oral commun., 1998).

PREHISTORIC ERUPTIVE ACTIVITY AT ANIAKCHAK VOLCANO

The Aniakchak volcanic center has been active for at least 850,000 years (Nye and others, 1997). Numerous eruptions from one or more stratocones produced lava flows and fragmental deposits now exposed in the walls of Aniakchak caldera and along the steep ridges that radiate away from it. Nye and others (1997) divided these old volcanic rocks into two units based on their chemical composition and appearance: an older unit consisting of lava flows and *volcaniclastic* rocks or deposits ranging in age from about 850,000 to 550,000 years and a younger unit consisting of lava flows ranging in age from about 440,000 to 10,000 years.

Little is known in detail about the eruptive history of Aniakchak between the last major glaciation in Alaska, which ended about 10,000 years ago, and the formation of the current caldera at Aniakchak (approximately 3,500 years BP or radiocarbon years before AD 1950). However, based on extensive studies of tephra-fall deposits on the Alaska Peninsula, Riehle and others (1999) concluded that Aniakchak was the source of at least 40 explosive eruptions in the last 10,000 years—more than any volcano in the eastern Aleutian arc. At least half of these explosive eruptions occurred about 10,000 to 3,500 years ago (fig. 3). Most of the deposits from these events extend north and northeast of the volcano, directions that are consistent with modern prevailing winds. Miller and Smith (1987) also reported a pyroclastic-flow deposit about 10,000 to 4,400 years in age and suggested that, on the basis of its size and extent, it records an early caldera-forming event at Aniakchak.

Modern Aniakchak caldera formed about 3,500 years ago during a violent, catastrophic eruption nearly 1,000 times the size (eruptive volume) of the August 1992 eruption of Mount Spurr volcano (fig. 1; Miller and Smith, 1977). During the caldera-forming eruption, draining of underground magma reservoirs caused an existing stratocone to collapse, thereby creating the deep *crater* that persists today (fig. 4 and pl. 1). The enormous impact of this eruption is evident in thick blankets of coarse, pumice-rich debris deposited by pyroclastic flows that flowed in all directions from Aniakchak. These deposits extend as much as 60 km, to Bristol Bay and the Pacific Ocean. Fine ash from this eruption has been identified as far away as the north shore of the Seward Peninsula, 1,100 km to the north (Riehle and others, 1987, p. 19–22; Begét and others, 1992). Moreover, careful analysis of these fallout deposits suggests that as many as 10 distinct, smaller explosive eruptions together spanned decades to centuries leading up to the climactic caldera-forming eruption (Riehle and others, 1999).

From about 3,500 years ago to the present, more than 20 eruptions occurred from vents on the caldera floor (figs. 3 and 5). Fallout from some explosive eruptions during this period has been traced north and northeast of the volcano as far as Kamishak Bay, 330 km from Aniakchak caldera (Riehle and others, 1999). We recognize at least two widespread tephra deposits from explosive eruptions that occurred during the period 3,500–900 B.P. During that interval, four lava domes were extruded on the caldera floor. Textural evidence indicates that these lava-dome eruptions occurred beneath a lake as deep as 100 m that formed within the newly created caldera and then drained catastrophically before about 900 years BP (McGimsey and others, 1994; Waythomas and others, 1996). Prior to or immediately after this draining, explosive eruptions of andesitic magma produced a cluster of three *tuff cones* in the southeastern part of the caldera.

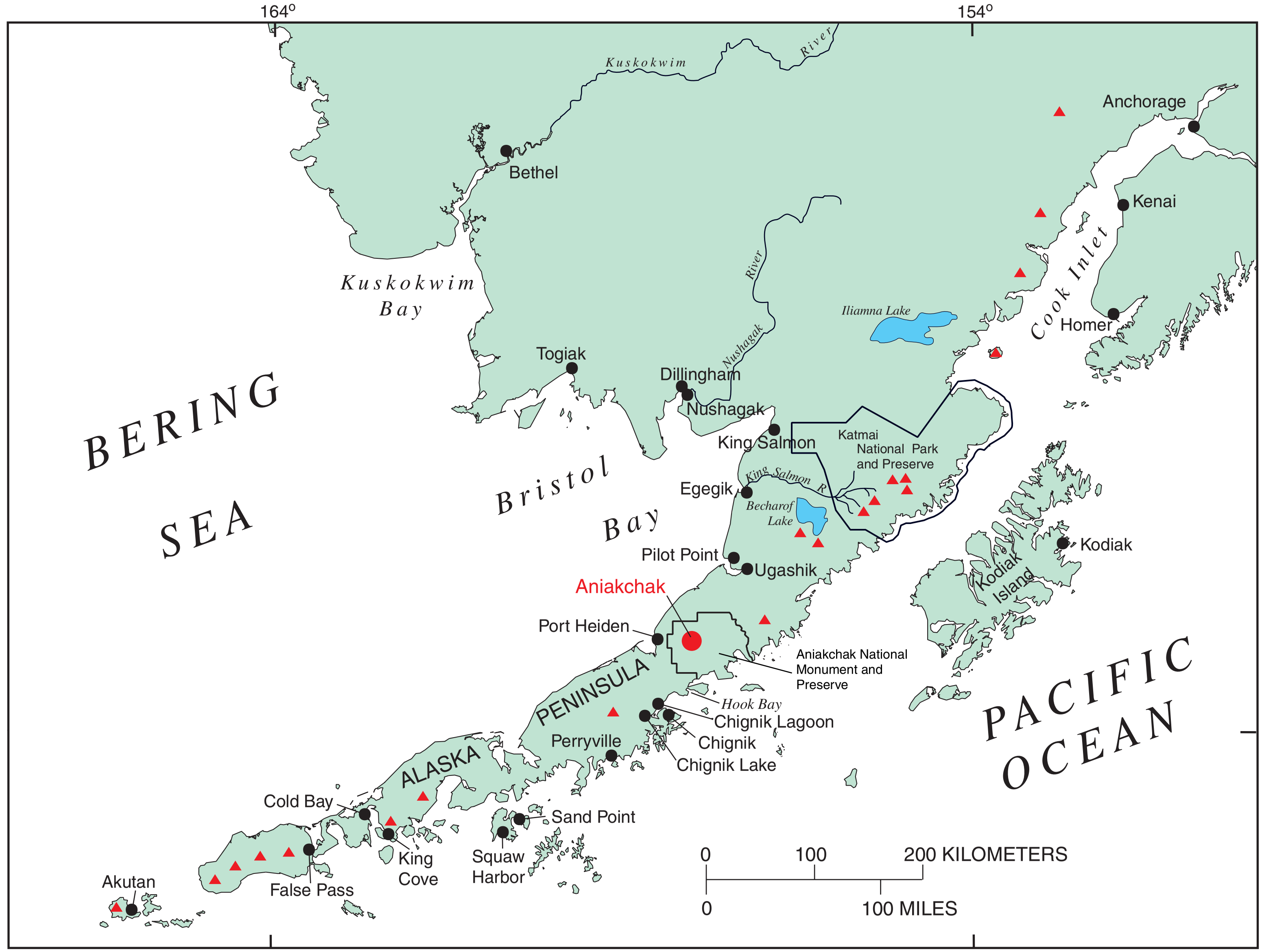

Figure 2. Location of Aniakchak volcano with respect to other historically active volcanoes (triangles) and nearby communities on Alaska Peninsula.

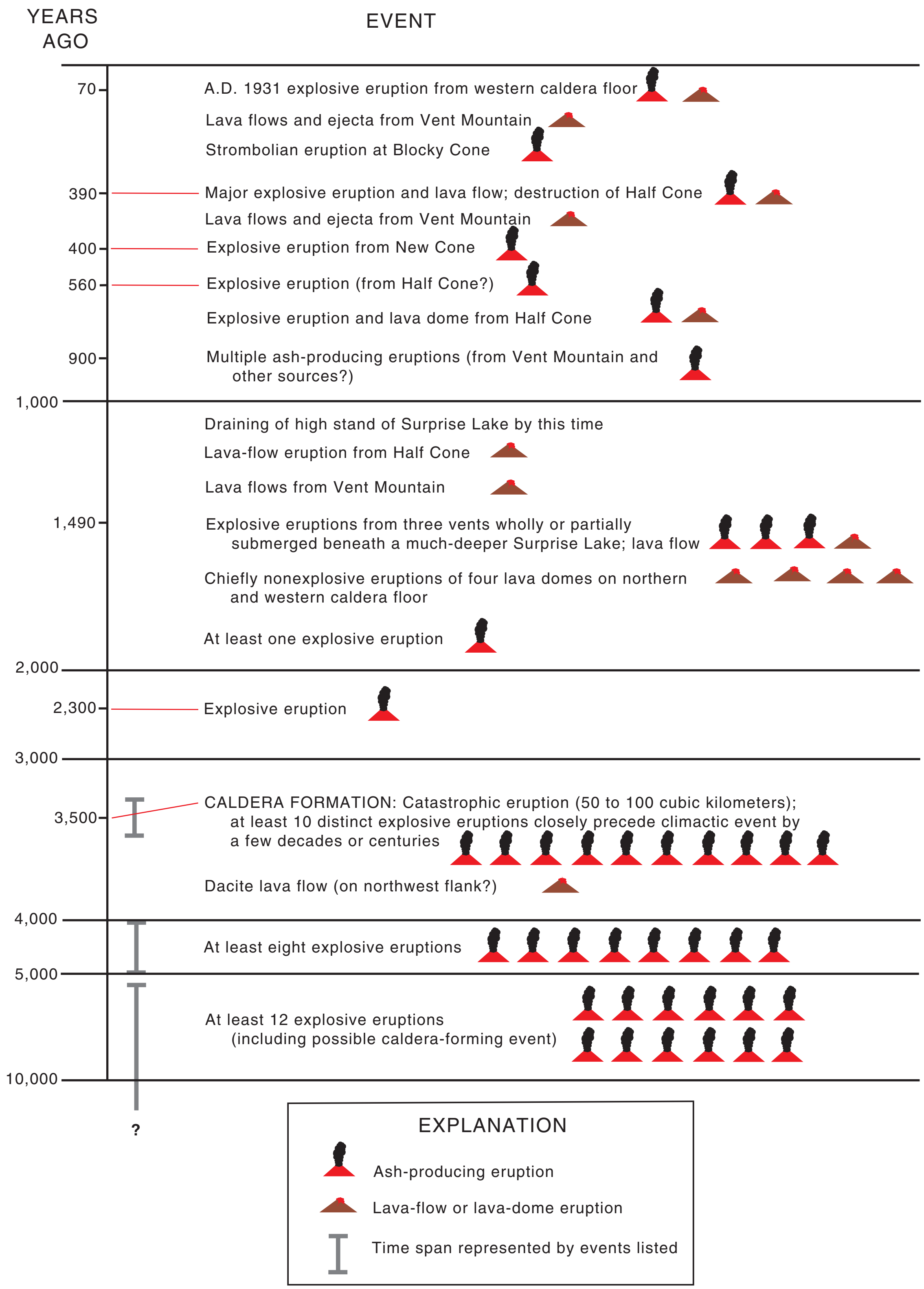

Figure 3. Inferred sequence of eruptions of Aniakchak volcano in last 10,000 years. Prehistoric eruptions (before mid-1700's, in Alaska) constrained by radiocarbon dating are connected by leaders to age in years before present. Other eruptions and events were placed in age order on the basis of stratigraphic, field, and geochemical evidence. Blocky Cone and New Cone (fig. 5) are informal names in local use.

Figure 4. View of Aniakchak volcano from Port Heiden airfield on a rare, clear day. Solid black line indicates present-day horizon, and dashed line indicates a hypothetical profile of precaldera stratocone. Airfield was constructed atop pyroclastic-flow deposits from caldera-forming eruption.

During the period from about 900 to 400 years BP, at least four significant explosive eruptions and some smaller events were recorded in deposits within and around Aniakchak volcano. Most of these resulted in fallout extending 10 km or more outside the caldera, and at least one eruption produced pyroclastic flows that overtopped the north caldera rim. Lava flows and domes also erupted in the caldera during this period.

Two young, but prehistoric, explosive events at Aniakchak occurred closely spaced in time about 400 years BP. The first is inferred to have originated from the flank of Vent Mountain, a prominent *intracaldera* cone (cover photo; fig. 5). This eruption dispersed energetic pyroclastic surges within the caldera and fallout to the north and northeast of Aniakchak. The second, and younger, eruption occurred at Half Cone, at the base of the northwest caldera wall (fig. 5), and was one of the most violent events in recent history at Aniakchak. An estimated 0.75 to 1.0 km^3 of material (about the size of the May 18, 1980, eruption of Mount St. Helens, excluding the debris avalanche) destroyed a preexisting edifice at Half Cone and inundated most of the caldera floor with pyroclastic flows, surges, and fallout many meters thick. Near the vent, these deposits are more than 40 m thick. A 10-cm accumulation of pumiceous *lapilli* and coarse ash from this eruption can be found at least 50 km to the north, at the surface or just below the modern root mat, and fine ash may extend as far as 330 km (Riehle and others, 1999). During the final phase of this eruption, a lava flow filled the basin formed during the collapse of Half Cone.

Other young prehistoric eruptions, which occurred in the summit crater and along the south flank of Vent Mountain, produced a field of blocky dacite lava flows against the south wall of the caldera. Explosive phases of these eruptions deposited coarse pumice and *lithic* debris, including ballistics, as far as a few kilometers from the vent but apparently did not result in widespread, coarse tephra fall outside the caldera. Minor eruptions immediately east and west of Vent Mountain produced a small scoria cone (locally called Blocky Cone; fig. 5) adjacent to Birthday Creek pass and two maar craters along the base of the southeast caldera wall.

HISTORICAL ERUPTIONS AT ANIAKCHAK VOLCANO

In the last 200 years, Aniakchak volcano is known to have erupted once—during about six weeks in May–June 1931. Documentation of the event is limited; the following summary is derived principally from the writings of University of Santa Clara missionary and explorer Hubbard (1931; 1932a,b), who visited Aniakchak in 1930 and 1931.

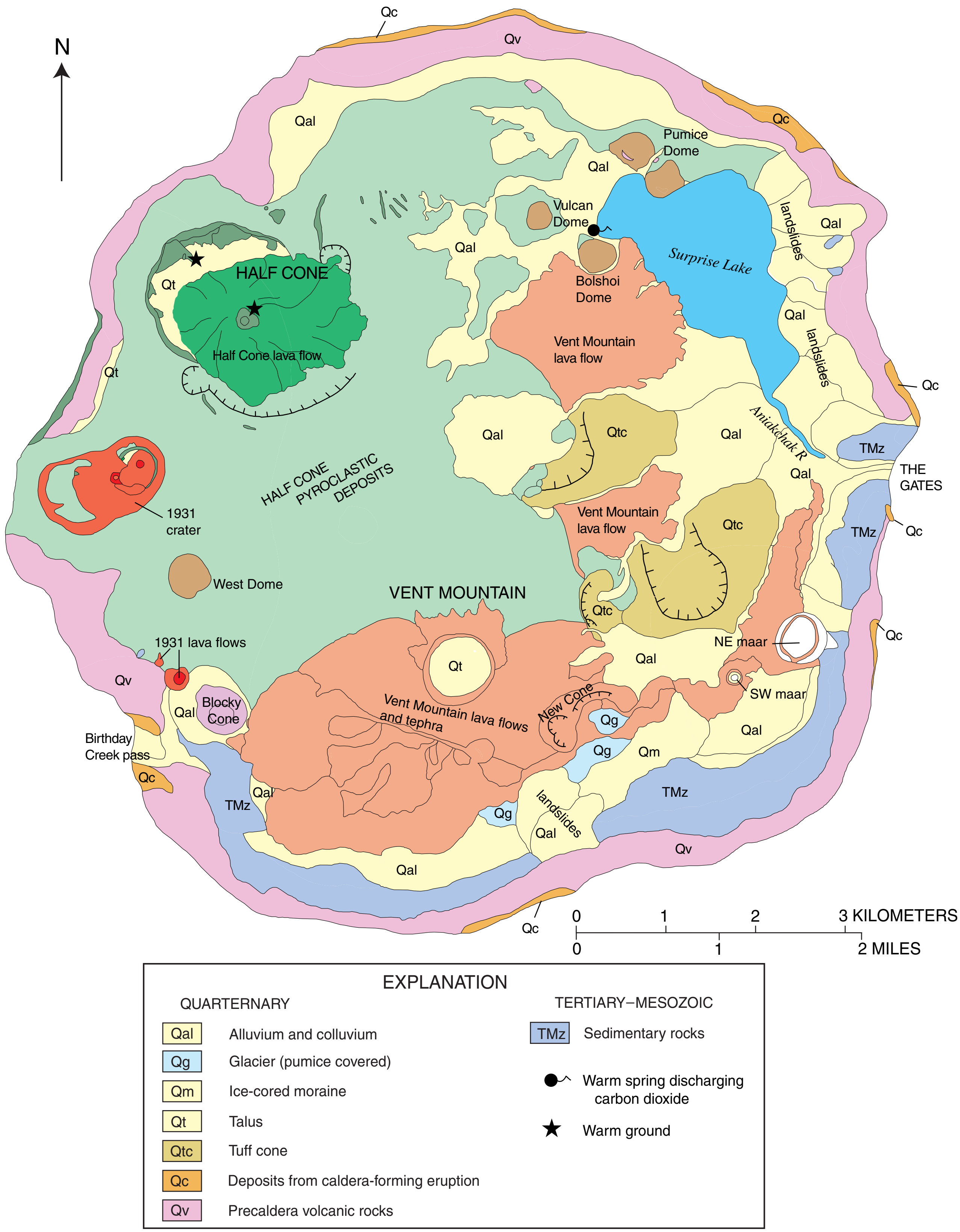

Figure 5. Simplified geologic map of Aniakchak caldera. (West Dome, Bolshoi Dome, Vulcan Dome, Pumice Dome, Blocky Cone, and New Cone are informal names in local use.)

