

Age of Formation of Kaguyak Caldera, eastern Aleutian arc, Alaska, Estimated by Tephrochronology

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ABSTRACT

Kaguyak Crater is the only Holocene caldera on the Alaska Peninsula whose age of formation has not yet been determined. Datable materials in a dacitic block-and-ash-flow deposit around the caldera have been sought without success. However, tephra deposits at sites north and east of the caldera have been found that are mineralogically and chemically similar to the ash-flow deposits. These deposits can potentially provide an age by correlation, but a complication is that some Holocene pyroclasts of nearby Augustine Volcano are mineralogically and chemically similar to the Kaguyak deposits. Thus, source assignment of the distal Kaguyak-like tephra deposits has been uncertain.

We have found that the compositions of ilmenite grains in Kaguyak and Augustine lapilli are uniquely indicative of these sources and thereby provide a basis for inferring sources of the distal deposits. FeO and TiO₂ contents of ilmenite grains in most of the distal deposits plot in fields characteristic of either Kaguyak or Augustine. Deposits at two sites are a mixture of Kaguyak-like and Augustine-like grains; we interpret these deposits to be a mechanical mixture of ash from both volcanoes. Two such eruptions need not have been precisely synchronous because succeeding grainfalls even years apart can become mixed by freeze-thaw cycles and bioturbation.

Radiocarbon ages limit the mixed deposit to between 3,660±100 and 3,850±100 radiocarbon (RC) years at one site and 3,360±25 and 3,620±25 RC years at the second site. The proximal Kaguyak ash-flow deposit contains neither soils nor erosional unconformities to indicate that caldera formation comprised separate eruptive pulses, and the coincidence of two mixed deposits within centuries of one another seems unlikely. Consequently, we believe that the mixed deposits at the two sites are the same geologic age; the radiocarbon dates within limits of 1 sigma analytical uncertainty can be interpreted as a single age of about 3,600 years. An age of 3,600 years is significant because it adds to the list of major eruptions in the eastern Aleutian arc between 3,400 and 4,000 RC years ago. The cause of such an apparent pulse in eruptive activity is uncertain, but involvement of multiple vents across nearly 1,000 km of arc suggests a regional process such as glacial rebound or a plate-wide process such as a slight change in direction or rate of subduction.

INTRODUCTION

There are eight Quaternary collapse calderas in the eastern Aleutian volcanic arc (fig. 1). Two of these are historic (Katmai and Novarupta), two are Pleistocene in age (Emmons and Ugashik), and three others (Veniaminof, Black Peak, and

Aniakchak) have been dated by the radiocarbon method (Miller and Smith, 1987). Kaguyak Crater, the northernmost caldera, is the only caldera on the Alaska Peninsula whose age has not yet been determined. Attempts by ourselves and by Swanson and others (1981) to find datable materials in pyroclastic-flow deposits that surround the caldera have not been successful. Thus, while sampling Holocene tephra deposits on the Alaska Peninsula, we specifically sought airfall equivalents of the Kaguyak pyroclasts. It became apparent that as many as three tephra deposits in the region resembled the near-vent Kaguyak deposits, which raised the possibility that there had been multiple Kaguyak eruptions. But then we discovered that Augustine Volcano, 100 km north of Kaguyak Crater, had produced tephra during late Holocene time that is chemically and mineralogically indistinguishable from the Kaguyak proximal deposits. We have found, however, that the composition of ilmenite grains in these Holocene deposits uniquely distinguishes an Augustine source from a Kaguyak source, and we infer that there was only one caldera-forming eruption of Kaguyak for which an age can be determined.

ROCKS AND DEPOSITS OF KAGUYAK CRATER

Kaguyak Crater comprises the remains of an andesitic stratocone that was truncated by collapse of a caldera 2.0 km in diameter (now lake-filled) and intruded by dacitic domes at least in part after caldera formation (Swanson, 1990; Riehle and others, 1993). A dacitic pyroclastic-flow deposit emplaced during caldera formation—the proximal deposit—surrounds the vent and is roughly 1 km³ in volume (J. Riehle, unpub. data), which indicates a "moderate to large" eruption (volcano explosivity index, VEI, of 4; Newhall and Self, 1982). Subtle layering in the deposit is indicated by reversals in pumice and lithic concentrations, but there is no evidence for internal erosion or soil development (fig. 2). Fossil fumarole pipes are found only near the top of the deposit. Pumice lapilli throughout the deposit are uniformly high-silica dacite in bulk composition (67-70% SiO₂); no banded pumice has been found.

The total of the evidence indicates that the entire deposit was emplaced during a single eruptive event, not multiple events of geologically different ages. AVEI of 4 places the eruption roughly between those of Mount St. Helens and Pinatubo in size; there may have been precursory activity, but the main eruption probably occurred over 12 to 24 hours. Because the deposit is compositionally homogeneous, comparison of chemical compositions of distal ash samples with those of lapilli in the proximal deposit should be straightforward. The only reported date for the proximal deposit is a

radiocarbon age of 1,080 years¹ of soil closely atop the primary deposit (Swanson and others, 1981).

DISTAL AIRFALL (TEPHRA) DEPOSITS

Our tephra samples were collected during the course of regional sampling of Holocene tephra deposits on the Alaska Peninsula, and during a study of the eruptive history of Augustine Volcano. We can distinguish a subset of tephra samples from our larger set that are chemically and mineralogically similar to the Kaguyak proximal samples. Only these Kaguyak-like samples are discussed in this report.

