Geologic Setting, Petrology, and Age of Pliocene to Holocene Volcanoes of the Stepovak Bay Area, Western Alaska Peninsula

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Abstract

Five volcanoes are situated north of Stepovak Bay on the western Alaska Peninsula; only one of these, Kupreanof volcano, had been reported prior to USGS reconnaissance geologic mapping of the area between 1982 and 1986. The volcanoes overlie sedimentary rocks of Eocene to late Miocene age and welded(?) tuff deposits of uncertain, but presumably late Tertiary, age. All five of the volcanoes are aligned northeast-southwestat the southeast end of the well-defined Chignik segment of the Aleutian arc. The group shows evidence of eruptive activity beginning approximately 4.7 Ma and continuing into Holocene time and represents one of the longest lived active volcanic centers on the Alaska Peninsula. Associated rocks are generally tholeiitic andesite in composition and have a limited range of mineralogy and texture. Extensive upper Tertiary and Quaternary andesite lava flows cap ridges and fill valleys in the vicinity of the volcanoes and, in some cases, extend to near sea level. Holocene eruptive activity, which occurred on four of the five Stepovak Bay group volcanoes, resulted in three small debris flows, two short lava flows, and a small cinder cone. Active fumaroles exist today on two of the volcanoes.

INTRODUCTION

The Stepovak Bay volcanoes consist of a chain of five relatively closely spaced Quaternary eruptive centers located along the Aleutian arc on the western Alaska Peninsula (figs. 1, 2). Kupreanof volcano, a stratovolcano nearly 1,900 m high, is the largest and best known of the group (Coats, 1950) and the only volcano of the group that has been formally named (fig. 2). The three southernmost volcanoes were located during reconnaissance geologic mapping in 1982 (Yount and others, 1985). Later work, through 1986, more completely defined these three volcanoes, and an additional center was discovered between these and Kupreanof volcano. For easy reference, the newly discovered centers are informally referred to by number (1–4), starting from the southwest (figs. 1, 2 and table 1).

The volcanoes, other than Kupreanof, were previously undiscovered chiefly because poor weather and limited access tend to prevent close examination of the area. A party from the Harriman Expedition of 1899 (Palache, 1904) stopped in Chichagof Bay southwest of the volcanoes but was limited to short excursions in the vicinity of the bay. Maddren (1919) and Eakins (1970) reported sulfur deposits and a fumarole that has since been determined to be on volcano 4, but neither author reported the volcanoes as eruptive centers. Burk's (1965) regional map of the Alaska Peninsula shows volcanic rocks in the area, but he did not recognize that these rocks include Quaternary volcanic centers that have had Holocene activity. All of these studies were handicapped by poor access and, until recently, an extremely poor quality topographic base map of the area. The area is remote enough that most rivers, streams, and peaks don't have names, even in local usage. The geologic information presented here is reconnaissance in nature; limited field time and, in particular, difficult access and poor weather continue to handicap studies in the area.

The discovery of these volcanoes is an outgrowth of geologic mapping in support of the Alaska Mineral Resource Assessment Program (AMRAP) studies in the Port Moller, Stepovak Bay, and Simeonof Island 1:250,000-scale quadrangles. M.E. Yount, R.L. Detterman, and J.W. Miller assisted in the mapping of the volcanoes and in discussions on the interpretation of the data; their help is gratefully acknowledged.

GEOLOGIC SETTING

The Stepovak Bay volcanoes occur at and define the southwest end of a N. 40° E. oriented linear segment of the generally northeast trending Aleutian volcanic arc, about 280 km northwest of the Aleutian trench. Here, this segment is informally referred to as the Chignik volcanic arc segment (fig. 1). This segment includes the better known and much larger Mount Veniaminof and Aniakchak Crater volcanoes (Coats, 1950). The Chignik segment is defined by major right-lateral transverse offsets of the Aleutian arc. The offset at the northeast end of the Chignik segment lies between Aniakchak and Yantarni volcanoes (Riehle and others, 1987). The southwest end of the Chignik segment lies between volcano 1 of the Stepovak Bay volcanoes and Mount Dana, the next Holocene volcanic center, which is located to the southwest. The intervening region contains small areas of Pleistocene volcanic flows and a Pleistocene dome (fig. 1, U1 and U2).

Three kinds of geologic transitions occur in the vicinity of the Stepovak Bay volcanoes. (1) Aeromagnetic and gravity data from the central Alaska Peninsula suggest that the underlying crust is transitional between oceanic crust of the Aleutian Islands and continental crust of the northeast end of the Alaska Peninsula (Case and others, 1981, 1987). (2) The southwest end of the Chignik segment closely corresponds to the northeastern end of the Shumagin seismic gap (fig. 1; Davies and others, 1981). (3) The southwest end of the Chignik segment also marks a transition in structural style of the Mesozoic and early Tertiary rocks of the Alaska Peninsula. The volcanoes rest in part on northeast-trending folds with generally gentle dips that are locally overturned and overthrust from the northwest (Detterman and others, 1981, 1987). Southwest of the volcanoes, the structural style is fault dominated rather than fold dominated, and thrusting was from the southeast rather than the northwest.

The Stepovak Bay volcanoes overlie sedimentary rocks of Eocene to Pliocene age. All but the southernmost of the volcanoes are built on rocks of the middle and upper Miocene Bear Lake Formation and the Pliocene Milky River Formation. The Bear Lake Formation is a shallow marine sandstone and conglomerate distinctive among Tertiary stratigraphic units on the Alaska

