Reconnaissance Geology of Southern Atka Island, Aleutian Islands, Alaska

By James R. Hein, Hugh McLean,
and Tracy Vallier

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Reconnaissance Geology of Southern Atka Island, Aleutian Islands, Alaska

By James R. Hein, Hugh McLean, *and* Tracy Vallier

Abstract

Atka Island, one of the central Aleutian Islands, is composed of two distinct parts: This report treats the southern part, consisting mostly of Tertiary igneous and volcaniclastic rocks, and ignores the northern part, consisting of the late Cenozoic Korovin volcanic complex. The oldest sedimentary rocks (preplutonic), middle Eocene to middle Oligocene in age, compose a sequence of bedded marine sandstone, mudstone, and minor conglomerate that interfinger with massive volcanic flows, volcanic breccia, and rare pillow flows. Younger sedimentary rocks, of Miocene (synplutonic) age, occur only on the north shore and consist of sandstone, volcanic conglomerate, black carbonaceous mudstone, and volcanic debris flows bearing fossil logs.

Sandstone consists of volcanic plagioclase, volcanic-rock fragments, clinopyroxene, opaque grains, and rare fragments of microfossils and quartz. Secondary minerals are pore-filling cements of smectite, chlorite, and zeolites. Metamorphic grade increases from east to west (toward the plutons) in the sedimentary and volcanic rocks, from zeolite through prehnite-pumpellyite to greenschist-hornfels facies, characterized by chlorite, epidote, amphibole, and quartz. Overall, metamorphic grade on Atka is higher than on adjacent Amlia Island.

Volcanic rocks, mostly basalt, basaltic andesite, and andesite, were extruded during three eruptive episodes. The earliest episode was submarine and of middle(?) and late Eocene and early Oligocene age; the second episode extruded basalt and basaltic andesite in middle and late Miocene time; and, finally, stratovolcanoes of mostly Quaternary age arose on the northern part of the island. Plutonic rocks were intruded during the early, middle, and late Miocene.

The three plutons that were dated apparently young toward the west. Plutonic rocks are gabbro, diorite, norite, tonalite, and quartz diorite; quartz diorite is the dominant plutonic-rock type. Most of these rocks have hypidiomorphic-granular textures, and euhedral to subhedral crystals of plagioclase, mafic minerals, and Fe-Ti oxides occur with anhedral quartz.

Plutonic and volcanic rocks show both calc-alkaline and tholeiitic trends. Differences in the state of differentiation can explain the two series.

Folds are generally gentle and open; however, dips of rocks locally exceed 70° where drag folds result from faulting. Faults of small displacement are common. Faulting produced a pronounced east-west-trending topographic lineament that extends from the head of Egg Bay to Atka Village. Most faulting appears to be extensional, related to the emplacement of plutons and unrelated to compression associated with plate convergence along the Aleutian Trench.

Although no metallic ore deposits of economic importance were found on Atka Island, geochemical indicators suggest that further exploration is warranted for Cu, Pb, Ag, Sn, and possibly other metals. Reservoir and source-rock properties of rocks that crop out on Atka show little promise for petroleum primarily because of alteration resulting from plutonism. Offshore basins, however, offer a greater potential for petroleum development.

INTRODUCTION

Atka Island is situated in the central part of the Aleutian Islands and is part of the Andreanof Island group (fig. 1). Atka sits atop the Aleutian Ridge, an ensimatic volcanic archipelago that separates Pacific oceanic crust south of the ridge from older oceanic crust north of the ridge that forms the floor of the deep Bering Sea. The southern part of Atka Island is about 85 km long and averages about 10 km in width. Atka is separated from adjacent Amlia Island to the east by the 2-km-wide Amlia Pass. Adak Island, 175 km west of Atka, is the nearest large community and was our logistic support center. Atka Village, located at the head of Nazan Bay, is inhabited by a small population of Aleuts. Besides the naval station on Adak Island, Atka Village is the only community in the Andreanof group of islands.

Atka Island is geographically and geologically composed of two parts, which are joined by a 3-km-wide isthmus separating Korovin and Nazan Bays (figs. 1, 2). The northern part of the island consists of an uppermost Tertiary and Quaternary volcanic terrane, the informally named Korovin volcanic complex, that includes historically active Korovin Volcano and an older stratovolcano, Mount Kliuchef. The elongate southern part of the island consists of Tertiary rocks underlying an east-west-trending mountainous ridge. Numerous elongate bays, rocky headlands, and small islands mark the shoreline of the southern part of the island.

Atka and Amlia Islands were among a small number of Aleutian Islands that had not previously been mapped geologically, even on a reconnaissance scale. Former work on southern Atka consisted of a brief description of fossil mollusks from shore exposures near Martin Harbor by Grewingk (1850), who visited the area during the period of Russian occupation. The Quaternary volcanic terrane of northern Atka Island was mapped by B. D. Marsh (Johns Hopkins University) in 1977 but not published.

We did reconnaissance mapping, mostly shoreline geology, and sample collecting of Tertiary rocks on Atka Island in 1977 and 1979 (table 1). This report presents data from our work and some broad interpretations based on them.

Table 1. Locations of samples of Atka Island rocks

Field No.	Latitude N.	Longitude W.
877-6-3a2,a4	52°15'	174°15'
877-7-3A,B,F	52°10'	174°25'
877-7-4C	52°10'	174°25'
877-9-1	52°15'	174°15'
877-9-2A	52°15'	174°15'
877-10-1A,b	52°05'	174°05'
877-10-2	52°05'	174°10'
877-10-5A,B	52°05'	174°15'
877-11-1A	52°05'	174°15'
877-12-1	52°05'	174°25'
877-12-4	52°05'	174°35'
877-12-8	52°05'	174°40'
877-12-9,A	52°00'	174°45'
877-13-1A	52°00'	174°25'
877-14-2d	52°00'	174°45'
877-14-3B	52°00'	174°55'
877-14-5 II	52°00'	175°00'
877-15-4	52°05'	175°10'
877-15-5	52°00'	175°05'
877-16-5	52°05'	174°45'
779-16-2	52°10'	174°10'
779-18-1A,C	52°10'	174°10'
779-19-1A	52°15'	174°20'
779-24-1A	52°05'	174°10'
779-24-2	52°05'	174°40'
779-24-3	52°05'	174°40'
779-24-4	52°05'	174°40'
779-24-5	52°05'	174°40'
779-24-6	52°05'	174°40'
779-24-7	52°05'	174°40'
779-24-8	52°05'	174°40'

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STRATIGRAPHY AND PALEONTOLOGY

Southern Atka Island consists of a sequence of middle and upper Eocene and lower Oligocene (preplutonic) sedimentary rocks, interbedded with volcanic flows and breccias, that are intruded by early, middle, and late Miocene plutons. A sequence of middle and lower upper Miocene (synplutonic and postplutonic) volcanic flows, breccia, and sedimentary rocks unconformably overlies the older rocks; and in the vicinity of the isthmus separating the Korovin volcanic complex and the southern part of the island, the postplutonic rocks are, in turn, overlain by mostly Quaternary volcanic rocks of the Korovin volcanic complex (figs. 1-3).

Paleogene sedimentary rocks

The oldest rocks on Atka Island are a sequence of bedded marine sandstone, mudstone, and minor conglomerate that interfinger with massive volcanic flows, volcanic breccia, and rare pillow flows. Sedimentary rocks exposed along the west shore of Amlia Pass are mainly massive coarse-grained volcaniclastic sandstone with planar bedding and gentle dips (figs. 1, 2). Framework grains consist of moderately sorted subrounded fragments of basalt and andesite in a matrix of authigenic clay and zeolite. Marine fossils include fragments of oyster shells and rare fragments of thick-walled gastropod shells. Shell fragments occur most commonly in massive pebbly sandstone. The section northwest of Cape Utalug (figs. 1, 4A) is thinner bedded and includes graded turbidite beds from 0.5 to 2.0 m thick; rare flute casts indicate westerly flow.

Thin-bedded to laminated fine-grained sandstone and siliceous mudstone sections are well exposed along the northeast shore of Egg Bay (fig. 4B) on the north side of Atka and at Tillamook Cove on the south side. The rocks in both areas are highly indurated and altered owing to their proximity to intrusive rocks. Calcium carbonate, mostly contributed by foraminifers, is abundant in some samples (for example, 877-7-3F, tables 2, 3). Beds of massive breccia that contain angular clasts of basalt and andesite interfinger with the sedimentary rocks. Volcanic breccia is most abundant along the north shore, especially between Bechevin and Wall Bays.