Kaguyak-like tephra samples are from seven sites on the northern Alaska Peninsula, Afognak and Shuyak Islands, and southern Cook Inlet (numbered sites, fig. 3). Reference samples are samples from an unambiguous source to which fine-grained distal samples may be compared. Reference samples for Kaguyak Crater are two pumice lapilli from the ash-flow deposits and a composite sample of fine lapilli from proximal site 1 (25 km east of the vent). Reference samples for Augustine Volcano are three late Holocene lapilli from Augustine Island (R.B. Waitt, unpub. data) and composites of two deposits, one coarse ash and the other fine lapilli, at proximal site 7 (25 km northwest of the vent). Assignment of

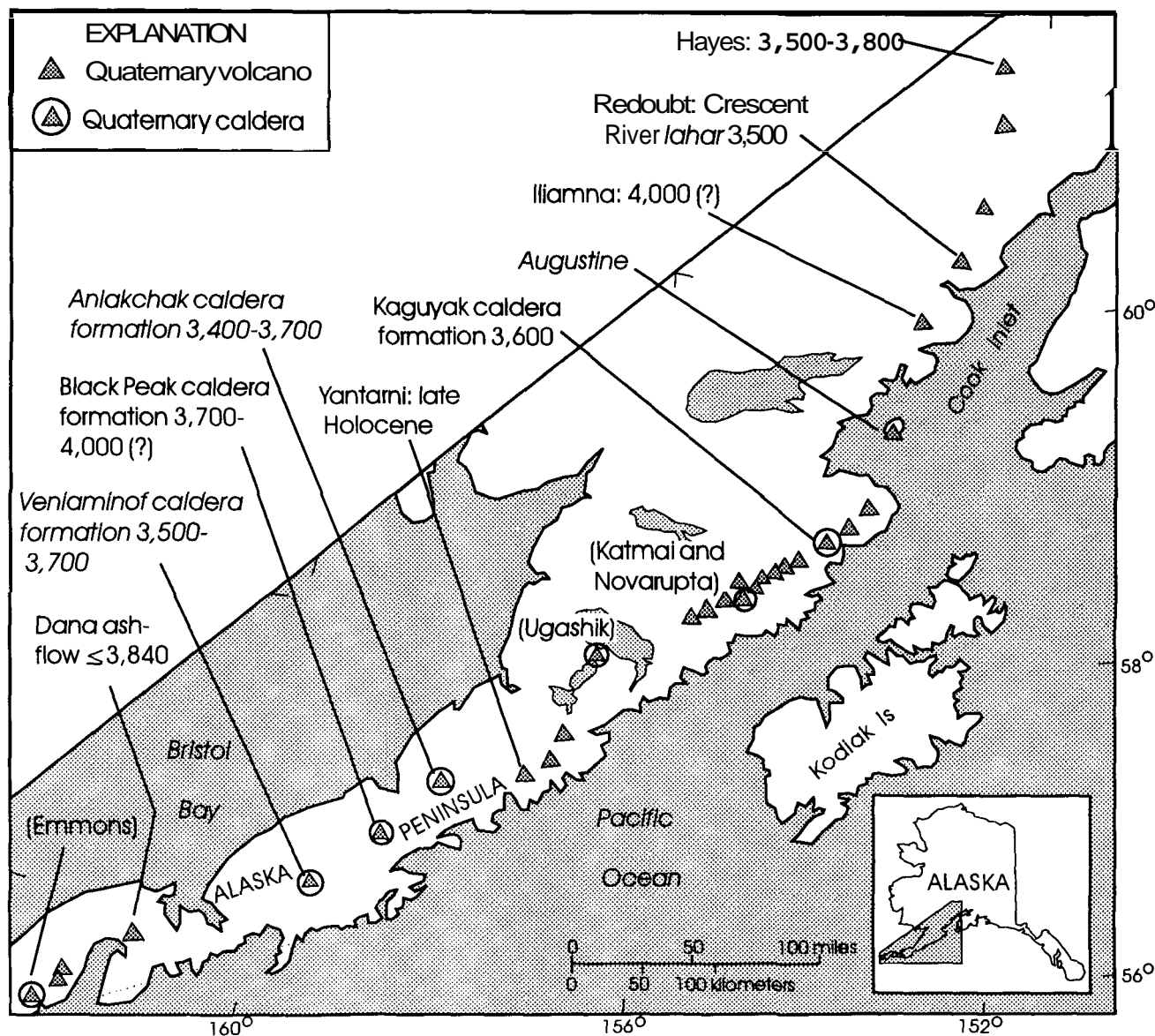


Figure 1. Quaternary volcanoes in the Alaska Peninsula segment of the Aleutian volcanic arc. Veniaminof, Black Peak, Aniakchak, and Kaguyak calderas formed during the period from 3.4 to 4.0 ka (uncorrected radiocarbon years), and Hayes, Redoubt, Iliamna, Augustine, Yantarni(?), and Dana had significant eruptions during the same period. Names of calderas that formed at times other than 3.4-4.0 ka are in parentheses. Radiocarbon ages (b.p.) of significant eruptions during the period 3.4-4.0 ka are shown; italics indicate volcanoes that also had other significant eruptions during Holocene time. Sources of ages: Hayes, Riehle (1985) and Riehle and others (1990); Redoubt, Riehle and others (1980); Iliamna, T.P. Miller, USGS, written commun., 1996; Augustine and Kaguyak, this paper; Yantarni, Riehle and others (1987); Aniakchak, Black Peak, and Veniaminof, Miller and Smith (1987) and Riehle, unpub. data; Dana, Yount (1990).

