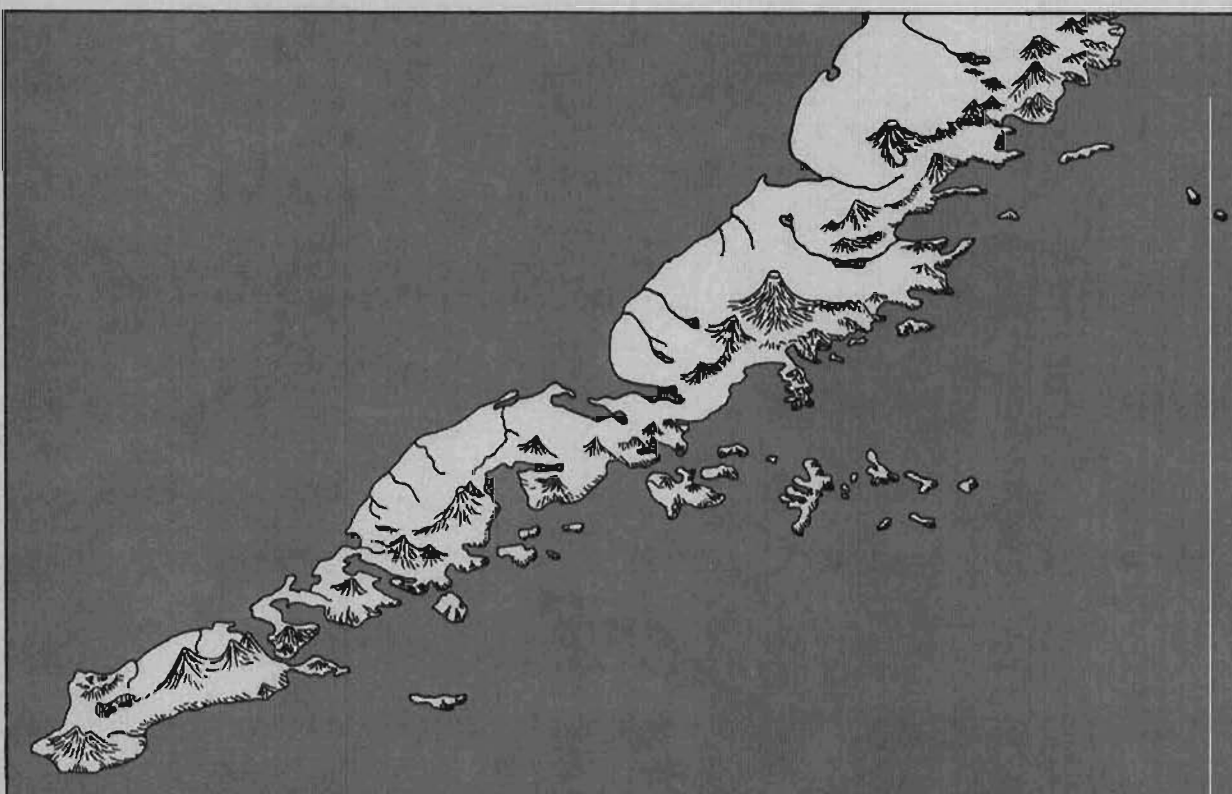
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

THE MESHIK ARC - AN EOCENE TO EARLIEST MIOCENE MAGMATIC ARC ON THE ALASKA PENINSULA

By
F.H. Wilson



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Bill Sheffield, *Governor*

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THE MESHIK ARC - AN EOCENE TO EARLIEST MIOCENE MAGMATIC ARC ON THE ALASKA PENINSULA

By
F.H. Wilson[1]

ABSTRACT

The Meshik arc is herein defined to include Eocene to earliest Miocene volcanic and hypabyssal rocks and the associated Meshik and Stepovak Formations of the central Alaska Peninsula. Igneous rocks range from basalt to dacite and yielded K-Ar ages of 48 to 22 m.y. The Meshik arc is oriented along the trend of the Alaska Peninsula, subparallel to the present-day Aleutian arc. Rocks of the Meshik arc are emplaced on Cenozoic, Mesozoic, and older clastic sedimentary rocks of the Alaska Peninsula terrane. Tectonic interpretation suggests: a) the arc represents a relatively stationary period in the otherwise mobile migration of the Alaska Peninsula terrane, b) subduction was an important process along the Alaska Peninsula during Tertiary time, and c) most migration of the Alaska Peninsula terrane since Cretaceous time took place in Paleocene and middle Miocene time.

INTRODUCTION

An early to middle Tertiary magmatic arc was identified during geochronologic and mapping studies on the central Alaska Peninsula (fig. 1). Though originally recognized by Burk (1965) as part of a continuous Tertiary volcanic sequence, the Meshik arc is a distinct phase in the Tertiary history of the Peninsula. The arc includes volcanic and hypabyssal rocks of basaltic to dacitic composition and intercalated volcaniclastic Eocene to earliest Miocene sedimentary rocks of the Meshik and Stepovak Formations (Burk, 1965; Detterman and others, 1981). Using the rock nomenclature recommended by Streckeisen (1979), whole-rock chemical analyses show that the igneous rocks range from leucobasalt to dacite (fig. 2, tables 1 and 2). K-Ar age determinations on volcanic and hypabyssal rocks associated with the arc range from 48 to 22 m.y., mostly within 40 to 30 m.y. (table 3).

The central part of the Alaska Peninsula (fig. 1) is composed of mildly deformed Mesozoic clastic rocks overlain and intruded by Tertiary volcanic and intrusive rocks (Detterman and others, 1981). The Chignik anticline, an anticline overthrust to the southeast, deforms both Mesozoic and Paleogene rocks, including those of the Meshik arc (Wilson, 1980; Detterman and others, 1981). The Mesozoic rocks are part of a far-traveled tectonostratigraphic terrane that makes up much of the Alaska Peninsula. Upper Mesozoic flysch of the Chugach terrane lies southeast of the Alaska Peninsula (Peninsular) terrane (Jones and others, 1981); southeast of this lies the active Aleutian Trench.

Burk (1965) contributed many of the original descriptions of Tertiary formations on the Alaska Peninsula; he recognized the Paleogene volcaniclastic and volcanic rocks (which he divided into the Tolstoi, Meshik, and Stepovak Formations) and identified what he thought were middle Tertiary plutons and an upper Tertiary (Pliocene) sequence of volcanic rocks.

The rocks of the Meshik arc crop out in a narrow belt on the Pacific side of the Peninsula around Chignik Bay (fig. 1). Drill holes and K-Ar dates (Brockway and others, 1975) indicate they also underlie the Alaska Peninsula part of the Nushagak - Bristol Bay Lowland of Wahrhaftig (1965).

The Meshik arc apparently extends northeastward into the vicinity of Mother Goose Lake (fig. 1). Southwest of Chignik Bay, rocks of the Meshik arc may extend through the Port Moller area. Igneous rocks of similar age, which may be related to the Meshik arc, also occur as part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973) and on the Aleutian Islands (Wilson, 1981).

STRATIGRAPHY - MESHIK FORMATION

The Meshik Formation is a volcanic and volcaniclastic unit named by Knappen (1929, p. 198-200) from exposures south of Aniakchak Caldera (fig. 1); he described a sequence of reverse-graded, andesitic volcaniclastic rocks that included interbedded bentonitic clay, fine sand, volcanic ash, and coarse agglomerate. The upper part of the formation is composed entirely of coarse volcanic materials, including agglomerate and numerous flows (Knappen, 1929, p. 198). According to Burk (1965, p. 99), the 1,500-m-thick Meshik Formation rests conformably on the Tolstoi Formation and is

[1]U.S. Geological Survey, 4200 University Drive, Anchorage, Alaska 99508-4667. Publication authorized by Director, U.S. Geological Survey.

