

Spectacular mobility of ash flows around Aniakchak and Fisher calderas, Alaska

ABSTRACT

Ash flows around Aniakchak and Fisher calderas in the Aleutian volcanic arc show evidence of having flowed over formidable topographic barriers at distances of tens of kilometres from their source. Ash flows swept down glaciated valleys on the south side of Aniakchak caldera, crossed a broad lowland with an altitude of less than 35 m, and continued on through passes as much as 260 m high in the Aleutian Range into the Pacific Ocean, a distance of some 50 km. North of Fisher caldera, ash flows flowed over a ridge barrier of 500 m and into the Bering Sea. Knowledge that ash flows have this mobility may help in understanding the distribution of other ash flows and in the discovery of their sources.

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INTRODUCTION

The effect of topography on channeling and controlling the distribution of ash flow around certain volcanic centers is well known (Williams, 1942; Smith, 1960). Ash flows, as they descend the steep slopes of a volcano, are usually channeled through valleys to basins and lowlands, where they commonly coalesce and spread out as large sheets. As a result, ash flows are generally considered to be confined to topographic lows. What is not so well documented is the ability of some ash flows to flow over various large topographic barriers and obstacles at distances of as much as tens of kilometres from their source. Evidence of this phenomenon has recently been observed during volcanological reconnaissance studies near Aniakchak and Fisher calderas in the eastern part of the Aleutian volcanic arc. The youthfulness of these ash-flow deposits and their good preservation, because of lack of erosion, allows their original extent and flow direction to be determined.

We have found ash-flow tuffs or related pyroclastic avalanche deposits to be associated with 17 of 49 major Quaternary volcanic centers in the eastern Aleutian volcanic arc between Umnak Island and Anchorage (Fig. 1, inset). The ash-flow tuffs typically are composed of pumice and

