Paleogene Sedimentary and Volcanogenic Rocks from Adak Island, Central Aleutian Islands, Alaska

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ABSTRACT

The Andrew Lake Formation on northern Adak Island, here redefined, consists of conglomerate, sandstone, chert, shale, and pyroclastic ejecta of late Eocene age. These strata were deposited in a marine basin no deeper than 500 meters. Nonrnarine to shallow marine volcaniclastic rocks, probably correlative in age with the Andrew Lake Formation, crop out in the Wedge Point area of southwestern Adak Island. The sedimentary rocks contain secondary minerals including chlorite, vermiculite, smectite, analcime, laumontite, clinoptilolite, wairakite, and the rare zeolite yugawaralite. These minerals reflect a complex history of alteration involving burial diagenesis, migration of hydrothermal solutions associated with intrusion of granodiorite plutons, and local thermal metamorphism caused by intrusion of dikes and sills. The late Eocene strata both at Andrew Lake and near Wedge Point overlie the Finger Bay Volcanics, which consists of highly altered interbedded flows and pyroclastic rocks that contain secondary minerals (chlorite, albite, actinolite, muscovite, epidote) characteristic of greenschist-facies metamorphism. The age of the Finger Bay Volcanics is unknown, but because of the contrast in degree of alteration and metamorphism between it and the overlying Andrew Lake Formation, it is believed to be late Paleocene or early Eocene. The late Eocene strata are low in total organic carbon and are therefore not considered a potential source rock for petroleum. ,

Other workers suggest that subduction of the Kula ridge spreading center beneath the Aleutian arc, 30 million years ago, resulted in an episode of regional greenschist-facies metamorphism throughout the arc. However, absence of metamorphism in the Andrew Lake Formation indicates either that the Kula ridge was subducted at an earlier time (about 50 m.y. ago) or that low-grade regional metamorphism did not accompany the subduction of the spreading center.

INTRODUCTION

Adak Island, part of the Andreanof group of central Aleutian Islands, consists of late Cenozoic stratovolcanoes that overlie uplifted Tertiary volcanic, sedimentary, and plutonic rocks (fig. 1). In general, most of the larger Aleutian islands are characterized by a Late Cretaceous(?) and early Tertiary mafic volcanic basement overlain by Paleocene volcanic and sedimentary rocks. Commonly, as on Adak Island, lower Tertiary rocks of the Aleutians are intruded by middle Miocene plutonic bodies, mostly granodiorite (Fraser and Snyder, 1959; Marlow and others, 1973; DeLong and others, 1978).

Marine volcaniclastic strata that crop out between Andrew Lake and Clam Lagoon on northern Adak Island (figs. 1 and 2) were mapped by Coats (1956) as part of the Finger Bay Volcanics and were tentatively dated as Paleozoic on the basis of leaflike impressions identified as *Annularia stellata*. Because rocks of unequivocal Paleozoic age were not known from other Aleutian islands, Scholl, Green, and Marlow (1970) re-examined these strata and found that the "*Annularia*" beds are in fact of middle or late Eocene age on the basis of foraminifers, dinoflagellates, and pelecypods. They named the fossiliferous strata the Andrew Lake Formation and reported that it rests depositionally on the Finger Bay Volcanic~,which they assumed to be of slightly older Tertiary age.

The Finger Bay Volcanics, defined by Coats (1947), occurs widely on Adak Island and is especially well exposed on southern Adak (Fraser and and Snyder, 1959). Fraser and Snyder (1959) found that, in general, the Finger Bay Volcanics consists of pervasively altered pyroclastic deposits and basaltic and andesitic flows. They deduced from dated rocks exposed on nearby Kanaga Island that the volcanic rocks of southern Adak are probably of Tertiary age. They also included bedded pyroclastic rocks, volcanic wacke, and argillite as part of the Finger Bay Volcanics. One of these sedimentary rocks sections is well exposed at Wedge Point on the Yakak Peninsula (figs. 1 and 3).