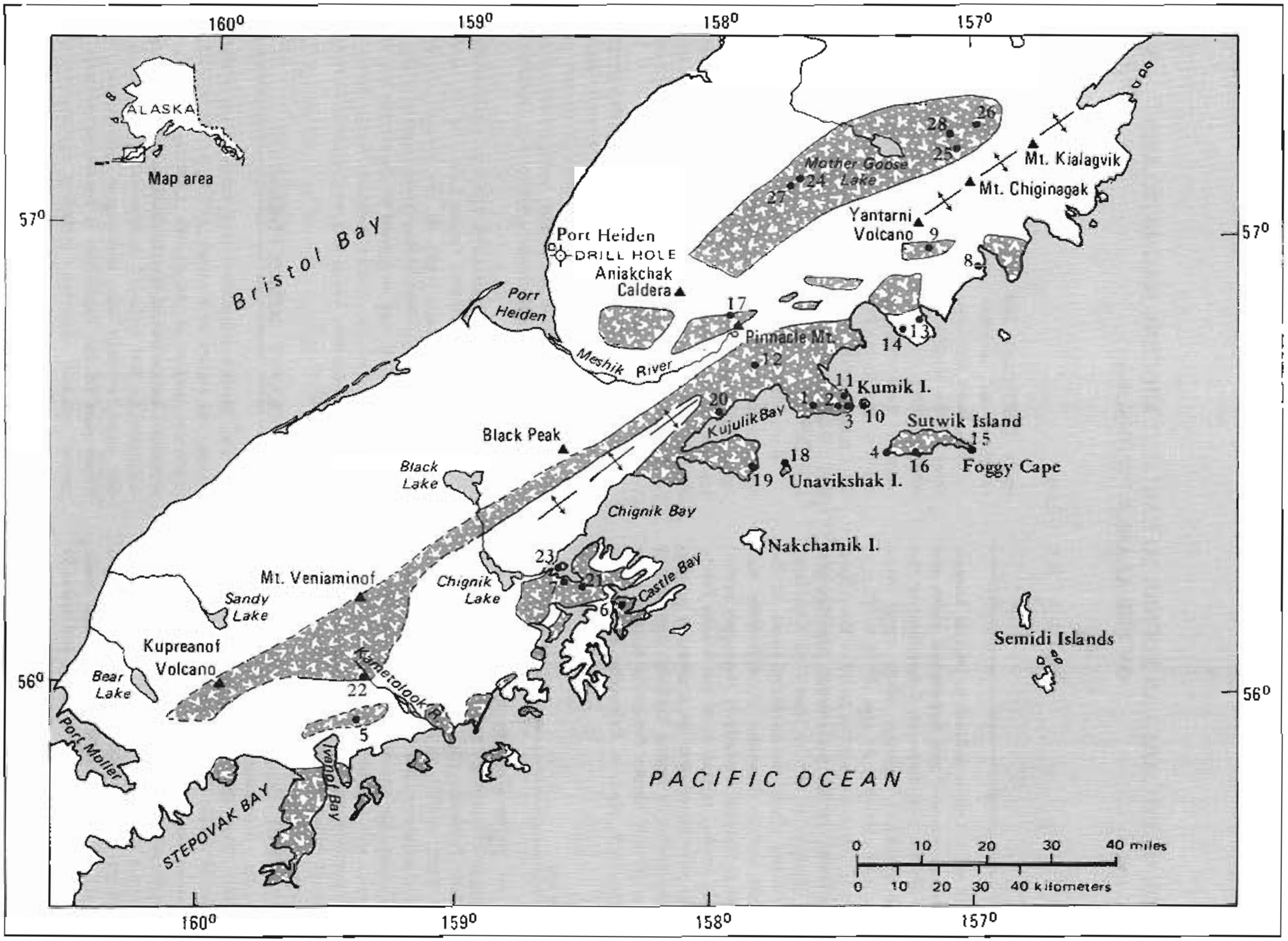
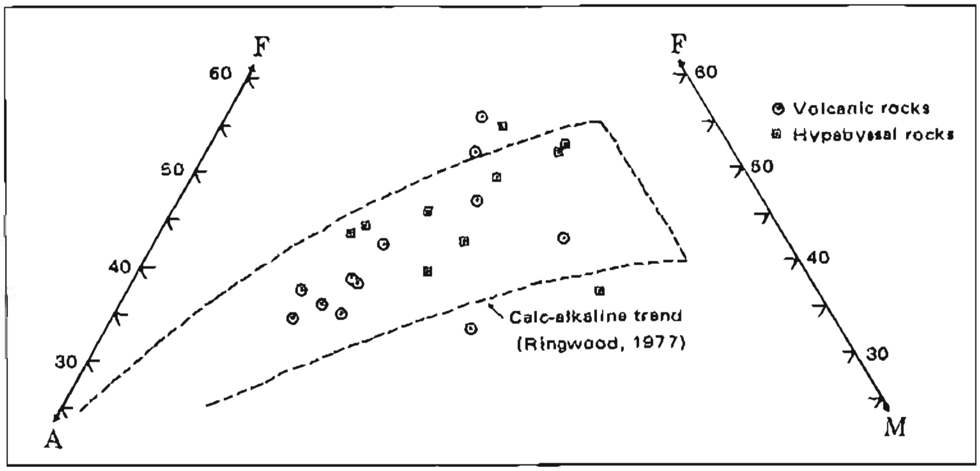


Figure 1. Map of the central Alaska Peninsula showing the approximate extent of the Meshik arc rocks (in gray). Boundaries dashed where inferred. Numbers refer to sample data in table 4. A drill hole at Port Heiden encountered a minimum of 1,500 m of Meshik Formation beginning at 2,800 m depth. Base modified from Alaska Environmental Information Data Center 1:1,000,000-scale base-map series, 1981.



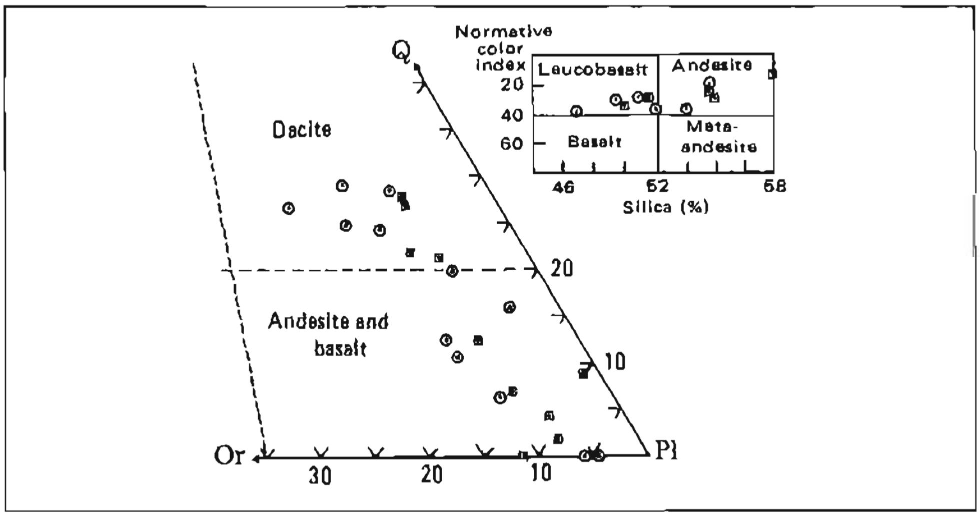


Figure 2. Ternary diagrams showing (top) proportions of Fe oxide (F), alkali (A), and Mg oxide (M) and (bottom) percentage of normative quartz (Q), orthoclase (Or), and plagioclase (Pl) for volcanic and hypabyssal rocks of the Meshik arc.

overlain unconformably by Pliocene and younger volcanic rocks or by alluvial and glacial debris. Detterman and others (1981) assigned the Meshik Formation an Eocene to Oligocene age on the basis of plant fossils and radiometric data and described the contact with the Tolstoi Formation as unconformable.