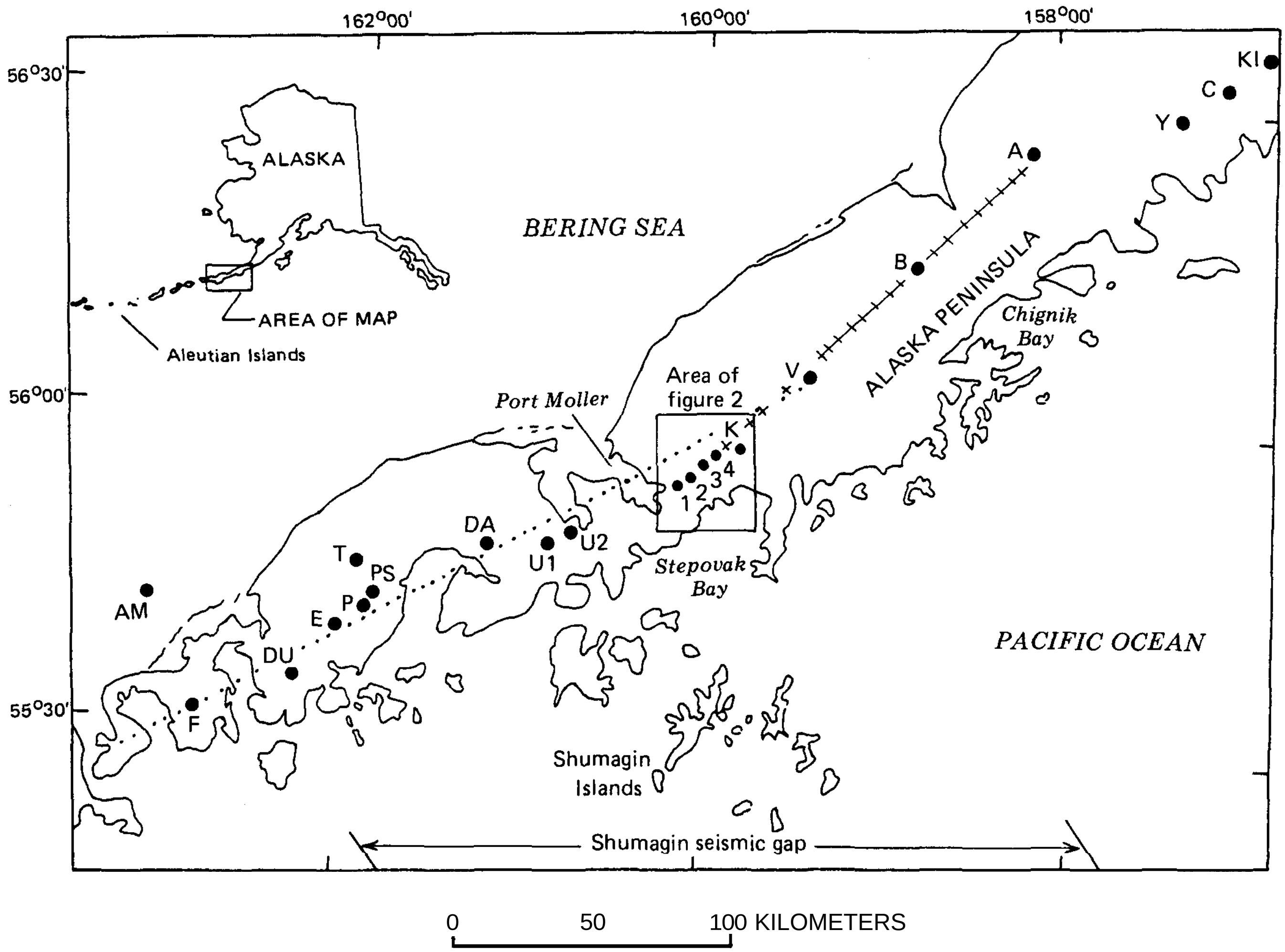


Figure 1. Locations of Quaternary volcanic centers of Aleutian arc on western Alaska Peninsula. Abbreviations: KI, Mount Kialagvik; C, Mount Chiginagak; Y, Yantarni volcano; A, Aniakchak Crater; B, Black Peak; V, Mount Veniaminof; K, Kupreanof volcano; 1–4, unnamed Stepovak Bay volcanoes; U1 and U2, unnamed Quaternary volcanic centers; DA, Mount Dana; T, Trader Mountain; PS, Pavlof Sister; P, Pavlof volcano; E, Emmons Lake; DU, Mount Dutton; F, Frosty Peak; AM, Amak volcano. Dotted line indicates Cold Bay volcanic arc segment of Kay and others (1982), hatched line indicates Chignik volcanic arc segment (see text).