The 1931 eruption was violent, included both explosive and *effusive* phases, and sent ash at least 600 km north of the volcano. The first sign of activity was noted about 10 a.m. on May 1, 1931, when residents of the former Meshik (now part of Port Heiden) saw a vigorous, white column of steam ascending above the crater[1]. By noon, residents reported ground shaking, rumbling noises, and the beginning of tephra fall from a large, black mushroom cloud, intermittently illuminated by lightning, over the caldera. Cloud height was estimated to be more than 6 km above sea level. Fallout in Meshik in the early stages of eruption included ash and pea- to egg-sized, frothy, black pumice that pelted homes. Radio communications with Chignik and other communities in southwestern Alaska were hampered repeatedly by static caused by ash in the atmosphere (Anchorage Daily Times, 1931; Fairbanks Daily News–Miner, 1931c). Ash fall was noted at Kanakanak (near Dillingham), 225 km north of the volcano (fig. 2; Fairbanks Daily News–Miner, 1931b). Observers describe a constant level of eruption until May 11, when an extremely violent explosion rocked the volcano. Heavy ash fall produced total darkness for several hours near the volcano. As much as several millimeters of black ash accumulated at Chignik, and greater amounts were recorded at Ugashik (fig. 2). Rafts of pumice containing individual fragments as much as 20 cm across reportedly were floating in Bristol Bay west of Meshik. A 10-km-wide swath of black ash and "almost complete darkness" observed from a boat in Bristol Bay attest to the severity of the fallout (Seward Daily Gateway, 1931a).

After May 11, the eruption apparently diminished in intensity until May 20, when explosions were heard at Ugashik (75 km northeast) and at an unspecified location more than 300 km away. Beginning on May 26, intermittent small ash plumes were reported over the caldera and Chignik residents reported "rumbling" like distant surf in the direction of Aniakchak. Several earthquakes, some described as "severe," were felt in Chignik and Hook Bay in late May.

Father Hubbard flew over the volcano on June 10, while the eruption was still in progress. His party first hiked to the caldera on June 13 and discovered moving, blocky lava flows at the bottom of two new explosion pits (figs. 6*A*, *B*). A third small lava flow issued from a knob slightly above the base of the west caldera wall (fig. 6*C*). Steam explosions had reamed a shallow pit in coarse ash and lapilli that blanketed a lava-flow field inside Half Cone (fig. 6*D*). Although accumulation of fallout was heaviest in the western and northwestern parts of the caldera, nearly all vegetation inside the caldera was destroyed or buried. Three small lakes in the western part of the caldera (Knappen, 1929) were filled completely with ash and lapilli, and Surprise Lake was cloudy with suspended ash. Hubbard also reported dead birds, presumably killed by carbon dioxide that had accumulated in low areas near the vent. The north rim of Vent Mountain's summit crater reportedly was steaming (Regan, 1987). Today, young-looking spatter deposits mantle this part of the crater rim on Vent Mountain, but whether the steaming reported by Hubbard's party was related to the 1931 eruption is unknown. (This part of Vent Mountain has not been reported steaming since 1931. In 1994, however, very weak steaming was noted near the west end of the fissure on Vent Mountain's south flank.)

Earthquakes during the 1931 eruption were strong enough to be felt in Chignik, 65 km away, and to destabilize the precipitous caldera walls. Hubbard (1932a) reported avalanches in progress inside Aniakchak in mid-June. The rock-avalanche lobes that extend from the south wall inside the caldera (fig. 5) may have formed in 1931.

[1]The Seward Daily Gateway (1931b) describes significant volcanic ash fall of unknown origin falling on freighters 500 km offshore from San Francisco on April 30, the day before Port Heiden residents first reported steam issuing from Aniakchak. Although the news article is vague and that residents would miss a significant ash eruption is hard to believe, to speculate that the mysterious ash may have come from Aniakchak is nonetheless intriguing. Other North Pacific volcanoes that were active at that time include Okmok and Akutan volcanoes in the Aleutians and Gorely volcano in Kamchatka (Simkin and Siebert, 1994.)

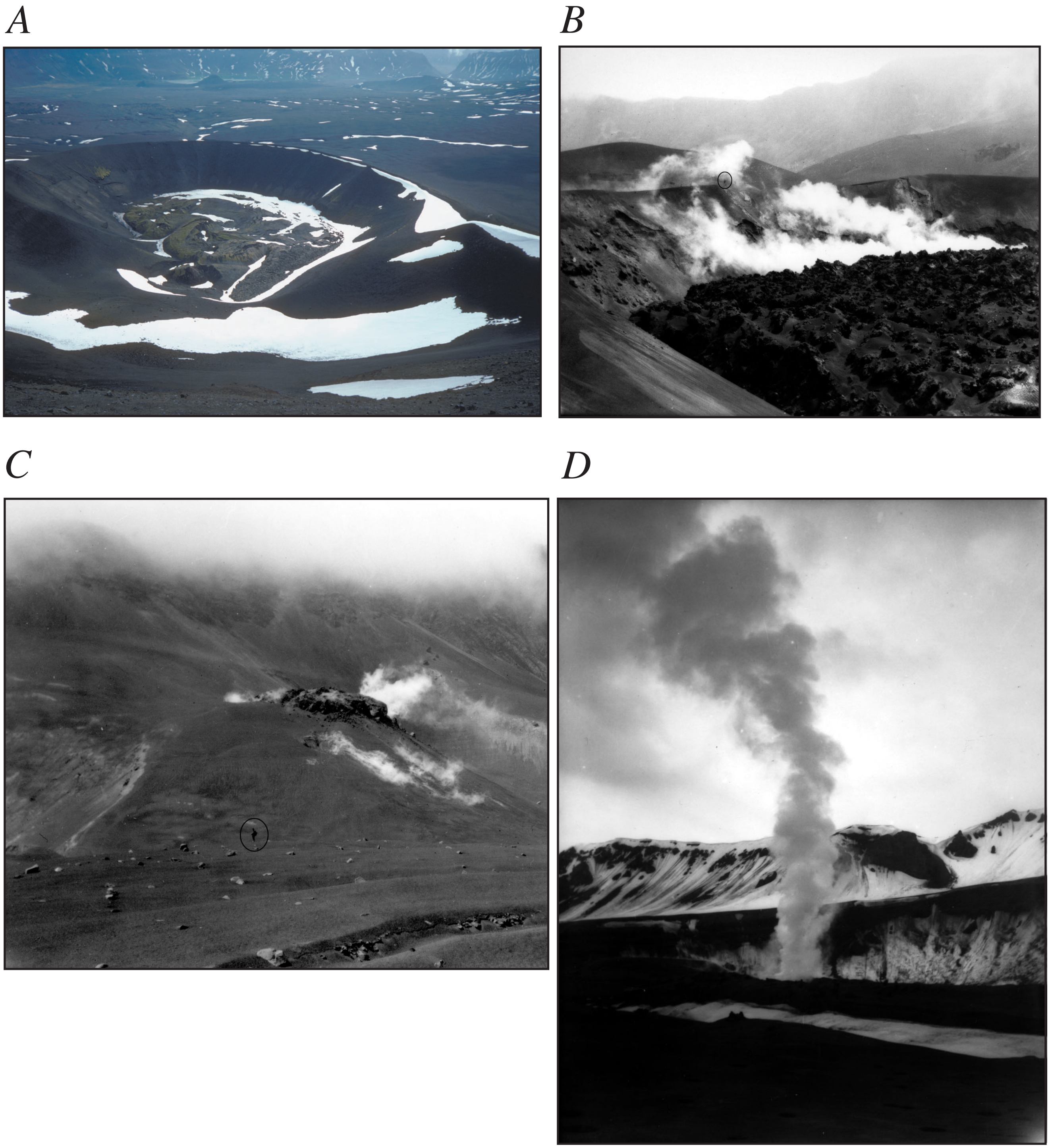

Figure 6. Photographs of 1931 eruption site and products, Aniakchak caldera. *A*, Oblique aerial view of main vent for 1931 eruption. Crater is 750 by 1,000 meters across and 120 meters deep and has a raised rim of ejecta from 1931 eruption. Lava flow and spatter field cover crater floor. Surprise Lake and The Gates are visible in distance, at top of photograph. View toward east-northeast. (Photograph by author R.G. McGimsey, June 30, 1992). *B*, A second lava flow covered floor of smaller explosion pit 2 kilometers south of main 1931 crater. Person is circled for scale. View toward south. (Photograph no. ACK-31-98, taken in 1931, from Hubbard Collection, Santa Clara University Archives). *C*, A third lava flow (informally called Slag Heap) erupted on lower slope of west caldera wall about 50 meters above caldera floor. Note volcanic bombs on surface. Person is circled for scale. View toward west. (Photograph no. ACK-31-96, taken in 1931, from Hubbard Collection, Santa Clara University Archives). *D*, Column of steam rising from explosion pit blasted through 1931 ejecta covering lava flow inside Half Cone. View toward west. (Photograph no. ACK-00-14, taken in 1931, from Hubbard Collection, Santa Clara University Archives).

Beyond the caldera rim, fallout from the 1931 eruption affected several hundred thousand square kilometers of southwestern Alaska. As much as 1 to 2 cm of ash may have fallen in Chignik (Fairbanks Daily News–Miner, 1931a). Ash reportedly was about 6 mm thick on Kodiak Island (presumably in the village of Kodiak), in Katmai National Monument[2], and on the Nushagak Peninsula, and a fine dusting was reported at Holy Cross, 600 km north of the volcano. Light ash fall was reported also at Squaw Harbor on Unga Island, 140 km southwest of Aniakchak. Reindeer and caribou losses from fallout were reported to be "heavy" at Nushagak, and dead swans and geese, believed to have died from ash ingestion, were noted at Ugashik (Hubbard, 1932a). From these scattered reports, we constructed a map showing the area most likely to have received noticeable amounts of ash fall (fig. 7).

[2]Designated Katmai National Monument in 1918; redesignated Katmai National Park and Preserve in 1980.

The volume of material erupted in 1931 is difficult to determine by traditional field methods because of the widespread dispersal of fine ash, much of it over water. In many places, because strong winds and rain have stripped the 1931 deposit completely, original thickness on land is difficult to measure accurately. Furthermore, eyewitness accounts are few and, from our experience, prone to exaggeration. Using limited field measurements and interpretation of written accounts of ash fall during and after the eruption, we estimate the total bulk volume of the 1931 deposits to be about 0.3 to 0.5 km^3.

The interaction of erupting magma and abundant water in part explains why the 1931 eruption was explosive. The conclusion that the eruption was *hydrovolcanic* was based on the presence of *accretionary lapilli*, as much as several centimeters in diameter (Hubbard, 1932a); rhythmic surge-and-fall deposits, exposed in the walls of the main vent; blocky lithic ejecta; and widely dispersed fine-grained ash. Also, Knappen (1929) noted standing water in the western part of the caldera prior to the eruption. That this shallow ground-water system persists is indicated by the presence of Surprise Lake and by the abundance of springs on the floor in the eastern part of the caldera. Future eruptions may include a similar strong hydrovolcanic component as hot rising magma mixes explosively with water.

VOLCANO HAZARDS AT ANIAKCHAK

A volcano hazard is any volcano-related process that is potentially threatening to life or property (fig. 8). These hazards may not necessarily occur in conjunction with eruptive activity. Volcano hazards at Aniakchak are considered proximal or distal depending on how far from the volcano a particular process presents a danger (table 1). In this report, proximal hazards—those of most concern within about 30 km of the volcano—are likely to result in death or injury to an individual within the area directly affected by an eruption. Distal hazards—those of concern more than about 30 km from the volcano—pose less of a risk because of greater lead times for warning and because the energy of many volcanic processes decays rapidly with distance from the vent. However, ash clouds, fallout, lahars, and floods are both proximal and distal hazards.

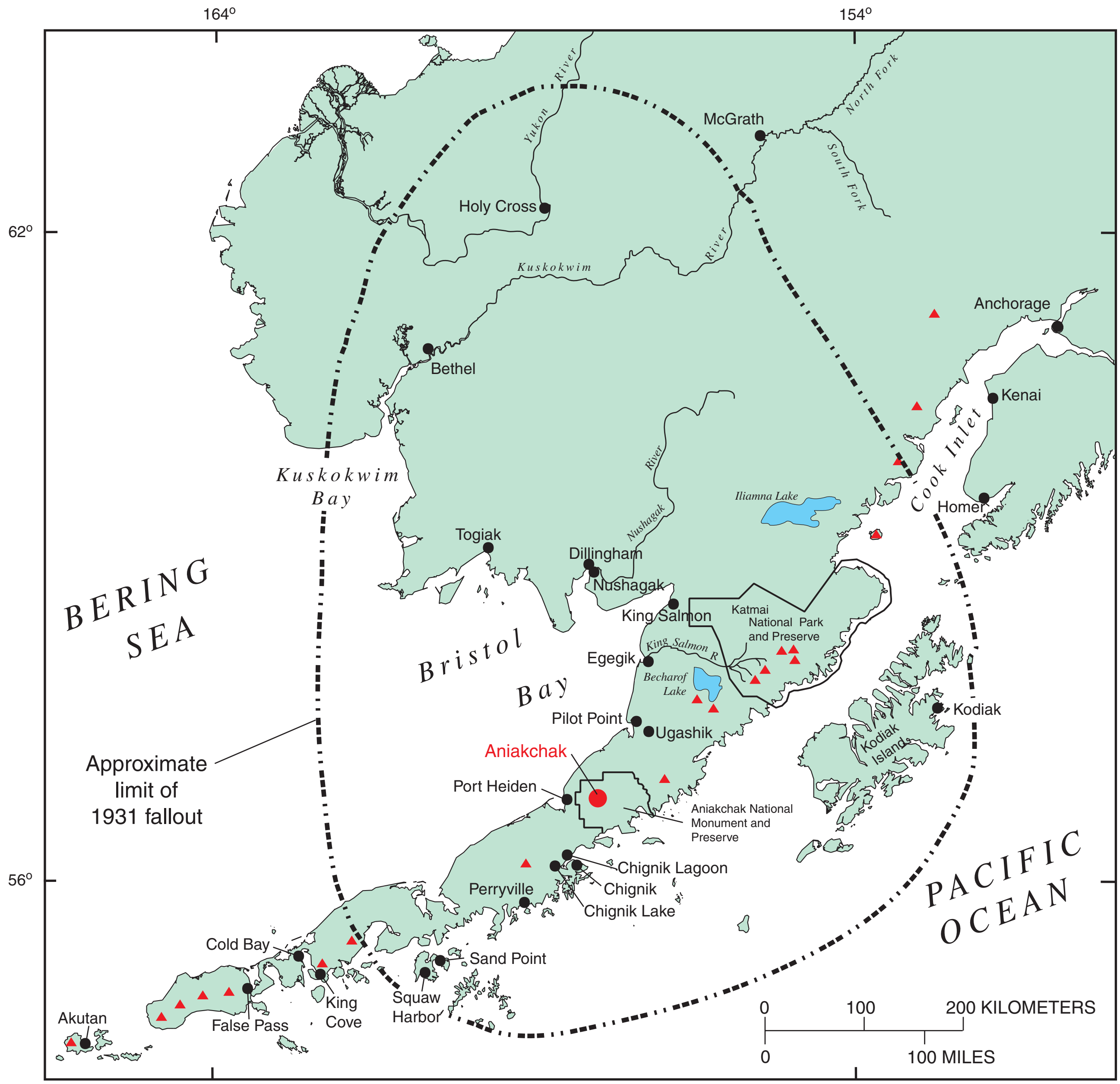

Figure 7. Inferred extent of area that received noticeable fallout from 1931 eruption of Aniakchak volcano. Compiled from few, mostly secondhand, sketchy accounts and limited field observations. Triangles indicate historically active volcanoes.

