Geologic Studies in Alaska by the
U.S. Geological Survey, 1997
U.S. Geological Survey Professional Paper 1614

Alagogshak Volcano: A Pleistocene Andesite-Dacite Stratovolcano in Katmai National Park

By Wes Hildreth, Judy Fierstein, Marvin A. Lanphere, and David F. Siems

Abstract

Alagogshak volcano, a newly recognized volcanic-front stratovolcano on the Alaska Peninsula rangecrest, 15 km southwest of Katmai Pass, produced 10–18 km^3 of andesite-dacite eruptive products during several episodes of activity in the middle and late Pleistocene. From a central vent marked by hydrothermal alteration and remnants of a cratered fragmental cone on the present-day drainage divide, glacially incised stacks of lava flows (57–66 percent SiO_2) dip radially and extend 6–10 km in most directions. Lava flows that make up four ridge-capping outliers well west of the volcano may also have erupted there. The medium-K calcalkaline Alagogshak eruptive suite is compositionally varied, probably reflecting independent evolution of different magma batches supplied in several episodes spread intermittently over at least 600,000 years. In contrast, the exclusively Holocene andesite-dacite suite (59–64 percent SiO_2) produced by the Mount Martin cone, which is centered 3 km northeast of Alagogshak, yields far more coherent compositional trends.

Introduction

While studying the volcanoes of the Katmai cluster (fig. 1), we recognized a glacially eroded vent complex of Pleistocene age on the Alaska Peninsula drainage divide, 3 km southwest of the active crater of Mount Martin. Mapping in 1996 and 1997 demonstrated this vent to be the source of most of the glaciated lava flows nearby and showed Mount Martin to be a small, much younger edifice, constructed entirely during the Holocene. This note describes the remnants of what we call the Alagogshak volcano, estimates its original extent and volume, and compares the compositions of its eruptive products with those of nearby Mount Martin.

Glacially Eroded Ediface

Surviving remnants of Alagogshak volcano are mapped in figure 2. The high point today is a rounded ice-capped knob at an elevation of about 6,020 ft (1,835 m) on the rangecrest 12.5 km northeast of Kejulik Pass, 15 km southwest of Katmai Pass, and 95 km southeast of the town of King Salmon (fig. 1). This summit forms the east rim of a glacially gutted vent complex, from which lavas flowed north toward Angle Creek, south into the forks of Kejulik River, and southeast into Alagogshak Creek.

The vent is an area of focused hydrothermal alteration about 800 m wide, now hollowed out as a cirque-amphitheater (fig. 3) occupied by a northwest-draining glacier. Preserved along its south rim (the present rangecrest) are outward-dipping agglutinates, beds of coarse scoria (57–58 percent SiO_2), and poorly sorted layers of phreatomagmatic ejecta rich in dense glassy blocks. Preserved along the north rim of the cirque (fig. 3) are part of the fumarolically acid altered core, a remnant of the old crater rim draped by stratified ejecta that dip both inward and outward, and an effusive lava flow of black glassy dacite (63.7 percent SiO_2) that dips 20° NW. and is as thick as 140 m.

Stacks of lava flows that dip radially away from the vent region are well preserved in four main sectors (fig. 2). In all sectors, the lavas were emplaced onto a ruggedly incised glacial terrain that had more than 1,200 m of local relief, cut entirely into subhorizontal siltstone and sandstone of the Jurassic Naknek Formation (Riehle and others, 1993). To the south, at the head of the east fork of Kejulik River, a set of glaciated benches that steps down from the summit to an elevation as low as 1,500 ft (450 m) consists of a stack of at least seven andesitic lava flows (57–63 percent SiO_2), which range from 10 to 30 m thick. At their present-day distal extremity, canyon-wall remnants of these flows range in elevation from 1,500 ft to as high as 2,300 ft (700 m), indicating that the stack was once at least 250 m thick there and suggesting that intracanyon lava flows formerly extended much farther downstream.

To the southwest, the Kejulik River cleaver is a stack of about 20 andesite-dacite lava flows (fig. 4) that dip gently away from the vent and range from 8 to 40 m thick and from 58 percent to 66 percent SiO_2. The greatest thickness of the stack preserved is 950 ft (300 m). One of the lavas thickens southward as a formerly intracanyon flow as thick as 80 m that today forms a sinuous interfluve along the east wall of the main Kejulik River (fig. 2), where its lowest basal elevation is 1,300 ft (400 m).

To the northwest, two glaciated lava-flow stacks of different ages face each other across the outlet gorge that drains the