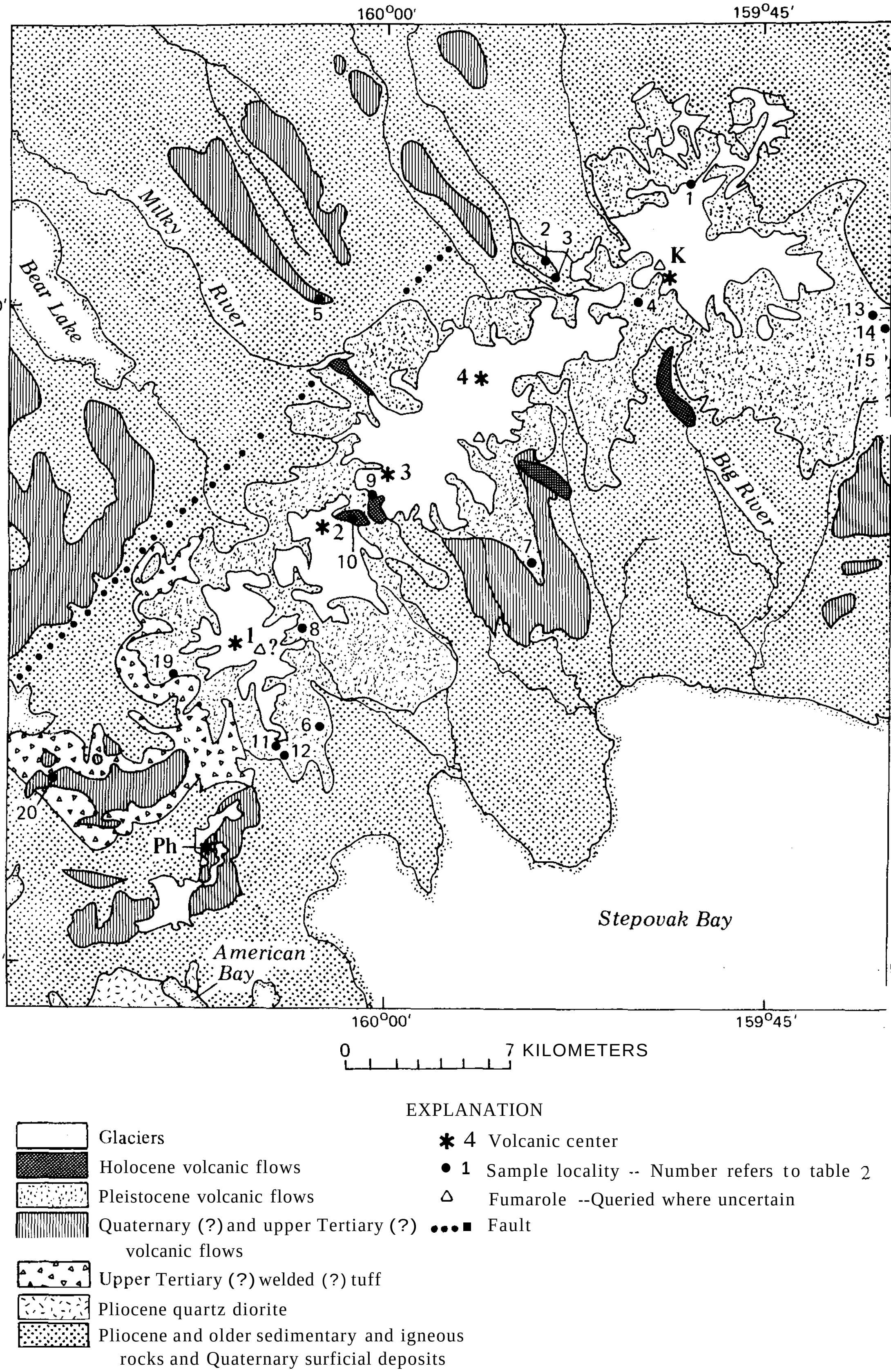


Figure 2. Simplified geologic map showing locations of Stepovak Bay volcanoes. Base map from Port Moller (1953), Stepovak Bay (1963), and Chignik (1963) 1:250,000-scale quadrangles. Volcanic centers shown by asterisks and identified by numbers except K, for Kupreanof volcano and Ph, for Pliocene(?) hypabyssal center.

Table 1. Location and summit elevation of the Stepovak Bay volcanoes; base elevation increases northeastward from 600 to 900 m

Volcano or center	Latitude	Longitude	Elevation (m)
Volcano 1	55.87° N	160.09"W	1.320
Volcano 2	55.91° N	160.04° W	1,325
Volcano 3	55.93° N	160.00" W	1,400
Volcano 4	55.95" N	159.96" W	1,555
Kupreanof	56.01' N	159.79° W	1,895

Peninsula because plutonic and chert clasts dominate over volcanic debris. The Milky River Formation crops out northwest of the volcanoes and consists of volcanic flows and agglomerate and sedimentary rocks composed mainly of volcanic detritus. At the type locality, located just northwest of Kupreanof volcano, the proportion of volcanic to sedimentary rocks increases upward (Detterman and others, 1981). The volcanic components of the Milky River are the earliest products of the Stepovak Bay volcanic centers. In the area immediately northwest of the volcanic centers, volcanic rocks dominate the Milky River Formation. Farther north, where the Milky River Formation is known only from drill core, sedimentary rocks composed of volcanic detritus dominate (Detterman and others, in press). In the Stepovak Bay region, the top of the Milky River Formation has not been defined, but it appears to be gradational with Pliocene and Pleistocene flows. On the southeast flank of the volcanic centers, the Eocene Tolstoi Formation crops out in a homoclinally southeast dipping section. In this area, the Tolstoi consists of fluvial siltstone, sandstone, and conglomerate. Thick welded(?) tuff deposits of uncertain but presumably late Tertiary age underlie volcano 1, the southernmost of the volcanoes.

South of the volcanoes, undated but presumably Oligocene, propylitically altered volcanic rocks crop out in a large area. A dacite dike intruding these has been potassium-argon dated at 8.27±0.24 Ma (DuBois and others, 1987). These altered volcanic rocks are probably part of the Meshik arc (Wilson, 1985), an Eocene to early Miocene precursor of the Aleutian arc. Overlying these 7 to 12 km south-southwest of volcano 1 is an area of Pliocene(?) flows. These Pliocene(?) flows are possibly related to a deeply eroded center (fig. 2, Ph); outcrops of hypabyssal rocks in a snowfield among these flows may be the root of this center.

At American Bay (fig. 2), the Oligocene volcanic rocks are intruded by a multiphase quartz diorite pluton of early Pliocene age (3.6±0.10 Ma, K-Ar, Nora Shew and F.H. Wilson, unpub. data, 1988). This pluton is 12 to 15 km south of volcano 1 and only 8 km south of essentially coeval flows from the volcanoes.

Flows, agglomerates, and clastic rocks that are early products of the volcanoes occur north of a valley northwest of the line of volcanoes. These older flows and clastic rocks, in part included in the Milky River Formation, and in part overlying the Milky River Formation, dip gently away from the volcanic centers. We infer that a concealed fault (fig. 2) projects through this valley, primarily because use of the dip to project the flows back to the area of the eruptive centers indicates significant vertical offset. This fault is aligned parallel to the line of volcanoes and is upthrown to the northwest. The inferred fault is poorly defined in the vicinity of Kupreanof volcano.

PETROGRAPHY

Our rock samples from the Stepovak Bay volcanoes have a limited range of mineralogy and texture. All are porphyritic and have approximately 10 to 40 percent phenocrysts. Phenocrysts of clinopyroxene and plagioclase are common to all, and hornblende is conspicuously absent. Plagioclase compositions determined from Carlsbad-albite extinction angles (Kerr, 1977, p. 295–298) range between An 55 and An 90, but no compositions between An 70 and An 80 were observed. The only identified clinopyroxene is augite, which is usually twinned. Olivine phenocrysts occur in more than half the samples, whereas orthopyroxene is uncommon. In only 2 of 17 samples do both orthopyroxene and olivine occur. Orthopyroxene, where it occurs, generally has a reaction rim of clinopyroxene. Olivine is most common in rocks having plagioclase compositions of An 55 to 70, whereas orthopyroxene occurs in rocks of all plagioclase compositions. The groundmass ranges from glass to fine-grained holocrystalline mixtures of plagioclase, clinopyroxene, and opaque oxides.

Hyalopilitic or pilotaxitic textures dominate in the samples examined, but some rocks have hyalophitic to subophitic texture. In some samples, angular phenocrysts with sharp boundaries in a glassy groundmass suggest that the rock was quenched. Other samples are subophitic rocks composed of partly resorbed phenocrysts in a partially crystalline groundmass. In a few samples, polysynthetically twinned, weakly zoned plagioclase phenocrysts coexist with untwinned or albite-twinned and strongly zoned plagioclase phenocrysts. Optical determination of the composition for both types of plagioclase phenocrysts was not possible in these rocks. Wilson and others (1983) found that the albite-twinned plagioclase phenocrysts typically were of much lower An content than coexisting polysynthetically twinned phenocrysts in the area to the north of the volcanoes. Discrete grains of opaque oxides are a significant minor component in all samples.

CHEMISTRY

The silica content of the lavas from Stepovak Bay volcanoes ranges from 50.3 to 62.7 percent (50.24 to 62.67 percent anhydrous, see table 2); using the IUGS chemical classification of volcanic rocks (Streckeisen, 1979) all samples are andesite, except for one, which is a leucobasalt. Using Gill's (1981) classification system for orogenic andesites, the rocks of the Stepovak Bay volcanoes that have anhydrous SiO_2 contents greater than 53 percent are medium-K orogenic andesite trending toward high-K orogenic andesite (fig. 3); samples that have less than 53 percent SiO_2 are basalt. Rocks containing less than 54 percent SiO_2 (anhydrous) are island arc tholeiites on the basis of a MnO-TiO_2-P_2O_5 ternary plot (fig. 4; Mullen, 1983). Chemical analyses (table 2) display slightly greater than normal iron-enrichment (fig. 5) for volcanic rocks of the Alaska Peninsula (see Wilson and others, 1983). There is no correlation with respect to age for assignment of a particular sample to either the tholeiitic or calc-alkaline classes.