¹All quantitative ages reported herein are in uncalibrated radiocarbon years.

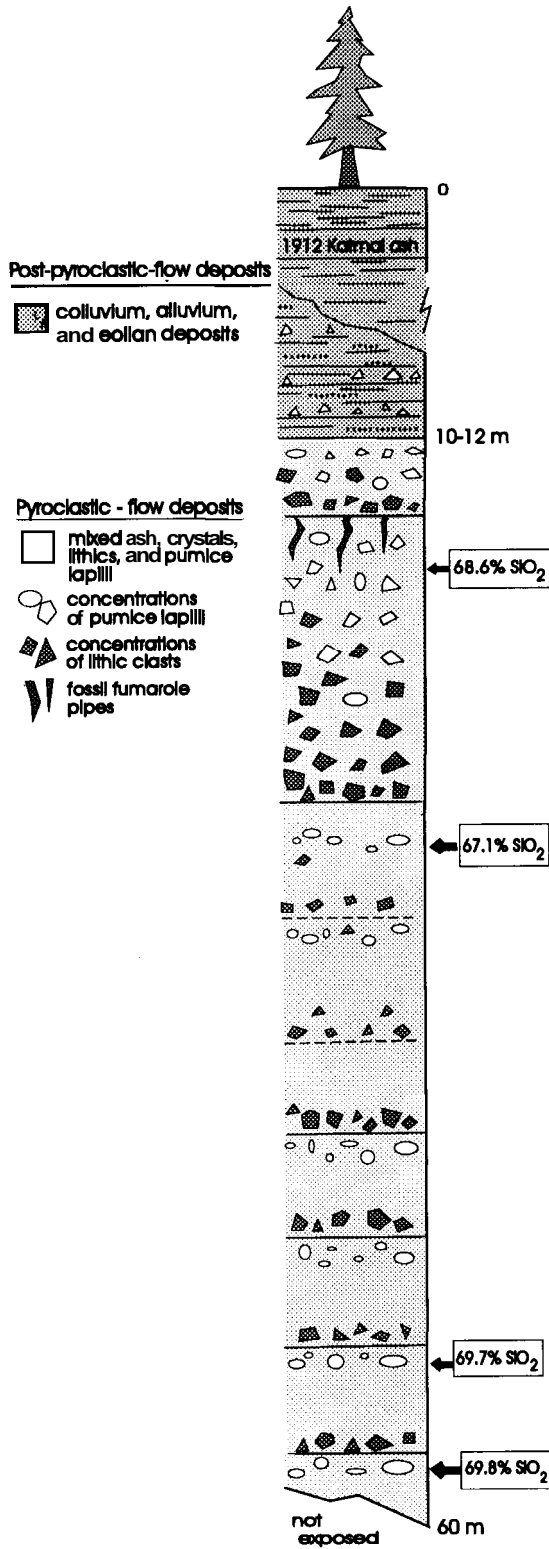


Figure 2. Composite section measured in pyroclastic-flow deposits formed during caldera collapse at Kaguyak Crater, Alaska. Bulk-rock silica contents of pumiceous lapilli, normalized to volatile-free basis, are shown in boxes (J.R. Riehle, unpub. data). Although the base is not exposed, nearby outcrops indicate that most of the deposit is exposed.

source for these reference samples is based on their coarse grain size close to the volcanoes. In contrast, Kaguyak-like samples of uncertain source at distal sites are mainly fine to medium ash.

All samples contain glass and minerals in subequal amounts. Mineral grains (fig. 4) are pyroxene, plagioclase, and opaque oxides; pleochroic brown-green hornblende is found in most samples as well. Analyses of glass separates from representative reference samples (table 1) indicate a high-silica rhyolitic composition for the glass.

CORRELATIONS AMONG THE SAMPLE SET

Because of the large differences among the densities of glass, mafic minerals, and plagioclase, the abundances of plagioclase and glass are not useful for comparison of tephra samples of different mean grain size. The densities of amphibole and pyroxene are, however, more similar to one another, so unless one phase differs significantly from the others in mean grain size, the proportions among these phases