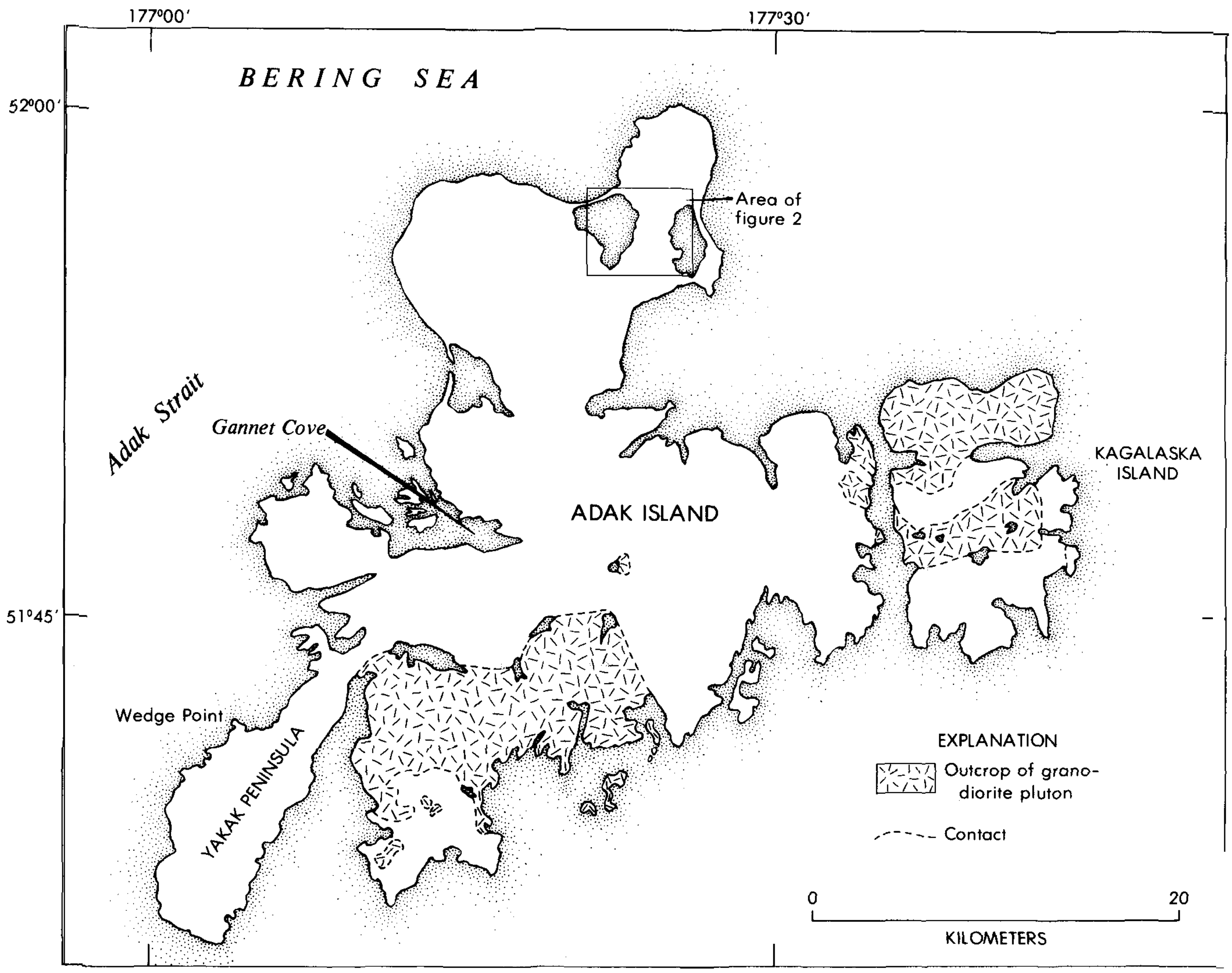

FIGURE 1.—Location of outcrops of granodiorite plutons on Adak and Kagalaska Islands in the central Aleutian Islands. Area of figure 2 is indicated by rectangle, Wedge Point area is shown in figure 3.

Here we present information on the petrology, mineralogy, stratigraphy, and depositional environments of the Andrew Lake Formation and the sedimentary and pyroclastic rocks at and near Wedge Point. We also assess the potential of these rocks as sources of hydrocarbons. We define mineral assemblages formed by hydrothermal processes as distinguished from assemblages developed by regional low-grade metamorphism. We speculate on the significance of the Paleocene history of Adak Island in the regional development of the Aleutian island arc and the early Tertiary plate-tectonic interaction of the Kula ridge with the Aleutian subduction zone.

ACKNOWLEDGMENTS

We thank Capt. T. P. Driver, commanding officer of U.S. Naval Station, Adak, for permission to work on the Naval Station and Comdr. Elton Himes for providing transportation and logistic support for fieldwork. The U.S. Naval Special Service Corps provided logistic support for our works on Yakak Peninsula. H. N. Meeks of the National Oceangraphic and Atmospheric Administration Observatory, Adak, provided a vehicle during part of our work. Paul T. Fuller was our able field assistant. C. E. Gutmacher provided X-ray diffractograms and processed a sample for K-Ar dating; G. B. Dalrymple made the K-Ar age determination. John Barron, Kristin MacDougall, Richard Poore, William Sliter, Fred May, and Louie Marincovich searched, often fruitlessly, for fossils. Kam Leong determined We Fe content of three samples by atomic absorption techniques. A. J. Koch, of Mobil Oil Corp., and George Claypool, U.S. Geological Survey, provided organic geochemical analyses and interpretation. We benefited from review