DISTRIBUTION, AGE, AND ERUPTIVE HISTORY

Pliocene and Pleistocene Products

All the volcanoes contribute to extensive upper Tertiary and Quaternary lava flows that cap ridges and fill valleys in the vicinity of the volcanoes. In some cases, these flows extend to near sea level. The flows are particularly extensive northwest of volcano 1 and southeast of Kupreanof, however, remnants of the flows are distributed around all of the centers. The oldest ages typically come from rocks most distant from the present volcanic centers; however, this may largely reflect to outcrop patterns. Closer to the present eruptive centers, older rocks are covered by younger flows.

Potassium-argon dating (table 3) indicates that the area has been the locus of volcanic activity for approximately the last 4.7 million years. A 4.65-Ma age was determined on an andesite flow (fig. 2 and table 3, locality 20) capping a ridge 9 km southwest of volcano 1. In this area, the volcanic rocks are erosional remnants of flows that filled valleys. Clearly defined lobes from flows and gross structures indicating that lavas that poured from ridges into valleys are well preserved. Much of the area overlain by these flows and by nearby volcano 1 is composed of hydrothermally altered welded(?) tuff of unknown but presumably late Tertiary age (fig. 2).

Outcrops of hypabyssal rocks (fig. 2, Ph) in a snowfield 7 to 12 km south-southwest of volcano 1 among Pliocene(?) flows may indicate yet another eruptive center related to the Stepovak Bay volcanoes.

An age of 3.35 Ma (locality 17, table 3) has been determined on an andesite flow 24 km west-northwest of volcano 1. A 3.87 Ma age (locality 16, table 3) has also been determined on a nearby stratigraphically lower andesite flow. These flows cap ridges underlain by rocks of the Milky River and Bear Lake Formations on the east side of Port Moller bay. Seventeen kilometers north of volcano 1, a sample of an andesite flow has yielded an age of 1.70 Ma (locality 21, table 3). The flows, which are presumably related to the Stepovak Bay volcanoes, form an areally extensive cap on rocks of the Milky River and Bear Lake Formations. They must have been highly fluid on eruption because they extend up to 25 km from the volcanic centers, and dip gently northward toward the Bering Sea. Although these flows overlie the Milky River Formation in this locality, in the adjacent Chignik quadrangle to the north, an andesite flow of similar age (3.53 Ma, locality 5, table 3) is included in the upper part of the Milky River Formation (Detterman and others, 1981).

Two mafic andesite flows from Kupreanof volcano yield ages of 0.57 Ma (locality 15, table 3) and approximately 2.1 Ma (Nora Shew and F.H. Wilson, unpub. data, 1988). Although these two flows are virtually identical chemically, the younger of the two flows is orthopyroxene, clinopyroxene, and olivine bearing whereas the older contains only clinopyroxene as a mafic phase. A clinopyroxene bearing leucobasalt flow from volcano 3 similar to the above flows from Kupreanof yielded a 1.48-Ma age (locality 7, table 3).

Remnants of late-glacial flows are found in the glaciated fault(?) valley northwest of the volcanoes and are further evidence of late Pleistocene volcanic activity.

Age determinations were attempted on three young andesite flows from volcano 1. An age of 0.53 Ma (locality 6, table 3) was obtained on a sample from volcano 1. A second sample has yielded a preliminary age of 0.4 Ma (Nora Shew and F.H. Wilson, unpub. data, 1988). Finally, we were unsuccessful in obtaining an age on the third sample; there was insufficient argon to calculate a reliable age (Nora Shew and F.H. Wilson, unpub. data, 1988). An estimated maximum age of approximately 0.05 Ma can be calculated for this sample, based on the lower limit of argon concentration that our system can generally measure and the potassium content of the sample.

Holocene Products

All of the Stepovak Bay volcanoes except volcano 1 have clearly had Holocene eruptions. These eruptions produced three small debris flows from Kupreanof and volcano 4 into late Pleistocene glacial valleys, a short lava flow from volcano 3, and a small cinder cone and lava flow from volcano 2 (fig. 2).

Table 2. Major element chemical analyses of rock samples from the Stepovak Bay volcanoes

[Localities 16, 17, 18, and 21 are west of the area shown on figure 2. These locality numbers are the same numbers used on figures 3 through 5. Volcanoes identified by volcano number or K for Kupreanof volcano]

Locality	1	2	3	4	5	6	7
Volcano	K	K	K	K	--	1	3
SiO_2	55.50	56.10	50.70	58.60	55.34	57.50	50.30
Al_2O_3	19.20	18.70	18.90	16.60	15.94	16.70	18.00
Fe_2O_3	2.83	3.34	5.26	4.56	2.51	2.91	2.91
FeO	5.23	5.03	3.90	3.51	5.41	5.22	6.83
MgO	3.30	2.80	3.00	2.40	5.78	3.26	6.70
CaO	8.09	8.27	9.70	6.17	8.35	7.08	11.30
Na_2O	3.40	3.10	2.80	3.90	2.90	3.39	2.21
K_2O	1.20	1.47	1.09	1.35	1.52	1.90	.71
TiO_2	.86	.97	1.12	1.12	.94	.94	.80
P_2O_5	.20	.20	.20	.30	.15	.26	.17
MnO	.16	.15	.13	.19	.14	.17	.18
CO_2	.08	.41	.27	.32	.18	.09	.11
H_2O+	.31	.45	1.12	.12	.64	.25	.40
H_2O-	.11	.21	1.87	.22	.59	.24	.17
Total	100.47	101.2	100.06	99.36	100.39	99.91	100.79
FeO*	7.78	8.04	8.63	7.61	7.67	7.84	9.45
FeO*/MgO	2.36	2.87	2.88	3.17	1.33	2.40	1.41
Latitude	56.05	56.01	56.02	56.01	56.00	55.84	55.90
Longitude	159.79	159.89	159.89	159.85	160.04	160.03	159.90
Field number	78ARh 52	78ARh 55	78ARh 55A	78ARh 56	78AYb 90	82AWs 45	83AWs 97