Because topographic base maps lack detail and geologic studies are only preliminary, the geographic boundaries of hazard zones presented in this report are considered approximate. Furthermore, the extent of a particular hazard relates directly to the size of the eruption and environmental conditions (such as wind direction and speed, depth of snowpack) at the time. Eruption size affects the total area at risk from a particular hazard; during a small eruption, a given hazard may affect only the immediate vicinity of the volcano. Unfortunately, the size and duration of an eruption is difficult to predict even when using modern instrumentation and monitoring techniques. Additionally, the extent of a particular hazard does not cease abruptly but rather commonly decreases gradually with increasing distance from the volcano. In the case of flowage hazards, the hazard also decreases gradually with height above an affected valley floor. Given these uncertainties, we have attempted in this report to

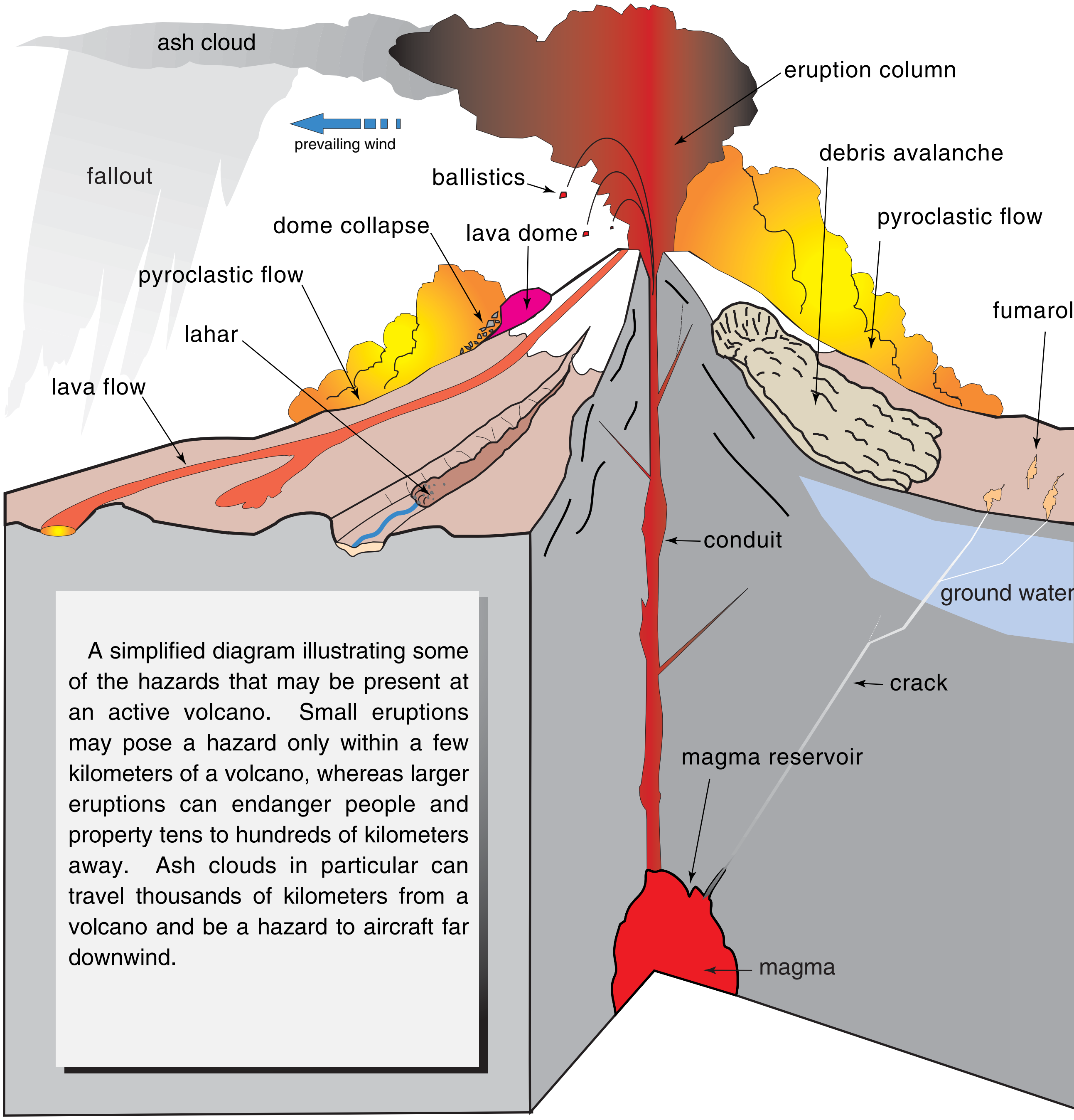

Figure 8. Simplified erupting stratocone and associated hazardous phenomena (modified from Meyers and others, 1997).

present a conservative view of hazards during the most likely types of eruptions expected at Aniakchak.

The next section, "Principal Volcano Hazards," describes the main hazards associated with volcanism at Aniakchak. Although some are generic volcanic phenomena applicable to many other volcanoes in Alaska and elsewhere, this presentation is tailored to the location and setting of Aniakchak and to our current geologic understanding of the volcano.

Principal Volcano Hazards

Ash Clouds

The greatest hazard from future eruptions at Aniakchak is airborne volcanic ash. Explosive eruptions produce vertical columns of ash and gas that, in the most extreme cases, can ascend 35 km (22 mi or 115,000 ft) or more above sea level. The height and

Table 1. Summary of volcano hazards at Aniakchak volcano

[Refer to fig. 8 and main text for description and schematic representation of some of these processes. In this report, “proximal” denotes areas as far as approximately 30 kilometers from volcano, and “distal” refers to areas more than about 30 kilometers from volcano]

Type of hazard	Distance		Comments
	Proximal	Distal	
Ash clouds	X	X	Severe hazard to aircraft even hundreds to thousands of kilometers downwind.
Fallout	X	X	Significant hazard to anyone in or around volcano and to nearby communities during large eruptions. Minor hazard or nuisance in distant communities.
Ballistics	X		Significant hazard to anyone in or around volcano during explosive eruptions.
Pyroclastic flows and surges	X		Significant hazard to anyone inside caldera during eruptions; possible hazard within 10 to 15 kilometers of volcano during large eruptions.
Lava flows and domes	X		Significant hazard in immediate vicinity of lava flow or dome; attendant pyroclastic surges, fallout, or ballistics increase area potentially affected.
Lahars and floods	X	X	Moderate hazard in all drainages downslope from eruption site and especially in Aniakchak River valley. Greatest hazard in winter, when snowpack is deepest. Failure of maar rim could produce transient flood in Aniakchak River.
Debris avalanches	X		Low-probability hazard at Aniakchak.
Volcanic gases and fumaroles	X		Minor to nonexistent hazard at present; could become severe local hazard if magma is injected at shallow levels below volcano.
Volcanic earthquakes	X		Presents minor hazard except for secondary effects such as rockfalls or landslides.
Tsunami or waves	X	X	Tsunami in Bristol Bay or Pacific Ocean are extremely low-probability hazard; disruption of Surprise Lake by earthquakes, landslides, other mass flows is hazard to shoreline and low-lying areas on eastern caldera floor.
Rockfalls and landslides	X		Persistent hazard to anyone near steep walls within caldera or in deep valleys outside caldera.

volume of an ash column depend on the size, duration, and type of eruption. In all eruptions, however, fine ash particles are carried upward by warm air and volcanic gas until captured by prevailing winds and carried away from the volcano as an ash cloud.

The most immediate hazard from an explosive eruption in Alaska is to aircraft, which may inadvertently enter the ash cloud. Volcanic ash can interfere with aircraft engine operation; damage electronics; and abrade leading edges of the wings, the windscreen, and other surfaces (Casadevall, 1994a, b). The consequences of such an encounter could be fatal. In 1989, a Boeing 747 jet bound for Anchorage entered an ash cloud from Redoubt Volcano and lost power in all four engines. For 5 minutes, the airplane fell towards the mountains before the flight crew was able to restart the engines and land safely (Casadevall, 1994a). Although the danger to jet aircraft is greater because the high operating temperatures of jet engines melt ingested ash, volcanic ash also can be hazardous to other aircraft. In addition to the effects of solid ash particles on aircraft performance and parts, acidic gases released in volcanic eruptions can form aerosol-laden clouds that remain in the atmosphere for months and accelerate corrosion of airplane parts.

The severity of the ash-cloud hazard to aviation depends on several characteristics of the ash plume: distance from the volcano, concentration and size of ash particles, rise rate, and dispersal pattern. However, any ash cloud is potentially harmful to aircraft and should be avoided. Risk from ash clouds is particularly severe at Aniakchak volcano, which lies directly beneath heavily traveled international air routes across the North Pacific (fig. 9). Ash clouds from even moderate eruptions can travel long distances and impact air traffic even thousands of kilometers away. Thus, the ash-cloud hazard from eruptions at Aniakchak includes potential impacts over Canada and the conterminous United States.

Fallout

As volcanic ejecta is transported downwind, it settles to the ground to form a blanketing deposit called fallout. In general, fallout deposits decrease in thickness and grain size with increasing distance from the volcano. The windspeed and the height of the *eruption column* are important controls on how much fallout accumulates downwind. Near the eruption site or vent, the fallout may be tens of meters thick and may contain bombs of pumice or denser rock more than a meter across. Even lightweight pumice can pose a hazard to people and structures; during the 1931 eruption of Aniakchak, fragments of pumice as much as 20 cm across were reported floating in Bristol Bay, and 5-cm-diameter pumice pelted homes in Meshik (old townsite), 25 km from the volcano.

At distances of 100 km, accumulation of ash is typically less than 10 cm from larger eruptions, and it may consist only of a barely perceptible dusting of fine ash from smaller events. During one of the largest *postcaldera eruptions* of Aniakchak, about 10 cm of ash was deposited 50 km downwind. This amount of ash accumulation could damage large areas of vegetation, temporarily clog streams, and possibly alter wildlife habitat for several years.

Fine ash can cause respiratory problems if inhaled, and it is highly irritating to the eyes. Grazing animals can be harmed or killed by ingesting ash-covered vegetation. Ash is abrasive and can damage mechanical equipment including cars, turbines, and computers. Heavy ash in the atmosphere can interfere with radio communications, and fallout on electrical lines can result in power outages. Ash is heavy and becomes even heavier when wet. Wet ash also makes roads very slick. Clean up can be difficult due to resuspension of dry, fine ash particles by wind and vehicular traffic. Along the Alaska Peninsula, where strong surface winds are common, ash lofted from the ground thousands of meters into the air can be hazardous for low-flying aircraft. In 1952, resuspension of Aniakchak ash resulted in a pilot's reporting possible eruptive activity (Volcanological Society of Japan and International Association of Volcanology and Chemistry of the Earth's Interior, 1987, p. 59).

Geologic evidence indicates that in the last 10,000 years, Aniakchak volcano has been the source of as many as 40 eruptions that resulted in widespread fallout on the Alaska Peninsula (Riehle and others, 1999). During its most recent eruption, in 1931, ash fell over a wide area in southwestern Alaska (fig. 7). Typically, these ash layers accumulate on the land surface and become buried by vegetation or by other sediment. Over time, deposits from many eruptions develop a stratified or layered record of activity. However, this record likely underestimates the actual number of explosive eruptions at Aniakchak because tephra deposits from small eruptions (or from large eruptions that produced great quantities of very fine ash) commonly are not well preserved. Recognition of these deposits in the geologic record may be difficult or impossible. Strong winds on the Alaska Peninsula rapidly remove fine ash deposits. Thus, despite the widespread dispersal of ash from the 1931 eruption, ash is difficult to find in some places only a few kilometers from the vent.

Given prevailing wind conditions in the region (fig. 10), future fallout from eruptions at Aniakchak is more likely to be focused in sectors extending north, northeast, and east of the volcano (fig. 11 and pl. 1). However, as illustrated by the 1931 eruption, fallout can occur in all directions from Aniakchak.

Ballistics

Some explosive eruptions can launch blocks of rock or pumice on arcuate trajectories from the vent. These projectiles, called ballistics or bombs, can be ejected in any direction and pose a hazard to people and structures within a few kilometers of the vent. However, even small rock fragments can be lethal at distances of as much as 4 to 5 km. Ballistic emplacement of dense lithic blocks within the caldera at Aniakchak is evident from recent activity at Vent Mountain and Half Cone and from two explosion

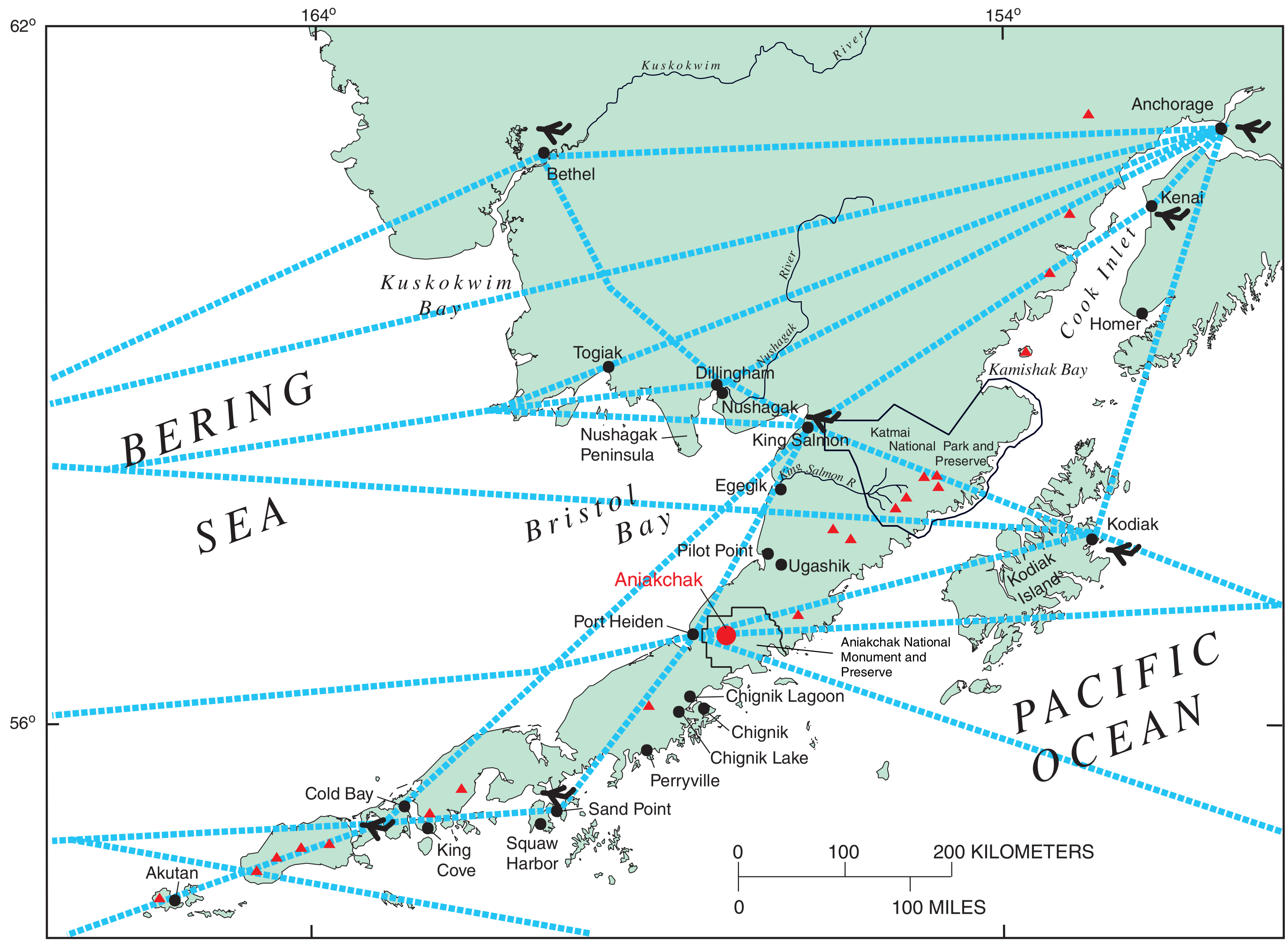

Figure 9. Location of Aniakchak volcano in relation to selected low- and high-level air routes (heavy dashed lines) over southwestern Alaska. Aircraft flying west of Alaska use fixed routes for travel to and from Asia; air routes to the southeast, called flex tracks, are used for flights between North America and Asia. Locations of flex tracks change daily on the basis of forecast winds. Airplane symbols indicate selected regional and international airport facilities. Triangles indicate historically active volcanoes.