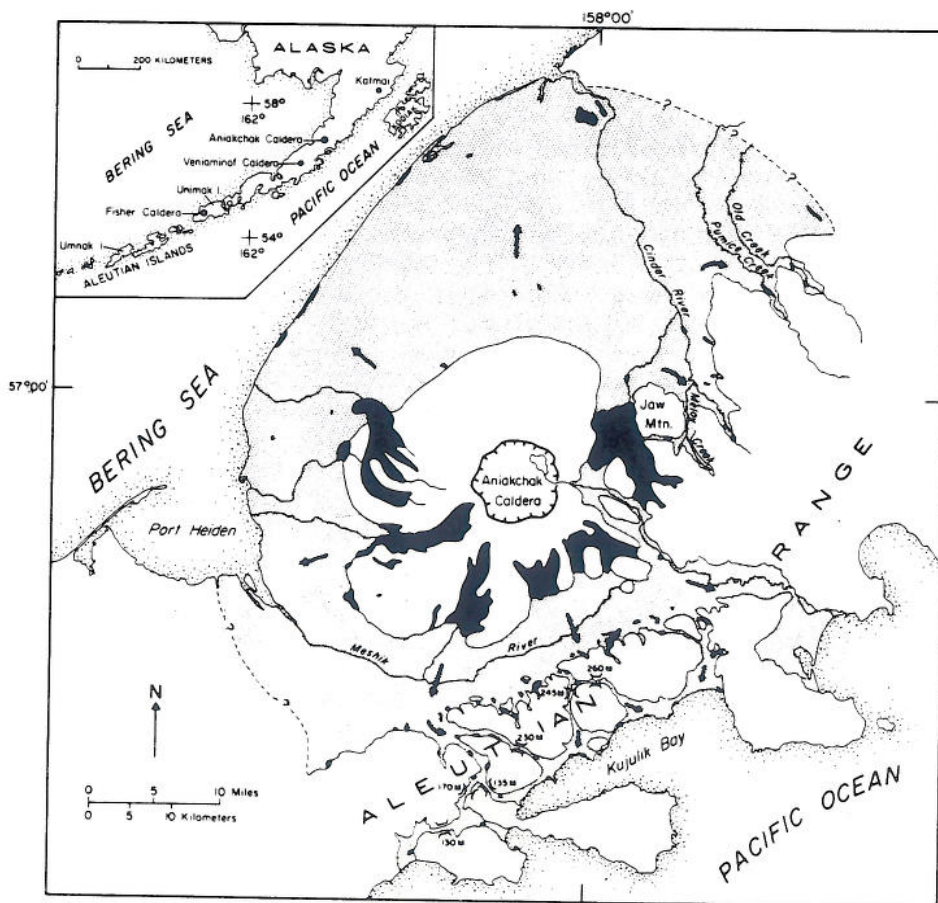


Figure 1. Distribution of ash flows around Aniakchak caldera, Alaska. Outcrops shown in solid pattern; inferred original distribution of ash flows shown in shaded pattern. Arrows denote postulated flow direction of ash flows; brackets and numbers denote mountain passes and their altitudes in metres. Inset is index map.

scoria bombs as much as 60 cm in diameter and subordinate lithic fragments in a matrix of fine to coarse ash, pumice, and lithic material. These ash-flow tuffs, typically unconsolidated and nonwelded, range in composition from basaltic andesite to rhyolite but are mostly dacitic. Compositional zoning is common; silicic basal tuffs are generally overlain by more mafic andesitic tuffs. In most cases the silicic and andesitic tuffs are separated by an intermediate zone containing fragments of silicic pumice, black andesitic scoria, and banded pumice. Collapse calderas ranging from 3 to 18 km in diameter and small dacitic volcanic centers characterized by Peléan-type domes now mark the source areas for these ash flows. At least some of the ash flows, and therefore the catastrophic eruptions that caused them, are very young. Ash flows from many of the volcanoes filled glaciated valleys, suggesting an age of less than 11,000 to 12,000 yr, the time of the last major deglaciation in the general area (Black, 1975). The ash flows in the Valley of Ten Thousand Smokes in Katmai National Monument were erupted in 1912, and ^{14}C dates of 3300 to 3700 B.P. have been obtained on charcoal fragments from the base of ash flows near Aniakhchak and Venimino calderas in the Alaska Peninsula (Miller and Smith, 1975). Organic material from the base of ash-flow tuffs associated with Fisher caldera yielded a ^{14}C age of $9,120 \pm 250$ yr (M. Rubin, written commun.; sample W3424, U.S. Geological Survey laboratory). Both Aniakhchak and Fisher calderas have been the site of post-caldera eruptions, some in historic time, of domes, lava flows, and pyroclastics.

Ash-flow tuffs associated with the small dacitic volcanic centers have a large air-fall component and are generally local in distribution, confined to a few valleys adjoining the volcano. Ash flows erupted from volcanic centers now characterized by large calderas have a quaquaversal distribution to distances of 50 km or more from their eruption sites.

ANIACHCHAK ASH FLOWS

Aniakchak caldera is a spectacular circular feature about 9.5 km in diameter near Port Heiden on the Alaska Peninsula, 670 m southwest of Anchorage (Fig. 1). The caldera is the result of the collapse of a large andesitic structure and has a total internal relief of about 1,000 m. Ash-flow tuff, emplaced during a caldera-forming eruption, is found in thick continuous exposures near the caldera and in isolated outcrops as far away as 50 km. The SiO_2