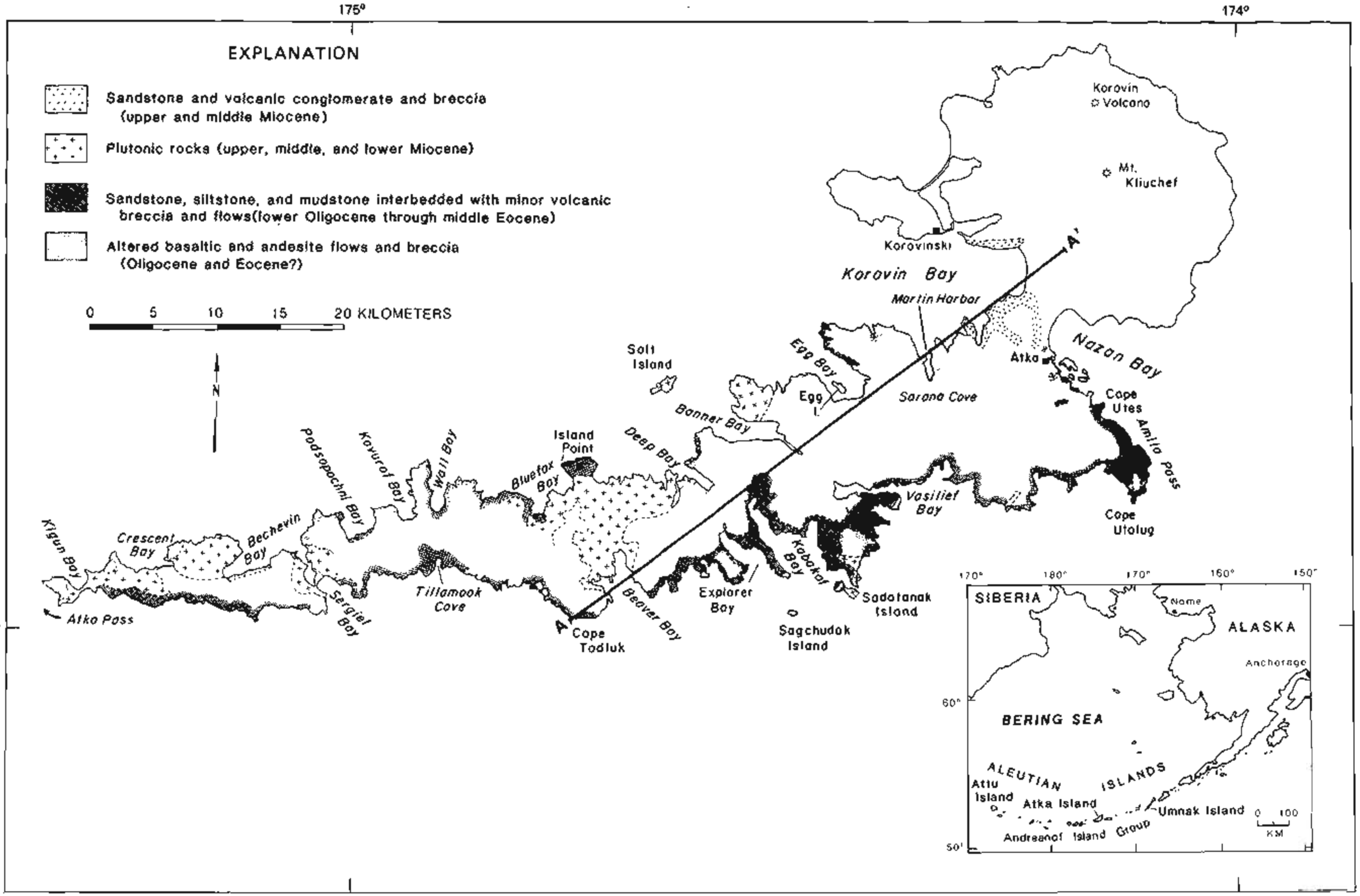

Figure 1. Geologic map of Atka Island, showing location of cross section A-A' in figure 3.

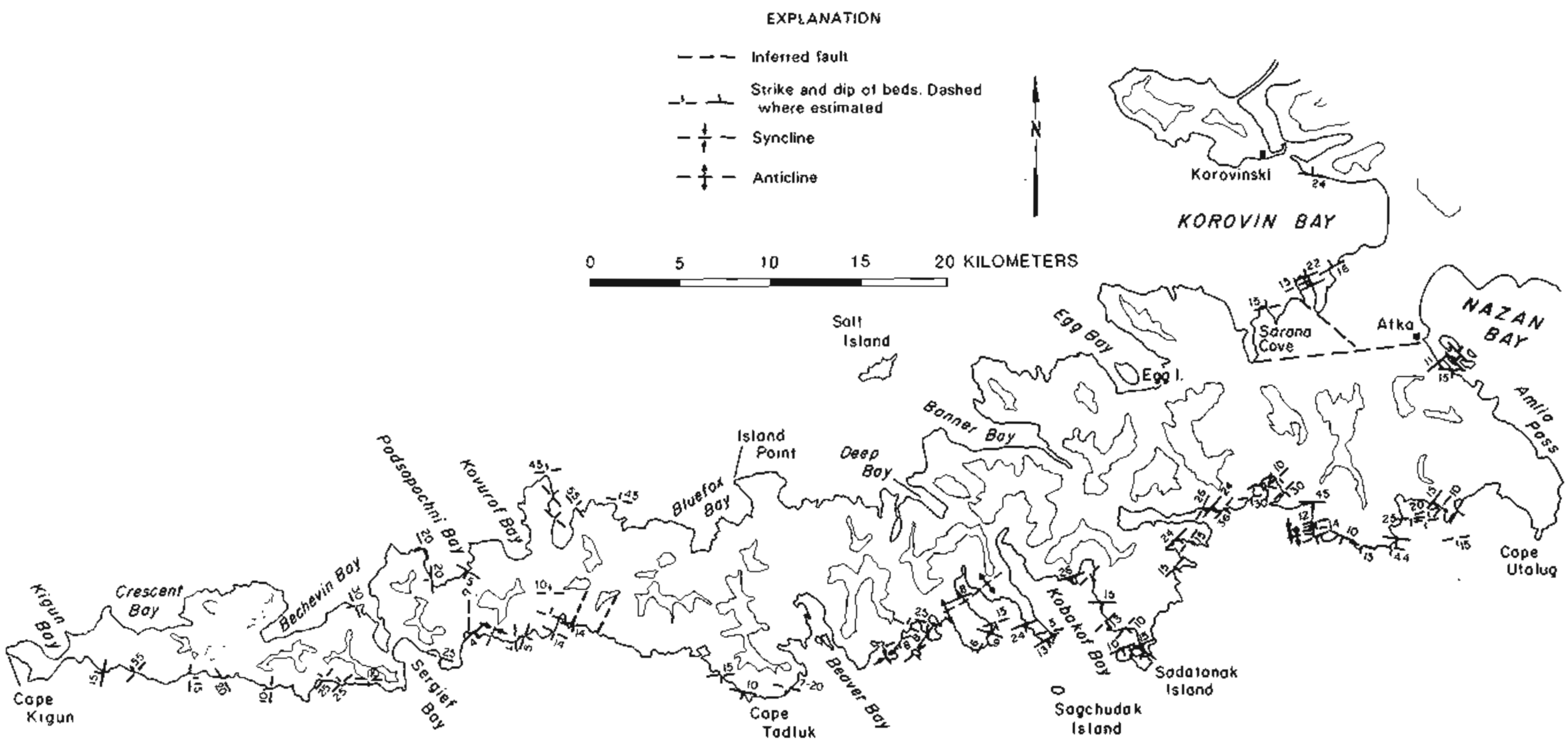

Figure 2. Structural map of Atka Island. Irregular outlines are 1000-ft contour.

Massive flows of dark-gray andesite and basalt also interfinger with strata of the sedimentary section. Pillowed flows, however, were observed at only three places along the south shore—3.75 km northwest of Cape Tadluk and on the north and south sides of the entrance to Vasilief Bay. The thickness of the preplutonic sedimentary and volcanic section, which is not accurately known, is probably between 1,000 and 2,000 m.

Near-vertical faults of unknown displacement interrupt most sections. Correlations are further hampered by rapid facies changes and by truncation of strata by conglomerate, breccia, and volcanic flows. A conspicuous characteristic of the sedimentary sequences is rapid changes in bed thick-nesses and grain sizes, both laterally and vertically. Total organic-carbon content of these beds is typically less than 0.5 weight percent (table 2).

Age-diagnostic fossils from the preplutonic sequence were recovered from only three places (table 3). Poorly preserved fragments of a bivalve, identified as Ostrea cf. O. tigiliana Slodkewitsch (1938), occur in pebbly sandstone along the shore northwest of Cape Utalug. The species is reported in Eocene and Oligocene rocks of the Alaska Peninsula and Kamchatka (L. N. Marincovich, written commun., 1979). Calcareous nannofossils from the same vicinity suggest a middle Eocene through early Oligocene age on the basis of lower-latitude correlations (table 3). Foraminifers were observed in thin sections of highly indurated fine-grained sandstone from the northeast shore of Egg Bay; one rock from Egg Bay is considered to be of Eocene age on the basis of the occurrence of Globigerina linaperta Finlay (table 3; Gerta Keller, written commun., 1982). Lithologically correlative strata on adjacent Amlia Island have an age of late Eocene and early Oligocene on the basis of several nannofossil assemblages (McLean and others, 1983). Thus, fossils from Atka Island and correlations with dated rocks from other Aleutian Islands suggest that the preplutonic sedimentary rocks were most likely deposited during part of or all of the middle and late Eocene and the early Oligocene, approximately 50-30 m.y. B.P.