(maar) craters along the south interior caldera wall. The entire caldera and areas within several kilometers of the rim should be considered at risk from ballistics during a typical explosive eruption (fig. 12).

Pyroclastic Flows and Surges

Some of the most dangerous phenomena associated with explosive eruptions are hot (as much as 800°C), mixtures of gas, ash, and volcanic-rock fragments that can reach speeds of as much as several hundred meters per second. These mixtures take two forms that pose slightly different hazards.

Pyroclastic flows are high-speed avalanches of fragmental material that form in several ways. Small and moderate-sized pyroclastic flows can be produced during the explosive or gravitational collapse of a growing lava dome or during sustained eruptions that produce a towering vertical column of tephra, a portion of which falls back to the ground and descends the volcano's flanks at high speeds. Pyroclastic flows tend to remain close to the ground, follow topographic lows, and travel as far as tens of kilometers from the volcano. Extremely large pyroclastic flows that form during catastrophic eruptions of enormous quantities of magma can be highly mobile; in extreme cases, they can surmount topographic features and travel 100 km or more. Such pyroclastic flows were produced during the caldera-forming eruption at Aniakchak about 3,500 years ago (Miller and Smith, 1977).

More dilute than pyroclastic flows, pyroclastic surges (sometimes called ash hurricanes) are turbulent mixtures of gas and volcanic-rock fragments. Surges also move at high speeds, are extremely mobile, and can surmount topographic obstacles hundreds of meters high. The largest pyroclastic surges travel many tens of kilometers. Surges commonly accompany pyroclastic flows and can develop rapidly as an ash cloud released from the denser pyroclastic flow. However, they also can form directly from explosions at a vent or from a collapsing lava dome. The presence of water (as shallow ground water, as snow or ice, or in lakes near the erupting vent) increases the likelihood of pyroclastic surges owing to steam-driven explosions as hot magma or rock fragments contact water.

Because evacuation is not possible in the path of approaching pyroclastic flows or surges, they typically kill nearly everything in their path.

Explosive eruptions at Aniakchak have produced pyroclastic flows and surges, commonly in conjunction with significant regional ash fallout. The 1931 eruption produced pyroclastic surges that principally were confined within the caldera, although they may have extended to the caldera rim or beyond but left little or no evidence of their passage. The most voluminous postcaldera pyroclastic flows and surges yet recognized were associated with an eruption at Half Cone about 390 years ago (fig. 13). In that case, pyroclastic flows and surges also were confined principally to the caldera and covered more than half the caldera floor with debris many meters thick. Dilute surges from this eruption also overtopped the northeast caldera rim and traveled as far as 3 km outside the caldera.

Future eruptions at Aniakchak are most likely to occur from vents within the caldera. Thus, because of topographic confinement by the caldera walls, the area inside Aniakchak caldera is at greatest risk from pyroclastic flows and surges during an eruption of any size. For moderate to large explosive eruptions, the caldera rim and areas outside the caldera also could be affected by *extracaldera* pyroclastic flows and surges. Delineation of a hazard-zone boundary for extracaldera pyroclastic flows and surges was based on our observation that postcaldera flow and surge deposits have been found no farther than 3 km beyond the rim. Recognizing limitations in our field data and the likelihood that surges can travel as far as several kilometers beyond the terminus of a pyroclastic flow (Gardner and others, 1994; Scott and others, 1996), we conservatively assign a hazard-zone boundary for pyroclastic surges and flows 5 km beyond the caldera rim for a typical explosive eruption (fig. 14).

Future eruptions much larger than those recognized in the postcaldera geologic record at Aniakchak cannot be ruled out. Modeling potential pyroclastic flow and surge runout from an exceptionally large eruption requires many assumptions about the mechanism of generation and factors involved (such as height of column before collapse) and a quantitative analysis of the topography surrounding the volcano. Instead, we choose to compare a recent eruption of appropriate magnitude: Pyroclastic flows and surges from the 1991 eruption of Mount Pinatubo, which produced 5 to 6 km^3 of material (more than five times the volume produced by the largest postcaldera eruption that we recognize at Aniakchak), traveled as far as 16 km from the vent (Scott and others, 1996). On this

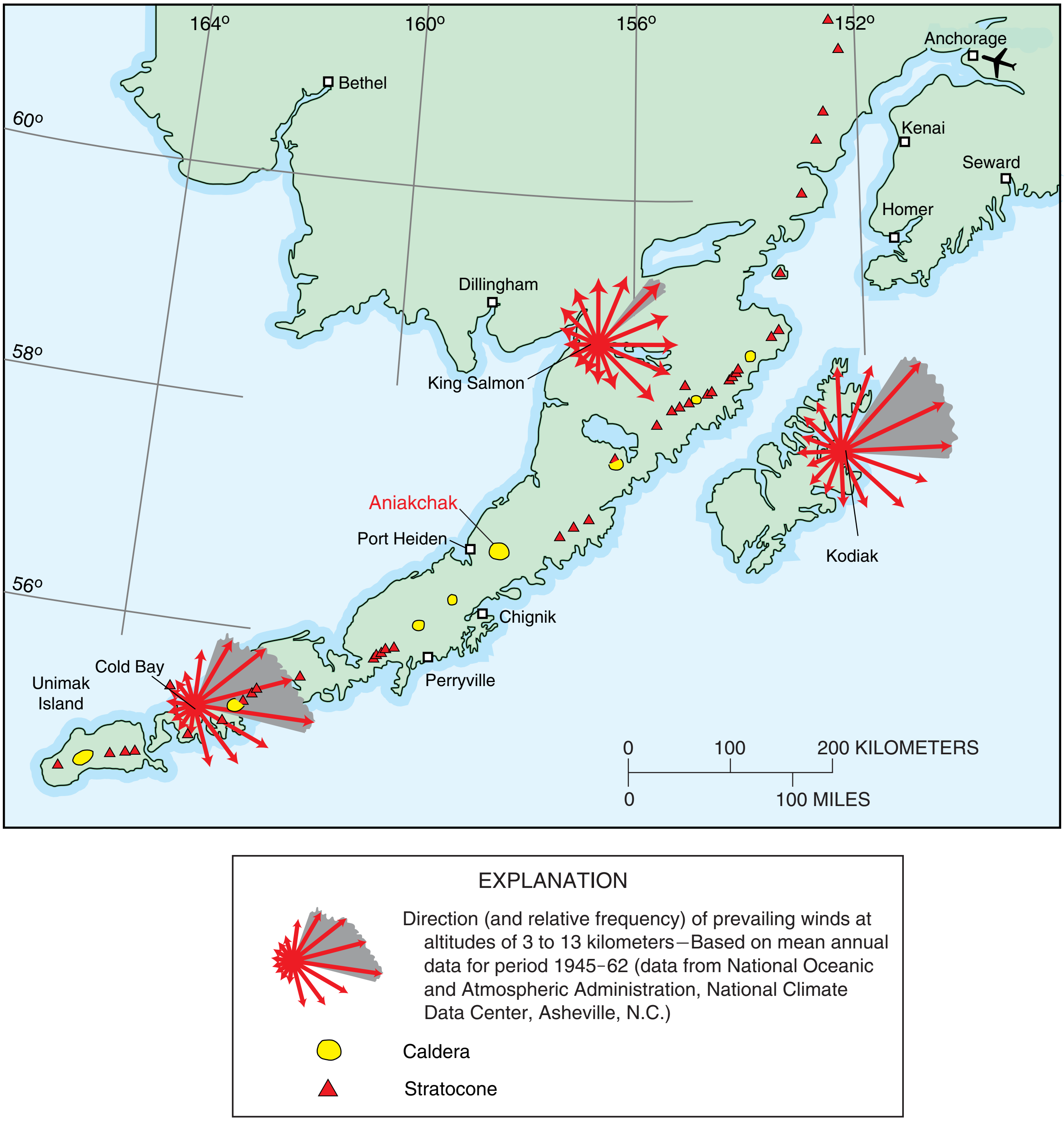

Figure 10. Prevailing-wind directions based on daily data from King Salmon, Cold Bay, and Kodiak. Vector lengths (red arrows) indicate relative frequency of those wind directions at altitudes of 3 to 13 kilometers during any given year. Wind directions that occur on 10 percent or more of observation days are shaded gray.

Figure 11. Areas most likely to be affected by fallout during future eruptions of Aniakchak volcano. Outer limit is based on maximum downwind distance of 1931 tephra fall (also shown). Significant eruptions that occur during high winds could send ash even greater distances from volcano, possibly as far as Canada and conterminous United States. Stipple indicates area most commonly downwind from Aniakchak (fig. 10).

basis, we adopt as a credible maximum outer limit for the pyroclastic flow and surge hazard zone to be at a 15-km distance from the rim at Aniakchak. However, although plausible, this scenario is well outside the range of documented eruptive behavior during the last 3,500 years at Aniakchak.

Lava Flows and Domes

When molten rock erupts nonexplosively at the Earth's surface, it can move downslope in elongate streams or fan-shaped lobes called lava flows, or it can accumulate in rounded piles of rubbly material called lava domes. Aniakchak volcano has been the site of both lava-flow and lava-dome eruptions throughout its history, and such eruptions are likely in the future.

In the last 3,500 years, lava flows have erupted from a number of sites on the caldera floor, most frequently and voluminously from Vent Mountain. Hazards posed by lava-flow eruptions are confined principally to the immediate area around the vent where lava flows follow topographic lows. During an

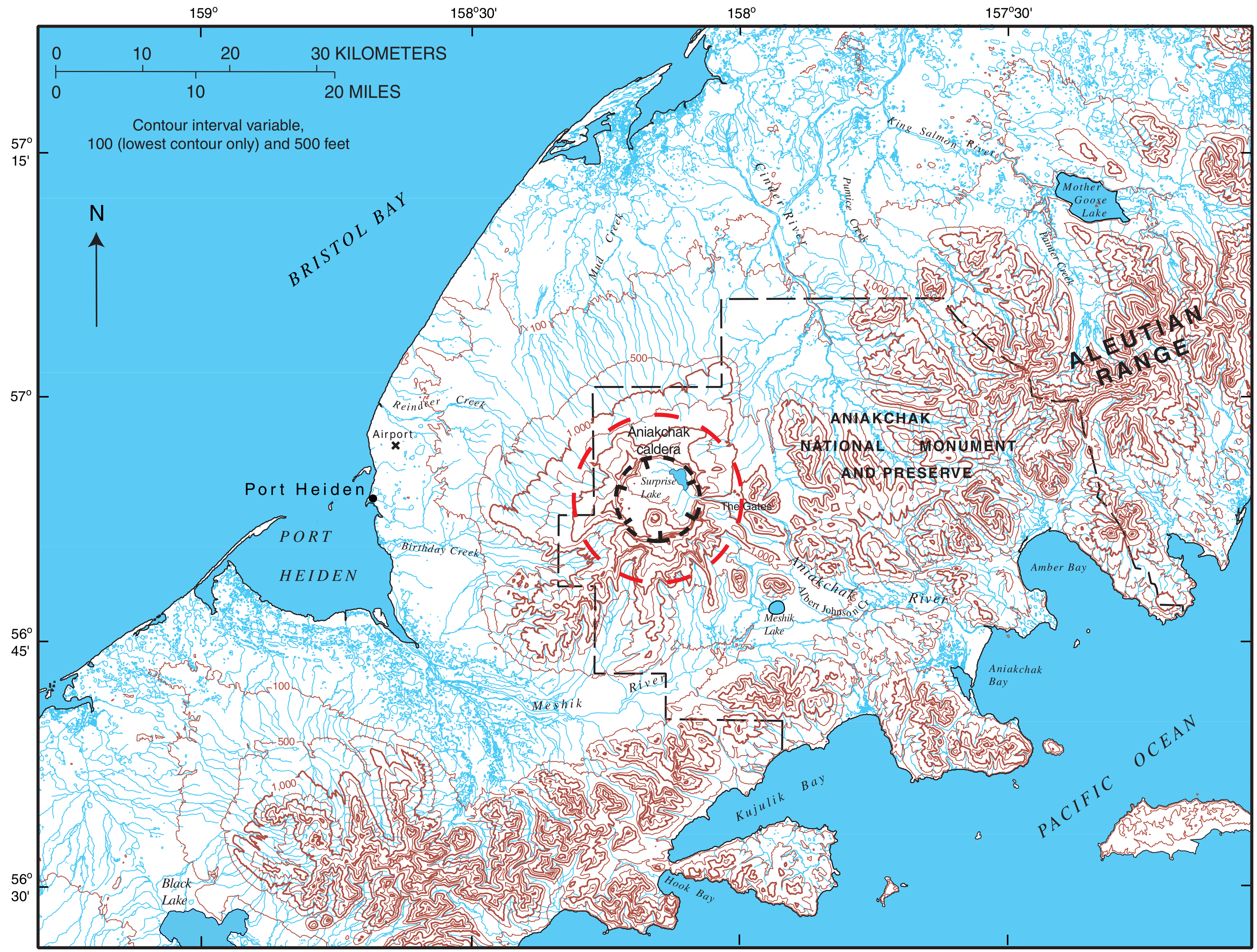

Figure 12. Areas most likely to be affected by ballistics during future eruptions of Aniakchak volcano. Red dashed circle represents radial distance of 5 kilometers beyond caldera rim—considered to be maximum range for ballistics during small to moderate-sized eruptions (Blong, 1996).