Locality	8	9	10	11	12	13	14
Volcano	2	1	2	1	1	K	K
SiO_2	62.70	59.90	58.40	54.40	53.20	55.80	51.20
Al_2O_3	16.30	16.50	16.80	16.90	16.30	16.40	17.20
Fe_2O_3	2.72	2.63	2.66	3.10	3.46	5.00	4.49
FeO	3.41	4.28	4.44	6.02	5.26	4.07	4.72
MgO	2.41	3.50	3.43	4.13	5.48	3.30	5.20
CaO	5.29	6.39	7.22	8.02	8.92	7.13	9.26
Na_2O	3.79	3.40	3.26	3.21	2.87	3.00	2.40
K_2O	2.45	1.98	1.82	1.53	1.57	1.62	1.07
TiO_2	.70	.78	.77	1.04	.93	.93	.88
P_2O_5	.16	.17	.16	.26	.23	.17	.17
MnO	.12	.14	.14	.17	.15	.17	.15
CO_2	.09	.02	.02	.02	.02	.73	.87
H_2O+	.30	.33	.57	.31	.41	1.32	1.79
H_2O-	.07	.12	.14	.45	.96	.14	.26
Total	100.51	100.14	99.83	99.56	99.76	99.78	99.66
FeO*	5.86	6.65	6.83	8.81	8.37	8.57	8.76
FeO*/MgO	2.43	1.90	1.99	2.13	1.53	2.60	1.68
Latitude	55.88	55.92	55.91	55.82	55.82	56.00	55.98
Longitude	160.06	160.02	160.02	160.06	160.06	159.66	159.65
Field number	83AWs 108a	83AYb 522	83AYb 523	83AYb 537	83AYb 538	84ADt 192	84AWs 176

The easternmost of the debris or block-and-ash flows originates from Kupreanof volcano. It consists of well-compacted, chaotically mixed volcanic-lithic fragments and possibly juvenile material ranging from pebble size to nearly 10 m in diameter set in a mud and volcanic ash(?) matrix. The tongue-shaped flow is strongly iron-stained on weathered surfaces, and individual fragments are rich in disseminated pyrite. Similar debris flows originate from volcano 4 and flow in opposite directions from its summit. The northernmost of these traveled over, and came to rest on, an alpine glacier. The southernmost flowed down a valley toward the Pacific Ocean

Table 2. Major element chemical analyses of rock samples from the Stepovak Bay volcanoes—Continued

Locality	15	16	17	18	19	20	21	22
Volcano	K	--	--	--	1	--	--	3
SiO_2	51.40	55.10	55.70	54.00	54.20	59.00	55.80	56.60
Al_2O_3	18.10	17.50	16.90	16.20	17.70	16.10	17.00	17.30
Fe_2O_3	1.40	3.91	4.44	4.49	9.61[1]	3.84	2.39	4.04
FeO	8.10	4.02	4.01	4.96	--	3.26	5.42	4.23
MgO	5.40	3.40	3.10	3.30	4.44	2.30	4.40	3.07
CaO	10.10	8.08	6.80	7.64	8.60	5.62	8.58	7.32
Na_2O	2.40	3.20	3.40	3.60	3.03	3.90	2.90	3.50
K_2O	.78	1.75	1.78	1.14	1.37	2.30	1.52	1.66
TiO_2	.85	1.03	1.12	1.42	.94	.94	.82	.96
P_2O_5	.13	.21	.30	.22	.19	.30	.16	.26
MnO	.17	.13	.13	.18	.16	.14	.15	.16
CO_2	.22	.28	.48	.74	--	.43	.06	.38
H_2O+	.05	.65	.57	.96	--	.74	.10	.47
H_2O-	.33	.03	.08	.81	--	.14	.07	.30
Total	99.43	99.29	98.81	99.66	100.24	99.01	99.37	100.24
FeO*	9.35	7.53	8.01	9.00	8.65	6.72	7.57	7.86
FeO*/MgO	1.73	2.21	2.58	2.73	1.95	2.92	1.72	2.56
Latitude	55.98	55.92	55.95	55.89	55.86	55.82	55.96	55.96
Longitude	159.66	160.47	160.45	160.31	160.15	160.23	160.28	160.05
Field number	84AWs 177	84AWs 197	84AWs 199	84AWs 200	84AWs 204	84AYb 633	85AYb 708	86AWs 398

[1] All Fe reported as Fe_2O_3, FeO not measured.