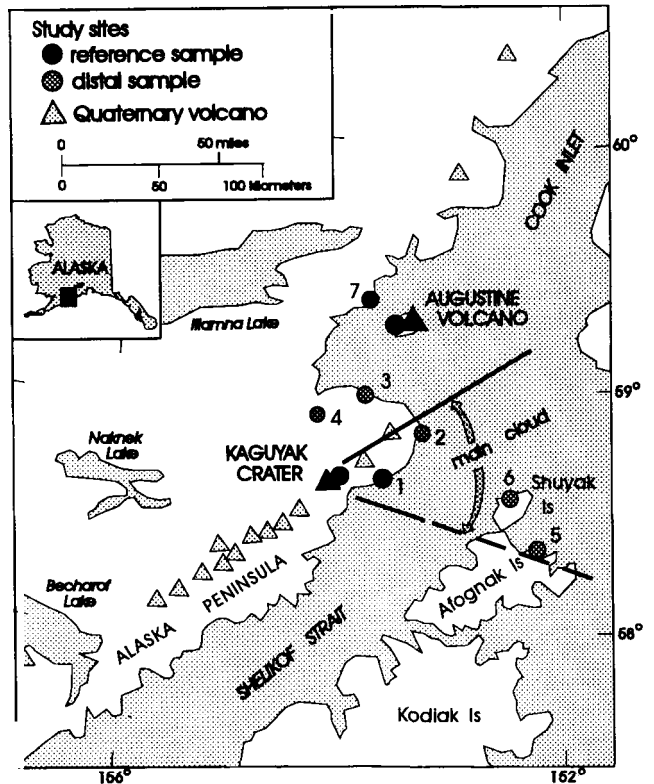


Figure 3. Sample sites in the region of Kaguyak Crater, northern Alaska Peninsula. Coarse-grained samples of unambiguous origin (reference samples) for Kaguyak Crater and Augustine Volcano are from proximal sites. Augustine samples are included because some are chemically and mineralogically indistinguishable from Kaguyak reference samples. Sites 2-6 are finer grained tephra deposits at distant sites that are chemically and mineralogically similar to Kaguyak reference samples. Because the coarsest and thickest airfall deposits that are attributed to Kaguyak occur at sites 1 and 2, the main Kaguyak ash cloud is inferred to have dispersed to the east of the volcano (area shown by heavy lines, dashed where extrapolated).

Table 1. Major-element analyses of glass separates from representative reference samples of Kaguyak Crater (Site 1) and Augustine Volcano (33D).

[Oxides reported as weight percent; values in parentheses after each oxide are the standard deviation as a percent of the reported value. The number of shards that make up the average for each sample is in parentheses after the total. Totals are less than 100% largely because some elements are not included (chiefly magmatic volatiles and secondary water of hydration) and because of analytical uncertainty and the presence of microvesicles. Analyses by JEOL electron microprobe: 15 keV, 0.01 microamps sample current, defocused beam and 15-second count times to minimize loss of alkalis. Basaltic and rhyolitic glass standards for all elements except Ti-hornblende and Mn_2O_3 . A rhyolitic glass was used as an internal standard (RLS132). Analysts: J.R. Riehle and C.E. Meyer]

Sample No.—	Site 1	33D
Na ₂ O	4.04 (3.0)	3.80 (3.5)
MgO	0.32 (7.6)	0.34 (18)
Al ₂ O ₃	11.9 (3.6)	12.2 (4.0)
SiO ₂	76.0 (0.7)	73.2 (0.9)
K ₂ O	1.85 (1.7)	1.78 (2.0)
CaO	1.74 (3.0)	1.77 (3.3)
TiO ₂	0.26	0.24
MnO	0.05	0.04
FeO _T	1.47 (3.8)	1.59 (4.1)
Total	97.6 (14)	95.0 (10)

can be a reliable basis for correlating proximal and distal deposits (fig. 4).

The major-element composition of glass has been widely used as a quantitative basis to correlate tephra samples (Smith and Okazaki, 1977; Sarna-Wojcicki and others, 1983), in part because the method affords a degree of precision that is difficult to attain by petrographic observations. In addition, microprobe analyses of glass separates are readily obtained, and (for homogeneous eruptions) the glass composition does not vary because of mechanical fractionation during transport in the ash cloud. The degree of similarity between two samples can be quantitatively expressed by the similarity coefficient (sc), which is the average of the ratios of the major oxides where the numerator is the lesser of the two values (for example, MgO_1/MgO_2 ; Borchardt and others, 1972). A perfect match has an sc of 1.00, but due to analytical uncertainty and the inherent variability that typifies most glasses, perfect matches of even the same grainfall are rare. On the basis of a combination of empirical observation and replicate analyses of sample splits, an sc of 0.96 or greater is considered to be permissive, if not conclusive, evidence of correlation as the same grainfall (Riehle, 1985; Riehle and others, 1992).

The Kaguyak-like samples can be distinguished from other Alaska Peninsula tephra samples on the basis of their glass compositions. The high sc's of the Kaguyak reference samples with the Augustine reference samples (table 2) and, in some cases, the similarity in mafic-phenocryst contents as well (fig. 4), illustrate the difficulty in identifying the sources of these pyroclasts. Most Holocene tephtras of Augustine Volcano have moderate to high ratios of amphibole to pyroxene (J. Riehle, unpub. data), but some of these Kaguyak-like Augustine tephtras have low ratios. Thus, a moderate or high ratio of amphibole to pyroxene in a distal sample precludes a Kaguyak origin, but a low ratio does not unambiguously indicate a Kaguyak origin.

On the basis of amphibole-to-pyroxene ratios, two of three Kaguyak-like deposits at distal site 5 (fig. 5, deposits I, J, and G) could correlate with Kaguyak (5-G and 5-I). However, we know of only one low-amphibole deposit at site 6 (6-C), a

site which is closer to Kaguyak Crater than site 5. This is a complication that we cannot resolve based only on glass composition and mineral contents.

ILMENITE COMPOSITIONS AS SOURCE INDICATORS OF THE TEPHRA SAMPLES

Magnetite and ilmenite compositions were used successfully by Downes (1985) to distinguish otherwise identical lobes of the White River ash deposit, Canada. We separated and analyzed a number of magnetite and ilmenite grains from our reference samples. Although the magnetite compositions are not separable by source, the ilmenite compositions unambiguously indicate the sources of these particular samples (fig. 6A). To investigate the reason for the success of this mineralogic source indicator, we converted the mineral compositions to temperature and oxygen fugacity. The late Holocene Augustine magmas had about 1 log unit higher oxygen fugacity (fig. 7) than the Kaguyak caldera-forming magma, a result that is consistent with the higher average amphibole content of the Augustine tephtras.