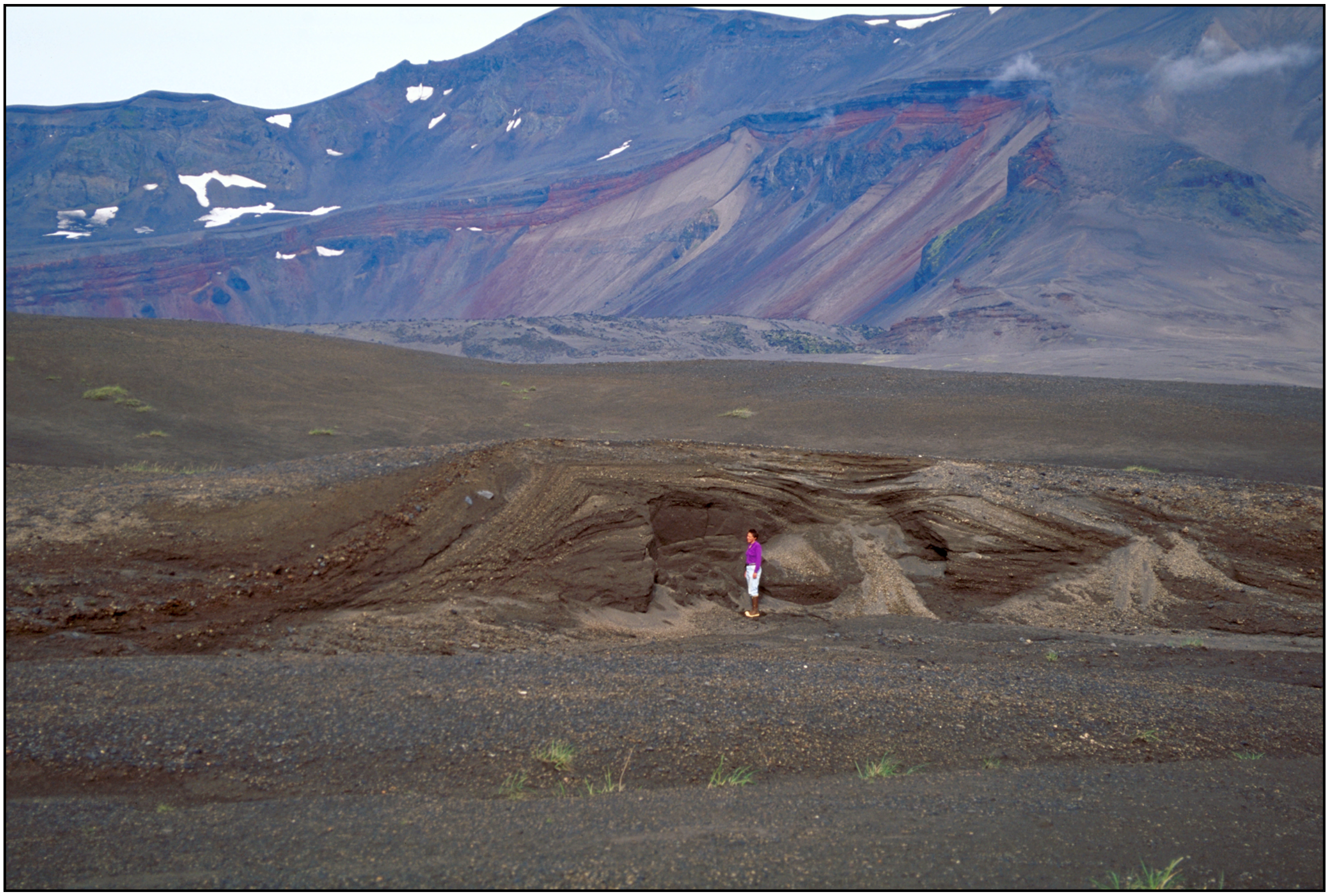

Figure 13. Pyroclastic-surge and pyroclastic-flow deposits from last violent eruption of Half Cone (about 390 years ago). Source vent is against caldera wall in distance. Geologist in foreground, for scale, is 1.6 meters tall. View is toward west. (Photograph by author R.G. McGimsey, July 27, 1993).

extended eruption, lava flows can create new topography that can channel subsequent flows into areas previously thought safe. Unlike pyroclastic flows and surges, lava flows of the type expected at Aniakchak move slowly (20 to 30 km/h), and therefore escape is almost always possible. Sudden explosions can occur where lava enters bodies of water or ramps against snow or ice. Lava flows that come into contact with snow or ice can generate enough meltwater to cause flooding. In some cases, thick, steep-sided *silicic* lava flows can become unstable and fall apart explosively in a sudden pyroclastic surge or avalanche.

Lava-dome emplacement, on the other hand, often is accompanied by other phenomena that are quite hazardous. As the viscous lava oozes out of the vent and accumulates on the surface—commonly into a steep-sided pile of large blocks—unstable sections can collapse suddenly and generate avalanches of hot rocks, pyroclastic flows and surges, and ballistic showers. Additionally, quiet effusion of a lava dome can change character and produce explosive tephra columns without warning. Lava domes have erupted onto the caldera floor at least five times in the last 3,500 years at Aniakchak and could form again during future eruptions. Although the direct effects of lava-dome eruptions are confined within the caldera, rarely a pyroclastic surge associated with a growing lava dome could overtop the caldera rim and affect the area immediately beyond the rim.

The hazard zone for lava-flow and lava-dome eruptions includes the entire caldera floor (pl. 1). The thick, blocky, *dacite* and *andesite* lava flows common at Aniakchak are not likely to flow through The Gates, a narrow opening in the caldera rim. Rather, if a lava flow reached The Gates, it would probably pond against The Gates' confining walls and widen within the caldera.

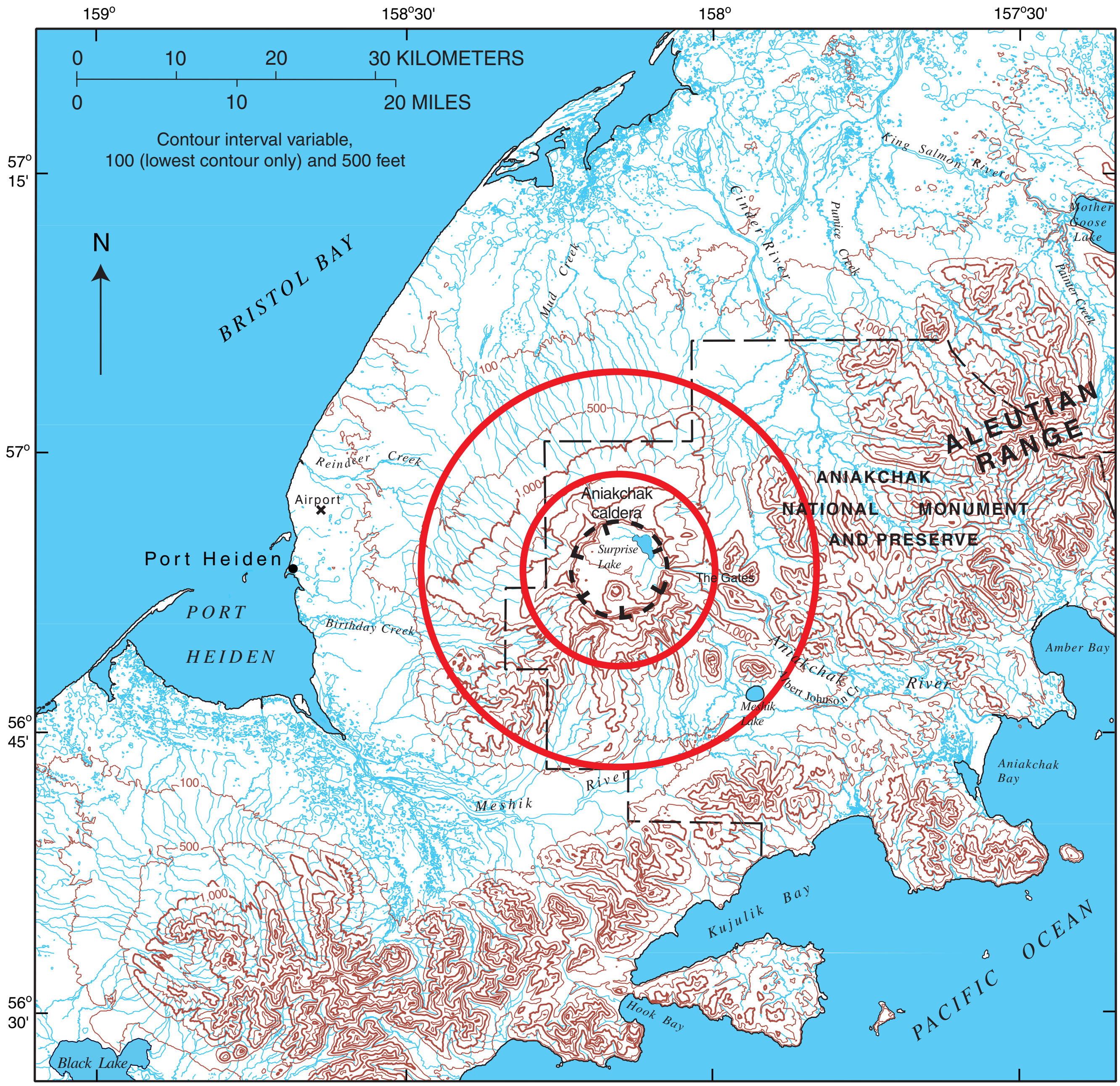

Figure 14. Areas most likely to be affected by pyroclastic flows and surges during future eruptions of Aniakchak volcano. Inner red circle includes entire caldera floor and represents hazard zone for pyroclastic flows and surges during eruptions typical of those that have occurred since caldera formation 3,500 years ago. Outer red circle includes additional area at risk during eruptions much larger than those documented in Aniakchak's recent history. Valleys and drainages are preferred pathways for pyroclastic flows, which tend to be ground-hugging avalanches. Surges are less confined by topography and can surmount ridges and extend well beyond a pyroclastic flow. In general, risk from pyroclastic flows and surges decreases with increasing distance from volcano as well as increasing height above valley bottom.

Lahars and Floods

Flowing mixtures of water and volcanic debris, called lahars, are possible on any volcanic slope, given water, abundant fragmental material, and a mechanism to combine them. Lahars can begin as simple water floods that incorporate an increasing amount of volcanic debris as they travel downslope. Lahars can transform downstream to a finer grained, more water-rich flow or flood wave. When highly sediment laden, lahars can be enormously destructive slurries of boulders, sand, and silt that take on the consistency of concrete when they come to rest. They can move as fast as 20 m/s in steep valleys and 5 to 10 m/s on more gentle gradients.

Lahars are a particularly grave hazard at steep, snow- and ice-clad volcanoes like Redoubt Volcano or Mount Rainier that are drained by valleys containing critical facilities or population centers downstream. At Aniakchak, the risk from a lahar is greatly mitigated by several factors: (1) the paucity of perennial snow and ice on the volcano, (2) the very small number of permanent facilities or populations downstream from the volcano, and (3) the channeling of all drainage from within the caldera (where eruption-generated lahars are most likely to occur) into the Aniakchak River (a wilderness waterway having no permanent settlements). Nonetheless, lahars or floods produced either by volcanic activity or by nonvolcanic processes could threaten wildlife, temporary camps, and recreational users of the backcountry.

Several scenarios could produce lahars or floods of potential consequence at Aniakchak: (1) an eruption that impacts areas of old snow and ice fields or heavy winter snowpack, (2) an eruption directly beneath Surprise Lake, (3) mixing of loose tephra on the flanks of the volcano with heavy rainfall and runoff, or (4) an impoundment of water and subsequent failure of a natural dam (with or without incorporation of fragmental debris into the floodwaters).

During summer, snow and ice accumulations within the caldera are minimal. An exception is on the south caldera wall where snow and ice are present as small hanging glaciers; a snowfield at the base of the wall; and a debris-mantled, marginally active glacier covering about 1 km^2 on the caldera floor. Heavy bombardment of these areas with hot pyroclastic debris or incision by a lava flow from Vent Mountain at any time of year could generate enough meltwater to produce small floods or lahars within the caldera and possibly along the Aniakchak River. During winter, much of the caldera floor is snow covered (although typical snowpack thickness is unknown). Even a small eruption could generate floods or lahars that would accumulate rapidly in the basin between Vent Mountain and the south caldera wall, drain into Surprise Lake, or drain into a small basin adjacent to Birthday Creek pass (fig. 5). Evidence of such a process occurring recently on a small scale is found on the north flank of Vent Mountain, where deeply incised gullies formed directly downslope from a young spatter deposit on the crater rim. Emerging from the gullies and extending for about 2 km downslope toward Surprise Lake is a cobble–boulder alluvial fan cut into pyroclastic-flow deposits that formed when Half Cone erupted about 400 years ago. The alluvial deposit probably represents a flooding event caused when hot spatter landed on snowpack high on Vent Mountain within the last 400 years.

Depending on the size of a lahar or series of lahars that entered Surprise Lake or the upper Aniakchak River, significant downstream flooding could occur outside the caldera along the course of the river. Lahars and floods along the river should be confined to the main channel and active flood plain for the first 15 km, where the channel is incised in bedrock or unconsolidated volcanic debris. From about the confluence with Albert Johnson Creek downstream, lahars or floods could spread laterally and impact adjacent low-lying areas. Because the width of the Aniakchak River and its flood plain generally increase downstream, the flow depths and velocities of lahars and floods would decrease with increasing distance traveled downstream.

In addition to melting snow and ice within the caldera, larger eruptions at Aniakchak volcano could deposit significant quantities of hot pyroclastic material on the rim and flanks of the volcano. In summer, only small patches of frozen ground and snow persist at the highest elevations along the south caldera rim and flank, and the chance of lahar generation is small. However, during the remainder of the year, hot ejecta could melt the seasonal snowpack and generate small lahars that sweep down the upper flanks and into larger drainages such as the Meshik and Cinder Rivers. To date, we have found no evidence to suggest that extracaldera lahars were generated by eruptions at Aniakchak in the last 3,500 years. Little is known about modern snow accumulation at higher elevations of Aniakchak; strong winds perpetually scour the surface and likely remove much of the winter snow cover. Nonetheless, because any drainages leading away from the volcano could experience some amount of flooding during wintertime eruptions, they are included in the potential inundation zone shown in figure 15.

Surprise Lake (mean depth, 13.7 m) is too shallow to suppress explosive fragmentation of magma reaching the lake bottom (Mahoney and Sonnevil, 1987). The principal hazard from an eruption directly beneath Surprise Lake would be from pyroclastic surges (see section titled “Pyroclastic Flows and Surges”). However, mixing of lake water and fragmental volcanic debris also could generate lahars or discharge highly sediment-laden water out of the caldera and into the Aniakchak River.

Another potential source of lahars in the vicinity of Aniakchak volcano is the unconsolidated tephra, from numerous eruptions, that blankets much of the land around the volcano. We know of no lahars forming spontaneously by mixing of this material with heavy rainfall at Aniakchak. However, in the event of another tephra-producing eruption, the addition of more fine material to the headwaters of drainages could cause secondary lahars during heavy rains.

Water floods also could occur in and around Aniakchak volcano. Even a small eruption in winter could melt enough snow to raise water levels in Surprise Lake and Aniakchak River temporarily. Moreover, a lava flow or landslide debris that enters the breach at The Gates could block the river and thus impound water. Such a dam could fail suddenly and release a surge of water down the Aniakchak River.

Other possible sources of flooding unrelated to volcanic activity are the two water-filled maar craters in the southeastern part of the caldera (fig. 5). At present, the smaller (150-m-diameter), southwestern maar appears to drain by seepage through buried permeable horizons to maintain a fairly constant water level. In early summer or midsummer when the water surface has been observed to be well below the level of the rim, sudden outflow from failure of the rim was not of concern. However, just east of this maar, a dry gully cut several meters into maar ejecta and the underlying lava flow indicates that at one time water spilled over the rim. Even if the level of the small lake in the maar were to rise to overtop the rim again, outflow would eventually drain into the much larger maar 600 m to the northeast.