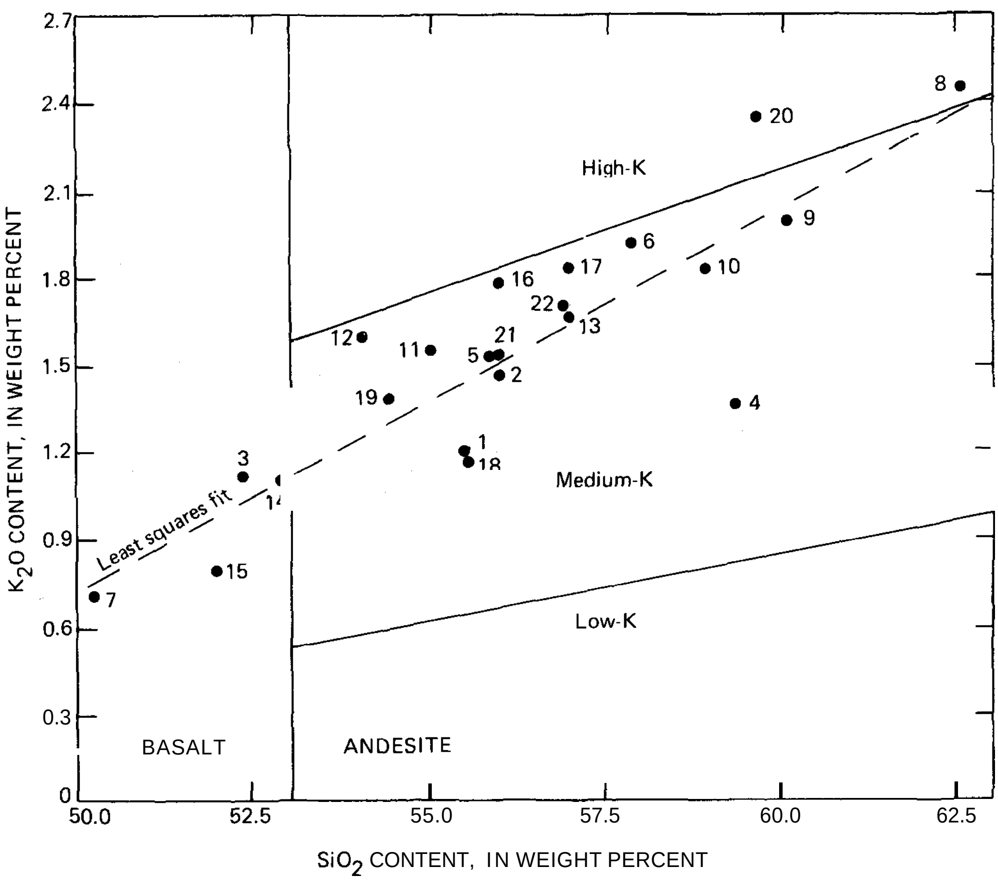


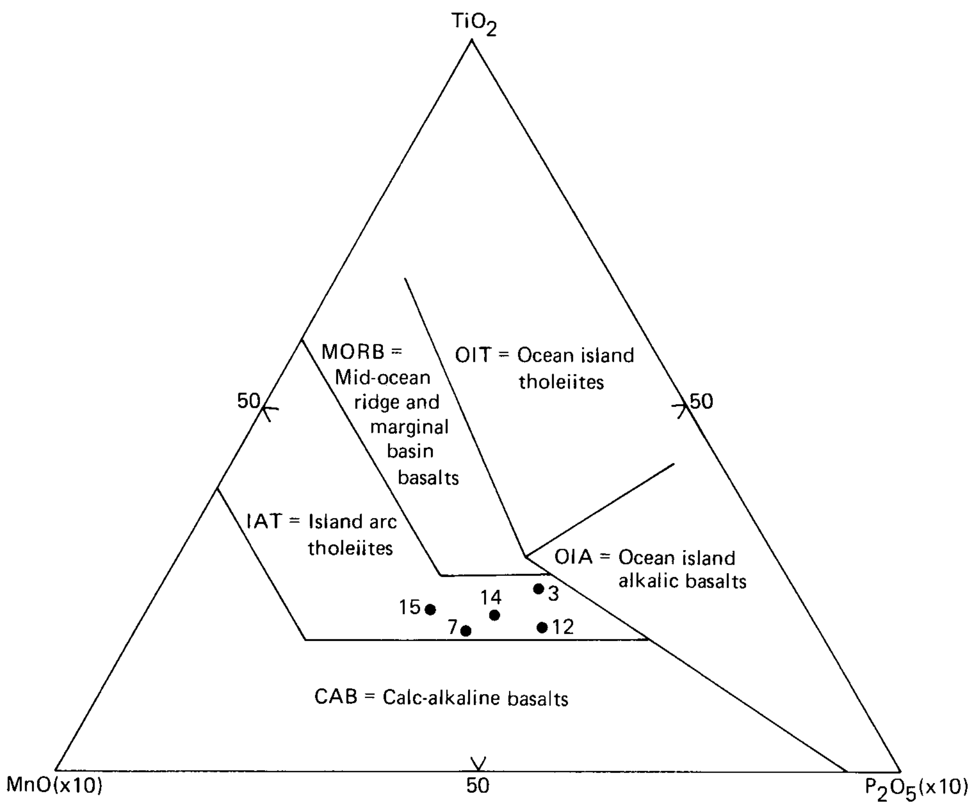
Figure 3. K_2O versus SiO_2 variation diagram for volcanic rocks of Stepovak Bay volcanoes showing boundaries between types of orogenic andesite and basalt as defined by Gill (1981). Sample numbers correspond to localities listed in table 2.

and was localized by the moraine of a glacier occupying an adjacent valley. All three debris flows have been incised 30 to 40 m by modern streams. The summit of volcano 2 is a 200-m-high cinder cone. An andesite lava flow extends from this cone a kilometer or more down slope along an arcuate path northeast then southeast into a stream valley; additional material cascaded down the north flank of the volcano. Volcano 3 has a thick andesite flow originating from an ill-defined ice-filled summit crater 300 m in diameter. This flow traveled approximately 1 km southwest from the crater into the same stream valley as the flow from volcano 2. Volcano 1 does not show unequivocal evidence of Holocene eruptive activity; however, it has an ice-filled summit crater of 500 m diameter that may be late Pleistocene in age. Holocene pyroclastic deposits are not conspicuous at any of the centers.

Maddren (1919) and Eakins (1970) reported an area of fumaroles north of Stepovak Bay. T.P. Miller (oral commun., 1982) reported of an area of fumaroles at Kupreanof volcano and it was commonly assumed that these were the same fumaroles. However, T.P. Miller (oral commun., 1988) later found that both Kupreanof volcano and volcano 4 had fumaroles (fig. 2). Aerial photographs from 1962 also suggest the presence of a fumarole on the southernmost of the centers, volcano 1 (fig. 2); however, U-2 aerial photographs taken in 1983 and our fieldwork did not further document this possible fumarole.

DISCUSSION

The Stepovak Bay volcanoes conform to some of the mineralogical, chemical, and textural characteristics of tholeiitic volcanic centers in the Aleutian arc as described by Kay and others (1982). The common characteristics include the absence of amphibole and the fact that most samples are tholeiitic on the basis of an FeO*/MgO versus SiO_2 plot (fig. 6; Miyashiro, 1974). The Peacock alkali-lime index for these centers is 62, which is typical of Alaska Peninsula volcanic rocks in general (Wilson and Shew, in press). This index is somewhat higher than the 57 to 59 considered normal by Kay and others (1982) for tholeiitic volcanic centers. Kay



EXPLANATION

● 3 Sample locality -- Number refers to table 2

Figure 4. MnO (×10)-TiO_2-P_2O_5(×10) ternary plot of volcanic rocks of Stepovak Bay volcanoes that have less than 54 percent SiO_2 (anhydrous) showing these rocks are island arc tholeiites (after Mullen, 1983).

and others (1982) suggested that andesite and dacite vitrophyres are restricted to the tholeiitic series in the Aleutian arc. However, though glass is common in the groundmass of about two-thirds of the samples from the Stepovak Bay volcanoes, this is not unusual for calc-alkaline and tholeiitic rocks on the Alaska Peninsula (Wilson and others, 1983, Riehle and others, 1987). Chemical data and standard discrimination diagrams suggest that the Stepovak Bay volcanoes should be considered fundamentally tholeiitic volcanic centers, though some calc-alkaline lavas have erupted. However, there are insufficient data to determine if the centers show evolution or systematic variation of magma chemistry with time.