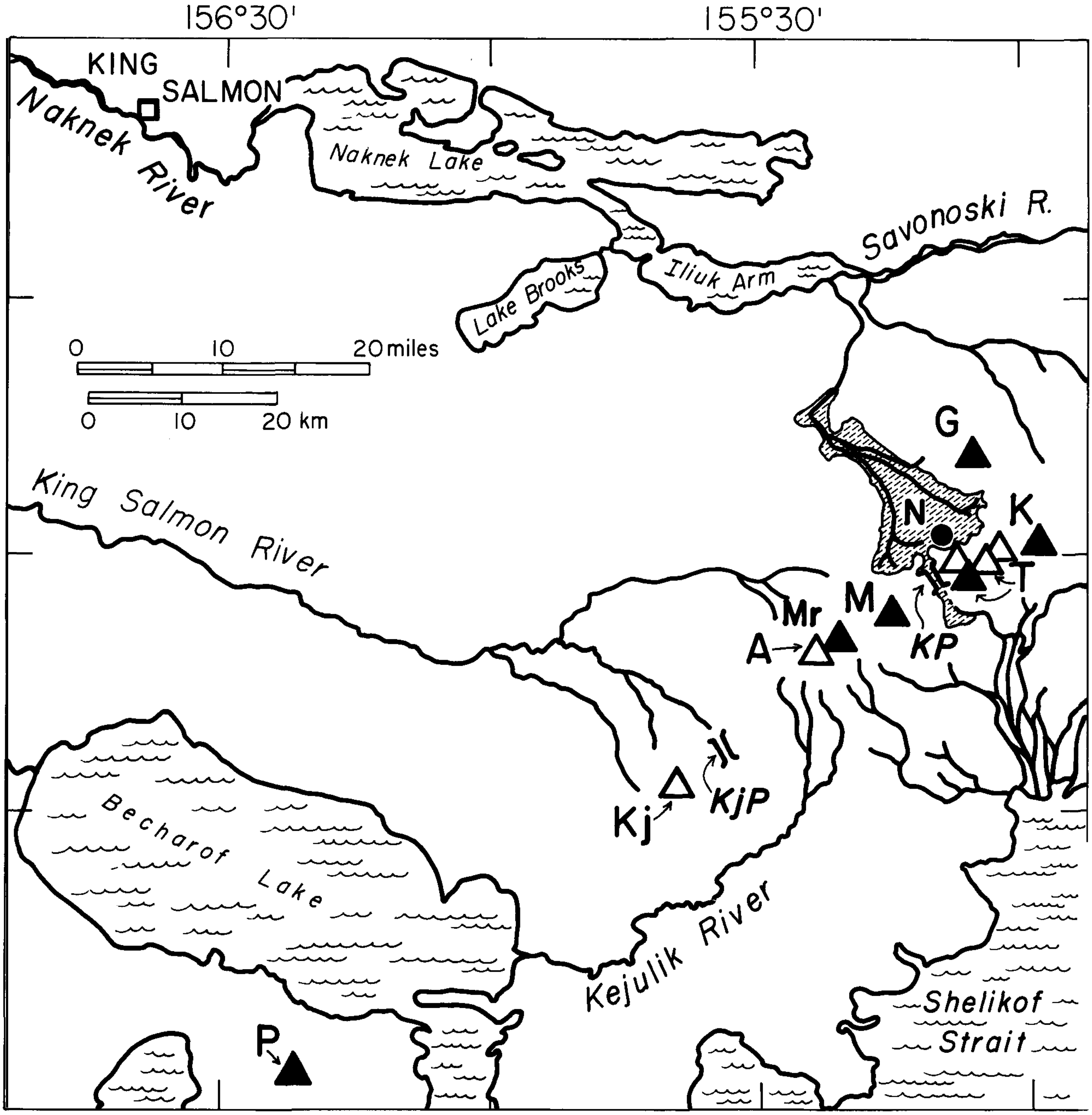

Figure 1. Map showing part of the stratovolcanic chain along the Alaska Peninsula, southeast of the town of King Salmon. Solid triangles indicate cones active during the Holocene; open triangles indicate Pleistocene cones long extinct. The Katmai volcanic cluster includes Alagogshak (A), Martin (Mr), Mageik (M), Griggs (G), Trident (T; three extinct cones and one recently active cone), and Mount Katmai (K). Farther southwest are Kejulik (Kj) and Peulik (P) volcanoes. Solid circle (N) indicates Novarupta, site of the great explosive eruption of 1912, when ignimbrite (shaded valley fill) was emplaced in the Valley of Ten Thousand Smokes (Hildreth, 1983). Low points along the volcanic axis, which here forms the Alaska Peninsula drainage divide, include Katmai Pass (KP) and Kejulik Pass (KjP).

vent-cirque glacier toward Angle Creek. Today, both stacks reach about 6 km from the vent, dipping 5"–10" NNW., but they originally extended many kilometers farther. The western (older) stack is a set of three or four andesite flows (60–63 percent SiO_2), each 50 to 125 m thick, that widely exhibit basal colonnades and thick entablatures of slender glassy columns that suggest ice-contact emplacement. The eastern stack begins with three dacite lava flows (each 64 percent SiO_2), one of which is 200 m thick, glassy, columnar, probably englacial, and descends to a basal elevation as low as 1,900 ft (580 m)—about 90 m lower than the nearby older stack. The dacites are overlain proximally by three or four more andesite-dacite lava flows (58–64 percent SiO_2) that are extensively covered by ice and till but include the thick crater-rim dacite illustrated in figure 3.

To the southeast, a single thick glassy andesite lava flow (61 percent SiO_2) descended steeply from the rangecrest and spread into Alagogshak Creek, where it now forms a glacially scoured plateau. Its base is today as low as 1,500 ft (450 m), but because the flow thickens to more than 100 m at its distal extremity, it must have extended much farther downstream prior to glacial excavation.