The larger (550-m-diameter) maar also contains a lake (unknown depth) that extends to within an estimated 10 to 15 m of a low spot, possibly an old spillway, on the north rim of the maar crater (fig. 16). This level likely changes with the season. Lake water seeps through porous fragmental volcanic debris in the maar wall and emerges from the ground as a spring 100 to 200 m north of the maar (this distance also changes seasonally with lake level and ground-water discharge). The spring discharge follows the boundary between an old lava flow and the base of the caldera wall and joins the Aniakchak River immediately inside The Gates. Should the maar lake level rise to the point of spillover, rapid erosion of the north wall of the large maar could precipitate a sudden release of water down this drainage. Additionally, a landslide off the steep adjacent caldera wall into the maar lake could generate a wave and destabilize the rim leading to a sudden release of water. A rapid draining of the maar lake by these processes not only would affect the small drainage from the maar but also could initiate flooding along the upper Aniakchak River.

Other Volcano Hazards

Volcanic Gases and Fumaroles

During eruptions, volcanoes emit copious amounts of gas to the atmosphere, principally water, carbon dioxide, sulfur dioxide, and hydrogen sulfide. (Minor gaseous constituents can include hydrogen, helium, carbon monoxide, hydrochloric acid, and hydrofluoric acid.) Volcanic gases can be released in lesser quantities from cracks in the ground, thermal areas, or vents (fumaroles) even when the volcano is quiet. Carbon dioxide is of particular concern because it is heavier than air, can collect in depressions, and, in concentrations of greater than about 30 percent, causes rapid suffocation (Stupfel and Le Guern, 1989).

At present, no point sources at Aniakchak emit volcanic gas in concentrations harmful to humans. At least one bubbling warm spring (24^{o}C), near Surprise Lake (fig. 17), produces carbon dioxide and helium gases that are magmatic in origin (R.B. Symonds, U.S. Geological Survey, written commun., 1998) but are not present at toxic levels. Other potential sources of carbon dioxide include a bubbling spring (observed but not sampled) in shallow water at the north end of Surprise Lake. Should new magma approach the sur-

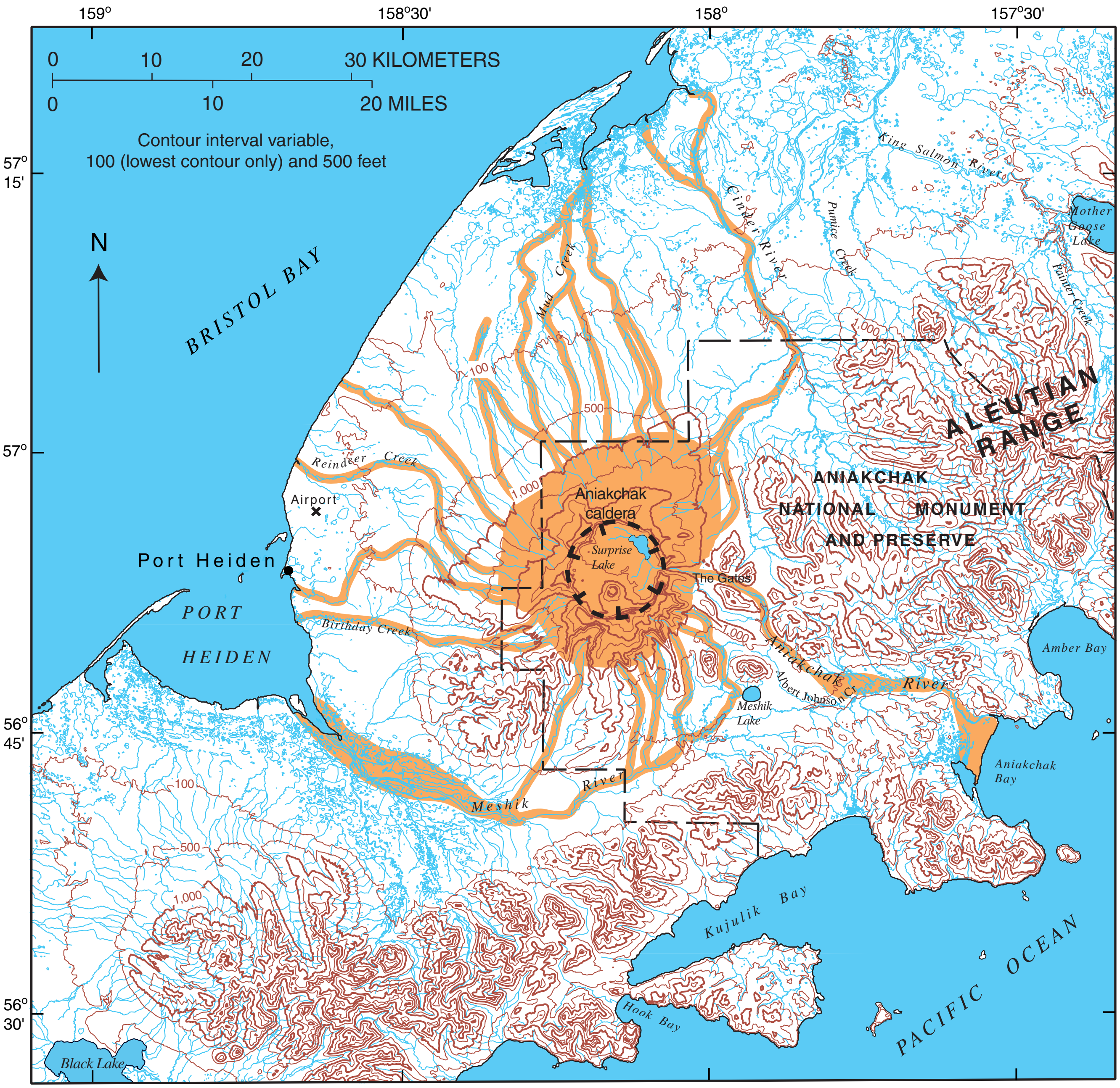

Figure 15. Areas most likely to be affected by lahars and floods (shaded) during future eruptions of Aniakchak volcano. Caldera floor and Aniakchak River drainage are at highest risk from lahars and floods generated inside caldera. Gently sloping uplands outside caldera also could be subject to localized flooding and lahar activity if hot ejecta melted sufficient snow and ice or if heavy rainfall remobilized loose ash deposits. All drainages leading away from caldera rim are at risk from lahars and floods if eruption at least as large as in 1931 occurs in winter; only the most significant drainages are highlighted here. Extent of inundation is difficult to determine because of extremely low relief near coast, meandering drainage patterns, and uncertainties in estimating size of possible flooding or lahar events. In general, risk from lahars and floods decreases with increasing height above valley bottom and with increasing distance downstream.

Figure 16. Water-filled maar crater (called NE maar in fig. 5) in southeastern part of caldera. Layered ejecta from multiple explosions form crater rim (dashed line); outcrop of underlying lava flow is visible in center foreground. Low spot in rim (arrow) is about 10 to 15 meters above lake surface. Ice persists on lake surface well into summer. View is toward southeast (Photograph by author C.A. Neal, June 24, 1992).

face or erupt, potentially lethal quantities of carbon dioxide and other gases could be released from these springs or other areas in the caldera.

In some places, areas of outgassing or outlets for geothermally heated water or steam produce hot springs or hot ground. Within the Half Cone basin are only a few scattered areas of warm ground (maximum temperature recorded in 1997, 52^{o}C). On the basis of observations by Hubbard (1931, 1932a), these areas of warm ground appear to have been somewhat hotter and more profusely steaming in 1930 and 1931. Although, at present, no ground at Aniakchak is known to be dangerously hot, this situation could change should magma rise to shallow levels below the volcano.

Volcanic Earthquakes

Volcanic activity nearly always is accompanied by earthquakes. Usually, volcanic earthquakes are not large enough to cause any damage or even be felt more than about 20 to 30 km from the volcano. At Aniakchak, the principal hazards related to earthquakes are rockfalls; avalanches; the collapse of unstable, loose debris; and sudden waves in Surprise Lake. Since seismic monitoring began at Aniakchak in 1994, only a few, very small earthquakes have occurred directly beneath the volcano. Ground shaking from regional earthquakes unrelated to the volcano can be much greater in magnitude and pose a more severe hazard to the area around Aniakchak. (Discussion of general seismic hazards is beyond the scope of this report. For more information, write the Alaska Earthquake Information Center, Geophysical Institute, 903 Koyukuk Drive, Fairbanks, AK 99775, or call them at 907-474-7320.)

Debris Avalanches

A debris avalanche is a rapidly moving mass or landslide of incoherent rock, soil, and debris. A debris avalanche forms during structural failure of a volcano's flank due to gravitational instability caused by erosion, hydrothermal weakening of bedrock, or deformation from magmatic intrusion. No geologic evidence of debris avalanches has been observed at Aniakchak. Furthermore, because the caldera lacks a large volcanic edifice having steep, outward-sloping flanks, this is an extremely low probability hazard at Aniakchak.

Tsunami and Waves in Surprise Lake

Only the largest of eruptions possible at Aniakchak would produce ash flows capable of reaching the Bristol Bay or Pacific shorelines and initiating a tsunami (Latter, 1981; Waythomas and Neal, 1998). Thus, tsunami are considered an extremely low probability hazard at Aniakchak.

Of more serious concern is the possibility of debris or other mass flows into Surprise Lake that could cause waves large enough to inundate the shoreline. Bathymetric data for Surprise Lake (Mahoney and Sonnevil, 1987) show a 19.5-m-deep basin in the northern reentrant (fig. 5). The average depth of the lake is 13.7 m (Mahoney and Sonnevil, 1987). A landslide from the caldera wall could enter Surprise Lake and cause a rapid but temporary rise in water level along the shoreline and an increase in discharge along the Aniakchak River. Runup from such an event is dif-

Figure 17. Warm spring, informally called Bolshoi Spring, on caldera floor (fig. 5). Water temperature ranged from 22.4 to 24.7°C when measured during summers from 1992 to 1997. View is toward south. (Photograph by author C.A. Neal, July 6, 1992).

ficult to estimate but could be as much as several tens of meters. The speed at which a wave might move across Surprise Lake can be estimated from the equation $v = (g \times h)^{1/2}$, where v is wave velocity, in meters per second; g is acceleration due to gravity, in meters per square second; and h is water depth, in meters. For $h = 14$ m, $v = 11$ m/s. Thus, a wave could move across the lake from the northeast shoreline to the southwest shoreline (near a common camping spot in the caldera) in about 2 minutes.

Another, related hazard limited to the shoreline of Surprise Lake would be oscillations of water level and waves caused by shaking from local earthquakes. Because wave height is controlled in part by water depth, the shallowness of Surprise Lake would minimize runup of such waves. However, it would be prudent to move upslope and away from the shoreline after a significant felt earthquake inside Aniakchak.

Rockfalls and Landslides

The steep walls at Aniakchak, especially the nearly vertical south wall, the crater wall and north flank of Vent Mountain, and the exposed walls of Half Cone, are prone to rockfalls and landslides. These can occur suddenly and without warning and can range from small trickles of pebble and gravel-sized fragments to avalanches of boulders and debris as much as tens of meters across. Snow and ice avalanches have occurred along the south caldera wall even in summer. Earthquakes and ground shaking related to volcanic eruptions also can induce rockfalls, landslides, and snow and ice avalanches.

COULD ANOTHER CALDERA-FORMING ERUPTION OCCUR AT ANIAKCHAK?

The catastrophic eruption that formed the caldera at Aniakchak 3,500 years ago is the type of event that, while extremely rare, is of enormous potential consequence. An eruption of this magnitude may occur on our planet only once or twice every thousand years (Simkin and Siebert, 1994). The world last witnessed such an event in 1815 at Indonesia's Tambora volcano, when as much as 100 km^3 of material was erupted violently; the eruption resulted in more than 90,000 fatalities, most due to crop failures brought on by ash-cloud-induced global cooling. Could this type of eruption—or anything approaching the size of this event—occur again at Aniakchak?

The short answer is "Yes." Geologic evidence suggests that in addition to the catastrophic eruption 3,500 years ago, at least one significant explosive eruption, far greater than those we have seen in the last 3,500 years, occurred at the precaldera Aniakchak volcanic center 5,000 to 10,000 years ago. More importantly, the silica-rich eruption products in the last several hundred years, including that of the 1931 eruption, strongly suggest the continued presence of a shallow reservoir containing magma capable of producing a large explosive eruption. Although this means that explosive eruptions are likely to occur, it does not necessarily imply that the next eruption will be large and catastrophic. A sufficient volume of magma to initiate an eruption large enough to induce caldera collapse probably has not had time to reaccumulate in the past 3,500 years.

In summary, another caldera-forming eruption could occur at Aniakchak. However, because such large eruptions are very rare, this event has an extremely low probability for many centuries to come. Furthermore, such an eruption would be preceded by increased earthquake activity, deformation of the ground surface, and increased discharge of heat and volcanic gas, all of which can be detected and measured by monitoring systems in use by the Alaska Volcano Observatory (AVO).

EVENT FREQUENCY AND RISK AT ANIAKCHAK VOLCANO

According to current understanding of volcanic deposits in and around the caldera, at least 20 separate eruptions have occurred at Aniakchak during the last 3,500 years. These data yield a simple eruption recurrence interval of approximately 175 years. Using available data for the last 10,000 years yields a similar average recurrence period. This is almost certainly an underestimate because of erosion and poor preservation of some deposits. This number also should be interpreted with caution because volcanoes rarely erupt at regular intervals. Instead, one eruption every 175 years, on average, roughly indicates the level of activity at Aniakchak during the last 10,000 years. Without a more detailed and precise chronology of past events, we can conclude only that the volcano has been frequently active since caldera formation.

Most of the postcaldera eruptions at Aniakchak produced fallout deposits and fields of ballistic debris within and immediately adjacent to the caldera; perhaps a third of these events were large enough to produce pyroclastic surges and flows, which deposited ash several hundred kilometers downwind. Many of the postcaldera eruptions also produced lava flows or domes, which were confined to the caldera. Except for one flood fan within the caldera, no significant eruption-related flooding or lahar activity within or around Aniakchak volcano has been documented.

In summary, although currently Aniakchak volcano shows no sign of renewed activity, an eruption could occur at any time. Minor eruptions would affect the area inside the caldera significantly. Associated ash fall and ballistics also could impact an area within several kilometers of the rim, and minor flooding could occur along the Aniakchak River. Larger eruptions, similar in size to the 1931 event, temporarily would alter the landscape and destroy vegetation and some wildlife in the vicinity of the volcano. Ash clouds and fallout could impact nearby communities significantly and interrupt air travel across the North Pacific and within Alaska, Canada, and the conterminous United States.

VOLCANO MONITORING AND ERUPTION RESPONSE AT ANIAKCHAK

Prior to most volcanic eruptions, the movement of magma and other fluids within a volcano produces earthquakes or other ground shaking that can be detected by seismometers. Aniakchak is one of 22 volcanoes in Alaska monitored by seismometers 24 hours a day. AVO operates six seismometers in and around Aniakchak Crater (fig. 18). Based on the record of recent eruptions at Aniakchak and at other well-studied and monitored volcanoes, any significant eruption most likely would be preceded for hours to months by increased earthquake activity. This could include earthquakes felt in Port Heiden.

Other methods that AVO uses to monitor volcanic unrest include daily observation by satellite to detect thermal anomalies or the presence of ash in the atmosphere, airborne and ground-based volcanic-gas measurements, lake- and spring-water chemical analysis, fumarole temperature measurements, and ground-deformation surveys. In 1994, a 10-station array of permanent benchmarks was installed around Aniakchak (Yamashita and others, 1996). Reoccupation of these benchmarks using global-positioning-system surveying equipment may allow detection of changes in ground elevation related to precursor activity. Also, prior to an eruption, areas of newly steaming ground, fumaroles showing increased steaming, or anomalous snowmelt within the caldera may be observed and reported to AVO by pilots, visitors, or nearby residents.

If signs of significant volcanic unrest were detected at Aniakchak, AVO would begin 24-hour staffing and would increase instrumental and other monitoring. AVO also would communicate with local, State, and Federal officials and the media through established procedures and maintain this communication throughout the crisis. Frequent updates of the status of the volcano and AVO's interpretations of activity would be released by fax, telephone, and the Internet (electronic mail and websites[3]) (fig. 19). If AVO determined that an eruption was imminent, this information would be released rapidly along with explanations of likely events and impacts. A graduated level-of-concern color code (table 2) would be used to explain the likelihood and (or) status of an eruption at Aniakchak.