Volcanic rocks of the Meshik Formation include dacitic to basaltic flows, agglomerate, and breccia (Wilson, 1980). These are commonly hydrothermally altered and are bright red, green, or brown; fresh or only slightly altered basaltic to dacitic plugs and flows are occasionally included in the formation.

GEOCHRONOLOGY AND PETROGRAPHY

Fresh, columnar-jointed basalt, andesite, and dacite plugs intrude genetically related flows within the Meshik Formation. Some flows and plugs were K-Ar dated with whole-rock, hornblende, plagioclase, and rare biotite samples (Wilson and others, 1981). Ages range from 42 to 22 m.y. (table 3; Wilson and others, 1981; Wilson, 1982), mostly in the 40-to-30-m.y. bracket. Of those samples less than 30 m.y. old (table 2), some may have been thermally affected by nearby late Tertiary magmatic activity. The other young ages are from rocks from areas immediately southwest of both Chignik Bay and Mt. Chiginagak.

Some Eocene and Oligocene intrusive rocks are found on the Alaska Peninsula and are included in the Meshik arc (as defined); they are apparently volcanic necks, similar to the plugs mentioned above, but more deeply eroded. K-Ar age determinations on these intrusions range from 48 to 33.5 m.y., slightly more than the less eroded plugs and flows.

The following descriptions characterize the igneous rocks of the Meshik arc. Table 4 describes dated and analyzed rocks, which range from hornblende dacite to two-pyroxene andesite and basalt. In the andesite and basalt, phenocrystic amphibole is the dominant mafic mineral; however, a few samples that contain hornblende also contain relicts of or pseudomorphs after pyroxene. The amphibole commonly shows resorbed edges and sieve texture and is rimmed by opaque oxides. In pyroxene-bearing rocks, pyroxene grains have sharp edges and may show sieve texture. The plagioclase, which is also phenocrystic, is generally strongly zoned, Carlsbad- and albite-twinned, and locally shows glomeroporphyritic texture. Andesite samples commonly have two populations of plagioclase averaging An_{35} and An_{60} or a single plagioclase averaging about An_{45-55}. In the two-plagioclase andesites, the more sodic plagioclase generally has resorbed edges. Plagioclase in basalt samples usually has a composition of An_{60-65}, whereas that in dacite samples tends to have a composition near

Table 1. *Bulk chemistry and normative minerals of volcanic rocks, Meshik Formation. Sample locations shown on figure 1.*

Field no.	77AWs-102	78AWs-18	78AWs-20	78AWs-31	78AWs-32	78AWs-58	78AWs-61	78AWS-98	78AWs-111	78AWs-134	79AWs-2
Map no.	5	11	12	15	16	19	20	21	22	23	24
Bulk chemistry											
SiO_2	45.59	49.14	61.67	55.54	52.21	57.49	61.58	49.57	48.58	59.98	56.20
Al_2O_3	17.11	19.02	16.45	18.45	15.88	16.66	16.48	16.53	19.04	16.40	16.10
Fe_2O_3	4.97	5.62	4.37	3.43	2.90	4.26	4.03	2.64	4.51	2.88	3.38
FeO	6.23	3.63	1.47	3.39	4.33	2.87	1.54	7.18	6.04	2.84	3.47
MgO	6.49	4.75	2.21	4.34	7.84	3.30	1.96	5.65	4.68	3.57	5.85
CaO	12.13	9.53	6.21	7.98	8.81	6.65	5.51	9.77	10.30	6.68	6.92
Na_2O	1.96	3.03	3.21	3.23	2.64	2.93	3.31	2.41	2.68	3.52	3.32
K_2O	1.13	0.81	1.25	1.21	0.93	1.44	1.20	0.15	0.83	1.08	1.51
TiO_2	1.03	0.74	0.69	0.75	0.69	0.80	0.59	1.46	1.02	0.77	0.97
P_2O_5	0.18	0.10	0.11	0.14	0.16	0.19	0.13	0.15	0.18	0.19	0.24
MnO	0.18	0.20	0.09	0.13	0.14	0.08	0.07	0.15	0.23	0.11	0.12
H_2O^+	2.02	1.00	0.71	0.33	0.81	1.01	0.92	2.07	0.72	0.48	0.62
H_2O^-	1.21	2.65	1.62	0.61	1.20	1.37	2.07	0.41	1.42	1.20	1.00
CO_2	0.16	0.13	0.27	0.05	1.10	0.80	0.21	1.23	0.08	0.06	0.11
Total	100.39	100.35	100.33	99.58	99.64	99.85	99.60	99.36	100.31	99.76	99.81
Normative minerals											
Quartz	---	3.09	23.17	9.24	4.21	17.42	24.25	5.17	1.21	17.14	9.19
Corundum	---	---	---	---	---	---	0.03	---	---	---	---
Orthoclase	6.88	4.96	7.56	7.15	5.69	8.80	7.36	0.93	5.00	6.51	9.10
Albite	17.10	26.65	27.79	27.33	23.14	25.65	29.05	21.32	23.12	30.38	28.64
Anorthite	35.62	37.18	27.41	32.37	29.77	29.02	27.47	35.38	38.20	26.28	25.05
Diopside-wollastonite	10.52	4.63	1.41	2.67	6.02	1.60	---	5.96	5.30	2.62	3.49
Diopside-ferrosilite	2.62	0.37	---	0.44	1.05	0.09	---	2.20	1.72	0.39	0.41
Diopside-enstatite	7.10	3.72	1.22	1.98	4.40	1.31	---	3.48	3.27	1.96	2.70
Hypersthene-ferrosilite	0.82	0.84	---	1.96	3.79	0.51	---	7.10	4.51	1.41	1.84
Hypersthene-enstatite	2.23	8.53	4.41	8.83	15.82	7.19	5.06	11.23	8.61	7.11	12.15
Olivine	7.23	---	---	---	---	---	---	---	---	---	---
Magnetite	7.43	8.44	3.10	4.97	4.36	6.39	3.61	4.00	6.67	4.26	5.00
Ilmenite	2.02	1.46	1.34	1.36	1.42	1.57	1.16	2.88	1.97	1.49	1.88
Apatite	0.43	0.24	0.26	0.32	0.38	0.46	0.31	0.36	0.42	0.45	0.57
Hematite	---	---	2.33	---	---	---	1.69	---	---	---	---
Total	100.00[a]	100.01[a]	100.00[a]	98.62	100.05[a]	100.01[a]	99.99[a]	100.01[a]	100.00[a]	100.00[a]	100.02[a]
Normative color index	40.0	28.0	13.8	21.8	36.3	18.1	11.5	36.1	32.1	19.2	27.5

[a]Chemistry normalized before norm calculation. CO_2 and H_2O dropped before normalization.