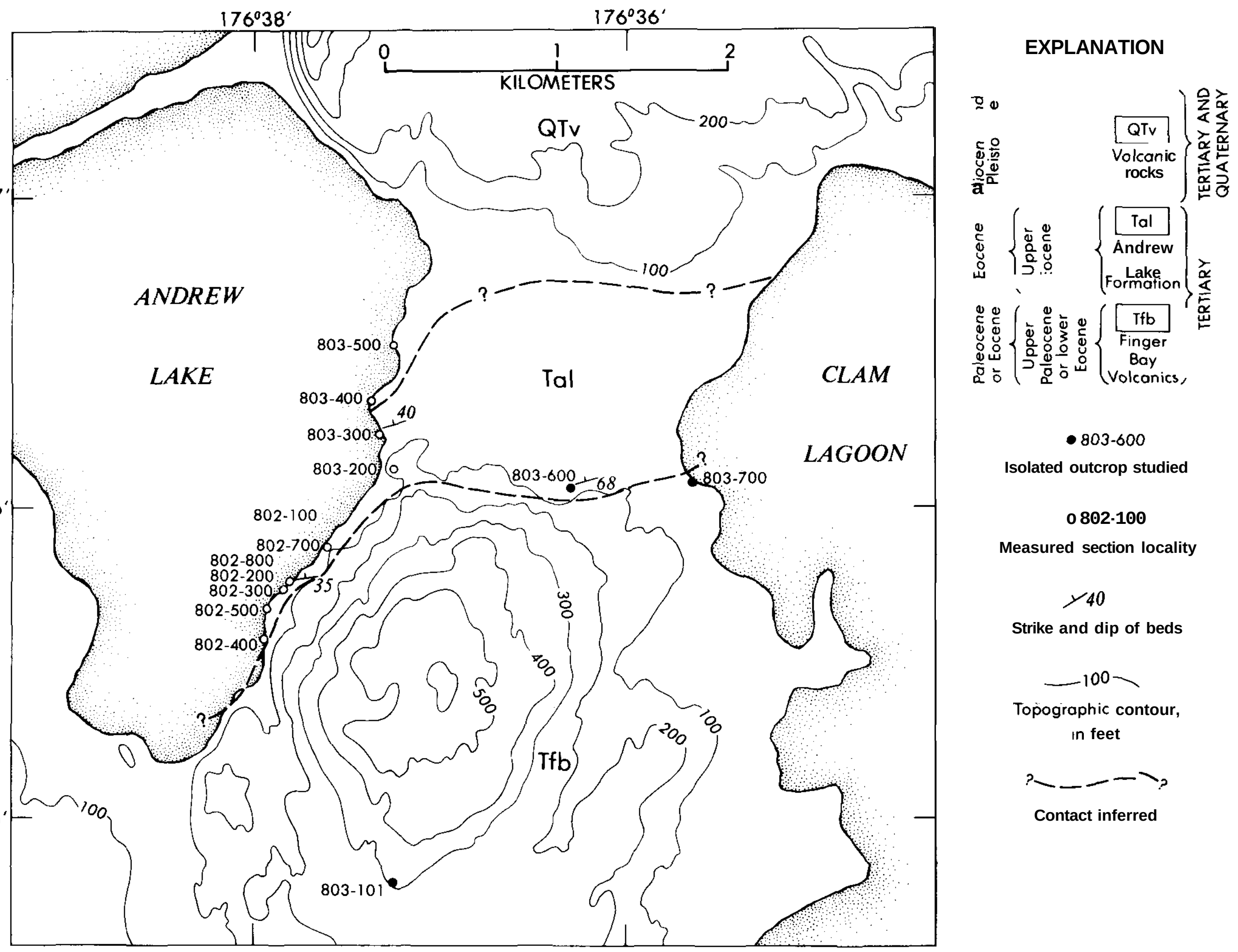

FIGURE 2.—Sample locations and topography of Andrew Lake area, northern Adak Island. (Note that No. 803–600, for example, includes all samples from 600 through 699.) Measured sections are keyed to figure 4. Base from Coats (1956).

by and helpful comments of R. R. Coats, D. W. Scholl, D. A. Swanson, M. S. Marlow, and A. K. Cooper, U.S. Geological Survey; Yotaro Seki, Saitama University, Japan; and A. C. Waters, University of California at Santa Cruz.

ANALYTICAL PROCEDURES

Bulk rock samples and mineral separates were powdered and examined with a Noreleo[1] X-ray diffractometer. Most rock samples were cut into thin sections for textural and mineralogical study. Three samples were analyzed for iron content with an atomic absorption spectrophotometer.

ANDREW LAKE FORMATION

Scholl and others (1970) defined and briefly described the Andrew Lake Formation. They suggested that it is more than 850 m thick, although only about 40 m of section is actually exposed in quarries and low cliffs along the east shore of Andrew Lake (figs. 2 and 4). An additional 30 m of sedimentary and pyroclastic rocks crops out south of the south limit of the Andrew Lake Formation as described by Scholl and others (1970). Although this lower section is only sparsely fossiliferous and its age is a matter of conjecture, we include it as part of the Andrew Lake Formation. Even with the addition of this section, the total thickness of the formation may not be greater than 800 m (fig. 4).

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

A composite stratigraphic section of the Andrew Lake Formation (fig. 4) compiled from outcrops located on figure 2 shows that the lower half of the section consists mainly of volcaniclastic sedimentary rocks. Volcanic sandstone and silty sandstone are most common, but they range from unsorted sandy