Middle and Upper Miocene (Synplutonic) Sedimentary Rocks

Synplutonic and postplutonic (on the basis of paleontologic and radiometric ages) sedimentary rocks crop out mainly around Martin Harbor on the south shore of Korovin Bay, and along the north shore of Korovin Bay east of the abandoned Russian settlement of Korovinski. Sedimentary rocks on the west shore of Martin Harbor include massive sandstone, volcanic conglomerate, and a bed of black carbonaceous mudstone, about 50 cm thick. This mudstone actually consists of coaly beds, 2 to 3 cm thick, interbedded with light-gray volcaniclastic sandstone. The beds crop out in the intertidal zone and probably constitute the section from which Cretaceous(?) leaf fragments had been collected (R. R. Coats, oral commun., 1977). Samples we collected contain woody and resinous debris but are barren of palynomorphs. Because the strata on both sides of Martin Harbor have similar structural attitudes, are similar in lithology, and contain oxyhornblende, we believe that the strata on the west shore may also be middle to late Miocene in age.

Previous work by Grewingk (1850) and R. R. Coats (oral commun., 1978) focused on sedimentary rocks bearing fossil logs, from the south shore of Korovin Bay at the mouth of Martin Harbor. Thes logs consist of carbonized and silicified stumps and assorted fragments of an unidentifiable species of conifer (fig. 5A). The plant debris occurs within a massive poorly sorted volcanic debris flow that contains boulder-size fragments of unaltered hornblende andesite (fig. 5B). Sandstone interbedded with the debris flow contains fresh oxyhornblende and slightly altered tuff.

Palynomorphs from the matrix of the log-bearing unit indicate a probable Homerian age (late middle and early late Miocene), or about 14-8 m.y. B.P. (Jack A. Wolfe, written commun., 1979). Additional age control on the Martin Harbor section is provided by a K-Ar age of 6.6 m.y. from an andesite plug that appears to intrude the sedimentary rocks (B.

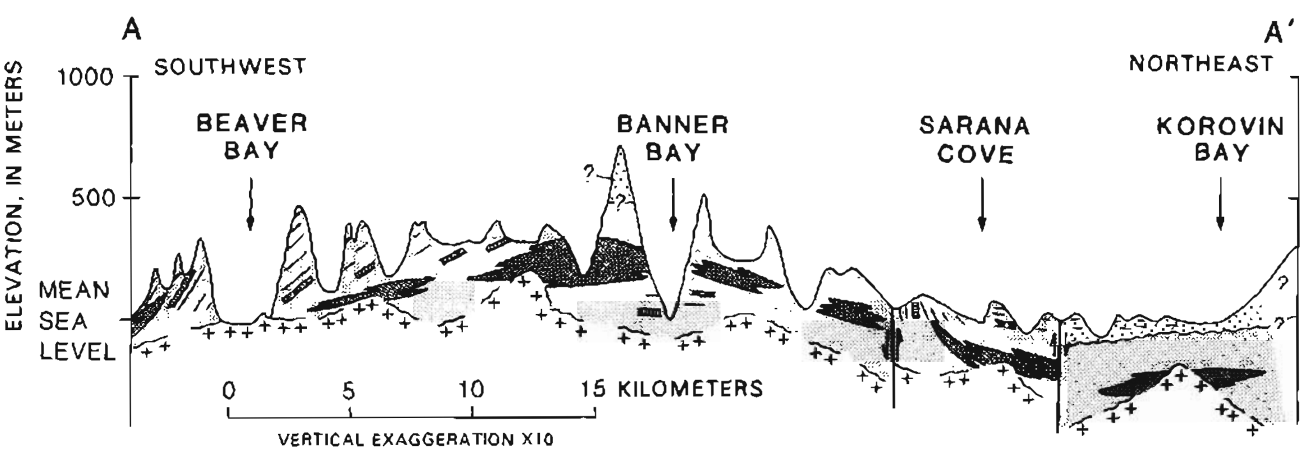

Figure 3. Schematic and interpretive cross-section of Atka Island.

D. Marsh, written commun., 1979) and thus places a minimum age on the sedimentary section. A basalt flow interbedded with the sedimentary rocks at the head of Martin Harbor yielded a K-Ar age of about 11 m.y. (table 4). Basaltic andesite associated with similar rocks on the south shore of Bechevin Bay yielded a whole-rock K-Ar age of about 12 m.y. (table 4).

A diatom assemblage from a 50-cm-thick siltstone bed interbedded with massive volcanic pebble-cobble conglomerate along the northeast shore of Korovin Bay indicates a Miocene age (J. A. Barron, written commun., 1980). Thus, synplutonic and postplutonic sedimentary rocks were probably deposited during the middle and late Miocene, about 14-7 m.y. B.P.

PETROGRAPHY OF SEDIMENTARY ROCKS

The sedimentary rocks in the area of Amlia Pass between Cape Utes and Cape Utalug are the least altered of the preplutonic strata. Westward from Cape Utalug toward Vasilief Bay, increasing alteration of the rocks probably reflects increased temperatures associated with the intrusion of Miocene plutons.

Primary framework grains in clastic rocks in the Amlia Pass area consist of fresh volcanic plagioclase, various volcanic-rock fragments (mostly porphyritic rocks with altered vitreous groundmasses), clinopyroxene, opaque grains, and rare fragments of microfossils and quartz. Secondary minerals are mostly pore-filling cements of smectite, chlorite, and suites of zeolites, including heulandite, analcime, stilbite, and minor laumontite and phillipsite. Clay minerals form rim cement in some rocks; the remaining pore space is filled with zeolites. Calcite and quartz cement some rocks. Chlorite replaces volcanic-rock fragments, and chlorite and smectite fill vesicles in the altered-rock fragments.

The sandstone and siltstone between Vasilief and Beaver Bays become increasingly altered toward Beaver Bay. Framework grains of plagioclase are albitized or replaced by laumontite. Volcanic-rock fragments are likewise replaced by suites of secondary minerals, including smectite, laumontite, chlorite, and, more rarely, epidote. Rare microfossils occur as ghosts or are strongly recrystallized. Clinopyroxene remains fresh; in places, ferromagnesian minerals are replaced by chlorite and calcite. Secondary quartz and chlorite commonly fill pores and replace glassy matrix. Laumontite is the dominant zeolite.