Two Kaguyak-like deposits were sampled at distal site 6. Ilmenite in sample 6-C plots in the Augustine field of FeO-TiO₂, whereas that in sample 6-F plots in fields of both Kaguyak and Augustine (fig. 6B). We infer that 6-F is a mechanical mixture of ash from both sources. Mixing does not require that the two eruptions have occurred at precisely the same instant because two grainfalls even several years apart can become mixed over the succeeding millenia by freeze-

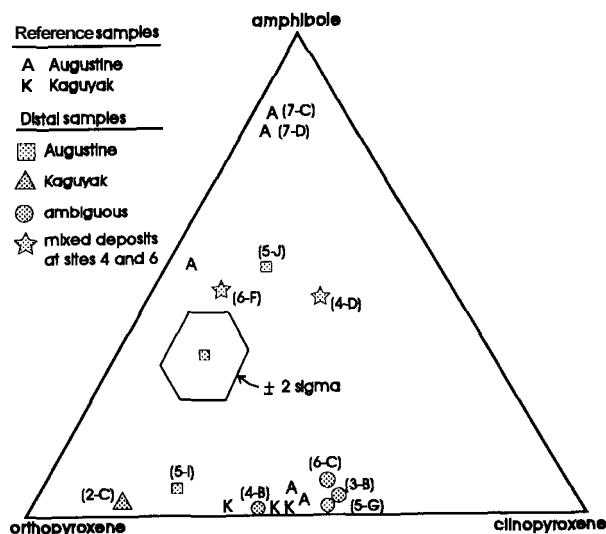


Figure 4. Mafic-phenocryst proportions of Kaguyak-like tephra deposits from the northern Alaska Peninsula and southern Cook Inlet region, Alaska. Reference samples are coarse, near-vent lapilli. Each distal sample has a glass composition that is highly similar to glass in Kaguyak reference samples. Assignment of distal samples to a source at Kaguyak or Augustine is based on the composition of ilmenite grains in the sample (discussed in the text). Phenocryst proportions determined by point counting of grain mounts, using a polarizing microscope; the typical uncertainty of measurement (± 2 sigma) is shown for one sample (150 points).

Table 2. Values of similarity coefficients *sc* for the glass composition of each **Kaguyak-like** sample compared with that of every other sample. [Perfectly identical compositions would have an *sc* of 1.00. Only values ≥ 0.95 are listed because smaller values do not support **correlation** as the same deposit. The high values here serve to (1) distinguish the samples in the data set from other Holocene samples in the region (J.R. Riehle, unpub. data), and (2) permit correlation of each sample in the data set with nearly every other sample. **Mafic-phenocryst proportions** (fig. 4) provide an additional basis for comparing these highly similar samples; underlined values are sample pairs that have similar phenocryst proportions. Note that Kaguyak reference samples are indistinguishable in both glass composition and phenocryst content from some Augustine reference samples. **Ilmenite** compositions have been used to distinguish between these sources.]

		Sample No.																
		1	37-D	37-H	5-G	5-I	5-J	7-C	7-D1	2-C2	3-B	41B	4-D	75-A	33-B	33-D	6-C	6-F
Kaguyak reference tephras	1	--	<u>0.97</u>	<u>0.96</u>	<u>0.97</u>					<u>0.96</u>	<u>0.96</u>			<u>0.95</u>		<u>0.97</u>	<u>0.96</u>	
	37-D		--	<u>0.97</u>	<u>0.96</u>		0.96			<u>0.98</u>	<u>0.96</u>	<u>0.97</u>	0.96	0.95		<u>0.97</u>	<u>0.96</u>	
	37-H			--	<u>0.96</u>	0.95	0.97	0.96	0.96	0.96	<u>0.99</u>	<u>0.97</u>		<u>0.98</u>	0.96	<u>0.98</u>	<u>0.98</u>	0.96
	5-G				--			0.96	0.97	0.96	0.96		0.95	<u>0.96</u>		<u>0.97</u>	<u>0.96</u>	
	5-I					--	0.95	0.97	0.96		0.96			<u>0.97</u>	<u>0.98</u>	0.96	<u>0.97</u>	<u>0.97</u>
	5-J						--	<u>0.96</u>		0.95	0.97	0.97		<u>0.98</u>		0.95	0.96	
Augustine reference tephras	7-C						--	<u>0.98</u>		0.96			0.95	0.97	0.97	0.96	0.96	0.96
	7-D1							--	0.95	0.96			0.97	0.97	0.97	0.97	0.97	0.96
	2-C2								--	0.96	<u>0.96</u>		0.96	0.95		<u>0.97</u>	0.95	
	3-B									--	0.97	0.97	0.97	<u>0.99</u>	<u>0.97</u>	<u>0.98</u>	<u>0.99</u>	0.96
	4-B										--	0.97	<u>0.96</u>	0.95	<u>0.97</u>	<u>0.97</u>	<u>0.97</u>	
	4-D											--	0.97		0.96	0.96		
	75-A													--	<u>0.97</u>	<u>0.97</u>	<u>0.98</u>	<u>0.95</u>
	33-B														--	<u>0.97</u>	<u>0.98</u>	<u>0.98</u>
33-D															--	<u>0.99</u>	<u>0.97</u>	
6-C																--	<u>0.96</u>	
6-F																	--	

Underline, similar mafic-phenocryst contents

thaw cycles and bioturbation. Sample 4-D also contains grains that plot in FeO-TiO_2 fields of both sources (fig. 6C). Of the other samples from which ilmenite grains were analyzed, each plots chiefly in one field or the other (fig. 6C).