Table 2. *Bulk chemistry and normative minerals of Eocene-Oligocene intrusive rocks. Sample locations shown on figure 1.*

Field no.	77AWs-30	77AWs-40	77AWs-74	77AWs-122	77AWs-137	77AMs-1	78AWs-5	78AWs-11	78AWs-17	78AWs-24	78AWs-35	78AWs-42	79ADt 23	79ADt 95	R41358A
Map no.	1	2	4	6	^	7	8	9	10	13	17	18	25	26	28
							Bulk chemistry								
SiO_2	59.17	50.02	59.80	64.74	66.60	55.54	54.47	63.46	47.14	54.11	62.79	58.19	58.60	57.10	62.03
Al_2O_3	17.64	18.15	15.40	16.18	16.12	17.56	16.02	15.60	17.11	17.47	16.40	17.53	16.10	15.50	15.18
Fe_2O_3	3.68	5.12	2.82	2.47	1.85	3.71	3.32	3.14	1.64	1.33	1.88	3.07	2.21	2.52	2.87
FeO	2.32	6.18	1.76	2.12	2.36	5.00	5.50	1.82	7.01	4.72	3.12	3.08	3.67	4.01	3.09
MgO	2.71	4.42	2.05	1.74	1.88	3.98	4.84	2.68	7.01	5.80	2.44	3.05	3.84	4.61	3.13
CaO	6.54	8.07	5.46	4.37	4.04	8.28	7.53	4.45	8.74	6.84	5.37	5.16	5.91	6.66	5.44
Na_2O	3.69	2.75	2.47	3.93	3.73	3.10	3.20	3.68	3.22	5.08	3.37	4.50	3.53	2.71	3.08
K_2O	1.12	1.19	2.65	1.37	1.99	0.61	1.38	2.16	0.49	0.71	1.75	1.65	1.78	1.89	1.86
TiO_2	0.52	0.83	0.53	0.53	0.65	0.95	1.04	0.71	0.96	0.87	0.55	0.75	0.63	0.79	0.60
P_2O_5	0.23	0.21	0.21	0.15	0.17	0.32	0.13	0.12	0.11	0.17	0.13	0.26	0.19	0.26	0.15
MnO	0.13	0.21	0.09	0.08	0.03	0.17	0.16	0.06	0.55	0.11	0.13	0.10	0.14	0.16	0.06
H_2O^+	1.22	2.83	2.18	0.86	0.97	1.68	0.86	1.95	3.08	1.26	1.85	1.35	1.84	2.17	0.95
H_2O^-	0.60	0.56	0.98	0.13	0.11	0.16	0.72	0.53	0.29	0.21	0.38	0.12	0.43	0.05	0.30
CO_2	0.69	0.34	3.51	0.08	0.05	0.17	0.24	0.05	2.09	0.20	0.23	0.05	0.78	1.26	0.19
Total	100.26	100.88	99.91	98.75	100.55	101.23	99.47	100.41	99.44	98.88	100.39	98.86	99.65	99.69	98.93
							Normative minerals								
Quartz	16.70	4.60	23.17	25.08	25.50	11.66	7.49	21.40	---	---	20.84	10.42	13.10	13.74	21.37
Corundum	---	---	---	0.66	0.89	---	---	---	---	---	---	---	---	---	---
Orthoclase	6.77	7.24	16.79	8.28	11.76	3.60	8.36	13.04	3.08	4.32	10.56	10.02	10.89	11.61	11.27
Albite	31.94	23.95	22.41	34.01	31.56	26.23	27.74	31.81	28.97	44.22	29.12	39.12	30.92	23.83	26.73
Anorthite	28.91	34.65	24.78	21.17	18.93	32.20	25.90	20.09	32.74	23.42	24.97	23.38	23.63	25.51	22.67
Diopside-wollastonite	1.15	2.15	1.17	---	---	2.84	4.81	0.69	5.26	4.32	0.57	0.49	2.27	2.95	1.67
Diopside-ferrosilite	0.08	0.73	0.04	---	---	0.88	1.49	---	1.92	1.23	0.20	0.10	0.64	0.74	0.36
Diopside-enstatite	0.93	1.30	0.98	---	---	1.78	3.02	0.60	3.09	2.80	0.34	0.35	1.48	1.99	1.17
Hypersthene-ferrosilite	0.53	5.59	0.17	1.32	1.79	3.99	4.59	---	2.46	3.38	3.39	2.03	3.64	3.70	2.13
Hypersthene-enstatite	5.98	10.03	4.49	4.43	4.68	8.13	9.33	6.22	3.95	7.71	5.86	7.45	8.42	9.95	6.83
Olivine	---	---	---	---	---	---	---	13.81	4.52	---	---	---	---	---	---
Magnetite	5.46	7.64	4.39	3.66	2.68	5.38	4.93	4.09	2.53	1.98	2.78	4.57	3.32	3.80	4.27
Ilmenite	1.01	1.62	1.08	1.03	1.23	1.80	2.02	1.38	1.94	1.70	1.07	1.46	1.24	1.56	1.17
Apatite	0.54	0.50	0.52	0.36	0.39	0.74	0.31	0.28	0.27	0.40	0.31	0.62	0.46	0.63	0.36
Hematite	---	---	---	---	---	---	---	0.39	---	---	---	---	---	---	---
Total	100.00[a]	100.00[a]	99.99[a]	100.00[a]	99.41	99.23	99.99[a]	99.99[a]	90.73[a]	95.48[a]	100.01[a]	100.01[a]	100.01[a]	100.01[a]	100 00[a]
Normative color index	15.1	29.2	12.3	10.3	10.4	24.8	30.2	13.4	34.6	27.4	14.2	16.1	21.0	24.7	17.6

[a]Chemistry normalized before norm calculation. CO_2 and H_2O dropped before normalization.

An_{40-45}. (Plagioclase compositions were determined by using Carlsbad-albite twinning.) Partial alteration of the feldspars to sericite or clay minerals is almost ubiquitous. Calcite and epidote are common alteration products, and in some rocks the groundmass is chloritized. Apatite is a common (and occasionally abundant) accessory. Quartz phenocrysts, generally with resorbed edges, sometimes occur in thin sections of andesite and basalt. A few thin sections---generally of basalt or leucobasalt---contain olivine. The groundmass of most Meshik arc rocks is fine grained and composed of plagioclase feldspar and opaque minerals or devitrified glass. Textures range from glomeroporphyritic to subophitic. The disequilibrium mineral assemblages in some of these rocks, particularly the coexisting plagioclase compositions and the partially resorbed quartz phenocrysts, suggest mixing of magmas.

The rocks described above are typical of most flows and plugs in the Meshik arc. Generally, the intrusive rocks (plugs) are characterized by hornblende and the extrusive rocks (flows) by pyroxene. Other common igneous rocks of the Meshik arc are agglomerate and breccia, including pyroclastic flows, rubble flows, and lahars; volcanic clasts are petrographically similar to the plugs and flows described above.

Figure 2 contains parts of AFM and normative quartz-orthoclase-plagioclase ternary diagrams for rocks of the Meshik arc; the lower diagram includes criteria used for the Streckeisen (1979) classification. The range and variability of chemical compositions of rocks of the Meshik arc are virtually the same as those of late Tertiary igneous rocks from the central Alaska Peninsula (Wilson and others, 1981). The Meshik arc rocks lie in the calc-alkaline field of Ringwood (1977). An attempt to test the convergence direction by using K_2O, K_2O/SiO_2, or K_2O in the limited ranges of SiO_2 vs. distance from any supposed paleosubduction zone (Dickinson, 1968; Nielson and Stoiber, 1973) failed. There was no indication of increasing K_2O with distance; all data groups either yielded random scatters of points or contained an insufficient number of points to yield meaningful plots, whether grouped by age, location, or chemical similarity.

In summary, the essential characteristics of the Meshik arc are:

1. Rocks of the arc include the Meshik Formation and related hypabyssal igneous and volcaniclastic rocks of the Stepovak Formation of the central Alaska Peninsula.

2. Radiometric dating (K-Ar) indicates that the arc was active between 48 and 22 m.y. B.P.; two-thirds of the age determinations on both intrusive and extrusive rocks fell between 40 and 30 m.y. B.P. Paleontologic evidence yields Eocene and Oligocene ages.

3. Volcanic and hypabyssal rocks range from basalt to dacite and many are deuterically or hydrothermally altered.

4. Sedimentary rocks are shale, siltstone, sandstone, and conglomerate, almost entirely composed of volcanic clasts and fragments.