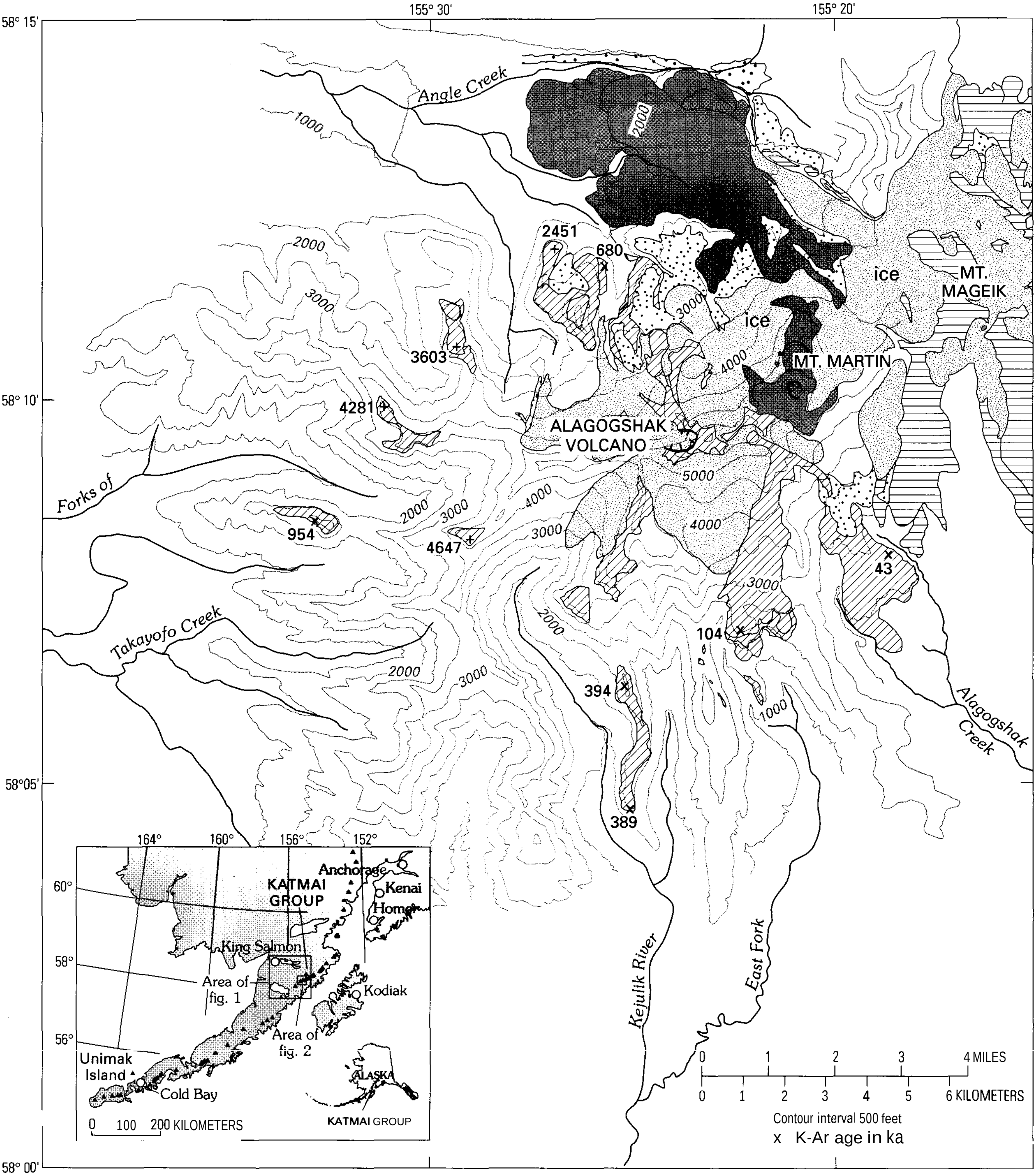

Figure 2. Distribution of Holocene eruptive products of Mount Martin (dark shading) and glacially eroded Pleistocene lavas of Alagogshak volcano (diagonal pattern). Their craters are indicated by hachures. Also shown is the western half of Mount Mageik (horizontal pattern) and various glacial deposits (stippled pattern). Pale shading is glacial ice, and uncolored regional basement is Jurassic Naknek Formation (plus scattered surficial deposits and a few Tertiary intrusive rocks, not indicated). Elevations (+) in feet (1 m=3.28 ft). Locations of samples dated by K-Ar method (table 1, this report; Shew and Lanphere, 1992) are indicated by "X" accompanied by age (in ka). Topographic base simplified from USGS 1:63,360 quadrangles Mt. Katmai A-4 and A-5.

Western Outliers

In addition to the four unequivocal outflow sectors just described, four craggy outliers of ridge-capping andesite 6–10 km west of the Alagogshak vent (fig. 2) may also have erupted there.

The northernmost outlier, at peak 3603 on the divide between tributaries of Angle Creek, consists of three, gently northwest dipping, andesite lava flows (57–61 percent SiO_2), each as thick as 100 m. Thick flow-breccia and glassy columnar zones suggest ice-contact emplacement. The southernmost (and

Figure 3. View northward from south-rim rangecrest across vent area of Alagogshak volcano, glacially gutted to produce an 800-m-wide cirque-amphitheater that opens to the northwest (left). Acid-altered crater-fill forms lower wall beyond ice. Black ridge is part of a 140-m-thick dacitic outflow lava (samples K-2089, 2089A) that dips 20° NW. (left). Knob 5290 at upper right is a crater-rim remnant, across which stratified ejecta drape both inward and outward.

Figure 4. Stack of twelve andesite lava flows (exposed above the ice) along upper part of Kejulik cleaver, at elevation 4,900–5,150 ft, 3 km southwest of the Alagogshak vent. View toward the northeast. As many as eight more flows, stratigraphically lower in the stack, form basal part of the cleaver (behind the camera).

smallest) of the outliers, capping peak 4647 on the divide between Kejulik River and Takayofo Creek, is a single lava flow of silicic andesite (62 percent SiO_2) as thick as 200 m. Between them, on the Takayofo-Angle Creek divide, a third outlier consists of coarse flow-breccia and four lava flows, three of which are atypically mafic (52–53 percent SiO_2) for Alagogshak and unusually rich in big clinopyroxene and plagioclase phenocrysts. Overlying these on the northwestern spur of the outlier (peak 4281), the fourth lava consists of a 100-m-thick flow of ordinary Alagogshak-type andesite (58 percent SiO_2). Finally, the fourth and westernmost outlier, which caps the ridge dividing two tributaries of Takayofo Creek (fig. 2), consists of a single phenocryst-rich andesite lava flow (61–62 percent SiO_2) as thick as 200 m. Shew and Lanphere (1992) reported a K-Ar age of 954±109 ka for plagioclase separated from this flow.