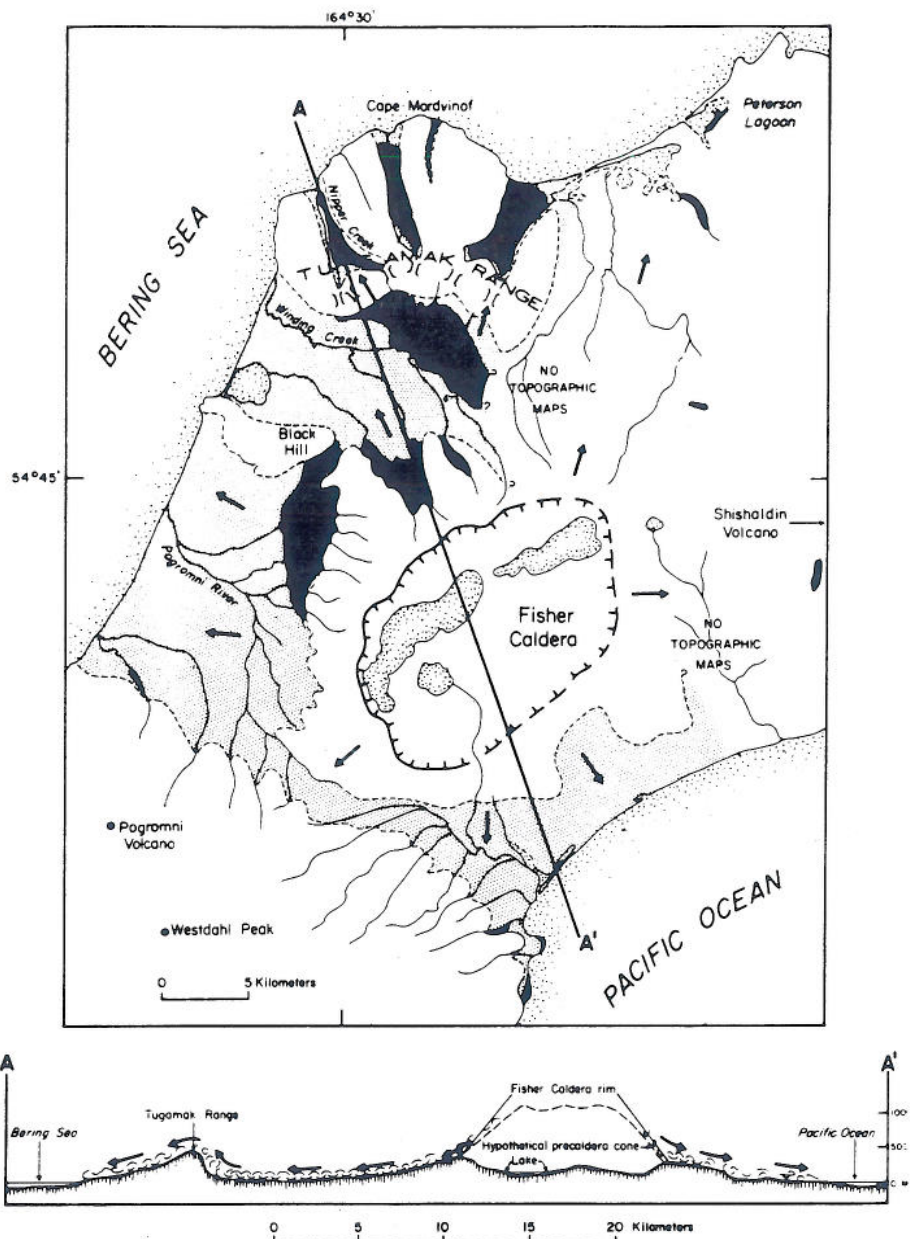


Figure 2. Distribution of ash flows around Fisher caldera, Unimak Island, Alaska. Outcrops shown in solid pattern; inferred original distribution of ash flows shown in shaded pattern. Arrows denote postulated flow direction of ash flows; brackets denote mountain passes. Cross-section along line A-A' illustrates inferred movement of ash flows over Tugamak Range.

content of analyzed pumice and scoria bombs in ash-flow tuff (around Aniakhchak caldera) ranges from 57.1% to 67.9%. The distribution of ash-flow tuff outcrops, traced by close reconnaissance with a helicopter and numerous landings, indicates that originally the flows covered an area of at least 2,500 km². The decrease in thickness of the deposits away from the volcano, their lithologic similarity, and the absence of any other suitable source volcano indicates that Aniakhchak was the source.