TECTONIC SIGNIFICANCE

The Meshik arc and possible correlative igneous rocks in the Aleutian Islands (Marlow and others, 1973) and in the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973) are evidence of subduction at a paleo-Aleutian trench during Eocene to Oligocene or earliest Miocene time. During middle and late Miocene time, the Bear Lake Formation (Burk, 1965) was deposited unconformably(?) on rocks of the Meshik arc; it has a large component of nonvolcanic clasts in the conglomeratic phase. However, clasts that appear to be from the Meshik Formation are common, and the Bear Lake Formation probably represents reworking of a variety of earlier rocks. Overlying the Bear Lake Formation are volcanic and volcaniclastic rocks of the present-day Aleutian arc, including the Milky River Formation (Detterman and others, 1981). K-Ar age determinations suggest that this magmatic activity began in latest Miocene time and continued to the present (Wilson and others, 1981).

The range of radiometric dates on rocks of the Meshik arc provides good evidence for magmatic activity that lasted at least 15 m.y. and possibly 26 m.y. (assuming the minimum ages are realistic); the activity was probably the result of subduction during Eocene, Oligocene, and earliest Miocene time. Radiometric dates of rocks from the Aleutian arc on the central Alaska Peninsula (Wilson and others, 1981; Wilson, 1982) also indicate at least 10 m.y. of subduction since late Miocene time.

Stone and Packer (1979) postulated large-scale migration of Baja Alaska (the Alaska Peninsula) on the basis of paleomagnetic measurements from Jurassic, Late Cretaceous, and Eocene sedimentary rocks. One speculation that can be made is that the terrane migrated when it was coupled to an oceanic plate (either the Kula or Pacific). Subduction under the terrane occurred when it was decoupled from the oceanic plate. If so, the Meshik arc and later Aleutian arc may indicate that most postulated migration between the Cretaceous and the present positions of the Alaska Peninsula occurred in Paleocene and middle Miocene time.

At some point during Tertiary time, the Kula-Pacific Ridge or its remnants were subducted under the Alaska Peninsula and the Aleutian Islands. DeLong and others (1978; 1980) and Farrar and Dixon (1980) suggested that this subduction may have occurred about 35 m.y. B.P. or during early Oligocene time in the Aleutian Islands. The model of DeLong and others (1978, 1980) predicts that subduction of the Kula-Pacific Ridge would cause a hiatus in activity in the subduction-related magmatic arc. The Kula-Pacific Ridge (fig. 3) would migrate along the paleo-Aleutian trench at a *(to p. 10)*

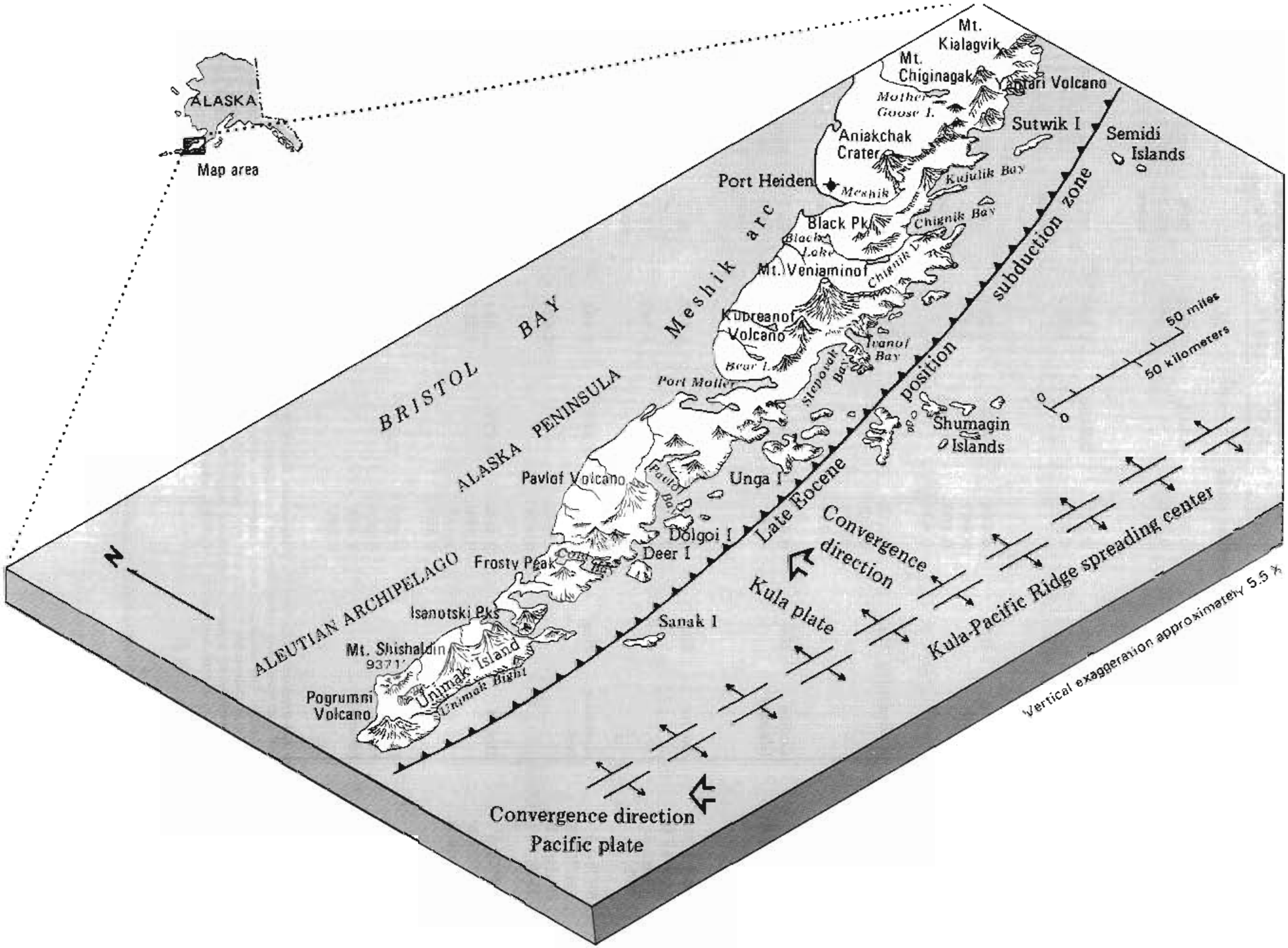


Figure 3. Schematic drawing showing orientation of tectonic elements during late Eocene time on the Alaska Peninsula. Convergence rate of Pacific plate and Alaska Peninsula assumed to be greater than full spreading rate of Kula-Pacific Ridge.

Table 3. *Potassium-argon ages, Meshik arc.*[a,b]