If an eruption began, all critical agencies, facilities, and the media would be given formal notification immediately. An emergency-response plan is in place that details procedures for dissemination of information regarding the nature and status of the eruption to appropriate authorities and the public. Depending on the size and severity of the eruption, AVO would monitor the activity through overflights and onsite observation; analysis of seismic and satellite data; and interpretation of pilot reports and other types of observations. As conditions changed, AVO would distribute information rapidly via fax, telephone, and the Internet (electronic mail and websites). In conjunction with the National Weather Service (National Oceanic and Atmospheric Administration), AVO would determine areas likely to be affected by fallout and communities within those areas would be notified by appropriate agencies.

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[3]Information on status will be posted frequently at <http:// www.avo.alaska.edu>. Also, weekly updates on erupting volcanoes are posted at <http://volcanoes.usgs.gov>.

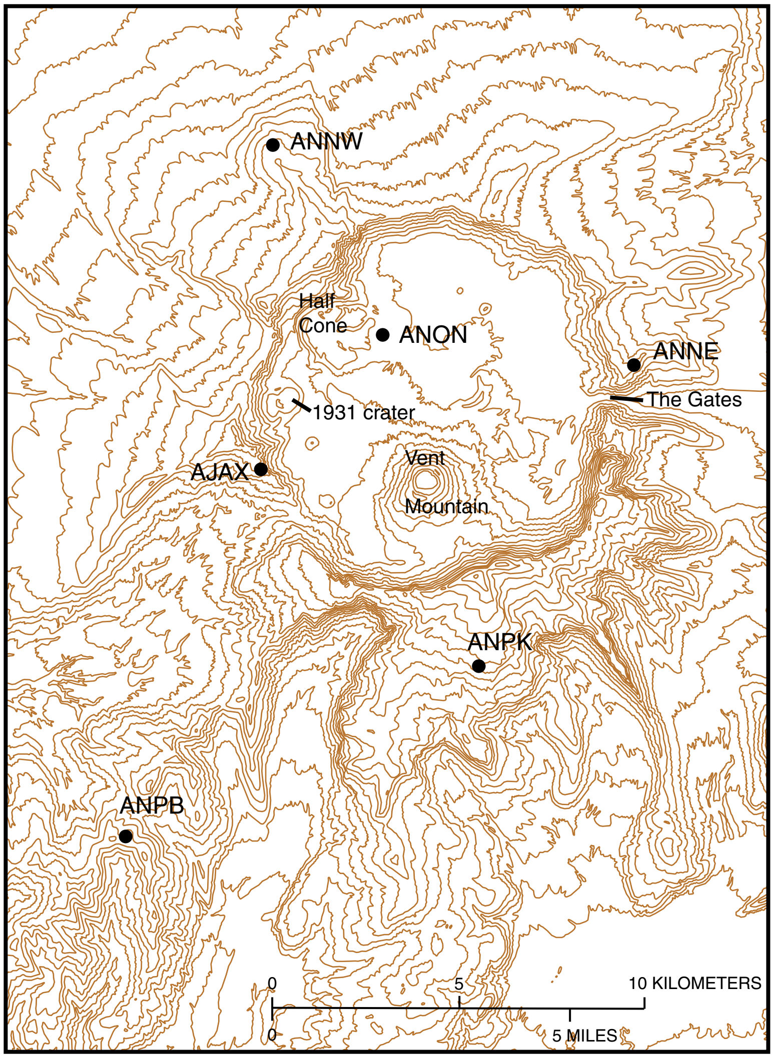

Figure 18. Location of six seismic stations in vicinity of Aniakchak Crater, as of July 2000. Data are telemetered to Port Heiden and sent by telephone circuit to Alaska Volcano Observatory.

AVO also would notify critical agencies and the public when eruptive activity had ceased and the probability of renewed eruption had decreased significantly. Such notification is important to minimize unnecessary evacuation or other precautionary measures such as carrying extra jet fuel or diverting aircraft. In the days and months after an eruption, AVO would continue to monitor the volcano for signs of activity and commence scientific studies of the deposits, the earthquake record and other instrumental data, and the effects of the eruption. Analysis of this information would lead to a better understanding of the volcano, which in turn would be used to update the hazard assessment and improve monitoring capabilities at AVO.

PREPARING FOR ERUPTIONS AT ANIAKCHAK VOLCANO

Key steps to mitigating impacts from future eruptions at Aniakchak volcano are awareness of the hazards, understanding of potential impacts, and taking appropriate precautions. When an eruption begins, it is too late to plan an effective response. Although the region that includes Aniakchak volcano is not experiencing rapid population growth, volcano-hazards information should be integrated into planning for infrastructure upgrades, land use, and development in potentially affected areas.

In 1999, about 600 people lived within 125 km of Aniakchak (Alaska Department of Community and

ALASKA VOLCANO OBSERVATORY

INFORMATION RELEASE
Monday, July 31, 2000 10:00 am ADT (1800 UTC)

ANIAKCHAK VOLCANO
56.88°N 158.15°W; summit elevation 1,341 m (4,400 ft)

LEVEL OF CONCERN COLOR CODE: **ORANGE**
LAST LEVEL OF CONCERN COLOR CODE: **YELLOW**

This morning at 8:30 ADT, the number of earthquakes recorded at Aniakchak volcano 670 km (420 mi) southwest of Anchorage on the Alaska Peninsula began to increase dramatically. The character of the earthquakes suggests magma is moving beneath the volcano. At this time, high levels of seismicity continue, and the likelihood of an eruption has increased significantly. We therefore are elevating our level of concern color code to ORANGE, indicating an explosive eruption is possible within the next few days. As of this information release, AVO is initiating 24-hour staffing.

As of yet, AVO has received no pilot or ground-based reports of visible changes at the volcano; satellite images examined thus far do not show any thermal anomaly. AVO will be dispatching scientists to the area to make additional observations.

ADDITIONAL INFORMATION

A voice recording of the current update is available by calling 907-786-7478. Information on the Alaskan volcanoes and AVO is posted on the Internet: http://www.avo.alaska.edu

PLEASE CONTACT AVO IF YOU HAVE ANY QUESTIONS OR COMMENTS

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Figure 19. Hypothetical information release from Alaska Volcano Observatory in response to probable scenario of volcanic unrest at Aniakchak.

Economic Development; <http://www.dced.state.ak.us/mra/CF_COMDB.htm>). This number grows to more than 4,000 during the summer fishing season. The National Park Service (<http://www2.nature.nps.gov/stats/>) reported 377 recreational visits to Aniakchak National Monument and Preserve in 1999. Public officials and land managers in the vicinity of Aniakchak volcano should be aware of the potential impacts of eruptions as described in this report and develop emergency-response plans to deal with the most likely of the possible scenarios. Like all operational plans, they should be reviewed, practiced, and updated periodically to ensure that necessary resources are in place and reaction time is minimized.

Residents of nearby communities and visitors to the area also should be aware of the hazards associated with possible eruptions at Aniakchak and other volcanoes on the Alaska Peninsula. Many of the recommended precautions are similar to those for other natural disasters that should be familiar to Alaskans—such as earthquakes, floods, and severe weather. Thus, in general, residents should gather adequate emergency supplies of food, water, and fuel; have a plan in place to protect their homes and businesses; and be prepared for prolonged isolation, disruption of services, and the possibility of rapid evacuation.

Table 2. Alaska Volcano Observatory Level-of-Concern color code

Color	Intensity of unrest at volcano	Forecast
GREEN	Volcano is in quiet, "dormant" state.	No eruption anticipated.
YELLOW	Small earthquakes detected locally and (or) increased levels of volcanic-gas emissions.	Eruption is possible in next few weeks and may occur with little or no additional warning.
ORANGE	Increased numbers of local earthquakes. Extrusion of lava dome or lava flows (nonexplosive eruption) may be occurring.	Explosive eruption is possible within a few days and may occur with little or no warning. Ash plume(s) not expected to reach 7,600 meters (25,000 feet) above sea level.
RED	Strong earthquake activity detected even at distant monitoring stations. Explosive eruption may be in progress.	Major explosive eruption expected within 24 hours. Large ash plume(s) expected to reach at least 7,600 meters (25,000 feet) above sea level.

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GLOSSARY

Accretionary lapilli. Spherical coherent mass (commonly 1 mm to 1 cm across) of cemented volcanic ash. Formed during explosive eruptions probably by accretion of particles in a wet eruption cloud.

Alluvium. General term for clay, silt, sand, and gravel deposited by running water.

Andesite. Volcanic rock composed of about 52 to 63 percent silica (SiO_2, an essential constituent of most minerals found in rocks).

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

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

Ballistic. Fragment ejected explosively from a volcanic vent on an arcuate trajectory. Also called a volcanic bomb.

Basalt. Volcanic rock composed of about 45 percent to 52 percent silica (SiO_2, an essential constituent of most minerals found in rocks). Basalt lavas are more fluid than andesite or dacite lavas, which contain more silica.

Caldera. Crudely circular volcanic depression (1 to 2 km or greater across); can be formed by collapse of a volcano during a large, explosive eruption.

Colluvium. General term for loose rock, soil, or other debris deposited by downslope creep or rainwash.

Composite volcano. High, steep-sided volcanic cone composed of layers of lava flows and fragmental debris. Also called a stratocone or stratovolcano.

Crater. Bowl-shaped, funnel-shaped, or cylindrical depression commonly near the top of a volcano and less than 1 km across. Can mark the site of volcanic vents.

Dacite. Volcanic rock composed of about 63 percent to 70 percent silica (SiO_2, an essential constituent of most minerals found in rocks). Dacite lavas are viscous (sticky) and tend to form thick blocky lava flows or steep-sided piles of lava called lava domes.

Debris avalanche. Rapidly moving, dry flows of rock debris, sand, and silt that commonly form during structural collapse of a volcano. Can travel considerable distances from the volcano, and the resulting deposits commonly have a hummocky surface.

Directed blast. Severe volcanic explosion 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.

Effusive eruption. Eruption that produces mainly lava flows and domes (as opposed to an explosive eruption).

Ejecta. General term for anything thrown into the air from a volcano during an eruption; synonymous with “pyroclast,” a term derived from words that mean “fire” and “broken piece.”

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

Eruption column. Ascending, vertical jet of erupting debris and volcanic gas that rises directly above a volcanic vent.

Explosive eruption. Energetic eruption that produces mainly ash and fragmental debris (as opposed to an effusive eruption).

Extracaldera. Occurring outside the caldera rim.

Fallout. General term for debris that falls to the Earth from an eruption cloud.

Fumarole. Small opening or vent from which hot gases are emitted.

Hydrovolcanic. Refers to explosive interaction (by heating or direct mixing) of magma with water. Also commonly termed “phreatomagmatic.”

Intracaldera. Occurring within the caldera depression.

Lahar. Destructive mixture of water and volcanic debris that has the consistency of wet cement and moves rapidly downstream.

Lapilli. Ejected rock or pumice fragments 2 to 64 mm in diameter.

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

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

Lithic. Synonym for “rock” in volcanic deposits. Commonly refers to fragments of preexisting rock (as opposed to newly erupted material).

Maar. Crater, commonly filled with water and characterized by a low rim of ejecta. Formed by explosive phreatic eruptions.

Magma. Molten rock beneath the Earth’s surface.

Magma reservoir. Storage area for or reservoir of molten rock beneath the Earth’s surface.

Mesozoic. Era of geologic time from about 225 to about 65 m.y. ago.

Moraine. Loose, varied debris deposited by a glacier. Typically forms mounds, ridges, or other distinct landforms.

Phreatic eruption. Type of eruption that involves primarily steam explosions, which may be driven by the heat of subsurface magma.

Plinian eruption. Type of explosive eruption that produces a steady vertical eruption column, which may reach tens of kilometers above the volcano. Commonly results in far-traveled ash clouds, widespread fallout of pyroclastic debris, and pyroclastic flows and surges.

Postcaldera eruption. Volcanic eruptions occurring after formation of a caldera.

Pumice. Highly vesicular volcanic ejecta. Owing to its extremely low density, it commonly can float on water.

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

Pyroclastic flow. Hot (as much as 800°C), chaotic avalanche of rock fragments, gas, and ash that travels rapidly (10 to several hundred meters per second) down the flanks of a volcano during an explosive eruption. Formed either by collapse of the eruption column or by failure of the front of a cooling lava dome. May be called an ash flow if pumice is present.

Pyroclastic surge. Low-density, turbulent hurricane of fine-grained volcanic-rock debris and hot gas. Differs from pyroclastic flow in that it is less dense. Can surmount topographic barriers, and commonly affects areas beyond those affected by pyroclastic flows.

Silicic magma. Magma that contains more than about 63 percent silica (SiO_2, an essential constituent of most minerals found in rocks). Generally viscous (sticky) and gas rich; tends to erupt explosively.

Stratocone. Steep-sided volcano, commonly conical in shape, built of lava flows and fragmental deposits from explosive eruptions. Also called a stratovolcano or composite cone.

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

Talus. Coarse, angular, rocky debris deposited in an unstable fan at the base of a steep slope.

Tephra. Any type and size of rock fragment that is forcibly ejected from the volcano during an eruption (ash, bombs, cinders, etc.). Also called pyroclastics.

Tertiary. Period of geologic time (beginning of Cenozoic Era) from about 65 to about 2 m.y. ago.

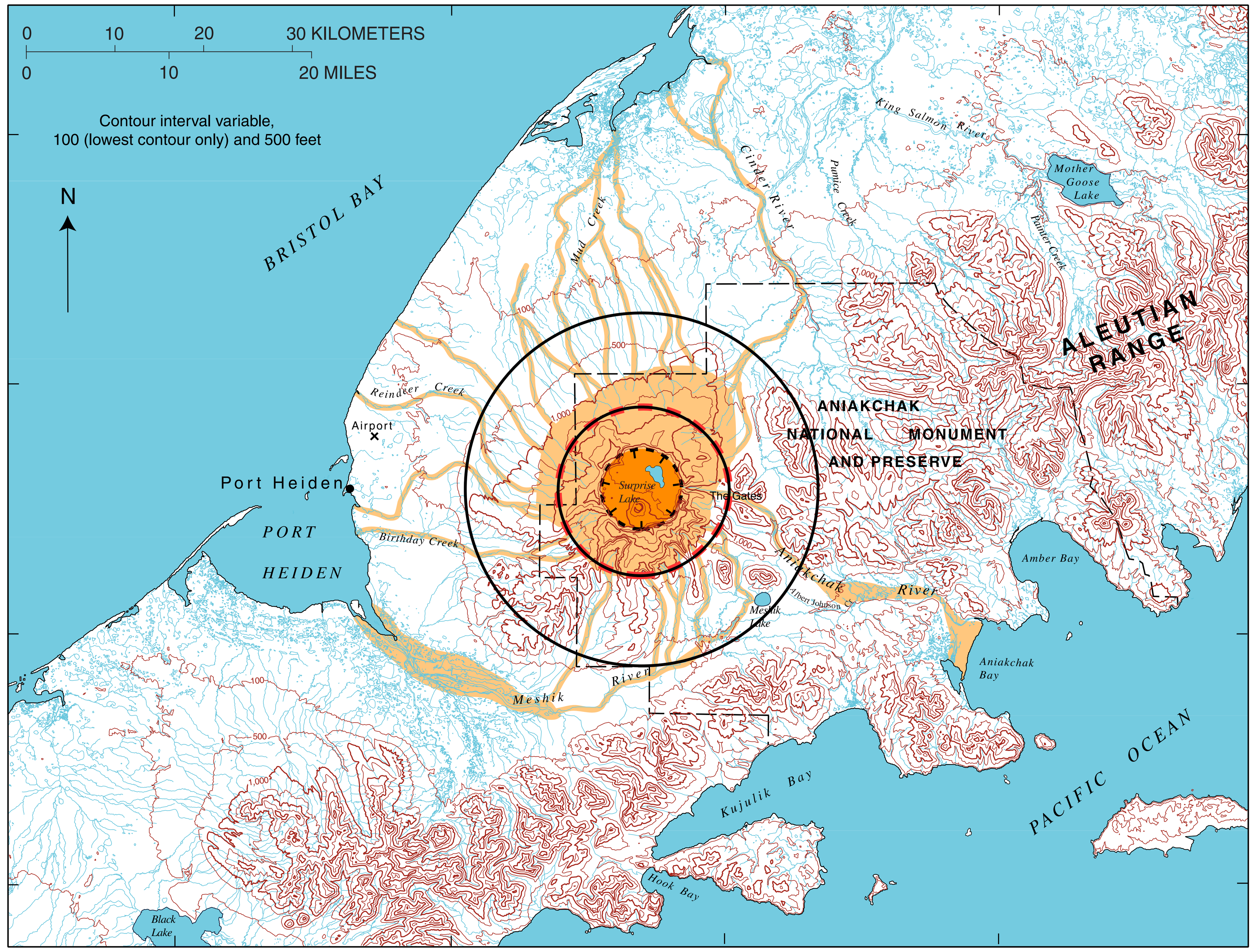
Tsunami. Ocean waves most commonly initiated by sudden displacements of the sea floor during earthquakes. Volcanic eruptions can cause tsunami if debris falls or flows rapidly into water or if explosive eruptions occur at or near sea level. Large tsunami are capable of significant runup, especially if the wave energy is focused by narrowing of inlets and bays.