The ash flows flowed down the sides of the precaldra cone, filling deep glacial valleys next to the volcano to a thickness

of 70 m or more. To the north and west obstructions existed, and the ash flows swept across the Bering Sea Lowland to the Bering Sea, where ash-flow tuffs are found in sea-cliff exposures 50 km from the center of the caldera. To the east and south of the volcano, where the rugged Aleutian Range rises to summits of 900 m the ash flows swept down deeply glaciated valleys on the south side of the volcano and across the Meshik River valley, a broad 8-km-wide lowland less than 35 m in altitude, bounded on the south and east by the Aleutian Range. Upon encountering the barrier formed by the Aleutian Range (Fig. 1), the ash flows swept up the narrow

valleys of the northwest-draining tributaries, flowed through passes as high as 260 m, and continued on down the south-east-draining tributaries to the Pacific Ocean, where exposures as much as 10 m thick occur along Kujulik Bay (Fig. 1). The ash flows not only moved up the rather steep valleys for distances of 6 km or more but also changed their direction of flow more than 90°, in some places several times. Ash flows that followed this sinuous route have been found more than 50 km airline from the caldera.

Ash-flow tuffs in the Aleutian Range and on the Pacific Ocean coast clearly are flows erupted during the Aniakchak caldera-forming eruption, as the ash-flow outcrop pattern allows the tracing of the ash flows from the Aniakchak source area. The ash flows on the Pacific side are clearly not air-fall pumice, as they are unsorted, nonstratified, and contain coarse pumice fragments as much as 30 cm in diameter. Locally, they also contain charcoal and fossil fumarolic pipes indicative of a high temperature of emplacement.

To the east of the volcano, the ash flows poured around hills more than 700 m in altitude to fill the intervening valleys to probable depths of 100 m or more just west of the main Aleutian Range (Fig. 1). The ash flows swept through the pass south of Jaw Mountain and into the Meloy Creek drainage of the Aleutian Range. They also swept around the north end of Jaw Mountain and into the Cinder River drainage. The occurrence of ash-flow tuff near the headwaters of the Cinder River, Pumice Creek, and Old Creek may represent "back-fill" from ash flows moving past the headlands separating these drainages.

FISHER ASH FLOWS

Fisher caldera, one of six volcanoes on Unimak Island in the eastern Aleutians (Fig. 1), is 11 km wide and 18 km long, with an internal relief of 1,072 m—one of the largest of the calderas in the Aleutian volcanic arc. Like the calderas of other major centers, it represents the collapse of a large andesitic stratcone. The caldera is surrounded by ash-flow tuff which, judged by the composition of analyzed pumice and scoria bombs, ranges in composition from 52.5% to 64.4% SiO₂. The distribution of ash-flow outcrops (Fig. 2) indicates that ash flows from the caldera-forming eruption moved down the sides of the precaldern cone(s) in a manner similar to the Aniakchak caldera-forming eruption. To the south, the ash flows traveled across a lowland directly into the Pacific