[1] Any use of trade names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

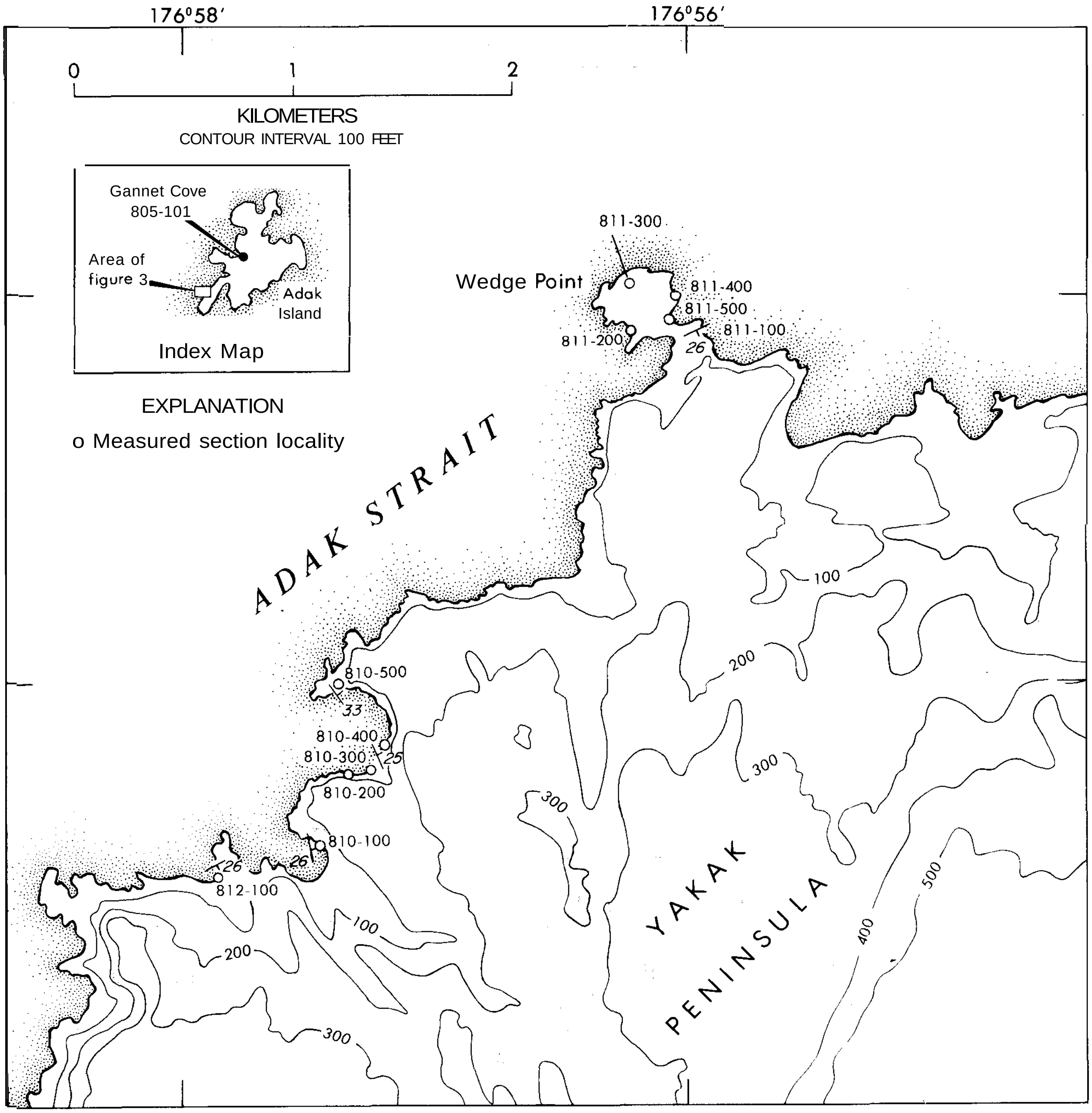

FIGURE 3.—Sample locations and topography near Wedge Point, Yakak Pensinsula, southwest Adak Island. Measured sections are keyed to figure 4. Note location of station 805–101 at Gannet Cove, western Adak Island (inset). Base from Fraser and Snyder (1959).

conglomerate to tuffaceous mudstone. Diatoms are rare in these rocks. Intercalated devitrified ash-fall tuff attests to coeval volcanism. Numerous dikes and sills cut this part of the Andrew Lake Formation. Descriptions of the samples studied are given in table 1, in stratigraphic order.

Overlying this relatively coarse grained clastic section are the only richly fossiliferous lower Tertiary strata known on Adak Island (fig. 4). These, strata mark the lower contact of the Andrew Lake Formation as defined by Scholl and others (1970). In this section are thin devitrified ash-fall tuff beds interbedded with quartz chert, laminated quartz porcelanite, siliceous. shale, laminated pyritic shale, calcareous chert, and the first recognized occurrence known to us of bedded quartz chert that contains abundant diatoms.