Tuff cone. Volcanic landform, commonly several hundred meters high, composed of loose volcanic fragments ejected during explosive, water-rich eruptions. Typically contains a crater and may be associated with a lava flow.

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

Volcaniclastic. General term for either unconsolidated deposits of volcanic origin or rocks composed of fragments of volcanic origin.

OPEN-FILE REPORT 00–519
PLATE 1



During the last 10,000 years, Aniakchak has erupted explosively at least 40 times, more than any other volcano in the eastern Aleutian arc (Riehle and others, 1999). Although Aniakchak shows no sign of unrest at present, explosive and nonexplosive eruptions will occur in the future.

EXPLANATION

Area most likely to be affected by ballistic fallout during future eruptions at Aniakchak

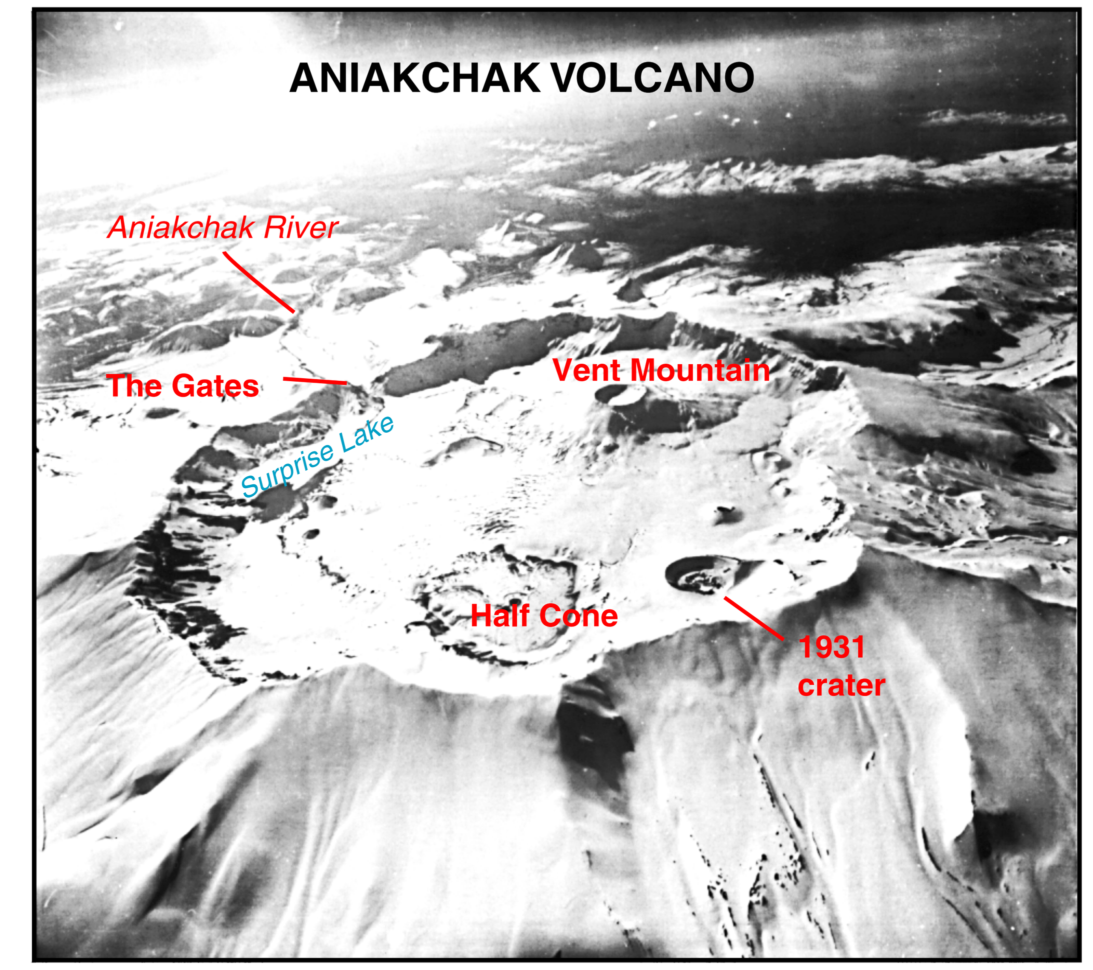
Areas most likely to be affected by pyroclastic flows and surges during future eruptions of Aniakchak. Inner circle represents likely maximum extent of pyroclastic flows and surges during typical large explosive eruptions at Aniakchak. Outer circle represents area at risk during eruptions larger than those documented since caldera formation 3,500 years ago

Approximate topographic boundary of Aniakchak caldera

Area most likely to be affected by lava flows and lava domes during future eruptions of Aniakchak

Areas most likely to be affected by lahars and floods during future eruptions of Aniakchak

Warm spring that is known source of carbon dioxide gas. Prior to or during future volcanic activity, this site or other sites inside caldera may emit volcanic gas in dangerous concentrations



Aerial view of Aniakchak, a 10-kilometer-diameter, 0.5- to 1.0-kilometer-deep caldera that formed during a catastrophic eruption 3,500 years ago. Since then, at least a dozen separate vents within the caldera have erupted, often explosively, to produce lava flows and widespread ash deposits. The most recent eruption at Aniakchak occurred in 1931 and was one of the largest eruptions in Alaska in the last 100 years. Photograph by U.S. Navy, May 9, 1943. View is toward east-southeast.

PRINCIPAL VOLCANO HAZARDS AT ANIAKCHAK

- **Ash clouds**
  During explosive eruptions, volcanic ash most likely will travel north, northeast, east, and southeast from Aniakchak. These ash clouds are a significant hazard to aircraft even thousands of kilometers downwind.

- **Fallout**
  During explosive eruptions, coarse debris and fine ash settle to the ground in accumulations ranging from many meters thick near the vent to a fine dusting hundreds of kilometers downwind. During large eruptions, Port Heiden may receive significant amounts of ash and coarse pumice fall.

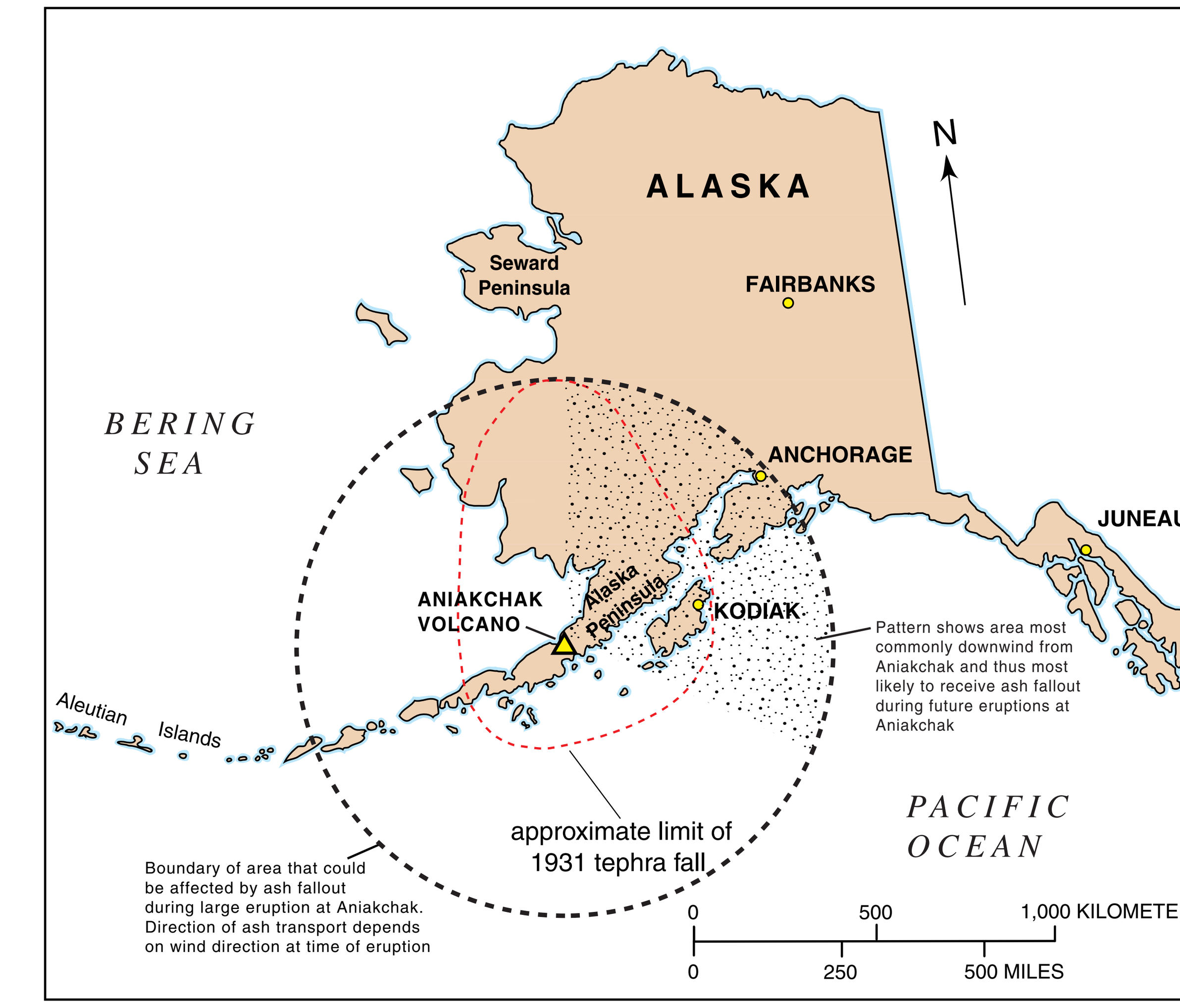
- **Ballistics**
  Explosive eruptions launch pebble- to boulder-sized fragments of rock or pumice on arcuate trajectories from the vent. These projectiles, called ballistics, pose a serious hazard to people and structures.

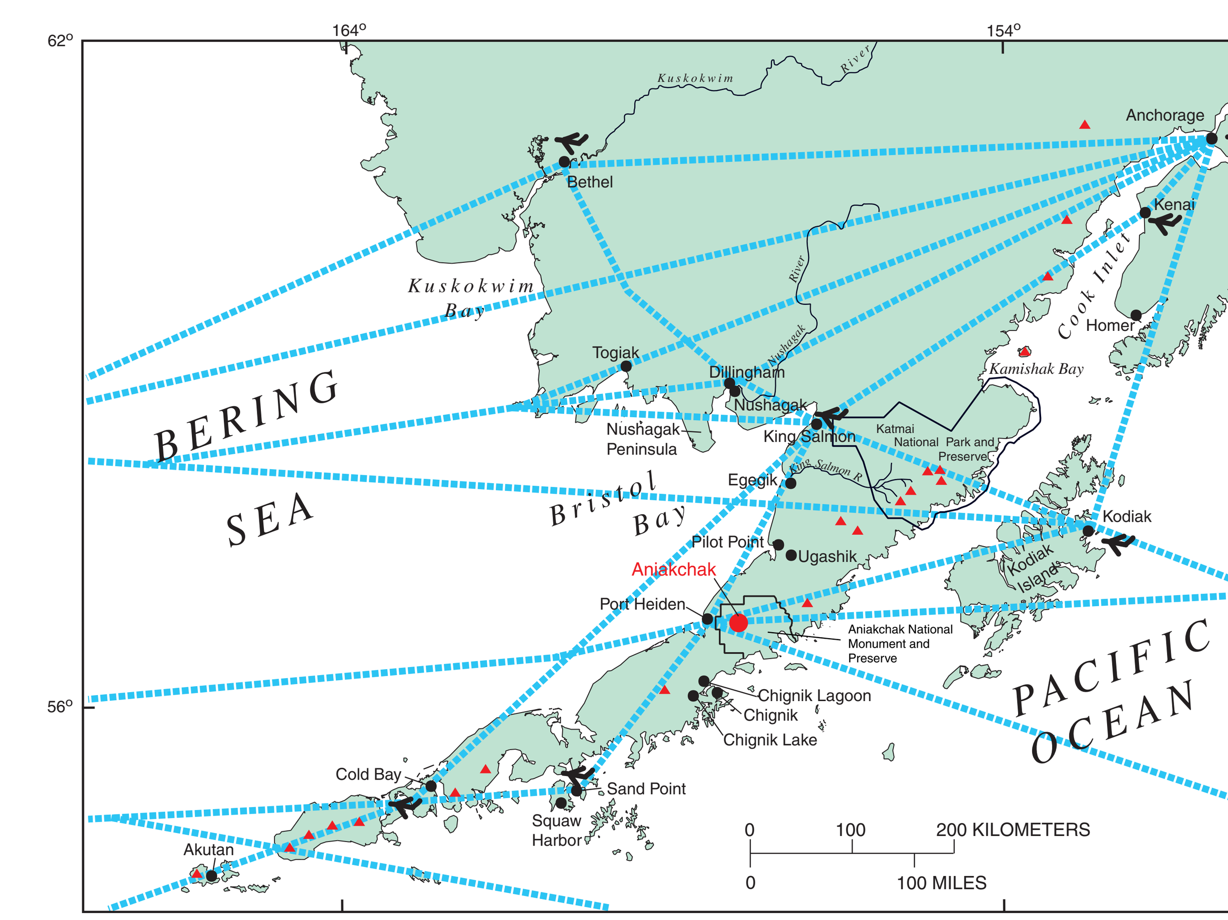
- **Pyroclastic flows and surges**
  Hot avalanches or blasts of volcanic gas, ash, and rock debris can travel at speeds in excess of 100 meters per second and destroy everything in their path. Only very large eruptions at Aniakchak will produce pyroclastic flows and surges that inundate areas far beyond the caldera rim.

- **Lava flows and domes**
  When molten rock erupts nonexplosively at the Earth's surface, it can form elongate lava flows or rounded mounds of rubble called lava domes. The immediate hazard from flows and domes is burial. Future lava flows and domes most likely will be confined to within the caldera at Aniakchak.

- **Lahars and floods**
  Hot ejecta can mix with snow, ice, and surface water to form water floods and destructive, fast-moving slurries of water, mud, sand, and boulders called lahars. All drainages leading away from Aniakchak could be affected by lahars and floods. Sudden release of impounded water from the large maar crater or from Surprise Lake could generate floods along the Aniakchak River.

HAZARD FROM VOLCANIC ASH





Aniakchak is beneath many aircraft routes (dashed blue lines) that pass over southwestern Alaska. An explosive eruption from Aniakchak could severely impact air traffic in the North Pacific, and ash clouds from Aniakchak could travel into Canadian airspace and over the rest of the continental United States.

PRELIMINARY VOLCANO-HAZARD ASSESSMENT FOR ANIAKCHAK VOLCANO, ALASKA

by

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2001