Ocean. To the east and west, they encountered the stratovolcano complexes of Shishaldin and Pogromni (Fig. 2), respectively, and swept partly up their steep sides before coming to a stop. Many ash-flow outcrops east of the caldera are not shown in Figure 2 because of the lack of topographic maps of this area. Outcrops in these three quadrants are confined to scattered sea-cliff exposures and protected valleys, as most of the ash flows have been eroded away or covered by later ash falls. To the north, however, the ash flows filled deep valleys and swept across the Winding Creek lowland to the base of an arcuate range of hills known as the Tugamak Range, about 15 km from the volcano (Fig. 2); ash-flow tuff outcrops are found across much of the broad lowland. Unlike the area south a Aniakchak caldera, the Tugamak Range forms a continuous east-west barrier with summits about 700 m in altitude and passes of about 500 m. Some ash flows may have been partly diverted by this barrier and flowed east or west to the Bering Sea. Ash-flow tuff is found east of the Tugamak Range; west of the range, it has probably been eroded away. Ash-flow tuff is found in all major valleys on the north side of the Tugamak Range and in scattered localities along the north coast; the tuff has a thickness of several tens of metres and is found at altitudes of from at least 330 m down to sea level. Ash-flow tuff identical in appearance is found at an altitude of about 200 m on the steep south slope of the range. Many of the ash-flow deposits on both sides of the Tugamak Range are characterized by large stacks and pinnacles composed of well-indurated material (Fig. 3). These features probably represent contact of the ash flows with water-saturated soil or with snow and ice, resulting in partial devitrification or other induration promoted by the action of steam. The ash-flow outcrop pattern and the similarity in appearance of ash-flow tuffs on both sides of the range strongly suggest that the ash flows flowed up and over the Tugamak Range, surmounting a topographic barrier of at least 500 m (Fig. 2).

The possibility that the south scarp of the Tugamak Range represents the northern rim of a second and older caldera has been pointed out to us by James R. Hein and David W. Scholl, who noted an apparent circular structure on MSS band 4 of LANDSAT photography. If such a structure existed, it could have been the source for the ash-flow tuff on the north flank of the Tugamak Range. We were unable to find any field evidence for this postulated structure in a re-examination of the area

in the summer of 1975, and it does not appear on the other 3 MSS bands of LANDSAT photography. The occurrence of ash-flow tuff high on both slopes of the range would seem to require the ash flows to have come from Fisher volcano. It is possible that the south slope of the Tugamak Range represents a fault scarp, but no sign of any post-ash-flow (<9,120 yr B.P.) uplift was observed along it.

The tuff filling the valleys on the north side of the Tugamak Range definitely appears to have been deposited from an ash flow. The deposits are poorly sorted, moderately well indurated, and show no stratification; more significantly, they contain fossil fumaroles indicating temperatures higher than would be expected in air-fall deposits at this distance from the volcano.

DISCUSSION AND SUMMARY

The ability of ash flows to cross over formidable topographic obstacles at considerable distances from their source has thus been demonstrated at both Aniakchak and Fisher calderas. Knowledge of this mobility may help in explaining the distribution of ash flows found elsewhere in the world and in finding their sources. Koch and McLean (1975, p. 540) found ash-flow deposits in basins in the Guatemalan highlands "that seemed inaccessible to an ash flow strictly confined to topographic lows." They suggested that these deposits might represent air fall from the distal parts of the ash flow. An alternative explanation may be in the ability of ash flows to move over topographic barriers as they did near Aniakchak and Fisher calderas.

A somewhat different proposal has been put forward by Aramaki and Ui (1966) and Ono (1965) to explain the puzzling occur-



Figure 3. Indurated ash-flow tuff on north side of Tugamak Range.

rence of ash flows from Ata and Aso calderas on Kyushu Island, Japan, at localities where they would have to flow over ridges with relief of 700 m or more. Although Matumoto (1943) evoked post-ash-flow uplift to explain the anomalous occurrences, Aramaki and Ui saw no sign of such movements. As an alternative, they suggested that a very thick fluidized layer existed at the climax of the eruption, reaching to an altitude sufficient to override the mountain ranges that surround the vent. As the eruption cloud collapsed, the top of the fluidized layer was lowered; the ash flows moved down the steep slopes, forming a steeply dipping welded deposit that increased in thickness from the middle of the slopes to the valley bottom. Aramaki and Ui judged that the maximum height of the fluidized layer must have been more than 500 m at a point 30 km from the vent. Yokoyama (1974), in his very detailed and well-documented study of the Ito pyroclastic flow deposits around Aira caldera, Kyushu, Japan, also concluded that a high fluidized layer of ash must have existed to explain the present distribution of ash deposits. He inferred that the top of the "fluidized bed" was higher than "all the basement mountains in southern Kyushu" (>1,000 m). This fluidized bed is thought to have moved radially from its source, to have collapsed on the surrounding mountains, and to have deposited ash that flowed off the steep slopes and collected in all the topographic lows within a 70-km radius of the center of Aira caldera.