The stratigraphically highest beds in the Andrew

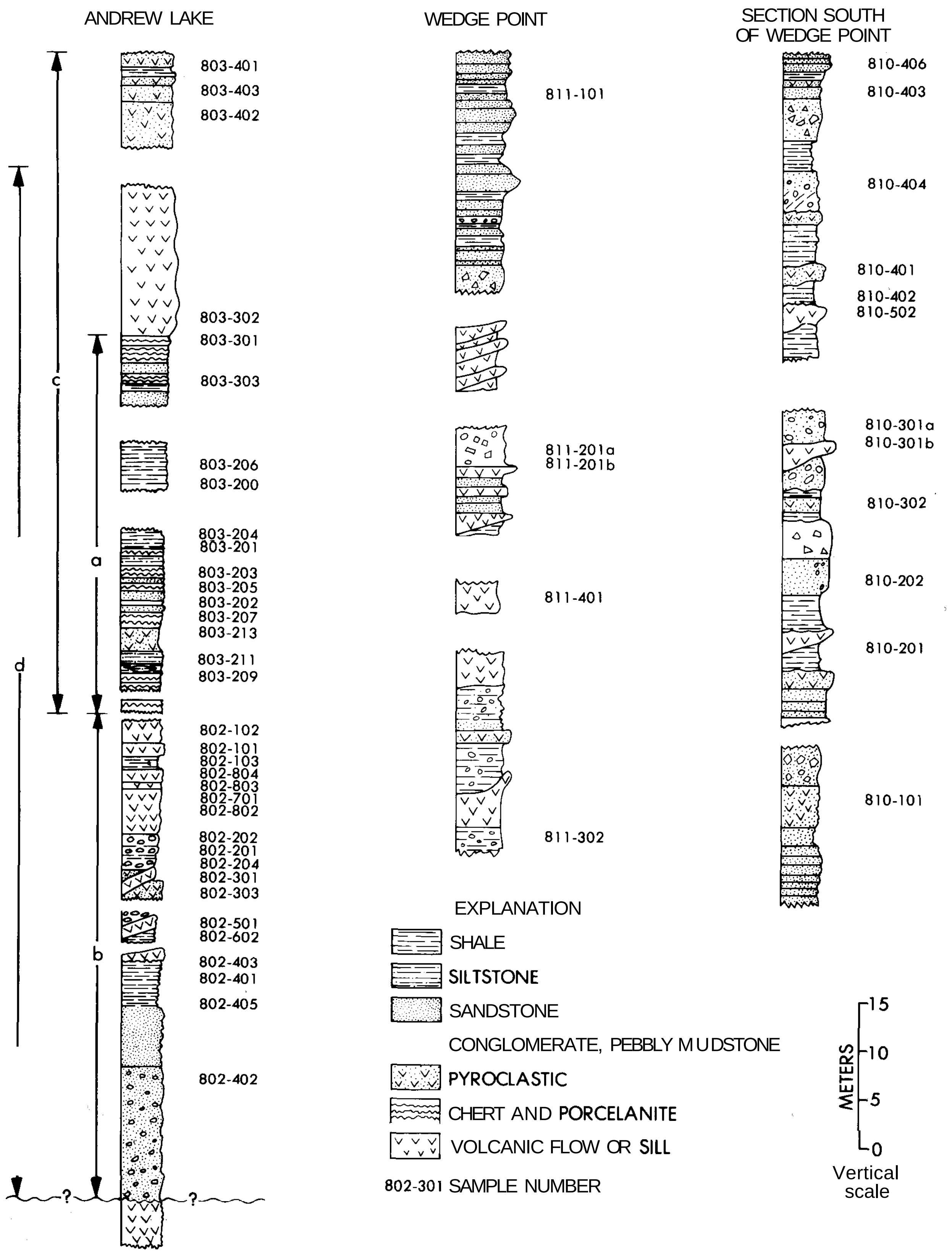

FIGURE 4.—Composite stratigraphic sections of Andrew Lake Formation and two sections near Wedge Point. Sections and sample localities are keyed to figures 2 and 3. Thickness of covered areas (breaks in sections) is unknown. Top part of Andrew Lake section and upper 7 m of Wedge Point section were measured. Queried line marks contact of Andrew Lake Formation with underlying Finger Bay Volcanics. (a) Chert-porcelanite section, (b) section rich with volcanic detritus, (c) Andrew Lake Formation as defined by Scholl and others (1970), and (d) Andrew Lake Formation as redefined.

TABLE 1.—*Description of rock samples from the Andrew Lake Formation, Finger Bay Volcanics, and Yakak Peninsula, Adak Island, Alaska*

[Locations and formations are keyed to figures 1, 2, and 3. Samples are listed in stratigraphic order starting at the base of the section. A, analcime: Ac, actinolite; Al, albite; Am, amphibole; Au, augite; B, biotite; C, calcite; Ca, chalcedony; Ce, celadonite; Ch, chlorite; Cl, clinoptilolite; Cr, chert; Cz, clinozoisite; E, epidote; F, fossil debris: Fe, iron oxides; H, hypersthene; He, heulandite; Ho, hornblende; I, illite; L, laumontite; M, magnetite: Mn, Mn-dendrites; Mu, muscovite; P, plagioclase; Ph, prehnite: Pr, piemontite; Pr, pyroxene; Py, pyrite; Q, quartz: S, stilpnomelane: Sm, smectite; Sp, sphene; St, stilbite; T, tremolite; V, vermiculite; Vg, altered volcanic glass; VRF, volcanic rock fragments; W, wairakite; Y, yugawaralite; Z, undifferentiated zeolites. Tr., trace. He and St occur only in sample 803 — 701]