Kay and others (1982) suggested there are tectonic controls on arc magmatism, and they proposed that tholeiitic volcanic centers occur at the ends of and between segments of the volcanic arc, whereas calc-alkaline centers occur within volcanic arc segments. They considered Mount Veniaminof, immediately to the northeast of the Stepovak Bay volcanoes, a tholeiitic volcanic center and used it to define the eastern end of their Cold Bay volcanic arc segment. By implication then, as within-segment volcanoes, the Stepovak Bay volcanoes should be calc-alkaline. However, the chemical and petrographic data for the Stepovak Bay volcanoes suggest they are best defined as tholeiitic volcanic centers though they exhibit some characteristics transitional to calc-alkaline rocks. On the basis of the Kay and others (1982) arc segment definition, it appears incorrect to terminate the Cold Bay arc segment at Mount Veniaminof. Possibly, the 65-km-long section of the Aleutian arc defined by the Stepovak Bay volcanoes and Mount Veniaminof represents a tholeiitic between-segment portion of the arc, as defined by Kay and others (1982). This would require the Cold Bay arc segment to end somewhere west of the Stepovak Bay volcanoes. Alternatively, by inclusion of the Stepovak Bay volcanoes to Mount Veniaminof

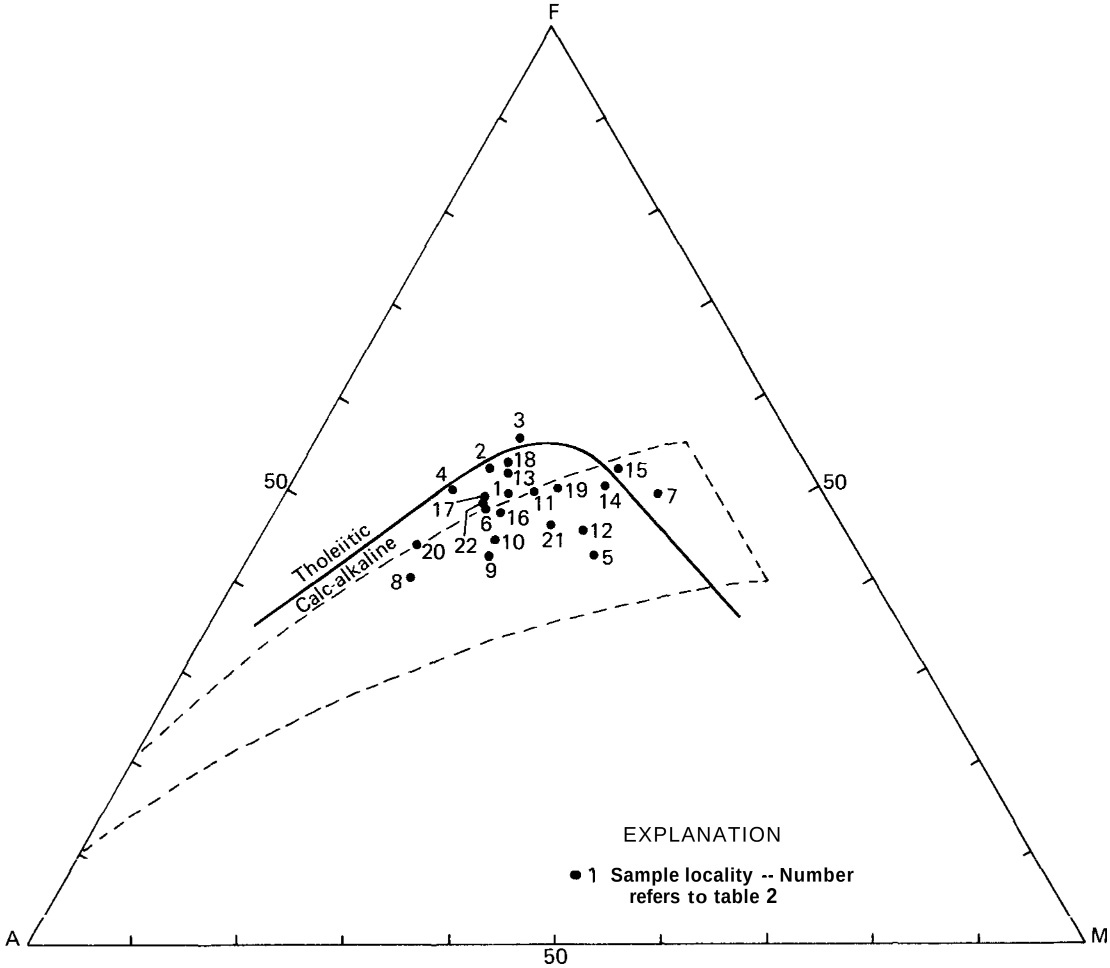


Figure 5. AFM ternary diagram of volcanic rocks of Stepovak Bay volcanoes showing slightly greater than normal iron enrichment. Dashed line indicates field for calc-alkaline rocks of Ringwood (1977) and solid line indicates division between tholeiitic and calc-alkaline rocks of Irvine and Baragar (1971). A is $Na_2O \pm K_2O$, F is total iron, calculated as FeO, and M is MgO.

Table 3. K-Ar age determinations of rocks forming the Stepovak Bay volcanoes

[Age determinations calculated using the following constants: $\lambda_{\epsilon} = 5.72 \times 10^{-10}$ year^{-1}, $\lambda_{\epsilon'} = 8.78 \times 10^{-13}$ year^{-1}, $\lambda_{\beta} = 4.962 \times 10^{-10}$ year^{-1}, $^{40}K/K = 1.167 \times 10^{-4}$ atom percent. Argon analysis and age calculation by Nora Shew and F.H. Wilson, potassium analysis by Sarah Neil, Stuart McPherson, Byron Lai, Terry Fries, and Larry Espos, U.S. Geological Survey. Potassium was determined using lithium metaborate fusion and flame photometry, generally following the methods of Engels and Ingamells (1970). Argon extraction and measurement were done using techniques of isotope-dilution mass spectrometry as generally described by Dalrymple and Lanphere (1969), with modification presented by Wilson (1980). The error assigned to each age is an estimate of the standard deviation of analytical precision using the method of Cox and Dalrymple (1967), together with an estimate of precision based on evaluation of the uncertainties in the concentration of the argon tracer and potassium measurements. All potassium and argon analyses were done in duplicate]

Locality and field number	Rock type and mineral dated	Latitude	Longitude	K_2O average percent	$^{40}Ar_{rad}$ x10-12	Ar_{rad} percent	Age (Ma)	Error m.y.
5	Andesite	56.00°N	160.04°W	1.382	7.346	32.15		
78AYb 90					6.701	36.72	3.53	0.27
6	Andesite	55.84°N	160.03°W	.356	.322	7.07		
82AWs 45					.225	5.01	.53	.14
7	Leuco-	55.90°N	159.90°W	.094	1.4949	2.39		
83AWs 97	basalt,				2.5347	4.41		
	plagioclase				2.0167	3.27		
					1.9497	3.81	1.48	.36
15	Andesite,	55.98°N	159.66°W	.104	.0891	1.58		
84AWs 177	plagioclase				.0808	1.62	.57	.06
16	Andesite,	55.92°N	160.47°W	1.562	8.6887	75.9		
84AWs 197	plagioclase				8.7360	56.5	3.87	.06
17	Andesite,	55.95°N	160.45°W	.376	1.7686	35.6		
84AWs 199	plagioclase				1.8507	35.5	3.35	.12
20	Andesite,	55.82°N	160.23°W	.416	2.7809	45.1		
84AYb 633	plagioclase				2.7861	39.1	4.65	.07
21	Andesite,	55.96°N	160.29°W	.906	2.1982	47.2		
85AYb 708	plagioclase				2.2447	53.3	1.70	.03

section of the arc in the spatially well-defined Chignik arc segment, tholeiitic centers may only indicate the position of areas of rapid magma transport to the upper crust.