Basal contacts of the outliers dip gently away from the Alagogshak center, except for the westernmost outlier, which is subhorizontal. As each of the four remnants rests upon Jurassic sedimentary rocks along low-angle contacts that are now perched 300–600 m above the floors of adjacent glacial valleys, it is clear on physiographic grounds that all the outliers are relatively old. No other source vent or dike has been recognized, however, between Alagogshak volcano and the still older Kejulik stratocone, 21 km farther southwest (Riehle and others, 1993; Shew and Lanphere, 1992). Our favored but inconclusive inference is that the lava flows of the outliers, at least most of them, represent eruptive phases of Alagogshak volcano older than the episodes that produced the andesites and dacites in the four more proximal sectors described above.

Geochronology

K-Ar ages were measured for whole-rock samples of andesitic lava flows in three of the proximal sectors described (table 1), employing the multiple-collector mass spectrometer at the U.S. Geological Survey (USGS) in Menlo Park (Stacey and others, 1981) and following the methods described by Hildreth and Lanphere (1994). Plagioclase K-Ar ages were reported previously by Shew and Lanphere (1992) for lava flows in the fourth sector, as well as for the old, westernmost outlier.

In the older stack of andesite lavas in the northwest sector, the basal flow (resting on Jurassic strata) gives an age of 680±20 ka. To the south, the top flow of the stack of seven andesite lavas at the head of the east fork of Kejulik River yields an age of 104±10 ka. To the southeast, the thick plateau-forming andesite lava flow at the head of Alagogshak Creek gives an age of 43±8 ka. All three nonglassy whole-rock samples provided satisfactory yields of radiogenic argon (6–13 percent $^{40}Ar^{*}$; table 1), permitting high-precision age determinations.

In the southwest sector, plagioclase separated from two of three andesite-dacite lava flows that make up the sinuous remnant of an intracanyon stack along the main fork of Kejulik River provided accordant ages of 394±46 ka and 389±71 ka (Shew and Lanphere, 1992). Finally, Shew and Lanphere (1992) measured an age of 954±109 ka for plagioclase from the crystal-rich andesite that makes up the westernmost outlier (fig. 2).

The apparent longevity of more than 600 k.y. (or 900 k.y. if the westernmost outlier did indeed erupt from the Alagogshak center) is greater than that of many andesite-dacite stratovolcanoes, but it is not extraordinary. In the Cascade arc, for example, high-precision K-Ar measurements in our Menlo Park laboratory indicate that the Adams, Baker, Hood, Lassen, Mazama, and Rainier volcanic centers have erupted intermittently for comparably long periods of time. Owing in part to its modest eruptive volume, however, the longevity of volcanism at Alagogshak seems to require that long periods of repose separated its episodes of eruptive activity.

Eruptive Volume

Much of Alagogshak volcano has been erosively stripped. Rapid rates of erosion have been promoted by Pleistocene expansions of glacial ice that repeatedly covered most of the Alaska Peninsula (Riehle and Detterman, 1993). Areas still covered by products of the Alagogshak center thus sum to less than 20 km^2, less even than the area (33 km^2) covered by the postglacial products of Mount Martin (fig. 2). Distribution of the remnants shown in figure 2 clearly indicates, however, that the area originally covered by Alagogshak lavas was at least 60 km^2 and, if the western outliers and distal intracanyon lava tongues are included, perhaps as much as 90 km^2.

Volume reconstruction is somewhat less certain. Because the central vent of Alagogshak straddles a rangecrest arête of Jurassic sandstone that today extends (at 1,550–1,620 m elevation) for more than 4 km west of its 1,835-m summit, it is obvious that a cone model is inappropriate for the volume calculation. From a modest vent cone perched on a basement high, lavas flowed steeply outward into cirques and valleys to the north, south, and west. Judging by the rim-draping fall and surge

Table 1. Whole-rock potassium-argon ages and analytical data.

[Analysts: potassium by D.F. Siems; argon by F.S. McFarland and J.Y. Saburomaru (Menlo Park, Calif.). Constants: $\lambda_\varepsilon = 0.581 \times 10^{-10}\ y^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10}\ y^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol]

Sample number	Location (see fig. 2)	Weight percent SiO_2	Weight percent K_2O	Radiogenic ^{40}Ar 10^{-13}mol/g	Radiogenic ^{40}Ar Percent	Calculated age
K-2049	Alagogshak Creek: Plateau-forming lava flow, 2,300 ft	61.1	1.644±0.008	1.007	6.0	43±8 ka
K-2135	Kejulik River, East Fork: Top lava of stack at 2,500 ft rim	57.7	1.580±0.004	2.369	9.0	104±10 ka
K-2074	Angle Creek, SE. Fork: Basal lava flow, W. wall of gorge at 2,300 ft	60.0	1.419±0.001	13.90	13.3	680±20 ka

deposits preserved on remnants of the crater walls (fig. 3), the vent cone is unlikely to have been more than 100–200 m higher than the present summit. By comparison, the present-day active crater of Mount Martin is about 225 m deep and the crater of Mount Mageik only about 100 m. Conservatively, then, if we assume original thicknesses of only 500 m for the perched vent region and an ***average*** of 250 m for the flanking stacks of outflow lavas, we estimate 10–13 km^3 for the Alagogshak edifice—or 13–18 km^3 if all the western outliers are assigned to Alagogshak. This is much larger than our estimate for modem Mount Martin (7 km^3) but far less voluminous than for nearby Mageik (30 km^3) and Griggs (20–25 km^3) volcanoes. No evidence has been found of voluminous tephra that might add appreciably to Alagogshak's eruptive volume, nor would the former existence of much glacially stripped fallout be expected on the basis of the generally low explosivity eruptive products preserved.