CORRELATIONS AMONG DISTAL SITES FOLLOWING PROVISIONAL SOURCE ASSIGNMENTS

Provisional source assignments based on ilmenite compositions can be tested for stratigraphic consistency (fig. 5). At distal sites 4, 5, and 6, there is only a single deposit that is either assigned to Kaguyak (5-G) or that is a postulated mixed deposit (4-D and 6-F). All other Kaguyak-like deposits at sites 4, 5, and 6 are assigned to Augustine. Ilmenite has not been analyzed from samples at sites 2 and 3. However, based on its coarse grain size and low amphibole-to-pyroxene ratio, 2-C is probably a Kaguyak deposit (although one which may include a fine-grained Augustine component). Deposit 3-B, which is presently classified as "uncertain," also has a low ratio of amphibole to pyroxene and so may consist chiefly of Kaguyak ash. Our mixed deposits have intermediate ratios of amphibole to pyroxene, which means that they cannot be exclusively Kaguyak ash (fig. 4). Examples of Augustine deposits that could be mixed with the Kaguyak ash include 7-C and 7-D, both of which have a high ratio of amphibole to pyroxene (fig. 4). Mixing of such a high-amphibole ash with Kaguyak ash would yield the observed intermediate ratios.

Grain-size differences among sites 1, 2, and 5 (fig. 5) indicate that the main Kaguyak ash cloud was dispersed approximately eastward (fig. 3). Mixed deposit 6-F is found near the center of this east-directed lobe; the pure Kaguyak

deposit at site 5 must have been beyond the limit of significant Augustine fallout. Another mixed deposit (4-D) is located north of Kaguyak Crater, which because of the 90-degree difference in azimuth raises the possibility of two separate Kaguyak eruptions. It is not uncommon, however, for surface winds in lower Cook Inlet to flow northward while winds aloft flow eastward under influence of the jetstream (L. Kelly, National Weather Service, Anchorage, written commun., 1996). Thus, the occurrence of Kaguyak tephra both to the east and to the north of the vent does not require separate eruptions during different wind patterns.

AGE OF THE DISTAL KAGUYAK DEPOSIT

Peat deposits immediately above and below the ash deposits were dated by radiocarbon methods and limit the age of the mixed deposits at sites 4 and 6. The values that are midway between each pair of limiting peat ages are 3,750 years at site 4 and 3,500 years at site 6 (fig. 8). This 250-year difference suggests that the mixed deposit at site 4 may be older than that at site 6. However, the results can also be interpreted as a single age for both sites; 3.6 ka is within ± 1 sigma analytical uncertainty of all four samples.

Closely succeeding eruptions of chemically similar pyroclasts from adjacent volcanoes may be unusual, but a second occurrence of such an event within 250 years of the first is even more improbable. Thus, we prefer the interpretation that the mixed deposits are the same geologic age and consist of a single Kaguyak ashfall, an interpretation that is consistent with the evidence for a single eruptive episode during emplacement of the Kaguyak ash flow. The August-

ine component of the mixed deposits could represent two different ashfalls; for example, one several years before and one several years after the Kaguyak eruption. Permissive evi-

dence of this possibility is the presence of two closely succeeding Kaguyak-like deposits at site 7 (fig. 5, 7-C and 7-D). Kaguyak tephra at site 5 (5-G) is found near the middle