Sample No.	Location	Rock type	Major primary constituents	Secondary minerals	Fossils	Comments
802 – 402	Andrew Lake area--	Sandy pebble conglomerate	VRF, Pr, P, Q, Vg	Al, V, Ch, Q, Fe, L	Diatoms --------	Poorly sorted up to 9 mm.
802 – 406	----do ------------	Silty mudstone and fine-grained sandstone.	Q, P, VRF, Pr, Vg	Al, V, Ch, Q, Fe	----do ----------	Burrowed, contorted lenses. bedding.
802 – 401	----do ------------	Lithic sandstone -------	VRF, P, Vg, Q, I	Q, V-Ch, Ce, Cl, Ch, Fe, Al	Barren ---------	
802 – 403	----do ------------	Lithic sandstone and siltstone.	VRF, Vg, I, P, Q	Ch. L, Q, Fe, V-Ch, Cl, S	Rare fragments--	Pods of vitric ash, lenses, contorted bedding.
802 – 602	----do ------------	Porphyritic dike -------	P, Pr, Q	V-Ch, L, Q, Fe, Al	Not looked for --	
802 – 501	----do ------------	Lithic sandstone and sandy and silty mudstone.	VRF, Vg, Pr, Q, P	Q, V-Ch, Ch, L, Al, Fe	Barren ----------	Lenses of organic matter, burrowed.
802 – 303	----do ------------	Pebble conglomerate and silty mudstone and sandstone.	Vg, VRF, Q, I, Pr	L, V-Ch, Q, Fe	----do ----------	Grains compact-penetrate. Conglomerate is well graded. Clasts to 12 mm.
802 – 301	----do ------------	Pumiceous ash-fall tuff?-	Vg, P, Pr	L, Q, V, Fe	----do ----------	Nearly totally replaced by laumontite.
802 – 204	----do ------------	Pebbly sandstone -------	VRF, P, Au, Q, Vg	Q, S, V-Ch, Fe, L, Al, Ph,	----do ----------	Very poorly sorted clasts to 13 mm.
802 – 201	----do ------------	Fine-grained sandstone and silty mudstone.	VRF, P. Q, Pr, Ac, E, C. Ph	Q, V-Sm, L. Al, Fe	----do ----------	Sandy layers are poorly sorted and crudely graded.
802 – 202	----do ------------	Fine-grained lithic sandstone.	P, Q, VRF, Mn, Au, Ac, E,	Q, Al, V, Ch, Fe. L	----do ----------	
802 – 802	----do ------------	Volcanic sill -----------	P, Q, Au, H, B	Ch, V	Not looked for --	K-Ar date 14 m.y.
802 – 701	----do ------------	Volcanic flow? or sill --	P, Pr, Q, B	Q, V, Ch	----do ----------	Pillow structures.
802 – 803	----do ------------	Altered vitric tuff ------	P, Vg, Q	V, Sm, Q	Barren ---------	
802 – 804	----do ------------	Volcanic siltstone ------	Q, P, Vg	Q, Z, Ch, V, C, Fe	Fragments -----	Pods of tuff.
802 – 103	----do ------------	Tuffaceous mudstone ---	Q, P, Vg, Pr, B	Q, C, Ch	Diatoms and radiolarians.	
802 – 101	----do ------------	Tuff? ----------------	P, Vg, Pr, Q	V-Ch, Fe, Al, Q. Ch	Benthic foraminifers.	Completely altered. 14 cm below dike.
802 – 102	----do ------------	Volcanic dike ----------	P, Pr, Q	V, Ch, Q	Not looked for --	
803 – 209	----do ------------	Black chert ------------	Q	Q, Tr, Z	Dinoflagellate ---	Much organic debris.
803 – 211	----do ------------	Vitric tuff ------------	Vg, P	Sm, Cl	Barren ---------	Friable.
803 – 213	----do ------------	----do ----------------	Vg, P, Pr	Sm-V, Ce, Fe, Q	----do ----------	Do.
803 – 207	----do ------------	Chert and porcelanite --	Q, P, I, F	Q, Fe, Ch	See table 2 -----	Late Eocene, upper bathyal.
803 – 202	----do ------------	Calcareous chert -------	Q, P, F	Q, C	Diatoms. radiolarians.	
803 – 205	----do ------------	Chert and porcelanite --	Q, P, F	Q, Py, Mn	Microfossil molds-	Burrowed, laminated.
803 – 203	----do ------------	----do ----------------	Q, P, F	Q, Py, Mn	----do ----------	Laminated.
803 – 201	----do ------------	----do ----------------	Q, P, F	Q, Py, Mn	----do ----------	
803 – 204	----do ------------	Siliceous shale --------	?	?	Benthic foraminifers.	Cretaceous through Oligocene.
803 – 200	----do ------------	Pyritic silty shale ------	Q, P, I. F	Q, C, Py, Ce, V	See table 2 ------	Laminated, late Eocene. upper bathyal.
803 – 206	----do ------------	Black silty shale -------	?	?	Barren ----------	
803 – 303	----do ------------	Diatom chert and siliceous shale with chert nodules.	Q, P, F, Am, VRF	Q, V-Ch, C, Fe	Diatoms, radiolarians. foraminifers.	Vermiculite clay nodules, shale is laminated.
803 – 301	----do ------------	----do ----------------	Q, P, F, VRF	Q. C. V-Ch, Fe	Diatoms. radiolarians, foraminifers, and fish.	Laminated shale, hematite pseudomorphs after pyrite.

Lake Formation described by Scholl and others (1970) include aquagene tuff, ash-fall tuff and possibly ash-flow tuff, and volcanic dikes (fig. 4). These pyroclastic rocks differ texturally and mineralogically (table 1) from strata in the lower part of the formation. Mild alteration of framework grains and traces of sideromelane (?) that has not devitrified contrast with the greater alteration shown by underlying rocks and suggest that this uppermost section may be younger than the underlying, more altered part of the section. Therefore, both the lower and upper contacts of this formation as originally proposed by Scholl and others (1970) are redefined here.

We redefine the base of the Andrew Lake Formation exposed along the southeast shore of Andrew Lake (fig. 2) to include the conglomerate at locality 802–400 (figs. 2 and 4); the underlying silicified

TABLE 1.—*Description of rock samples from the Andrew Lake Formation, Finger Bay Volcanics, and Yakak Peninsula, Adak Island, Alaska—Continued*