Mount Martin

Mount Martin is a small Holocene successor volcano that barely overlaps the northeastern edge of the glaciated Alagogshak edifice. Its inception postdates the last known activity at Alagogshak by about 30,000 years (table 1), and its fumarolically active crater lies 3 km northeast of the ravaged central vent of Alagogshak. Mount Martin consists of a small fragmental cone and, descending 10 km northwestward, a staircase of 10 overlapping coulees of blocky dacite, each 75–100 m thick. Although its summit exceeds 6,100 ft (1,860 m) in elevation, the 2-km-wide cone itself has local relief of only 500 m, owing to its construction (like Alagogshak) upon a high ridge of Jurassic basement rocks. Of the total eruptive volume estimated for Mount Martin (7 km^3), the small cone thus makes up less than 5 percent and the 31-km^2 lava-flow field about 95 percent (fig. 2). Scoriaceous and massive glassy (phreatomagmatically ejected) blocks of the cone are andesitic (58.9–61 percent SiO_2), whereas the sequence of coulees is largely dacitic (62.5–64.2 percent SiO_2; table 2). Despite its high ring of active glaciers (fig. 2), erosion of the cone and coulees is insignificant, indicating that Mount Martin is a Holocene volcano in its entirety. The glaciated lava flows adjacent to Martin's western flank are readily distinguishable, chemically and stratigraphically, as having erupted at Alagogshak volcano. The cone of Mount Martin is marked by a persistent steam plume derived from as many as 20 vigorous fumaroles that are precipitating sulfur in the talus northwest of a shallow acid lake on the floor of its 300-m-wide crater.

Composition of Eruptive Products

Nearly all lava flows from Mount Martin and most of the exposed flows surviving at Alagogshak were sampled, as were glassy blocks of juvenile ejecta from the rims of both craters. Major-element determinations by X-ray fluorescence spectroscopy are given in table 2 and illustrated in figure 5. Essentially all samples from both volcanoes are plagioclase-rich two-pyroxene andesites and dacites, all of which also carry Fe-Ti-oxide rnicrophenocrysts, but none of which contain amphibole, biotite,

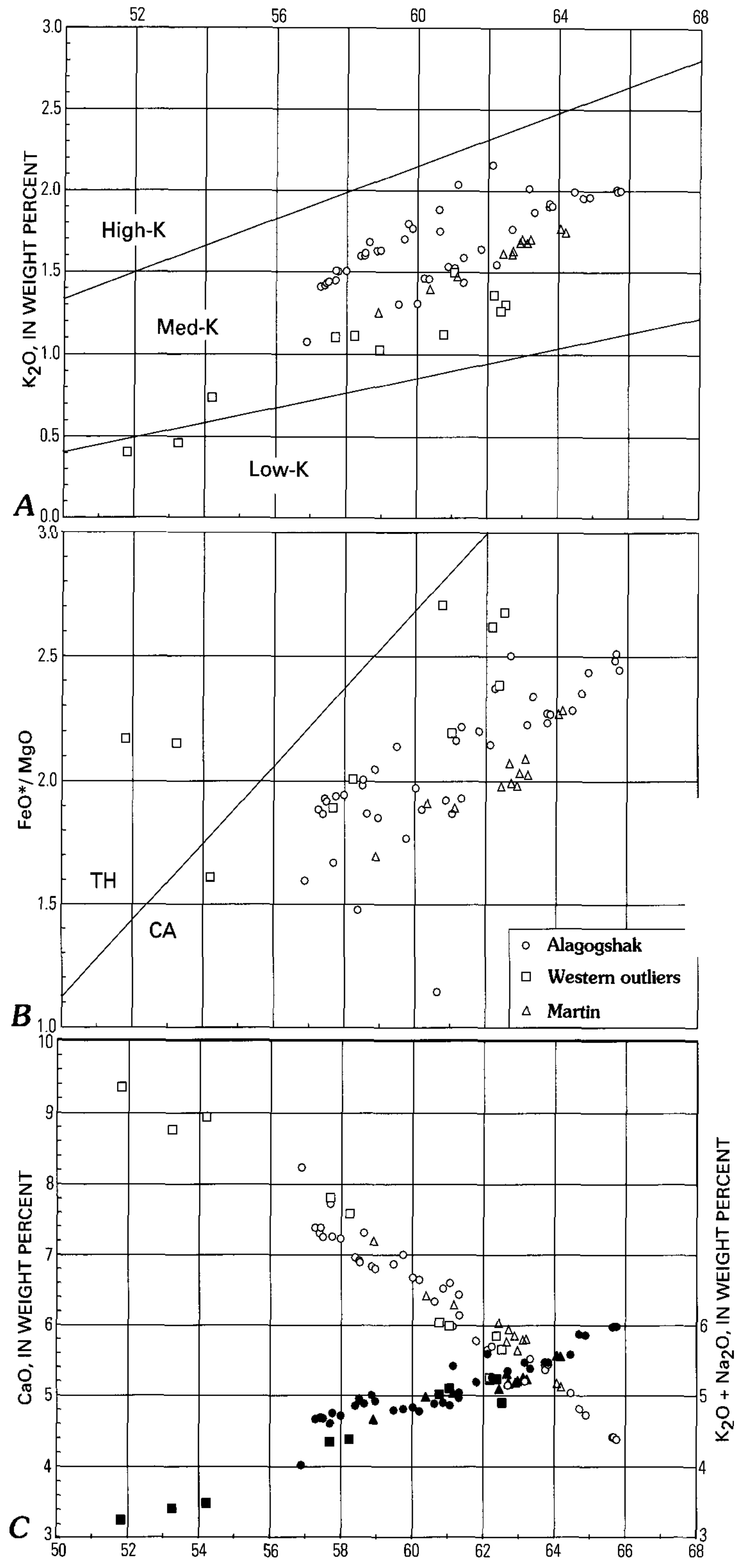

Figure 5. Whole-rock compositional data for Alagogshak and Martin volcanoes and the western outliers: *A*, K_2O vs. SiO_2; *B*, FeO^*/MgO vs. SiO_2; *C*, ($K_2O + Na_2O$) (closed symbols) and CaO (open symbols) vs. SiO_2. TH/CA is conventional boundary between tholeiitic and calcalkaline suites in panel *B*. FeO^* is total iron calculated as FeO.