Sample (map no.)	Lat-long (quadrangle)	Rock type	Mineral or component dated	Mean percent K_2O	Weight percent K_2O	$^{40}Ar_{rad}$ (moles/gm) $\times 10^{-11}$	Percent $^{40}Ar_{rad}$	Age ± 1σ (m.y.)
				Intrusive rocks				
77AMs-1	56°13.5'N	Andesite	Hbl	0.344	0.343	1.301	29.6	26.2 ± 0.57
(7)	158°28.6W	(dike)		0.342		1.389	15.3	27.9 ± 0.86
	(Chignik						mean	27.1 ± 1.58
	A-2)							
77AWs-30	56°38.2'	Andesite	Hbl	0.317	0.319	1.666	29.1	35.9 ± 1.03
(1)	156°35.3'	(dome)		0.321		1.700	35.2	36.7 ± 0.79
	(Sutwik Is.						mean	36.3 ± 1.42
	C-5)							
77AWs-40	56°38.2'	Leuco-	Hbl	0.466	0.467	2.287	24.2	33.7 ± 0.60
(2)	157°28.9'	basalt		0.467		2.456	36.7	36.2 ± 0.56
	(Sutwik Is.			0.468			mean	35.0 ± 1.95
	C-5)			0.465				
77AWs-46	56°38.2'	Andesite(?)	Hbl	0.310	0.311	1.712	19.8	37.81 ± 1.58
(3)	157°27.7'			0.311				
	(Sutwik Is.			0.311		1.827	27.8	40.31 ± 0.91
	C-5)			0.313			mean	39.1 ± 1.80
77AWs-74	56°32.5'	Dacite	Bio	8.46	8.48	43.81	43.7	35.5 ± 0.64
(4)	157°20.0'	(dome)		8.50		41.26	74.0	33.5 ± 0.59
	(Sutwik Is.						mean	34.5 ± 1.60
	C-4)							
77AWs-122[c]	56°11.7'	Dacite	Hbl	0.338	0.329	1.125	24.1	23.57 ± 0.59
(6)	158°19.0'			0.324				
	(Chignik			0.332		1.009	17.5	21.17 ± 0.47
	A-1)			0.323			mean	22.4 ± 1.86
78AWs-5[d]	56°56.5'	Andesite	Plag[e]	0.483	0.483	3.402	45.5	48.56 ± 0.55
(8)	156°57.0'	(sill)		0.485				
	(Sutwik Is.			0.482		3.354	40.4	47.64 ± 0.29
	D-3)			0.481			mean	48.1 ± 0.89
78AWs-11[f]	56°59.0'	Dacite	Hbl	0.495	0.492	1.381	30.5	19.42 ± 0.16
(9)	157°07.5'			0.492		1.357	31.0	19.08 ± 0.16
	(Sutwik Is.			0.487				
	D-4)			0.492			mean	19.3 ± 0.33
78AWs-17	56°38.7'	Leuco-	Hbl	0.397	0.401	1.911	33.3	32.84 ± 0.48
(10)	157°25.0'	basalt		0.405		2.068	36.2	35.52 ± 0.51
	(Sutwik Is.	(dome)		0.405			mean	34.2 ± 2.02
	C-5)			0.395				

[a]Potassium was determined by flame photometry using lithium metaborate fusion (Engels and Ingamells, 1970) by Byron Lai, D. Vivit, and Paul Klock. Argon was extracted and measured using standard techniques of isotope-dilution mass spectrometry, especially as described by Dalrymple and Lanphere (1969). The analytical error assigned to each age is an estimate of the standard deviation of analytical precision using the method of Cox and Dalrymple (1967) and my calculated estimates of uncertainties in the concentration of ^{38}Ar tracer and potassium measurements. I performed sample preparation, argon extraction, and data reduction with assistance from Nora Shew, Rita Taylor, Brian Ho, and L.B. Gray, except for sample R-41358A, which was analyzed by M.L. Silberman.

[b]Constants used: $\lambda_{\epsilon} = 5.72 \times 10^{-11} yr^{-1}$

$\lambda_{\epsilon}' = 8.78 \times 10^{-11} yr^{-1}$

$\lambda_{\beta} = 4.963 \times 10^{-10} yr^{-1}$

$^{40}K/K = 1.167 \times 10^{-4}$ mol/mol

[c]Minimum age, possibly reset due to proximity to Devils batholith. Impure hornblende concentrate with inclusions of plagioclase.

[d]Age may be too old, possibly due to excess argon.

[e]Whole rock and plagioclase are HF treated (Wilson, 1980).

[f]Minimum age, possibly reset due to nearby Quaternary volcanism.

Table 3. (con.)

Sample (map no.)	Lat-long (quadrangle)	Rock type	Mineral or component dated	Mean percent K_2O	Weight percent K_2O	$^{40}Ar_{rad}$ (moles/gm) $x10^{-11}$	Percent $^{40}Ar_{rad}$	Age ± 1σ (m.y.)
78AWs-24	56°47.3'	Andesite	Hbl	0.430	0.430	2.161	30.9	34.59 ± 0.55
(13)	157°11.8'	(sill)		0.428		2.020	35.2	32.36 ± 1.65
	(Sutwik Is.			0.431				
	D-4)			0.430			mean	33.5 ± 1.69
78AWs-27	56°47.9'	Autolith	Hbl	0.391	0.391	2.150	32.9	37.8 ± 0.32
(14)	157°13.7'	in dacite(?)		0.394		2.019	27.7	35.5 ± 0.31
	(Sutwik Is.	dome		0.391				
	D-4)			0.387			mean	36.7 ± 1.67
78AWs-35	56°49.1'	Dacite	Hbl	0.366	0.365	1.800	36.0	33.93 ± 0.16
(17)	157°56.3	(dome)		0.364		1.858	18.9	35.01 ± 0.33
	(Sutwik Is.			0.365				
	D-6)			0.366			mean	34.5 ± 0.85
78AWs-42	56°30.4'	Andesite	Hbl	0.662	0.662	3.182	48.7	33.08 ± 0.14
(18)	157°43.1'			0.663		3.123	46.6	32.46 ± 0.14
	(Sutwik Is.			0.663				
	C-6)			0.661			mean	32.8 ± 0.48
79ADt-23	57°12.1'	Altered	Hbl	0.502	0.503	2.475	44.1	33.9 ± 0.17
(25)	156°58.8'	andesite		0.503		2.563	36.1	35.0 ± 0.16
	(Ugashik			0.504				
	A-3)			0.504			mean	34.5 ± 0.87
79ADt-95	57°14.9'	Andesite	Hbl	0.732	0.732	3.670	48.6	34.5 ± 0.29
(26)	156°54.6'			0.738		3.811	44.1	35.8 ± 0.29
	(Ugashik			0.725				
	A-3)			0.732			mean	35.2 ± 1.01
R41358-A	57°14.2'	Dacite	Hbl	1.056	1.048	5.298	52.0	34.8 ± 0.45
(28)	157°03.0'			1.050		5.367	57.0	35.2 ± 0.45
	(Ugashik			1.037				
	A-4)						mean	35.0 ± 0.70
Do.	Do.	Do.	Bio	8.67	8.70	39.67	77.0	31.4 ± 0.90
				8.77				
				8.67				
			Volcanic rocks					
77AWs-102	55°57.0'	Leuco-	WR[e]	1.136	1.103	6.583	83.3	41.01 ± 0.88
(5)	159°21.0'	basalt		1.085		6.363	79.1	39.65 ± 0.85
	(Stepovak			1.100				
	Bay D-5)			1.089			mean	40.3 ± 1.56
78AWs-18	56°37.5'	Leuco-	WR	0.765	0.777	4.171	60.7	36.91 ± 0.63
(11)	157°34.5'	basalt		0.786		4.252	69.2	37.62 ± 0.64
	(Sutwik Is.			0.790				
	C-5)			0.767			mean	37.3 ± 1.03
78AWs-20	56°43.0'	Dacite	WR	1.395	1.378	7.089	84.8	35.40 ± 0.34
(12)	157°49.5'			1.374		7.562	72.6	37.73 ± 0.40
	(Sutwik Is.			1.374				
	C-6)			1.368			mean	36.6 ± 1.73

Table 3. (con.)