Sample No.	Location	Rock type	Major primary constituents	Secondary minerals	Fossils	Comments
803 – 302	Andrew Lake area	Volcanic dike	P. Pr	Al, Ch. V	Not looked for	
803 – 403	do	Aquagene tuff	Vg, P. VRF. Pr	Q. W, V, Ce, rare C	do	Unaltered minerals and some glass (?).
803 – 403	do	Ash-flow tuff	Vg, VRF, P, B, Au, Cz	Q, W. Sm. CI, Ch, C, V	do	Unaltered minerals.
803 – 401	do	Ash-fall tuff	Vg, P, B, Am	Q. Cl, W. V, Sm	Barren	Unaltered minerals and some glass (?).
803 – 601	do	Clayey siltstone	Q, P, F	Ch, V-Ch. Fe, Q	Foraminifers, echinoid.	
803 – 602	do	Lithic sandstone	P, Q, VRF	V-Ch. C. Q, Ch, Al	Barren	Baked by nearby dike.
803 – 604	do	do	P, VRF, Q	V-Ch, C. Q, Ch. Al, Fe	do	Do.
810 – 101	South of Wedge Point.	Welded tuff	Vg, P, Pr	Y, Ch, Ce, Fe. I-Mu, L	do	Purple with green mottling.
810 – 201	do	Volcanic dike	P, Pr, Vg	Vesicles: Q, S-Ce-Ch, L or C; Matrix: Fe, C, Q	Not looked for	
810 – 202	do	Lithic sandstone	VRF, P. Pr	Y. Q, Al, Ch. Fe	Barren	Poorly sorted, compact, grains penetrate.
810 – 302	do	Tuff	?	?	do	
810 – 301a	do	Pebbly mudstone	Vg, P. Au. VRF	Y, Q, Fe. Ch, V. Tr, L. Al	do	Lahar.
810 – 301b	do	Volcanic flow	P, Au	Vesicles: W, S, L: Matrix: Al, Fe, I	Not looked for	
810 – 502	do	Sandy shale	?	?	Barren	
810 – 402	do	do	?	?	do	
810 – 401	do	Ash-flow tuff	Vg, Au, P	I, Ch, V. Ce, C, Fe, Tr. Y, L	Not looked for	Slightly welded.
810 – 404	do	Pebbly mudstone	Vg, P, W	An. Q. Ch, Ce, Y(?)	Barren	Pumiceous lahar.
810 – 403	do	Lithic sandstone	VRF, P. Pr	An. Fe, clays	do	Banded, well sorted, crudely graded.
810 – 406	do	do	VRF, P, Pr, Q	Z, Q, Ch, Fe	do	Poorly sorted, graded.
812 – 104	do	Silicified ash	Vg, P	Q, Ch. Fe. C	Spicules?	
811 – 302	Wedge Point	Pebbly mudstone	?	.	Barren	
811 – 401	do	Volcanic dike	Au, P. Sp, M	Vesicles: Q, Ch+S+Ce, L, Q, Tr, Pr. E; Matrix: Q. L, Al, E, Fe, Ch. I	Not looked for	More than 50 percent altered to quartz and laumontite.
811 – 201a	do	Pebbly mudstone	Vg, P, Pr, M	Q. C, Ch. S, Ce. Fe. A	Barren	Pumiceous.
811 – 201b	do	Volcanic dike	P. Au, M	Vesicles: L, S+Ch+L, Q; Matrix: Q, Fe, Ch	Not looked for	
811 – 101	do	Silty sandstone	Vg, P, M, Au, Q	Q, Fe, Ce, I-Mu. Y, L, A	Barren	Poorly sorted. pumiceous.
811 – 201	do	Volcanic wacke	VRF, P. Pr, Q	Al, Q, Y. Fe, L, Ch	do	
803 – 101	Southeast of Andrew Lake.	Lithic sandstone	P, Q. B, VFR, Ho. Cr	Ac-T, E, Q, Fe, Ch, V	do	Finger Bay Volcanic~.compact.
805 – 101	Gannet Cove	Quartzite and epidosite	Q, P, Cg, F, B	E, C, Q, Mu, Fe, Ch, Pi?	Ghosts of microfossils.	Finger Bay Volcanic~.poorly sorted:
803 – 701	Clam Lagoon	Hydrothermal vein	W, Ca, V, Cl, He, St	Not looked for	Not looked for	Vein cuts Finger Bay Volcanics.

volcanic rocks are assigned to the Finger Bay Volcanic~.The top of the formation is in the area covered by tundra between outcrop localities 803–300 and 803–400 (figs. 2 and 4).

Fossils (table 2) indicate that the strata of the redefined Andrew Lake Formation were deposited in a marine environment, probably at water depths between 200 and 500 m. Sediments were reworked by bottom currents and by infauna. Lenses containing diatoms or devitrified ash are locally abundant; however, laminated porcelanite, black pyritic shale, and laminated shale from the middle part of the section suggest that the depositional basin was for a time "starved" or cut off from active terrigenous sedimentation. Consequently, mainly biogenic material accumulated, although an active infauna was not present.

Other sedimentary structures and current-direction indicators are rare. They include ripple laminations and poorly developed graded bedding. Sandstone beds are graded and have flute casts, and sandstone and shale sequences are rythmically bedded, which suggests deposition by turbidity currents. Rare crossbedding indicates eastward current flow. Deposition of most of the Andrew Lake Formation is ascribed to a combination of biogenic-pelagic, turbidity-current, hemipelagic, and pyroclastic processes.

SECONDARY MINERALS

Most rocks of the Andrew Lake Formation are silicified and in part altered to clay minerals and iron oxides (table 1). In most samples, plagioclase of intermediate anorthite content is partly altered to albite. In the lower part of the section where volcanogenic sedimentary rocks, pyroclastic debris, and volcanic dikes and sills are abundant, quartz and

TABLE 2.—*Foraminifers from the Andrew Lake Formation*

[Fossils identified by Kristin McDougall, R. Z. Poore, and W. V. Sliter]

Sample No.	Benthic forams	Other microfossils	Age range	Depth of water
802–101	*Bathysiphon* sp.		Indeterminate	
803–200	*Cyclammina pacifica?*	Echinoid spines	Late Eocene	Upper bathyal.
	Cyclammina sp.	Radiolarians		
	Dentalina sp.			
	Eponides sp.			
	Gyroidina soldanii d'Orbigny			
	Lenticulina sp.			
	Valvulineria sp.?			
803–207	*Bathysiphon eocenicus*	Echinoid spines	Late Eocene	Upper bathyal.
	Bathysiphon sp.	Fish debris		
	Cyclammina pacifica Beck	Radiolarians		
	Dentalina sp.			
	Eponides sp.			
	Gyroidina soldanii d'Orbigny			
	Lenticulina sp.			
	Melonis umbilicatulus (Montague)			
803–601	*Cyclammina* sp.	Echinoid spines	Intermediate	
803–204	*Bathysiphon eocenicus?*		Cretaceous through Oligocene.	
	Rhabdammina eocenica?			

laumontite occur as interstitial cement and replace volcanic debris along with vermiculite, chlorite, smectite[2] and vermiculite-chlorite (randomly interlayered). Some volcanic rock fragments are almost completely altered to iron oxides and clays. Locally calcite, analcime, clinoptilolite, and stilpnomelane replace volcanic debris.