Table 2. Chemical analyses of eruptive products.

[The ten major oxides are normalized to H_2O-free totals of 99.6 weight percent (allowing 0.4 weight percent for trace oxides and halogens). Determinations by wavelength-dispersive X-ray fluorescence in USGS laboratory at Lakewood, Colo.; D.F. Siems, analyst. "FeO*" is total iron calculated as FeO. "Original total" is the volatile-free sum of the ten oxides, as analyzed, before normalization, with total iron calculated as Fe_2O_3. LOI, weight percent loss on ignition at 900°C]

Sample no.	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Original total (dry)
					ALOGOGSHAK VOLCANO							
K-2049	61.1	0.70	16.1	6.55	0.13	3.50	6.60	3.33	1.53	0.15	0.13	99.40
2049-i	56.9	0.72	16.7	7.83	0.15	4.90	8.24	2.94	1.08	0.15	0.56	98.66
2074	60.0	0.73	17.1	6.63	0.14	3.36	6.68	3.52	1.31	0.17	0.51	98.58
2075	62.2	0.67	16.5	6.31	0.12	2.66	5.70	3.71	1.55	0.17	0.31	98.81
2076	62.7	0.70	16.4	6.44	0.13	2.57	5.15	3.58	1.76	0.15	0.81	98.43
2077	60.2	0.66	16.4	6.93	0.14	3.67	6.65	3.31	1.46	0.15	0.24	98.72
2078	60.6	0.64	14.7	6.46	0.13	5.65	6.34	3.00	1.88	0.17	1.55	97.77
2079	61.3	0.68	16.6	6.59	0.13	2.97	6.14	3.60	1.44	0.17	0.56	98.41
2080	61.8	0.67	16.3	6.60	0.13	3.00	5.78	3.55	1.64	0.17	0.72	98.49
2081	64.5	0.69	15.4	5.67	0.11	2.48	5.04	3.59	1.99	0.15	0.12	98.85
2082	63.7	0.69	15.6	5.86	0.12	2.62	5.36	3.55	1.92	0.16	0.51	98.39
2083	63.8	0.69	15.6	5.75	0.11	2.54	5.44	3.56	1.90	0.15	0.02	99.23
2087	62.1	0.76	16.0	6.27	0.12	2.92	5.65	3.43	2.16	0.19	-0.03	99.31
2088	58.6	0.73	16.4	7.40	0.14	3.96	7.31	3.20	1.68	0.18	0.02	99.11
2089	63.7	0.69	15.6	5.83	0.11	2.56	5.43	3.57	1.90	0.16	0.00	99.18
2089-A	63.3	0.71	15.7	6.07	0.12	2.60	5.52	3.51	1.87	0.16	0.11	98.92
2099	59.0	0.77	16.7	7.25	0.14	3.91	6.80	3.29	1.63	0.18	0.06	99.03
2100	59.8	0.74	16.2	6.86	0.14	3.88	7.01	3.01	1.80	0.18	1.34	97.60
2102	58.5	0.81	17.1	7.34	0.14	3.70	6.92	3.35	1.60	0.19	0.09	98.99
2103	57.3	0.80	17.2	7.79	0.14	4.13	7.39	3.25	1.41	0.18	0.22	99.04
2104	57.4	0.80	17.4	7.61	0.14	3.94	7.39	3.26	1.43	0.19	0.15	98.86
2105	57.8	0.79	17.1	7.66	0.14	3.95	7.26	3.24	1.50	0.18	0.24	98.76
2106	61.2	0.77	16.1	6.72	0.13	3.11	5.99	3.38	2.04	0.19	1.20	97.74
2107	58.9	0.82	16.9	7.28	0.13	3.55	6.83	3.37	1.63	0.19	0.24	98.77
2108	57.4	0.80	17.3	7.68	0.14	4.11	7.31	3.27	1.42	0.19	0.26	98.99
2109	63.2	0.69	16.3	5.84	0.11	2.62	5.20	3.45	2.02	0.18	0.74	98.32
2110	57.5	0.81	17.3	7.72	0.14	4.02	7.26	3.23	1.44	0.18	0.30	98.93
2111	58.0	0.80	17.1	7.57	0.14	3.89	7.23	3.20	1.51	0.18	0.25	98.67
2112	58.5	0.80	17.0	7.43	0.14	3.71	6.90	3.31	1.62	0.19	0.26	98.87
2120	64.7	0.63	15.7	5.33	0.12	2.27	4.81	3.91	1.95	0.18	0.01	99.27
2121	65.6	0.61	15.5	5.08	0.12	2.05	4.42	3.97	2.01	0.17	0.14	98.96
2122	59.5	0.70	17.1	7.04	0.14	3.29	6.87	3.49	1.30	0.19	0.81	98.55
2123	58.4	0.75	16.2	7.23	0.14	4.90	6.96	3.25	1.60	0.17	0.76	98.63
2124	65.8	0.60	15.6	4.99	0.12	2.04	4.38	3.98	2.00	0.17	0.15	99.01
2125	65.7	0.60	15.7	4.94	0.12	1.97	4.42	3.99	2.00	0.18	0.23	99.13
2135	57.7	0.73	16.3	7.66	0.14	4.58	7.72	3.15	1.45	0.18	0.15	98.54
2140	64.9	0.62	15.8	5.26	0.12	2.16	4.72	3.90	1.96	0.18	0.19	99.00
2141	60.9	0.69	16.4	6.53	0.13	3.39	6.53	3.36	1.53	0.15	0.59	98.91
2142	61.3	0.70	16.1	6.49	0.12	3.36	6.44	3.38	1.59	0.15	0.11	99.07
2259	60.6	0.75	16.6	6.70	0.14	3.24	6.31	3.31	1.75	0.21	0.84	98.27
2260	59.9	0.75	16.7	6.90	0.14	3.44	6.63	3.20	1.77	0.23	0.90	98.34
2261	59.6	0.75	16.6	7.13	0.14	3.46	6.82	3.18	1.70	0.20	0.82	98.45
2262	57.7	0.76	16.7	7.53	0.14	4.32	7.56	3.16	1.51	0.22	0.03	100.00
2263	60.3	0.70	16.9	6.56	0.13	3.21	6.84	3.33	1.46	0.17	0.27	98.77