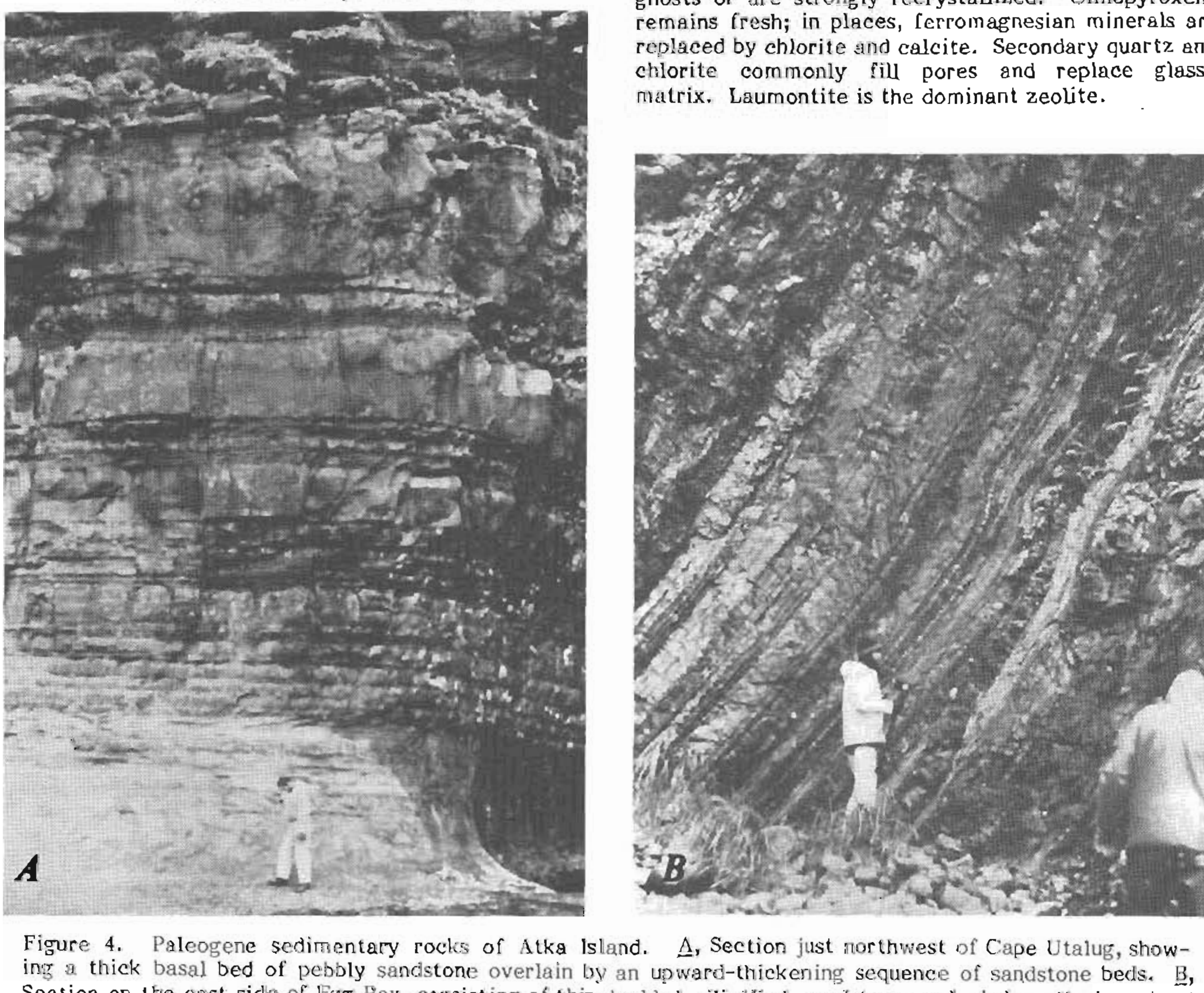

Figure 4. Paleogene sedimentary rocks of Atka Island. A, Section just northwest of Cape Utalug, showing a thick basal bed of pebbly sandstone overlain by an upward-thickening sequence of sandstone beds. B, Section on the east side of Egg Bay, consisting of thin-bedded silicified sandstone and shale, dipping about 70°. Some beds contain abundant foraminifers.

On the south side of Explorer Bay, prehnite becomes an abundant secondary mineral in altered feldspathic subwacke. Other secondary minerals that replace feldspar and glassy volcanic groundmass are quartz, chlorite, and laumontite. Minor pumpellyite, natrolite, and mordenite also occur.

Prehnite and quartz are major secondary minerals in altered tuffaceous siltstone interbedded with pillow basalt about 3.5 km northwest of Cape Tadluk along the central coast. Interpillow chert is composed of quartz and minor amounts of prehnite, epidote, zeolites, and celadonite. Much interpillow sediment is replaced volcanic glass that was spalled from pillows when the flows entered the sea. Plagioclase is completely replaced by prehnite, and zeolites and silica replace volcanic glass in the matrix. The pillow lava also contains abundant prehnite and pumpellyite and accessory epidote, chlorite, and stilpnomelane. Pumpellyite replaces plagioclase and fills some vesicles. Other vesicles are filled with quartz, chlorite, minor epidote, feldspar, pyroxene, and prehnite. Pyrite veins also occur in the section.

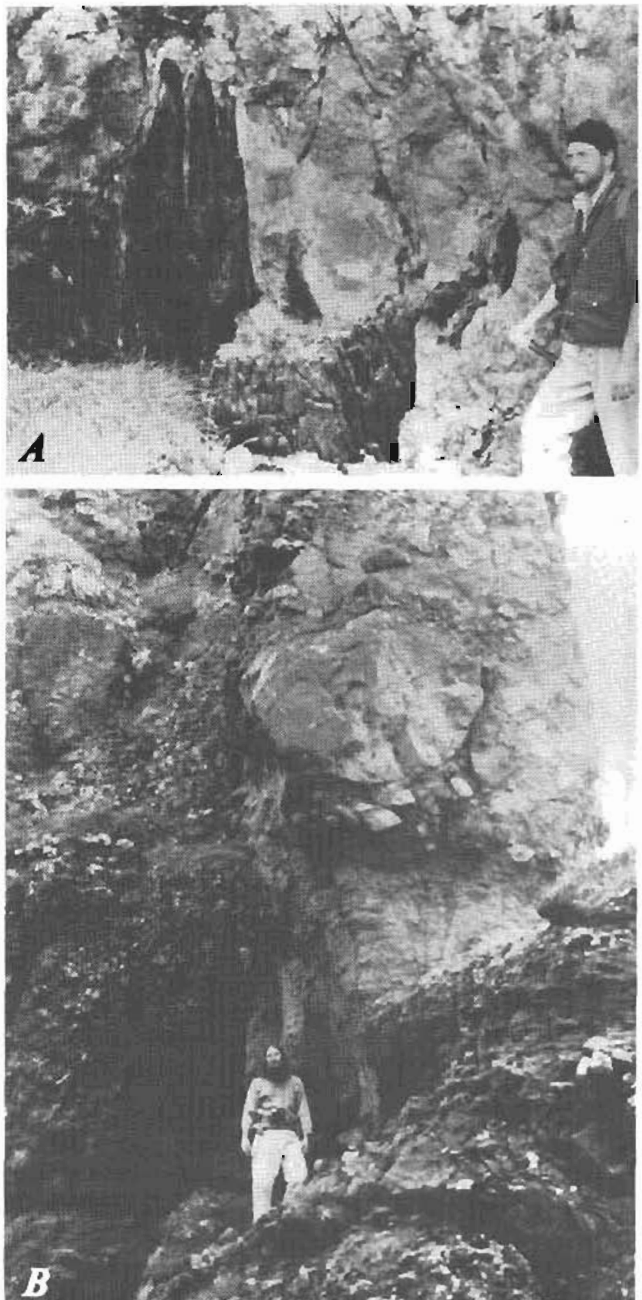

Figure 5. Synplutonic and postplutonic rocks of Atka Island. A, Carbonized and silicified logs near Martin Harbor, enclosed in volcanic debris flows. B, Boulder- to sand-size volcanic debris flows of Neogene age near Martin Harbor.

Preplutonic sedimentary rocks in the western part of the island, from Tillamook Cove to Atka Pass, are strongly altered, owing to the intrusion of plutonic rocks that crop out discontinuously between Sergief and Kigun Bays. Some rocks close to the contact with the pluton at Sergief Bay are hornblende-hornfels facies and have a metamorphic granular texture. They are composed of quartz, epidote, piedmontite, altered green hornblende with hematite rims, and large patches of pyrite. Pyrite also is common along the margins and within the Sergief Bay pluton.

Sequences of altered sedimentary rocks on the north shore of Atka Island crop out in Podsopochni Bay, along Island Point, and along the northeast shore of Egg Bay. Primary framework grains of porphyritic pyroxene andesite contain albitized plagioclase microlites and groundmass glass replaced by chlorite, epidote, calcite, and quartz, with traces of prehnite and pumpellyite and suites of zeolites including natrolite, heulandite, and analcime.

The Egg Bay section consists of highly indurated thin-bedded fine-grained sandstone and laminated siltstone. Sandstone is a poorly sorted wacke composed of altered glassy volcanic-rock fragments, clinopyroxene, recrystallized foraminiferal tests, albitized plagioclase, and the opaque minerals hematite and magnetite. Secondary minerals include analcime, quartz, calcite, chlorite, and traces of several other zeolites that may be clinoptilolite, heulandite, and thompsonite. Rare ghosts of radiolarians appear in laminated siltstone.

Miocene sandstone surrounding Martin Harbor consists of angular, fresh grains of plagioclase, oxyhornblende, quartz, and volcanic-rock fragments cemented by quartz and clay minerals, mostly smectite. Fossilized logs contained in interbedded volcanic debris flows are silicified. Black carbonaceous mudstone and sandstone consist of plagioclase, quartz, pyrite, rare zeolites and K-feldspar, and a great variety of clay minerals, including chlorite, smectite, vermiculite, and mixed-layer varieties of these three clay minerals.

IGNEOUS ROCKS

The igneous rocks of the Aleutian Islands have been discussed mainly by Byers (1961), Coats (1952, 1962), DeLong (1974), Marsh (1976, 1982), Kay (1977, diorite of the Sergief Bay pluton; quartz diorite from the Crescent Bay pluton (hornblende) is 8.5 m.y. old. Thus, the plutons appear to young toward the west. The radiometric ages, however, were determined on relatively fresh and unaltered rocks, and we recognized more highly altered plutonic rocks both in the field and in thin section. Therefore, other, older plutons probably occur on Atka Island. Confirmation of the apparent younging of plutons to the west and the possibility that older plutons occur will require more detailed sampling and dating of a statistically significant number of rocks.

Volcanic rocks

Most of the Tertiary (pre-Korovin volcanic complex) volcanic rocks are basalt, basaltic andesite, and andesite. They are typically porphyritic and contain euhedral phenocrysts of plagioclase, clinopyroxene, and Fe-Ti oxides in a groundmass of secondary minerals. Plagioclase is commonly mottled and partially albitized; in some rocks, it is completely replaced by calcite or prehnite. Pyroxene phenocrysts are generally unaltered, but in some rocks they are completely replaced.

Secondary minerals replace glassy groundmasses, rim or fill vesicles, and fill fractures. Secondary minerals include several types of zeolites, calcite, chlorite, epidote, prehnite, pumpellyite, and smectite. Radiometrically dated volcanic rocks (table 4) are extensively altered. Sample 877-9-1 (table 6), for example, contains calcite, smectite, zeolites, and chlorite; other samples are similarly altered.