Sample (map no.)	Lat-long (quadrangle)	Rock type	Mineral or component dated	Mean percent K_2O	Weight percent K_2O	$^{40}Ar_{rad}$ (moles/gm) $\times 10^{-11}$	Percent $^{40}Ar_{rad}$	Age ± 1σ (m.y.)
78AWs-31	56°33.0'	Andesite	WR	1.258	1.260	5.553	90.5	30.35 ± 0.47
(15)	156°59.6'			1.265		5.505	84.9	30.10 ± 0.14
	(Sutwik Is.			1.261				
	C-4)			1.257			mean	30.2 ± 0.49
78AWs-32	56°31.6'	Andesite	WR	0.981	0.983	4.432	67.1	31.05 ± 0.48
(16)	157°11.7'			0.983		4.332	72.2	30.36 ± 0.13
	(Sutwik Is.			0.985				
	C-4)			0.983			mean	30.7 ± 0.70
78AWs-58	56°30.4'	Dacite	WR	1.554	1 543	7.694	90.6	34.32 ± 0.61
(19)	157°49.4'			1.557		7.748	89.8	34.56 ± 0.36
	(Sutwik Is.			1.530				
	C-6)			1.530			mean	34.4 ± 0.73
78AWs-61	56°36.1'	Dacite	WR	1.210	1.210	6.107	94.8	34.74 ± 0.16
(20)	157°58.9'			1.213		5.985	86.4	34.05 ± 0.16
	(Sutwik Is.			1.206				
	C-6)						mean	34.4 ± 0.54
78AWs-98	56°12.7'	Leuco-	WR	0.201	0.201	6.486	20.4	22.31 ± 0.33
(21)	158°19.9'	basalt		0.200		5.826	25.8	20.05 ± 0.38
	(Chignik			0.199				
	A-2)			0.203			mean	21.2 ± 1.68
78AWs-111	56°01.4'	Leuco-	WR	0.957	0.971	5.615	65.9	39.72 ± 0.79
(22)	159°20.2'	basalt		0.997		5 449	78.8	38.56 ± 0.77
	(Chignik			0.974				
	A-5)			0.957			mean	39.1 ± 1.37
78AWs-134	56°17.1'	Dacite	WR	1.093	1.116	4.296	57.3	26.54 ± 0.56
(23)	158°35.2'			1.134		4.195	66.6	25.92 ± 0.51
	(Chignik			1.132			mean	26.2 ± 0.87
	B-2)			1.106				
79AWs-2	57°06.5'	Andesite	WR	1.564	1.547	6.249	80.0	27.85 ± 0.26
(24)	157°38.2'			1.547		6.291	79.0	28.03 ± 0.25
	(Ugashik			1.534				
	A-5)			1.543			mean	27.94 ± 0.38
79ACe-20	57°05.9'	Basalt	WR	0.563	0.563	2.007	52.5	24.6 ± 0.15
(27)	157°43.1'			0.565		2.060	40.0	25.2 ± 0.13
	(Ugashik			0.561				
	A-6)						mean	24.9 ± 0.49

rate dependent on ridge orientation, the rate of convergence between the ridge and overriding plate, and segmentation of the ridge to arrive at a paleo-Aleutian trench off the central Alaska Peninsula. About 5 to 10 m.y. is necessary for arrival of the Kula-Pacific Ridge at the paleo-Aleutian trench off the central Alaska Peninsula assuming that:

1. The Kula-Pacific Ridge was oriented approximately east-west.
2. Orientation of the Aleutian Islands-Alaska Peninsula block was about the same during Oligocene and Miocene time as at present. This results in a convergence distance of approximately 3 degrees of latitude.
3. The Kula plate and the plate that included the central Alaska Peninsula (North American plate?) were oriented approximately north-south and converged at a

Table 4. *Descriptions of dated and analyzed rocks. Map numbers shown on figure 1.*

Map no.	
1	77AWs-30, andesite, Cape Kumlik. Light-greenish-gray, porphyritic andesite with hornblende phenocrysts and strongly zoned glomeroporphyritic plagioclase phenocrysts (about An_{55}, although some phenocrysts are An_{30}). Pyroxene pseudomorphs of calcite with chlorite or talc. Abundant accessory manganese-bearing purple apatite. Groundmass with abundant opaque oxides and possibly devitrified glass. Thoroughly fractured, probably protoclastic texture.
2	77AWs-40, leucobasalt, Cape Kumlik. Dark-green, porphyritic leucobasalt with hornblende phenocrysts up to 10 mm diam. Altered plagioclase phenocrysts ($An_{>50}$). Abundant calcite, chlorite, and epidote. Hornblende phenocrysts partially altered to chlorite. Phenocrysts and groundmass fractured; may be cataclastic rather than protoclastic. Dike in mineralized area.
3	77AWs-46, andesite(?), Cape Kumlik. Dark-green, porphyritic andesite(?) with chloritized amphibole phenocrysts and altered, zoned plagioclase phenocrysts (An_{35} and An_{55}). Minor quartz. Rock is deuterically altered; calcite is common. In mineralized area.
4	77AWs-74, dacite, Sutwik Island. Relatively fresh biotite phenocrysts(?) in thoroughly altered, tan dacite. Hornblende phenocrysts altered to opaque oxides and calcite; sericitized plagioclase of indeterminate composition; quartz and abundant accessory apatite and sphene.
5	77AWs-102, leucobasalt, Ivanof River, Stepovak Bay Quadrangle. Dark-gray, fine-grained leucobasalt flow with laths of plagioclase (An_{55-60}) and phenocrysts of clinopyroxene in groundmass of interstitial glass. Hyalophitic texture.
6	77AWs-122, dacite, Castle Bay. Light-gray, iron-stained dacite with hornblende and plagioclase phenocrysts ($An_{30?}$) in fine-grained groundmass. Some quartz, hydrothermal(?) biotite, and sericite. Hornblende is sparsely distributed in long laths. Hyalophitic texture.
7	77AMs-1, andesite, Mallard Duck Bay. Propylitically altered hornblende-andesite dike that intrudes volcanic pile of Mallard Duck Bay prospect. Plagioclase and hornblende phenocrysts in fine-grained groundmass of devitrified glass. Disseminated hydrothermal chlorite and epidote are abundant.
8	78AWs-5, andesite, Nakalilok Bay. Gray, fine- to medium-grained andesite. Orthopyroxene and clinopyroxene with unaltered plagioclase phenocrysts (An_{45}). Minor groundmass of opaque oxides, fine-grained plagioclase, and iddingsite(?). Some calcite. Intersertal porphyritic texture.
9	78AWs-11, dacite, north edge, Sutwik Island Quadrangle. Gray, porphyritic dacite with phenocrysts of green hornblende and plagioclase. Strongly zoned and Carlsbad-twinned plagioclase phenocrysts are of indeterminate composition due to sericitic alteration. Cataclastic porphyritic texture; phenocrysts shattered and dislocated. Miarolitic(?) cavities filled with rusty quartz crystals.
10	78AWs-17, leucobasalt, Kumlik Island. Green, porphyritic leucobasalt. Large phenocrysts of hornblende (>1 cm) and augite. Unevenly distributed xenoliths rich in hornblende and plagioclase. Minor plagioclase phenocrysts (An_{60}) are sericitically altered. Abundant calcite, chlorite, and sericite in fine-grained groundmass.
11	78AWs-18, leucobasalt, Cape Kumlik. Dark-green, porphyritic leucobasalt. Plagioclase (An_{55}) phenocrysts and minor pyroxene in groundmass largely composed of glass and devitrified glass. Hyalopilitic texture. Very minor iddingsite(?). Dike intrudes sediments of Tolstoi Formation.
12	78AWs-20, dacite, North fork, Kujulik Bay. Green-gray hornblende-dacite sill or plug in Meshik Formation. Hornblende and plagioclase (An_{55}) phenocrysts in groundmass of glass. Plagioclase is glomeroporphyritic.
13	78AWs-24, andesite, Cape Kunmik. Light-gray, porphyritic hornblende andesite. Green, pleochroic hornblende phenocrysts in groundmass of hornblende and sericitically altered plagioclase. Sphene and actinolite alteration products from pyroxene. Weakly developed flow structure. Sample collected from rubble mixed with hornfels apparently along upper contact of intrusion.
14	78AWs-27, autolith, Cape Kunmik. Coarse-grained, dark-brown-black autolith composed of pyroxene and hornblende collected from dacite(?) dome. Plagioclase in sill is strongly zoned with An_{60} cores. Autolith almost entirely composed of pyroxene and hornblende with very minor interstitial plagioclase. Pyroxene was originally subcalcic augite, but is now exsolving orthopyroxene and hornblende. Heteradcumulate texture.

Table 4. (con.)