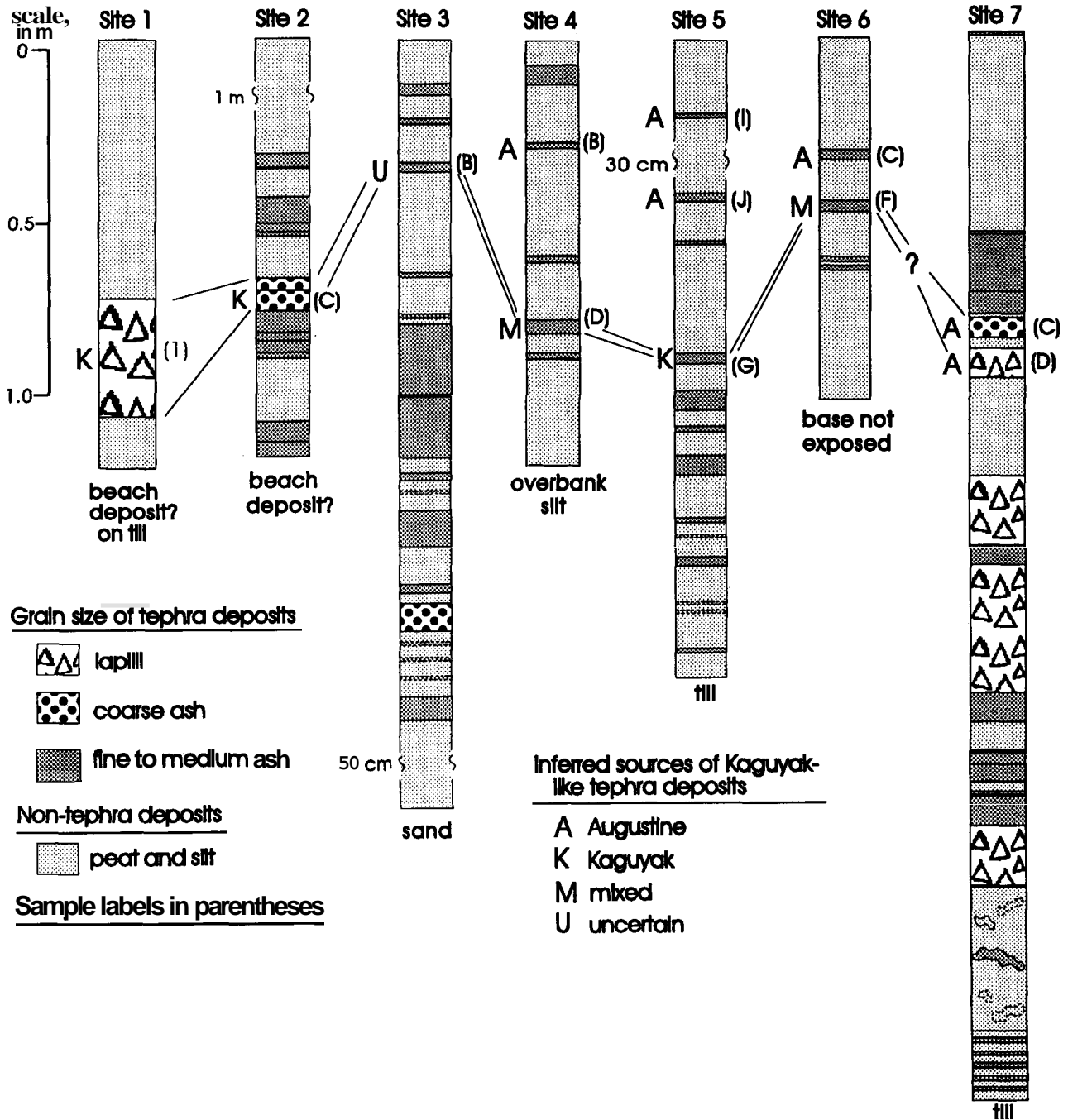


Figure 5. Geologic columns showing the stratigraphic setting of sampled Kaguyak-like tephra deposits from the northern Alaska Peninsula, Afognak and Shuyak Island, and southern Cook Inlet (fig. 3). Reference samples of Kaguyak Crater include the lapilli deposit at site 1 (25 km east of the vent). Reference samples of Augustine Volcano include coarse-grained deposits C and D at site 7 (25 km northwest of the vent). Distal deposits of Kaguyak-like tephra at sites 2 through 6 are labelled according to inferred sources on the basis of ilmenite compositions (discussed in the text). Only one deposit is inferred to be the *airfall* equivalent of the Kaguyak caldera-forming eruption; that deposit is indicated by lines that correlate from sites 1 through 6. Augustine reference deposits at site 7 (queried lines) represent ashfalls that are postulated to have mixed with Kaguyak deposits at sites 4 and 6.