The available data suggest major tilting and differential uplift from the southeast along the axis of the Alaska Peninsula. This tilting and differential uplift has combined with glaciation to result in the best preservation of the Milky River Formation and the Stepovak Bay volcanoes on the northwest side of the Alaska Peninsula. The evidence in support of tilting and differential uplift includes the exposure of the pluton at American Bay, which is similar to plutons associated with porphyry copper systems. A depth of emplacement of 1.5 to 3 km or more is typically suggested for the porphyritic plutons in models of copper porphyry systems (Sillitoe, 1973; Sutherland Brown, 1976). This is also a reasonable estimate of the depth of emplacement for the quartz diorite pluton of early Pliocene age at American Bay only 8 km south of essentially coeval flows from the Stepovak Bay volcanoes. Erosion of approximately 2 km of cover was probably required to expose this pluton and indicates tremendous differential erosion compared to the nearby volcanic flows. No major fault systems have been mapped between the exposures of plutonic and volcanic rocks, hence tilting and differential uplift are good explanations for the observed effect. Additionally, raised terraces, uplifted sea caves on the Pacific Ocean coast, drowned moraines on the Bering Sea coast, and other field evidence (R.L. Detterman, F.R. Weber, and F.H. Wilson, unpub. data, 1988) support the suggestion of differential uplift on the Alaska Peninsula. Quaternary glaciers flowed from the south and southwest and were

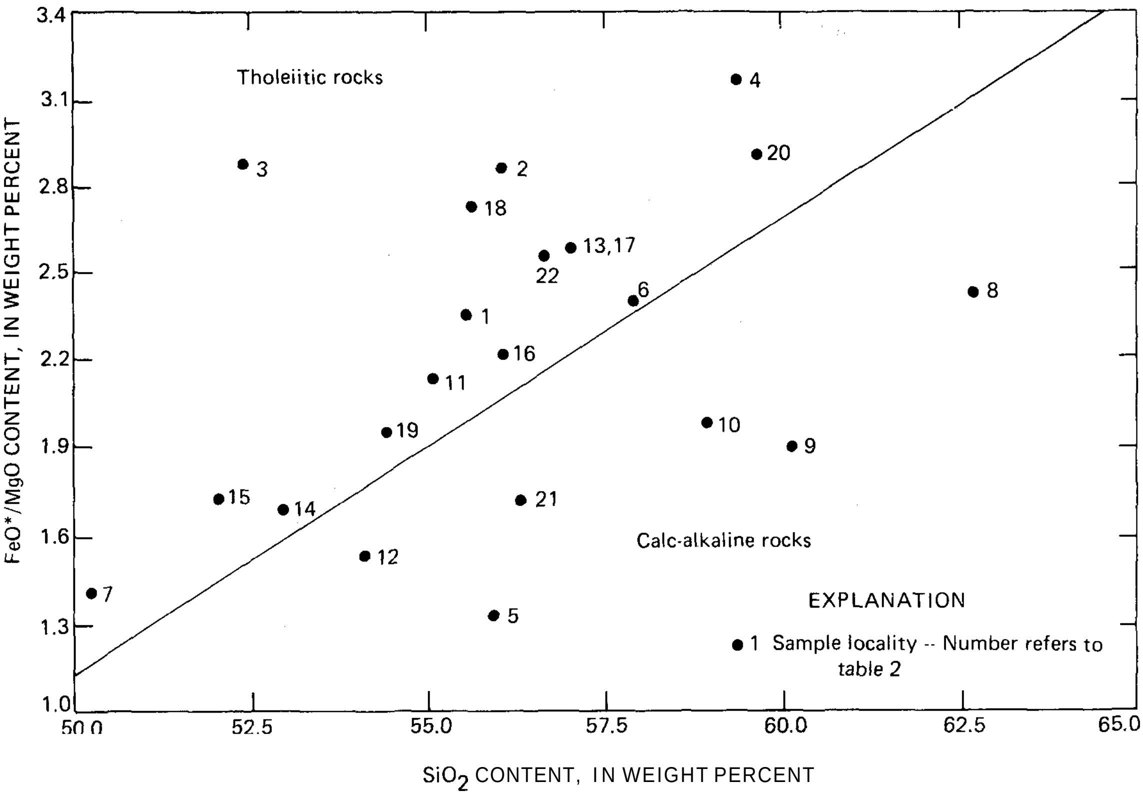


Figure 6. FeO^*/MgO versus SiO_2 variation diagram for volcanic rocks of Stepovak Bay volcanoes showing that most rocks are tholeiitic. FeO^* is total iron, calculated as FeO. Boundary between tholeiitic and calc-alkaline fields after Miyashiro (1974).

largest on the southeast side of the Alaska Peninsula in this area (Weber, 1985); this glaciation caused the preferential removal of rocks on the southeast.

SUMMARY OF CONCLUSIONS

Three of the five Stepovak Bay volcanoes were first recognized as Quaternary volcanic centers in 1982, and an additional one was recognized in later field work. The five volcanoes represent the latest phase of more than 4.65 million years of eruptive activity north of Stepovak Bay. As such, they represent one of the longest lived active volcanic centers on the Alaska Peninsula. The oldest products of the volcanoes were voluminous andesite flows. These flows, in part mapped in the Milky River Formation, are now exposed capping most of the ridges in the vicinity of the volcanoes. Holocene eruptive activity has consisted of a number of debris and lava flows from at least four of the volcanoes, and at present there are active fumaroles on two of the volcanoes. Volcanic eruptions have occurred along the entire of the chain of volcanic centers throughout their history.

Rocks erupted throughout the history of the volcanoes have a limited range of mineralogy and texture. Plagioclase compositions range widely, and the presence of olivine is correlated with the lowest An-content plagioclase. The Stepovak Bay volcanoes are generally tholeiitic and occur at the southeast end of the herein defined Chignik segment of the Aleutian arc.

Data from the volcanoes and nearby plutonic rocks agree with other data that suggest major tilting and differential uplift from the southeast along the axis of the Alaska Peninsula. In combination with glaciation, this has resulted in the best preservation of the volcanoes on the northwest side of the Alaska Peninsula.

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