Massive flows of pale-gray holocrystalline fine-grained andesite crop out along the south shore between Vasilief Bay and Sadatanak Island. The rocks are essentially unaltered and form much of the highland area between Kobakof and Vasilief Bays. On the point of land directly north of Sadatanak Island, massive flows of holocrystalline andesite that concordantly overlie relatively unaltered sedimentary rocks grade laterally into discordant intrusive diorite. Field relations and petrographic similarities suggest that the extrusive rocks are comagmatic with the plutonic rocks. Although time did not permit closer examination, we believe that much of the island above 300-m elevation may be composed of these comagmatic middle Miocene andesitic flows and breccia.

Geochemistry

A thorough discussion of the igneous-rock petrogenesis, including alteration, is beyond the scope and purpose of this report and, in fact, should be attempted only after more field relations are

Table 5. U-Pb analyses of zircon from tonalite (sample 779-25-1) of the Beaver Bay pluton, Atka Island

[All isotopic compositions normalized to absolute values by means of replicate analyses using U.S. National Bureau of Standards Pb standards 981 to 983. Common Pb corrections: $^{206}Pb/^{204}Pb$, 19.0; $^{207}Pb/^{204}Pb$, 15.6. $^{207}Pb/^{206}Pb$ ages for the sample are insignificant because of the slight enrichment of radiogenic Pb and the uncertainty in correcting for the common isotope ^{207}Pb, although these ages are concordant. Thus, the composite $^{238}U/^{206}Pb$ age of 15.1±0.1 m.y. should represent an accurate cooling age for the pluton]

Fraction size	^{238}U (ppm)	^{206}Pb (ppm)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$	Age (m.y.)	
						$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Coarse------	330.8	0.674	0.4188	0.1122	0.004475	15.15±0.15	15±30
Fine--------	426.8	.861	.2827	.08724	.002754	15.00±0.15	34±20

Table 6. Classification, ages, textures, and mineralogy of chemically analyzed Tertiary igneous rocks of Atka Island

[Sample numbers correspond to those in figure 8 and table 7. Ages: P, preplutonic; S, synplutonic; --, not determined. Textures: D, diabasic; F, felty; H, hypidiomorphic granular; I, intersertal; P, porphyritic; X, pilotaxitic. Minerals: Act, actinolite; An, analcime; Bio, biotite; Ca, calcite; Chl, chlorite; Cpx, clinopyroxene; Ct, clinoptilolite; Ep, epidote; Gl, glass; H, hornblende; He, heulandite; Hm, hematite; Ol, olivine; Opx, orthopyroxene; Or, orthoclase; Ox, Fe-Ti oxides; Pl, plagioclase; Pr, prehnite; Qtz, quartz; Sm, smectite; Sp, sphene; Ze, zeolites. (x), determined by X-ray diffraction]

Sample	Field No.	Rock type	Age (m.y.)	Texture	Primary minerals	Secondary minerals	Remarks
1	877-13-1A	Gabbro------------	--	H	Pl,Cpx,Ox,Op,	Act,Chl,Pr,Qtz,Or(x)	Metamorphosed.
2	877-12-9A	Hornblende norite-	17.5	H	Pl,H,Opx,Bio,Cpx,Ox	Ct(x)	Relatively unaltered.
3	877-12-1	Diabase-----------	--	D	Pl,Cpx,Ox	Chl,Pr,Ca,Hm,Qtz(x),Ze	Metamorphosed.
4	877-12-8	Meladiorite-------	18.1	H	Pl,H,Bio,Ox,Opx	Act,Chl,Sp	Relatively unaltered.
5	877-14-5II	Quartz diorite----	12.4	H	Pl,Cpx,Opx,Bio,Qtz,H,Ox	Act	Do.
6	779-25-1	Quartz diorite----	15.1	H	Pl,Bio,H,Qtz,Cpx,Ox,Opx	Act	Do.
7	877-10-5B	Basalt------------	P	P,X	Pl,Cpx,Ol,Ox	Sm,Ca,An(x),He(x)	Abundant zeolites.
8	877-9-1	Basalt------------	11.1	P,X	Pl,Cpx,Ox,Gl,H,Opx	Ca,Sm,Ze,Hm,Chl	Altered.
9	779-18-1A	Basaltic andesite-	P	F,P	Pl,Ox	Ep,He(x),Chl,Hm,Qtz,Sm	Highly altered.
10	877-12-4	Andesite----------	S	I,P	Pl,Ox,Gl	Chl,Sm,Ca,Ep,Pr,Sp	Metamorphosed.

determined and additional laboratory data are available. We can, however, discuss the range of rock compositions, comment on the differentiation trends, and compare the rocks with other rocks from the Aleutian Islands.

Tables 6 and 7 list the ranges in composition of the modal mineralogies and chemical analyses, respectively. SiO_2 contents, corrected for H_2O and CO_2, range from 47.5 to 66.3 weight percent (L. A. Morgenson and others, unpub. data, 1983). Al_2O_3 content is relatively high, similar to that of rocks in other island arcs (Gill, 1981). TiO_2 content ranges widely, from 0.46 to 1.43 weight percent plutonic rocks and from 0.57 to 1.32 weight percent volcanic rocks. The average TiO_2 content for 16 mafic rocks (less than 52 weight percent SiO_2) is 0.82 weight percent. Na_2O content ranges widely; some high values are apparently related to zeolitization and (or) albitization. K_2O content does not exceed 2.73 weight percent in the plutonic rocks and 1.26 weight percent in the volcanic rocks. In general, the range in SiO_2 contents, the high Al_2O_3 and low TiO_2 contents, and

Table 7. *Chemical analyses of representative Tertiary igneous rocks of Atka Island*

[Major-element analyses in weight percent; minor-element analyses in parts per million. Major elements and some minor and trace elements determined by X-ray fluorescence, and FeO by wet chemistry; *, determined by neutron activation. Sample numbers correspond to those in table 6. --, not determined or below detection limit]

Sample-----	1	2	3	4	5	6	7	8	9	10
					Major-element oxides					
SiO_2-------	49.66	50.12	50.82	52.60	60.02	61.10	48.51	50.08	53.20	58.45
TiO_2-------	1.17	.63	.94	.86	.58	.63	.66	.87	.84	.96
Al_2O_3------	15.61	14.84	16.48	19.17	16.02	16.10	14.40	16.94	21.20	15.47
Fe_2O_3------	4.05	4.68	4.30	2.91	2.31	1.55	3.89	3.19	3.53	4.44
FeO--------	7.62	5.71	5.30	3.94	2.87	3.02	4.35	4.63	3.83	4.20
MgO--------	6.00	7.20	5.50	5.20	4.40	4.04	7.50	5.60	1.12	3.70
CaO--------	9.41	10.99	8.10	8.62	6.28	5.44	11.57	11.13	8.95	3.22
Na_2O-------	3.49	3.66	4.28	4.33	4.11	3.61	4.31	3.52	3.26	5.46
K_2O--------	.54	.90	1.11	.74	2.08	2.52	.70	.75	.25	.29
P_2O_5-------	.20	.18	.18	.25	.15	.14	.14	.17	.13	.17
H_2O^+-------	1.76	.67	2.39	1.25	.56	.85	2.11	.03	2.75	3.10
H_2O^--------	.88	.14	.74	.16	.50	.10	2.02	.83	.41	.63
CO_2--------	.12	.30	.35	.05	.09	.46	.82	1.90	.04	.37
Total---	100.51	100.02	100.49	100.08	99.97	99.56	100.98	99.64	99.53	100.46
					Minor and trace elements					
Mn---------	1,208	1,805	1,053	651	759	629	1,324	1,100	2,330*	1,123
Rb---------	--	23	17	--	--	45	11	11	--	--
Sr---------	266	388	295	697	403	501*	137	402	634	137
Zr---------	59	37	104	74	148	181*	44	67	--	74
Cr---------	89	294	96	75	164	119	397	157	10	75
Sc*--------	42	38	32	16	18	14	47	35	21	25
Co*--------	38	27	31	18	32	16	42	26	20	23
Ni*--------	31	55	39	47	71	--	71	31	--	47
Ba*--------	134	110	225	194	128	388	319	220	--	--
La*--------	5.02	9.78	6.45	7.71	5.29	13.00	2.12	5.75	6.13	7.45
Ce*--------	12.00	22.30	14.50	17.50	13.30	27.90	4.96	13.50	13.60	18.50
Nd*--------	10.40	14.10	10.70	11.00	9.47	16.60	5.92	11.30	9.55	13.20
Sm*--------	2.72	3.31	2.78	2.58	3.12	3.60	1.53	2.77	2.45	3.89
Eu*--------	.96	.87	.89	1.02	.98	.92	.58	1.01	.83	1.05
Gd*--------	3.84	3.21	3.34	2.18	--	3.08	2.24	2.40	2.75	4.65
Tb*--------	.57	.47	.55	.42	.56	.45	.33	.41	.49	.78
Yb*--------	2.12	1.35	2.04	1.36	2.12	1.50	1.17	1.47	1.77	3.39
Lu*--------	.35	.23	.34	.20	.34	.22	--	.24	.27	.56
Hf*--------	1.46	1.50	1.70	1.07	1.36	5.33	--	1.74	1.84	3.37
Ta*--------	--	.46	.11	.07	.14	.33	--	.07	.09	.25
Th*--------	.78	1.76	1.16	.25	1.09	3.72	.26	.89	.98	1.29
U*---------	.43	.82	.63	.14	.69	2.12	.16	.58	.56	1.06

the range in alkali contents are similar to those of the late Cenozoic volcanic rocks in the Aleutians (S. Kay and others, 1982).