quartz, or sanidine. Microdioritic blebs and clots, predominantly made up of pyroxene and plagioclase but generally containing a little glass, are common in the products of both centers. Some of the andesites that have less than 59 percent SiO_2 additionally carry a little olivine, as do mafic magmatic inclusions present in some Alagogshak lavas.

Thirteen samples from Mount Martin range from 58.9 percent to 64.2 percent SiO_2 and plot rather tightly (fig. 5) relative to the scattered compositional arrays for 44 samples from the long-lived Alagogshak center (54.2–65.8 percent SiO_2). All samples from both volcanoes fall in the medium-K field (fig. 5*A*), and both suites define calcalkaline differentiation trends

Table 2. Chemical analyses of eruptive products — Continued.

Sample no.	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Original total (dry)
ALOGOGSHAK VOLCANO — Western outliers, north												
K-2085	61.0	0.69	16.7	6.71	0.14	3.06	5.99	3.60	1.50	0.17	0.25	99.12
2085-i	54.2	0.63	19.9	7.48	0.15	4.65	8.95	2.75	0.74	0.14	0.98	98.45
2086	57.7	0.74	17.1	7.55	0.16	3.99	7.81	3.24	1.10	0.18	0.78	98.22
2253	58.9	0.64	17.2	6.98	0.14	3.67	7.63	3.16	1.03	0.17	0.12	99.53
ALOGOGSHAK VOLCANO — Western outliers, middle												
K-2168	58.2	0.72	17.2	7.47	0.15	3.72	7.58	3.27	1.11	0.18	0.21	99.23
2254	53.2	0.90	18.0	10.20	0.18	4.74	8.76	2.96	0.46	0.19	0.01	99.01
2255	51.8	0.92	18.3	10.66	0.20	4.91	9.36	2.85	0.40	0.16	-0.09	99.12
ALOGOGSHAK VOLCANO — Western outliers, south												
K-2257	62.2	0.73	16.5	6.76	0.14	2.58	5.25	3.86	1.36	0.22	2.72	95.72
2258	62.5	0.71	16.3	6.65	0.14	2.49	5.65	3.59	1.30	0.21	3.34	94.90
ALOGOGSHAK VOLCANO — Western outliers, westernmost												
K-2169	62.4	0.70	17.2	5.60	0.13	2.35	5.84	3.97	1.27	0.21	1.14	98.10
2256	60.8	0.74	17.0	7.07	0.16	2.61	6.04	3.89	1.12	0.21	0.27	98.08
MOUNT MARTIN												
K-2066	63.1	0.67	15.8	5.88	0.12	2.82	5.79	3.58	1.67	0.15	0.16	99.37
2067	62.4	0.66	16.0	6.04	0.12	3.05	6.03	3.48	1.61	0.15	0.04	99.25
2068	62.7	0.66	16.0	5.88	0.12	2.94	5.94	3.53	1.63	0.15	-0.05	99.31
2090	64.2	0.69	15.7	5.63	0.12	2.47	5.13	3.80	1.75	0.15	0.16	98.89
2093	63.2	0.65	15.7	5.83	0.12	2.87	5.79	3.53	1.70	0.15	-0.01	99.17
2094	62.9	0.68	15.7	5.97	0.12	3.01	5.85	3.52	1.67	0.15	0.24	98.85
2095	63.0	0.66	16.1	5.90	0.12	2.90	5.63	3.51	1.69	0.14	0.51	98.72
2096	62.7	0.65	16.1	5.86	0.12	2.93	5.94	3.56	1.62	0.15	0.19	99.00
2097	62.7	0.69	16.1	5.98	0.12	2.89	5.76	3.70	1.61	0.15	0.05	98.97
2098	60.4	0.73	16.5	6.73	0.13	3.52	6.42	3.59	1.39	0.17	-0.03	99.30
2115	61.2	0.72	16.2	6.46	0.13	3.42	6.29	3.56	1.47	0.17	-0.13	99.52
2170	64.1	0.67	15.8	5.59	0.12	2.47	5.17	3.80	1.76	0.15	0.12	99.16
2333	58.9	0.73	16.7	6.99	0.14	4.12	7.20	3.41	1.25	0.16	0.36	98.30

(fig. 5*B*). Alkali-lime intersections at 63–63.5 percent SiO_2 (fig. 5*C*) define calcic suites for both Alagogshak and Martin, similar to the zoned suite ejected at nearby Novarupta in 1912 (Hildreth, 1983).