Map no.	
15	78AWs-31, andesite, Foggy Cape. Dark-gray, porphyritic andesite with plagioclase phenocrysts (An_{55}) and phenocrysts of orthopyroxene and clinopyroxene. Groundmass of very fine grained plagioclase and pyroxene. Weak development of flow structure. Very minor alteration of plagioclase.
16	78AWs-32, andesite, Sutwik Island. Dark-gray andesite with phenocrysts of plagioclase (An_{55-60}) and minor clinopyroxene. Serrate texture with medium- to very fine grained crystals. Orthopyroxene phenocrysts apparently altered to bastite. Weak development of flow structure. Feldspar unaltered.
17	78AWs-35, dacite, Pinnacle Mountain. Light-gray dacite with phenocrysts of green, pleochroic hornblende and plagioclase (An_{60}). Rare quartz phenocrysts(?) partially resorbed. Very fine grained groundmass, primarily of feldspar. Most plagioclase phenocrysts are broken and dislocated; general alignment of hornblende phenocrysts indicates weak development of flow structure.
18	78AWs-42, andesite, Unavikshak Island. Gray, porphyritic andesite with phenocrysts of plagioclase (An_{55}), hornblende, and opaque oxides. Phenocrysts range from 4 mm to near groundmass and all show resorption. Plagioclase zoned; alteration varies with zoning. Hyalophitic, porphyritic texture.
19	78AWs-58, dacite, VABM Easy. Gray-brown, porphyritic dacite with hornblende and plagioclase (An_{55}) phenocrysts. Groundmass of fine-grained plagioclase, glass, and opaque oxides. Pilotaxitic texture.
20	78AWs-61, dacite, VABM Julik. Gray-green, porphyritic dacite. Phenocrysts of hornblende and plagioclase ($An_{55?}$) in extremely fine grained groundmass of plagioclase(?) and glass. Hornblende phenocrysts outlined in opaque oxides. Interiors of some plagioclase phenocrysts altered; most fresh. Hand sample appears coarse grained due to abundance of phenocrysts and nature of groundmass.
21	78AWs-98, leucobasalt, Mallard Duck Bay. Dark-gray, fine-grained leucobasalt. Glomeroporphyritic phenocrysts of plagioclase ($An_{65?}$) and orthopyroxene in groundmass of plagioclase, clinopyroxene, orthopyroxene, divitrified glass, and opaque oxides. Plagioclase fresh and unaltered. Pilotaxitic texture.
22	78AWs-111, leucobasalt, Kametolook River. Dark-green-brown, porphyritic leucobasalt with fine-grained groundmass of pyroxene, plagioclase, and glass. Plagioclase (An_{55}) phenocrysts fractured; fractures contain glass. Hyalopilitic texture. Pyroxene altered to fine-grained secondary phases. Abundant opaque mineral (magnetite?) in groundmass.
23	78AWs-134, dacite, Chignik Island. Dark-gray, medium- to fine-grained porphyritic dacite. Medium-grained phenocrysts of plagioclase (An_{40-45}) in fine-grained groundmass of plagioclase, orthopyroxene, clinopyroxene, and quartz. Some plagioclase crystals show fractures and dislocations. Fractures filled with devitrified glass indicate protoclastic, subophitic texture.
24	79AWs-2, andesite, Meshik Formation. Brown-weathering, very fine grained andesite flow. Contains sparsely distributed phenocrysts of orthopyroxene, clinopyroxene, and rare plagioclase (minimum An_{50}) in flow-textured groundmass of very fine grained plagioclase, amphibole or augite, and glass.
25	79ADt-23, Rex Prospect. Propylitically altered hornblende-andesite porphyry. Closely packed phenocrysts of hornblende and plagioclase (An_{54}) in groundmass of devitrified glass, plagioclase, and sericite. Most plagioclase phenocrysts partially altered to sericite; many hornblende phenocrysts partially altered to chlorite and calcite. Abundant epidote.
26	79ADt-95, andesite, Meshik Formation. Deuterically altered hornblende-andesite porphyry. Phenocrysts of green, pleochroic hornblende in groundmass of fine-grained, anhedral plagioclase crystals ($An_{66?}$) and devitrified glass. Small proportion (<5%) of quartz crystals, some of which are subhedral or euhedral. Some hornblende altered to calcite and chlorite.
27	79ACe-20, basalt, Meshik Formation. Porphyritic, flow-textured olivine basalt. Phenocrysts of olivine and uralized pyroxene(?) in fine-grained groundmass of plagioclase (minimum An_{62}), opaque minerals, olivine, and augite(?). Olivine phenocrysts altered to iddingsite on grain boundaries, and some plagioclase crystals have cores that appear to be chlorite or uralite.
28	R41358A, dacite, Rex Prospect. Biotite-hornblende dacite. Abundant phenocrysts of relatively fresh plagioclase, poikiolitic hornblende, and quartz in sparse groundmass of quartz, plagioclase, and minor potassium feldspar. Minor biotite present and appears to be primary or formed in reaction relationship with hornblende; it is not hydrothermal. Hornblende has inclusions of plagioclase and quartz and shows minor replacement by chlorite. Pyrite present and concentrated around and within hornblende and biotite grains.

rate of about 6 cm/yr.

4. Segmentation of the ridge was minor (and does not significantly affect estimates of ridge position).

I suggest that the hiatus in magmatic activity postulated by the model of DeLong and others (1978) is the lull in volcanic activity that began about 25 m.y. B.P. and separates the Meshik and Aleutian arcs in the central Alaska Peninsula.

An alternative explanation for the lull in magmatic activity during middle Miocene time is cessation of subduction at the paleo-Aleutian trench, which implies migration of the Alaska Peninsula terrane on the basis of the coupling-migrating, decoupling-subducting assumption. In support of this, Stone and Packer's (1979) paleomagnetic interpretation suggested limited post-Eocene migration of the Alaska Peninsula.

Byrne (1979) alternatively suggested, on the basis of marine magnetic anomalies, a Paleocene demise for the Kula-Pacific Ridge and little or no subduction along the Alaska Peninsula during Tertiary time. However, assuming that the existence of a volcanic arc is indicative of subduction, the 30-to-40 m.y. history of volcanism for the Meshik and Aleutian arcs strongly suggests that subduction was in fact important during Tertiary time on the Alaska Peninsula.

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William W. Barnwell, Deputy State Geologist

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.M.R. Ashwell, Minerals laboratory technician
.W.B. Atencio, Chemist
.K.B. Faris, Chemist
.M.K. Polly, Minerals laboratory technician
.N.C. Veach, Chemist

Geologic Mapping

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.D.D. Adams, Geological assistant
.M.D. Albanese, Geologist
.J.D. Blum, Geologist
.T.K. Bundtzen, Geologist
.L.E. Burns, Geologist
.R.A. Combellick, Geologist
.J.E. Decker, Geologist
.J.T. Dillon, Geologist
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.L.L. Lueck, Geologist
.R.D. Merritt, Geologist
.R.J. Motyka, Geologist
.C.J. Nye, Geologist

Oil and Gas

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.D.L. Bertossa, Geological assistant
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.E.E. Harris, Geological assistant
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.M.E. Pritchard, Cartographer
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.S.M. Weum, Geophysicist
.B.K. Wilson, Geological assistant

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.E.E. Becia, Natural resource manager
.M.S. Christy, Geologist
.K.H. Clautice, Geologist
.G. Dickison, Natural resource manager
.T.G. Johnson, Data control specialist
.W.A. Petrik, Geological assistant

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.S.J. Carrick, Hydrologist
.E.J. Collazzi, Hydrologist
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.M.A. Moorman, Geologist
.J.A. Munter, Hydrologist

[1]In addition to the permanent staff listed above, DGGS has employec over 100 students in the Department of Natural Resources Student Intern Program.
[2]Section or Unit Chief
[3]Acting Section Chief