Many of the rocks have high FeO_T/MgO ratios (Fig. 6) at low SiO_2 content, indicative of iron-enrichment (tholeiitic) differentiation trends (Miyashiro, 1974; Kay, 1977; Kay and others, 1982). Other rocks are calc-alkaline and have relatively constant FeO_T/MgO ratios at all SiO_2 values. For comparison, the young volcanic rocks from the Korovin volcanic complex on Atka are tholeiitic (Marsh, 1982).

The trace elements also have a wide range of values. Particularly noteworthy are the relative abundances of Sr, Ti, and Zr in the mafic volcanic and plutonic rocks (fig. 7), and the REE abundances (fig. 8). An Sr-Ti-Zr ternary diagram (fig. 7) confirms the tholeiitic and calc-alkaline composition of the mafic rocks. None of the Tertiary rocks, however, is really a low-potassium island-arc tholeiite (LKT), even though the trace-element distributions plot in that field (Fig. 7).

The geographic positions of young volcanic centers in the Aleutian Island arc were correlated with their magmatic differentiation trends by Kay and others (1982), who concluded that the tholeiitic centers form either between or at the end of arc segments, where magmas can more easily reach the surface (for example, by rapid ascent). Calc-alkaline volcanoes, in contrast, occur in the middle of these segments, where transit through the upper plate above

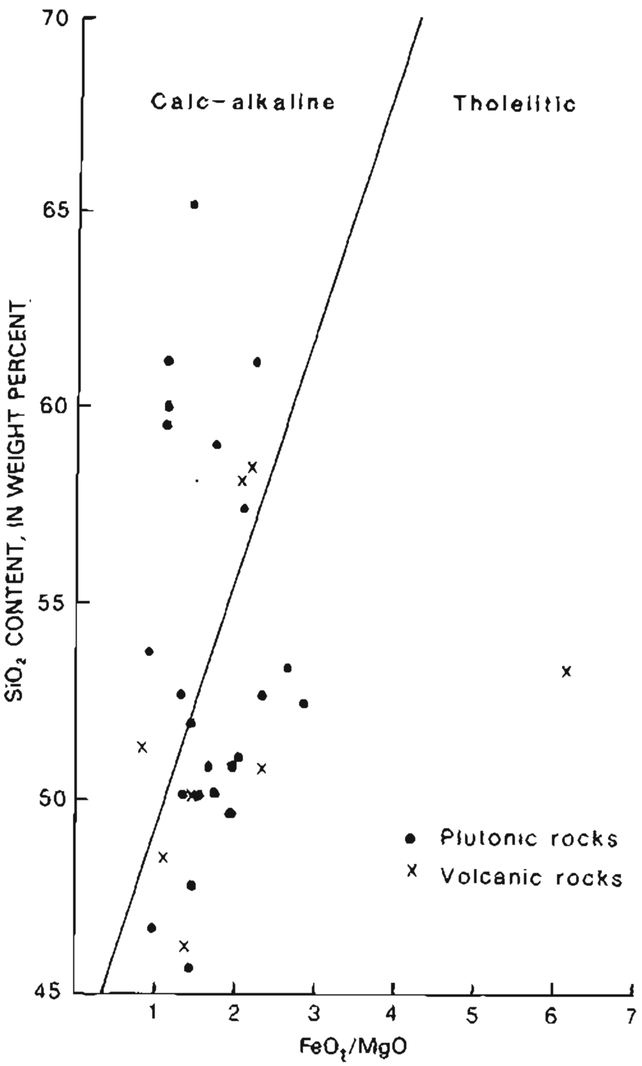

Figure 6. SiO_2 content versus FeO_T/MgO ratio for Tertiary rocks of Atka Island after (Miyashiro, 1974, and R. Kay, 1977). Analytical data from L. A. Morgenson and others (unpub. data, 1983). Values not corrected for H_2O and CO_2 contents.

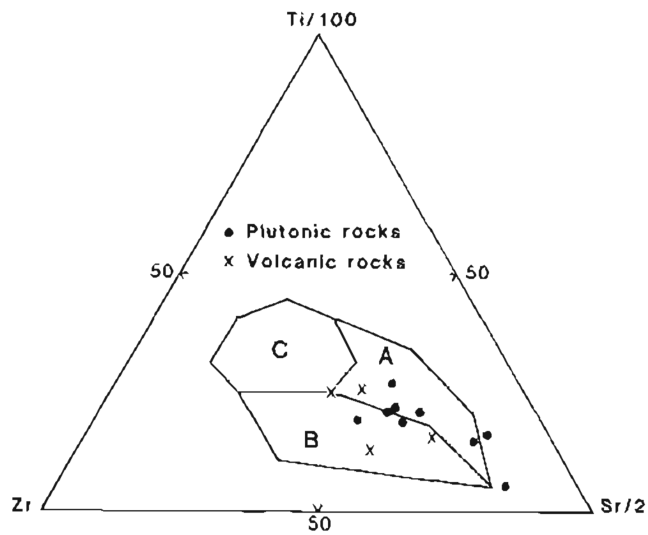

Figure 7. Triangular diagram of Sr-Ti-Zr content of plutonic and volcanic rocks (after Pearce and Cann, 1973). All mafic rocks from Atka Island plot in or near the A (low potassium tholeiite) and B (calcalkaline basalt) fields.

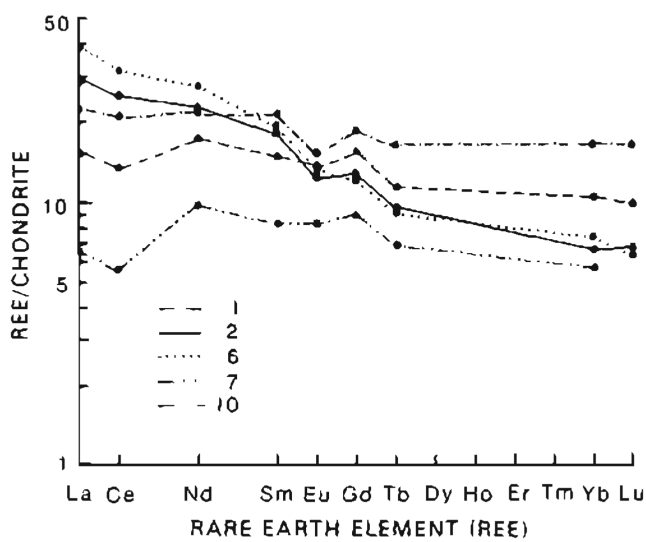

Figure 8. Rare-earth element (REE) plot for selected rocks from Atka Island (tables 6, 7). Sample 7 is extremely depleted in REE, and sample 10 has a small Eu anomaly.

a subduction zone is more difficult. The correlation of tectonic position with differentiation trend is more difficult with the older Tertiary rocks because of problems with age determination and because the tectonic regimes change over time in island arcs.

Kay and others (1982) concluded that the similarity between the most primitive basalts from both differentiation series suggests initial crystallization from the same primitive parent magma. Apparently, initial crystallization was along an Fe-enrichment trend that was continuous for the tholeiitic series but was interrupted for the calc-alkaline series. Therefore, differences in the style of differentiation can explain these two distinct series.

REGIONAL PATTERNS OF ALTERATION

In all the rock types, the most common secondary minerals are quartz and chlorite. Smectite, zeolites (mainly heulandite, analcime, and laumontite), calcite, pumpellyite, prehnite, epidote, and amphibole also commonly occur (fig. 9). In some sedimentary rocks, secondary calcite occurs as recrystallized foraminifers and nannofossils. Other secondary minerals are alteration products of volcanic debris, vesicle infillings, or cement in sedimentary rocks. Secondary minerals not plotted in figure 9 include kaolinite, albite, hematite, pyrite, goethite, apatite, and sphene.