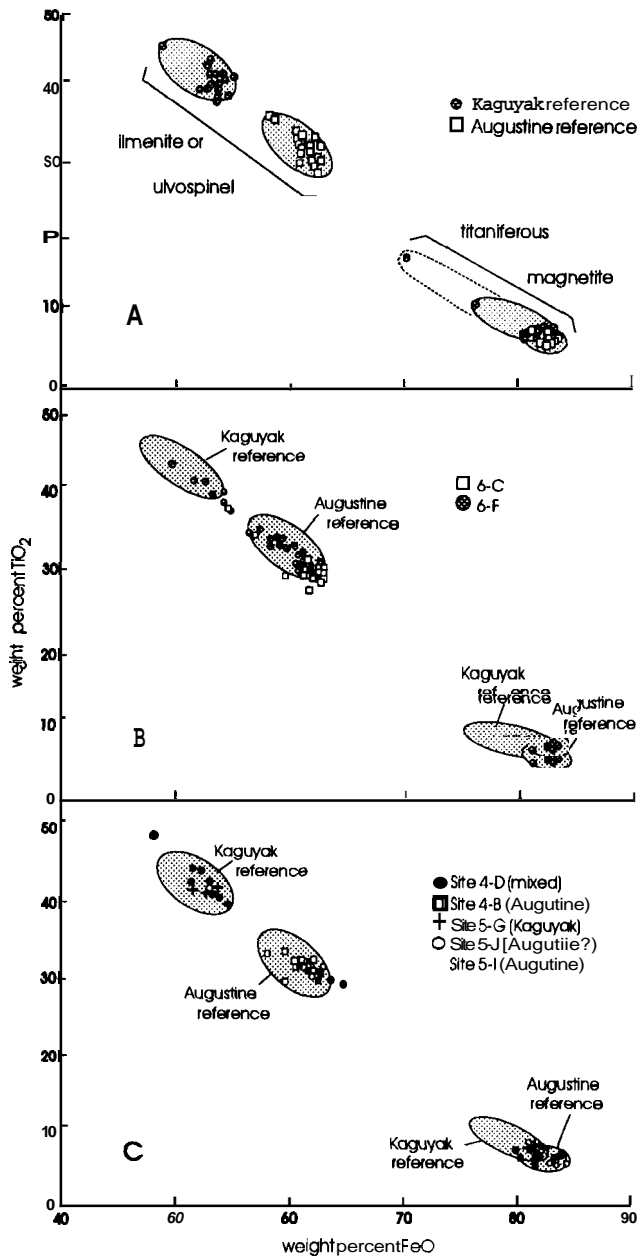


Figure 6. FeO and TiO₂ contents of magnetite and ilmenite grains in Kaguyak-like tephra deposits, northern Alaska Peninsula. See figures 3 and 5 for sample sources. Analyses by JEOL electron microprobe, 15 keV and 0.3 microamp sample current, focussed beam, 20-second count times. Standards: synthetic MgAl₂O₄ (Mg, Al), clinopyroxene (Si), Tiebaghi chromite (Cr), and synthetic oxides for Fe, Mn, Ti, Ni, and V. Analysts J.R. Riehle, C.E. Meyer, and L.C. Calk. (A) Magnetite and ilmenite grains in three reference samples of Kaguyak pyroclasts and four reference samples of Augustine pyroclasts. Ilmenite compositions uniquely indicate the sources of these late Holocene pyroclasts. Shaded areas outline the compositional fields for each volcano and are reproduced on parts B and C. (B) Distal deposit 6-C has chiefly Augustine-like ilmenite grains, but 6-F has both Kaguyak-like and Augustine-like ilmenite grains and is interpreted to be a mixture of Kaguyak and Augustine grainfalls. (C) Other distal deposits plot mainly in the field of either Kaguyak or Augustine ilmenite compositions, except that 4-D also appears to be a mixed deposit.

of a section that apparently represents the entire Holocene (fig. 8; section rests on glacial till). Assuming slightly greater compaction of the non-tephra deposits in the lower part of the section than in the upper part, the stratigraphic position of 5-G is broadly consistent with an age of 3.6 ka.

IMPLICATIONS OF THE NEWLY ESTIMATED AGE OF CALDERA FORMATION

An age of about 3.6 ka for formation of Kaguyak caldera is notable because it means that four of six Holocene calderas on the Alaska Peninsula formed within a few hundred years of one another, between about 3.4 and 4.0 ka (see ages in Miller and Smith, 1987). Moreover, a number of other volcanoes in the eastern Aleutian arc also had major eruptions during this period (fig. 1). These 3.4 to 4.0-ka eruptions were the only significant Holocene activity at some volcanoes, but other vents had many Holocene eruptions in addition to those during this period.

We have no evidence for the cause of such a remarkable pulse of eruptive activity in the eastern Aleutian arc at this time, nor do we know if the pulse involved the western part of the arc. But such widespread volcanic activity must somehow involve the tectonic plates, either by postglacial rebound of the upper plate or by a slight change in the direction, rate of convergence, or the dip of the downgoing plate. We suggest that vertical tectonism in the upper plate may have accompanied the eruptive pulse and that field evidence for such tectonism may still be preserved in uplifted marine terraces, river incisions, or tsunami deposits formed as a result of large earthquakes.

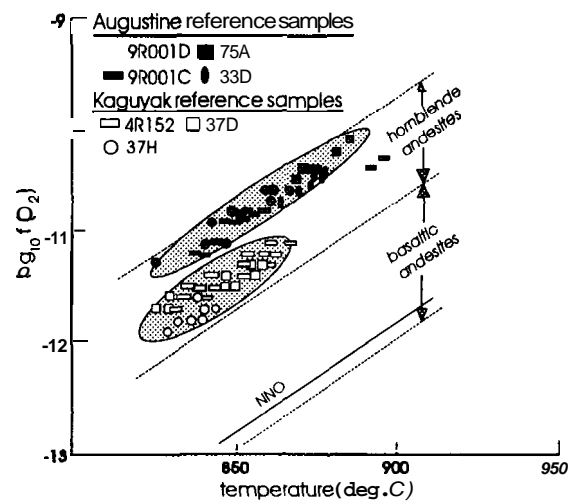


Figure 7. Temperature and oxygen fugacity calculated using the model of Andersen and Lindsley (1988) for magnetite and ilmenite pairs in Kaguyak and Augustine reference samples. Only pairs that satisfy the Mg/Mn equilibrium criteria of Bacon and Hirschmann (1988) are plotted. Fields for pyroxene (basaltic) andesites and hornblende andesites (Carmichael, 1991) show that the higher oxygen fugacity for the Augustine pyroclasts is consistent with the higher average amphibole content of the Augustine samples. Shaded areas emphasize the separation of the two sources.

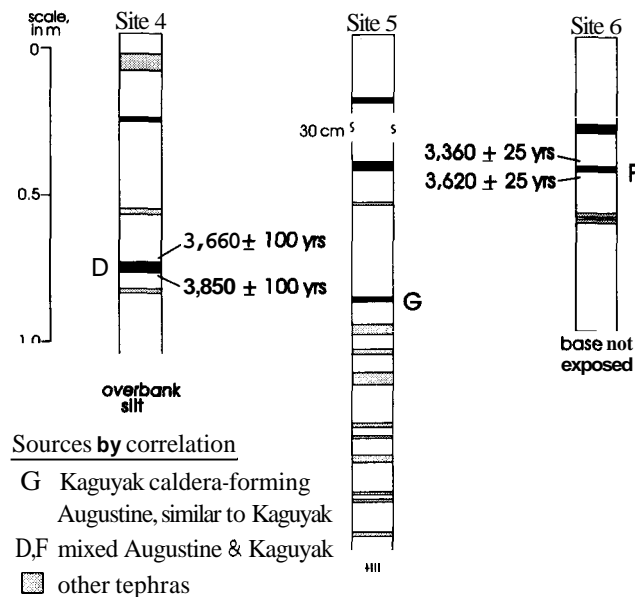


Figure 8. Peat samples dated by radiocarbon method limit the age of the mixed deposits at sites 4 and 6. The stratigraphic position of correlative deposit 5-G (approximately middle Holocene) is broadly consistent with the radiocarbon ages of deposits 4-D and 6-F. [Laboratory numbers: site 4, Isotopes I-16,120 (above) and I-16,121; site 6, University of Washington Quaternary Isotope Laboratory QL4813 (above) and QL4814.]

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