No sign of such a widespread thick "fluidized layer" is apparent from a study of the distribution of ash-flow tuff around Aniakchak caldera. Ash-flow tuffs on the north slopes of the Aleutian Range, for example, are found only at lower altitudes than ash-flow tuffs in the passes of the range; this argues against a subsiding fluidized layer. Some valleys on the Pacific Ocean side of the Aleutian Range east and south of the caldera are devoid of ash flows. These valleys lie well within the radius of any expectable fallout from a "thick fluidized layer" of ash, were such a layer responsible for the Aniakchak ash flows. The valleys are at elevations that would have been flooded by any "fluidized layer" not confined to the drainage channels now occupied by ash-flow deposits. The general confinement of ash flows to certain valleys in the Aleutian Range suggests that they were channeled through these valleys and at a velocity sufficient to overcome a difference in relief of more than 200 m at distances of 20 to 40 km

from the vent. Indeed, one pass with 470-m relief lies in a direct line 25 km southeast of Aniakchak and may well have channeled ash flows to Kujulik Bay.

In the case of the Fisher ash flows and their relationship to the Tugamak Range, the distribution of ash flows would be much the same regardless of whether a thick "fluidized layer" existed or whether the ash flows moved up and over the range.

Rock and snow avalanche phenomena are helpful in the study of the distribution and mobility of ash flows. Avalanches commonly have high mobility, crossing valleys and traveling considerable distances upslope. The Saidmarreh landslide in western Iran fell 1,500 m and crossed a 14-km-wide valley before climbing 460 to 610 m up and over a flanking ridge (Kent, 1966); similar phenomena have been noted in other landslides. This mobility appears to be largely a function of momentum acquired in the initial fall from the point of origin, subsequently aided by reduced friction during flow because of a trapped cushion of compressed air (Shreve, 1966; Kent, 1966). Ash flows also probably make use of an air cushion, but they have the additional properties of elevated temperature and escaping gas and a dominant component of ultrafine particles. All of these properties tend to enhance the mobility of ash flows over cold avalanches. In addition, as pointed out by many students of ash flows (for example, Reynolds, 1954; O'Keefe and Adams, 1965), fluidization mechanics impart a certain degree of inflation to the ash-flow bed. It is not surprising, therefore, to see evidence that certain ash flows have traveled short distances upslope when they encounter barriers and longer distances up confining valleys. Until our present study, however, there have been very few documented examples.

Smith (1960, p. 804) has emphasized the importance of a high vertical eruption column in the formation of many nonwelded ash-flow deposits, arguing that mixing with air in the eruption column is the only reasonable explanation for the nonwelded nature of thick deposits erupted at magma temperatures. Supporting evidence for the high eruption column is found in the sorting characteristics of many deposits that have lost fines to the atmosphere to the degree that the lognormal particle distribution pattern of normal nonsorted ash flows is skewed toward the coarse size fraction. The paucity of fine ash and large amounts of coarse pumice and scoria in many of the Aleutian arc ash-flow deposits may be seen by field inspection alone. With few

exceptions, these same deposits are mostly nonwelded and contain ash flows showing a high degree of mixing of pumice types. Much of this mixing occurred after discrete blocks of pumice had formed but before they were incorporated into discrete ash flows. A high vertical eruption column seems required to explain the characteristics of most of the caldera-associated ash-flow deposits of the Aleutian arc and specifically the early phases of the eruptions from Aniakchak and Fisher calderas. A high vertical eruption cloud may provide extra momentum to ash flows by acting as a steep slope down which fallback material is fed directly into the ash flows, causing upslope movement of ash flows such as occurred near Aniakchak and Fisher calderas.

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