Secondary minerals suggest that most of the rocks were subjected only to zeolite-facies metamorphism. Albite-epidote-hornfels- and hornblende-hornfels-facies rocks also occur but primarily on the west half of the island (west of Explorer and Banner Bays). Secondary minerals from the west half of Atka are dominated, in decreasing order of abundance, by chlorite, epidote, quartz, prehnite, amphibole, and pumpellyite, whereas those from the east half of Atka are dominated by quartz, chlorite, smectite, heulandite, analcime, laumontite,

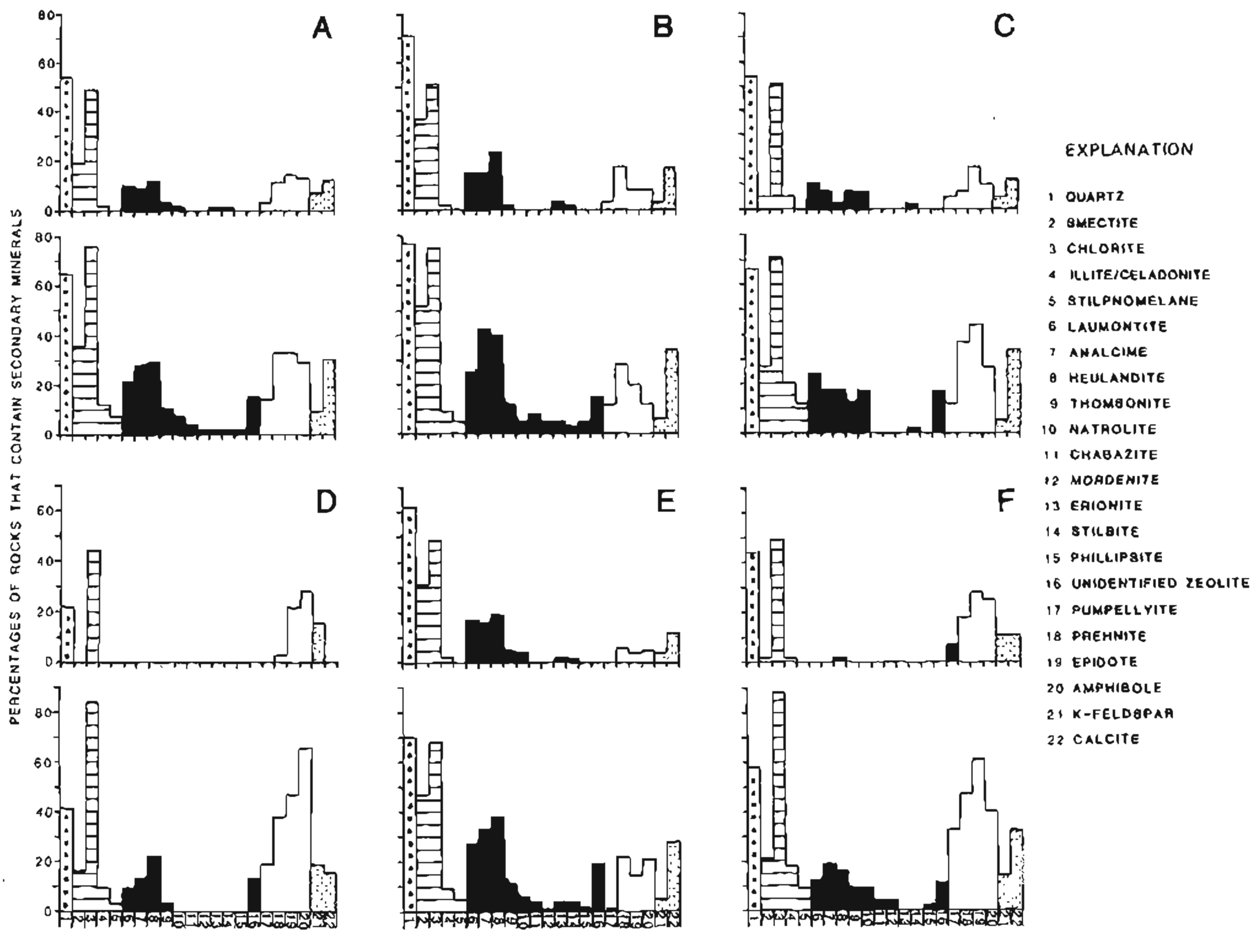

Figure 9. Alteration products of Atka Island rocks. A, All rocks, based on 138 samples. B, Sedimentary rocks, based on 65 samples. C, Volcanic and pyroclastic rocks, based on 41 samples. D, Plutonic rocks, based on 32 samples. E, All rocks from east half of island, based on 81 samples. F, All rocks from west half of island, based on 57 samples. Upper histograms are for only extensively altered rocks; lower histograms are for all altered rocks within each numbered category.

and calcite. Higher grade metamorphic-mineral assemblages on western Atka reflect the influence of the intrusion of plutons there. Even though the higher grade minerals are more abundant to the west, more rocks are extensively altered to the east, 39 versus 55 percent (table 8), assuming that the rocks collected are representative of the bulk of rocks that make up the island. Of all the rocks collected on Atka Island, 48 percent are extensively altered.

Table 8. Percentages of extensively altered rocks of Atka Island

Rock type	East half	West half	Whole island
Sedimentary--------	64	42	56
Volcanic-----------	49	39	45
Plutonic-----------	26	35	32
All----------------	55	39	48

The rocks were divided into sedimentary, volcanic and pyroclastic, and plutonic categories. The sedimentary rocks contain the most abundant suite of secondary minerals (56 percent extensively altered) because they are composed of partly altered volcanic-rock fragments and are cemented by a variety of authigenic minerals. In contrast, the plutonic rocks include the fewest samples that are extensively altered (32 percent); the volcanic rocks are intermediate (45 percent extensively altered; table 8). Extensive alteration of some of the plutonic rocks, primarily to chlorite, amphibole, and epidote minerals, suggests albite-epidote-hornfels- and, possibly, lower hornblende-hornfels-facies metamorphism at temperatures probably near 350° to 500°C.

In comparison with adjacent Amlia Island (McLean and others, 1983), Atka Island rocks are much more extensively altered—30 versus 48 percent, respectively. The dominant clay mineral on Atka is chlorite, and on Amlia smectite. Amlia rocks contain more zeolites, whereas Atka rocks contain more of the low-grade metamorphic minerals pumpellyite, prehnite, epidote, and amphibole. Again, these differences probably reflect the positions of plutons on Atka Island; none crop out on Amlia.

STRUCTURE

Folds

The overall east-westward trend of Atka Island probably reflects the major structural features of the southern part of the island. As seen in shoreline outcrops, stratified rocks in the southeastern part of the island generally strike east-west and dip 10°–20° S. (figs. 2, 3). Dips locally exceed 70° where drag folding has occurred adjacent to faults. A large open anticline that trends northeast-southwest crosses the midpoint of Explorer Bay. Small folds of presumed local extent are common along the southeastern part of the island.

Attitudes of the stratified rocks west of Beaver Bay are more irregular, probably complicated by intrusion of plutonic rocks; however, dips rarely exceed 25°. On the north side of the island, beds of massive sandstone and volcanic breccia in Wall Bay strike northwest and dip 35°–55° NE. A thin-bedded sequence of fine-grained sandstone and siltstone exposed on the northeast shore of Egg Bay likewise strikes northwest and dips 65°–80° NE. (fig. 4B).

Faults

Faults of presumably small displacement are abundant within the stratified sequences. The dip of most faults is near-vertical, and adjacent strata are little deformed except where drag folding has occurred, for example, along the northeast shore of Egg Bay and northwest of Cape Utalug.

Faulting has created a pronounced east-west-trending topographic lineament that extends from the head of Egg Bay to Atka Village. The fault zone is well exposed in the seacliff just south of the village.

Most faulting appears to be extensional in origin, probably related to the emplacement of plutons in the central and western parts of the island, and unrelated to compression associated with plate convergence along the Aleutian Trench.

RESOURCE POTENTIAL

Resources in many island arcs, especially the Aleutian arc, have not been adequately evaluated because most of the arc is under water, because those parts above water generally are associated with active volcanism, and because of logistic problems. Massive sulfides, Kuroko-type deposits, tin, gold, and other mineral deposits, however, are known from the Tertiary rocks of volcanic arcs (for example, Sato, 1977). Atka Island rocks are worthy of extensive studies for economic minerals.

Bottom sediment from seven streams that drain the Beaver Bay pluton were sampled to analyze for concentrations of metals. Sample 779-24-8 (bulk) contains relatively high concentrations of Cu (700 ppm), Pb (300 ppm), and Ag (1.0 ppm) (table 9); sample 779-24-5 (bulk) contains similar enrichments. Sn is high (100 ppm) in one sample (table 9). The average contents of 6 minor elements in 32 igneous rocks of Atka Island are also listed in table 9; these average values are comparable to those in rocks of the Beaver Bay pluton alone. Comparison of the river silt with the igneous rocks clearly shows enrichments of Mn, Cu, Pb, Sn, Ag, and Zn in the silt. Ag content of 1 ppm is an enrichment of 25 times over the average for granite, 10 times over that for basalt, and 14 times over that of average continental crust (Taylor, 1964). Sn at 100 ppm is enriched 33 times over the average for granite, 100 times over that for basalt, and 50 times over that for average continental crust. From these few data, the possibility of ore deposits associated with the Beaver Bay pluton cannot be evaluated, but future explorations should concentrate on the elements listed in table 9; other elements are not enriched.