The rocks of both volcanoes are typically low-Ti arc suites, most having TiO_2 contents of only 0.60–0.82 percent; the two most mafic samples (K-2254, K-2255, both from the middle outlier) have 0.90–0.92 percent TiO_2. Relatively primitive material has not erupted here, as all but one sample represents magma that had evolved to less than 5 percent MgO. Contents of Al_2O_3 are mostly <17.5 percent, although the three samples lowest in SiO_2 (fig. 5; all from the western outliers) have higher Al_2O_3 values of 18.0–19.9 percent.

Relatively mafic magmatic inclusions, generally finer grained than the host lava and typically 1–10 cm across, are common in a few Alagogshak lava flows, are sparse to absent in most, and were not found in products of Mount Martin. The two such inclusions analyzed (samples K-2049-i and K-2085-i) are among the least silicic (56.9 percent; 54.2 percent SiO_2) eruptive products sampled here.

Two subparallel trends are conspicuous for Alagogshak data in the K_2O-SiO_2 panel (fig. 5*A*), one suite having about 0.4 weight percent more K_2O than the other at any given SiO_2 content. The suite higher in K_2O includes (a) near-vent scoria; (b) 11 of 12 samples from the southerly (East Fork) sector; (c) 4 of 10 samples from the southwesterly (Kejulik cleaver) sector; and (d) 5 of 16 samples from the northwesterly (Angle Creek) sector. On the other hand, the trend lower in K_2O includes the southeasterly (Alagogshak Creek) lobe, all lavas of the western outliers, and the entire Holocene suite from Mount Martin, as well as many lavas of the Kejulik cleaver and Angle Creek sectors (fig. 5*A*). No mineralogical difference is recognized between the lavas lower and higher in K_2O, which are interstratified without any consistent age distinction. Lavas lower in K_2O include those dated at 954 ka, 680 ka, 389 ka, and 43 ka, as well as the crater-rim dacite (fig. 3) and all the postglacial products of Mount Martin.

The sample richest in MgO (K-2078; 5.65 percent MgO), which stands out from the rest in figure 5B by virtue of its low FeO/MgO ratio, is anomalous also in its relative Al_2O_3 deficiency (14.7 percent Al_2O_3; table 2). The sample is an olivine-bearing, plagioclase-rich, two-pyroxene andesite (60.6 percent SiO_2) belonging to the suite higher in K_2O and does not appear in thin section to be olivine-accumulative. It is from the basal colonnade of a 75-m-thick flow that makes up ridge 2451 at the northwest limit of the Angle Creek sector.

Resting on Jurassic sandstone, this flow is likely to be one of the oldest in the sector.

Conclusions

The simple central-vent Alagogshak stratovolcano produced 10–18 km^3 of eruptive products, mostly andesite-dacite lava flows, in several eruptive episodes spread widely over at least 600,000 years. About two-thirds of the Alagogshak volcano has already been stripped by glacial erosion, even though substantial lava production took place as recently as 43±8 ka. The eruptive focus shifted in the Holocene to Mount Martin, 3 km northeast. In contrast to the coherent compositional arrays for eruptive products of Mount Martin, the variety of compositions erupted at Alagogshak probably reflects independent evolution of successive magma batches that arose at widely separated intervals in its long history.

Like Alagogshak, the adjacent volcanic-front edifice to the southwest, Kejulik volcano (fig. 1), is apparently now extinct (Riehle and others, 1993; Shew and Lanphere, 1992). This leaves a 76-km-long inactive gap along the front between the Holocene cones of Mount Martin and Mount Peulik (fig. 1). So lengthy a gap accentuates the anomaly of the adjacent Katmai cluster (Hildreth, 1983), where the recently active Martin, Mageik, Trident, Griggs, and Katmai stratovolcanoes are all closely spaced along a 25-km reach of the volcanic arc.

Acknowledgments

Michelle Coombs and Dave Tucker contributed substantially to the fieldwork, Tracey Felger to the map preparation, Forrest McFarland to sample preparation, and James Saburomaru to the K-Ar dating. John Paskievitch arranged and anchored the sometimes difficult logistics, and pilot Paul Walters got us where we needed to go (fig. 4). Game McGimsey and Chris Nye provided helpful reviews of the manuscript.

References Cited

Hildreth, W., 1983, The compositionally zoned eruption of 1912 in the Valley of Ten Thousand Smokes, Katmai National Park, Alaska: Journal of Volcanology and Geothermal Research, v. 18, p. 1–56.

Hildreth, W., and Lanphere, M.A., 1994, Potassium-argon geochronology of a basalt-andesite-dacite arc system: The Mount Adams volcanic field, Cascade Range of southern Washington: Geological Society of America Bulletin, v. 106, p. 1413–1429.

Riehle, J.R., and Detterman, R.L., 1993, Quaternary geologic map of the Mount Katmai quadrangle and adjacent parts of the Naknek and Afognak quadrangles, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-2032, scale 1:250,000.

Riehle, J.R., Detterman, R.L., Yount, M.E., and Miller, J.W., 1993, Geologic map of the Mount Katmai quadrangle and adjacent parts of the Naknek and Afognak quadrangles, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-2204, scale 1:250,000.

Shew, N., and Lanphere, M.A., 1992, Map showing potassium-argon ages from the Mount Katmai and adjacent parts of the Naknek and Afognak quadrangles, Alaska Peninsula, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2021-E, scale 1:250,000.

Stacey, J.S., Sherrill, N.D., Dalrymple, G.B., Lanphere, M.A., and Carpenter, N.V., 1981, A five-collector system for the simultaneous measurement of argon isotope ratios in a static mass spectrometer: International Journal of Mass Spectrometry & Ion Physics, v. 39, p. 167–180.

Reviewers: Game McGimsey, Chris Nye.