Table 9. Metallic-element contents in bulk and heavy-mineral separates of sediment fractions from drainages in the Beaver Bay pluton, Atka Island

[All values in parts per million. Average is for 8 extrusive and 24 intrusive igneous rocks of Atka Island. All elements determined by emission spectroscopy except Mn, which was determined by X-ray spectroscopy. A total of 22 of the Pb values were below the limit of detection of 7 ppm; for the probable maximum average value of 9 ppm Pb, half of the 7-ppm detection limit--3.5 ppm--was arbitrarily chosen to average with the other values]

Sample----	779-24-2		779-24-3		779-24-4		779-24-5		779-24-6		779-24-7		779-24-8		Average
	Bulk	Heavy	Bulk	Heavy	Bulk	Heavy	Bulk	Heavy	Bulk	Heavy	Bulk	Heavy	Bulk	Heavy	
Ag-------	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.7	<0.2	<0.2	<0.2	<0.2	<0.2	1.0	<0.2	<0.2
Cu-------	300	70	150	70	100	70	700	150	200	70	300	70	700	70	61
Mn-------	2,000	3,000	1,500	3,000	1,500	5,000	1,500	3,000	2,000	3,000	1,500	3,000	1,500	2,000	1,149
Pb-------	70	150	30	30	200	30	150	100	100	70	50	10	300	100	9
Sn-------	5	100	<2	10	<2	50	15	7	5	50	<2	7	30	10	<2
Zn-------	200	500	200	500	150	500	200	500	200	500	150	700	300	500	93

Small amounts of pyrite are concentrated in the contact zone around the Sergief Bay pluton, in black shale on the west side of Martin Harbor, and occur with goethite, in the fault zone near Atka Village. None of these concentrations of iron is large enough or of high enough grade to warrant development.

Small bodies of hydrothermally deposited silica and iron (now hematite) occur between volcanic flows on tiny Uyak Island in Nazan Bay (table 10). At about 20 weight percent Fe_2O_3 these deposits are too small and too low in grade for development. Sb at 394 ppm is significantly enriched in these hydrothermal bodies—about 2,000 times over that of average continental crust, average basalt, and average granite (Taylor, 1964). On Atka Island, Sb averages 0.100 and 0.343 ppm for 8 extrusive and 24 intrusive igneous rocks, respectively; a single anomalously high value of 55 ppm Sb was measured for a basaltic andesite but was not included in the average, which would be 6.99 ppm Sb for the extrusive rocks with it included.

The reservoir and source-rock properties of rocks that crop out on Atka Island show little promise for the generation and accumulation of petroleum. The proximity of the sedimentary rocks to young plutons is responsible in large part for the reduction in porosity and permeability. Offshore basins, however, may show greater promise (Scholl and others, 1975; McCarthy and others, 1984) because the rocks are less altered and have reservoir potential.

SUMMARY AND CONCLUSIONS

Southern Atka Island consists primarily of middle and late Eocene and early Oligocene (approx 30-50 m.y. old) volcaniclastic rocks deposited in nearshore (probably intertidal) upper slope environments. Deposition occurred on fan-delta, shelf, and Aleutian Ridge summit-basin depositional sites. Sediment transport was by rivers, debris flows, and turbidity currents. Lava flows, pyroclastic deposition, and the intrusion of hypabyssal dikes and sills were contemporaneous. This Eocene and Oligocene sequence is recognizable on many of the Aleutian Islands, and at each site the oldest sequence is datable by fossils (for example, Scholl and others, 1975; Hein and McLean, 1980; McLean and others, 1983; McLean and Hein, 1984). On Adak and some other Aleutian Islands, an older group of gabbroic and basaltic rocks containing minor amounts of intercalated sedimentary rocks also occurs (Citron and others, 1980; Hein and McLean, 1980; Kay and others, 1983). These older rocks, which are part of the initial or early series of Marlow and others, (1973), probably are about 55 m.y. old (Hein and McLean, 1980); the bulk of the Aleutian Ridge formed rapidly during the early Tertiary.

The Paleogene sequence on Atka was intruded by plutons during early, middle, and late Miocene time (18-8.5 m.y. B.P.). Intrusion of plutons caused albite-epidote- and hornblende-hornfels-facies metamorphism (350°-$500^{\circ}C$) of the surrounding rocks on western Atka Island, and zeolite- to prehnite-pumpellyite-facies metamorphism (200°-$300^{\circ}C$) of the more distant rocks on eastern Atka Island. Plutons may have been emplaced during three separate periods at about 15 m.y., 12 m.y., and 9 m.y. B.P., but our data are insufficient to confirm this possibility. We also believe that an older group of plutons may occur on the island.

Subaerial to shallow-marine (shelf) sediment and volcanic debris flows were deposited during the Neogene on Atka Island, about 14-7 m.y. B.P., contemporaneously with some of the intrusive activity. Conifer forests, which no longer exist anywhere along the Aleutians, were burned and buried by volcanic avalanches and flows. Black carbonaceous shale, containing mostly terrestrial plant debris, accumulated in small subaerial basins containing stagnant water. Neogene igneous plugs and dikes subsequently intruded the sections about 6 m.y. B.P. Synplutonic sedimentary rocks were also altered, mostly to zeolite facies but, in places, to higher metamorphic grades. Secondary quartz and chlorite are ubiquitous in Atka Island rocks.

The Miocene, especially the middle Miocene, was a time of extensive and voluminous igneous activity along the entire Aleutian Island arc (Coats, 1952, 1962; Marlow and others, 1973; Scholl and others, 1976; Hein and others, 1978). Middle Miocene plutons and contemporaneous volcanic rocks, like those on Atka Island, are known from many of the Aleutian islands (Citron and others, 1980). For example, middle Miocene plutons intrude the volcaniclastic rocks on Adak, Unalaska, and Kagalaska Islands (Carr and others, 1970; Marlow and others, 1973) in the Aleutian chain. Middle Miocene volcanic rocks exclusive of plutonic rocks occur on Shemya Island (Cameron and Stone, 1970). An older plutonic event of Oligocene age (approx 32-30 m.y. B.P.) recorded in rocks only on Adak (Citron and others, 1980) and Umnak Islands (McLean and Hein, 1984), and, possibly, on Amlia Island, has not been found on Atka Island, although volcanism occurred at that time on Atka Island; we believe that with detailed mapping it may also be found on Atka Island. Two much older episodes of plutonism are recorded in the rocks at the east end of the Alaska-Aleutian Range batholith (early and middle Jurassic and late Cretaceous and early Tertiary; Reed and Lanphere, 1973), but not on any of the Aleutian islands.

Thus, igneous events recorded on Atka Island include major Eocene and Oligocene volcanism (approx 50-30 m.y. B.P.), major early, middle, and late Miocene plutonism and volcanism (18-8 m.y. B.P.), and latest Miocene through Holocene volcanism which includes the Korovin volcanic complex of the northern part of Atka Island.

A higher metamorphic grade is observed in rocks from Atka Island relative to adjacent Amlia Island to the east, where plutons do not crop out. Whereas zeolites and smectite dominate on most of Amlia Island, prehnite, pumpellyite, epidote, amphibole, and chlorite dominate on Atka. Some plutons of Atka were extensively altered, primarily to chlorite, amphibole, and epidote, indicative of albite-epidote- and hornblende-hornfels-facies metamorphism. Similar degrees of metamorphism were noted for Adak Island (Paleogene) plutons and adjacent rocks 175 km west of Atka (Hein and McLean, 1980; Kay and others, 1983). As with the Eocene and Oligocene sedimentary rocks on Adak and Amlia Islands, the rocks on Atka show styles of deformation and metamorphism, and textures of sandstones, that indicate only shallow levels of burial without regional metamorphism. Alteration and metamorphism result from hydrothermal activity that is driven by shallow-seated plutons and, locally, by dikes and sills.

Table 10. Chemical analysis of a silica and hematite hydrothermal deposit (sample 779-18-1C) in Nazan Bay, Uyak Island

[Major-element analyses in weight percent; minor- and trace-element analyses in parts per million. Analytical methods: 1, X-ray fluorescence; 2, neutron activation; 3, emission spectroscopy]

	Value	Analytical method
Major-element oxides		
SiO_2	77.6	1
Al_2O_3	.43	1
TiO_2	.003	3
Fe_2O_3	19.5	1
MgO	.015	3
CaO	.30	1
Na_2O	.073	2
K_2O	<.02	1
P_2O_5	.21	1
MnO	.004	--
Loss on ignition	1.12	--
Total	99.26	
Minor and trace elements		
B	50	3
Ba	50	3
Ce	6.2	2
Co	1.30	2
Cr	1.6	2
Cs	1.16	2
Cu	20	3
Dy	4.5	2
Eu	.599	2
Gd	4.2	2
La	6.87	2
Lu	.631	2
Nb	15	3
Nd	13.0	2
Ni	15	3
Sb	394	2
Sc	3.84	2
Sm	2.97	2
Sr	20	3
Tb	.72	2
U	.47	2
V	300	3
Y	70	3
Yb	3.70	2
Zn	70	3
Zr	78	2

Gentle open folds and extensional faulting are related to the emplacement of plutons and not to compression associated with plate convergence along the Aleutian Trench. The dominant tectonic regime since the Eocene has been mild extension and high-angle normal faulting. As on Amlia and Umnak Islands (McLean and others, 1983; McLean and Hein, 1984), little vertical tectonic movement during the Holocene is indicated by the undeformed wave-cut terraces.

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