Three samples (802–202, –201, –204 in fig. 4) from the upper part of this section rich in volcanic detritus contain abundant actinolite, epidote, chlorite, and calcite. These minerals, commonly found in greenschist-facies metamorphic rocks, occur as detrital minerals in these three samples (table 1). Adjacent to dikes and sills, however, secondary prehnite and epidote have formed (for example, prehnite in sample 802–204, table 1).

Because minerologically unstable volcanic debris is less abundant, fewer secondary minerals characterize the chert-porcelanite part of the section. Quartz and minor calcite and pyrite are the most important secondary minerals. Quartz indiscriminately replaces most sediment components and fills all available void space; thus abundant siliceous shale and porcelanite are produced. Calcite replaces quartz and is therefore a relatively late stage mineral.

Ash-fall tuff in the Andrew Lake Formation has altered to smectite and minor clinoptilolite. In places smectite was subsequently converted to vermiculite. Locally vermiculite, chlorite, hematite, and celadonite replace volcanic detritus (table 1).

Pyroclastic rocks that overlie the Andrew Lake Formation as redefined herein contain unaltered framework grains, but most of the glassy volcanic material is replaced by wairakite and to a lesser extent by clinoptilolite, quartz, and celadonite. Vermiculite, smectite, chlorite, and iron oxides are present; calcite is rare (table 1). Plagioclase is of intermediate composition. Celadonite in this part of the section is blue, whereas lower in the section it is green.

Secondary mineral assemblages or mineral facies in the stratigraphic section can indicate the history of burial metamorphism of the rocks. Accordingly, quartz, vermiculite, vermiculite-chlorite, smectite, chlorite, iron oxides, and celadonite are ubiquitous. Clinoptilolite is present in places but is most common at the top. Stilpnomelane and laumontite are in the lower part; wairakite occurs near the top of the section. Calcite and pyrite are mainly at midsection (table 1).

AGE

The Andrew Lake Formation was assigned a middle or late Eocene age by Scholl and others (1970) on the basis of microfossils and megafossils. Our collections of benthic foraminifers (table 2) indicate that the Andrew Lake Formation was deposited during the late Eocene, virtually identical to the foraminiferal age assigned in Scholl and others

[2] Smectite is the internationally accepted group name for the clay minerals that include montmorillonite, nontronite, and saponite (Brindley and Pedro, 1976). It is used as a general term.

TABLE 3.—*K-Ar data and age for an andesite sill, Andrew Lake Formation*

[Potassium measurements by A. Berry; argon measurement and age calculation by A. Berry and E. Sims]

Sample No.	Mineral	Percent K_2O	$^{40}Ar_{rad}$ (moles/g)	$^{40}Ar_{rad}$ / $^{40}Ar_{total}$	Calculated age (millions of years)
802 – 802	Plagioclase	0.079	1.640×10^{-12}	0.04	14.4±3.5

^{40}K decay constants: $\lambda_\epsilon = 0.572 \times 10^{-10}$/yr, $\lambda_\epsilon' = 8.73 \times 10^{-13}$/yr, $\lambda_\beta = 4.905 \times 10^{-10}$/yr. Abundance ratio $^{40}K/K = 1.167 \times 10^{-4}$ percent atomic.

(1970). According to Berggren (1972), late Eocene represents an absolute age of 37.5 to 43.0 m.y.

A K-Ar date on fresh plagioclase from an andesite sill cutting the Andrew Lake Formation was 14.4±3.5 m.y. (table 3).

We speculate that the pyroclastic rocks that overlie the Andrew Lake Formation as redefined, but included in the formation by Scholl and others (1970), are part of a younger series of volcanic rocks. These strata are structurally concordant with the lower part of the formation, but the unaltered framework grains and only mild alteration of glass shards differ markedly from the relatively high degree of alteration of samples from only slightly lower stratigraphically. Similar mild alteration is typical of other Neogene volcanic rocks on Adak; for example, the sill (802–802) cutting the Andrew Lake Formation dated by the K-Ar method as middle Miocene (table 3). Perhaps these little-altered pyroclastic rocks are associated with the intrusion of Miocene granodiorite plutons and related dikes and pyroclastic deposits (Fraser and Snyder, 1959). However, eruption of the pyroclastic rocks at any time after the Eocene cannot be ruled out.

HYDROCARBON POTENTIAL

Two samples of shaly siltstone were analyzed for TOC (total organic carbon), EOM (chloroform extractable bitumen), and R_o (vitrinite reflectance). These quantities, as well as EOM/TOC, are listed in table 4. Sample 803–204 (fig. 4 and tables 1 and 4) contains 0.41 weight percent of TOC, the highest value recorded for any rocks on Adak Island. This value, however, is still below the 0.50 weight percent quantity generally considered to separate a possible source rock from one with no source-rock potential. The R_o value of 2.1+ indicates that sample 802–804 has been heated well beyond the level of crude oil stability (A. J. Koch, written commun., 1976). A low EOM/TOC ratio can be interpreted as resulting from the "cracking" of organic material; the breakup of organic compounds probably resulted from the heat produced by nearby intrusions such as the numerous dikes and sills observed in outcrop.

TABLE 4.—*Organic geochevnistry of Tertiary sedimentary rocks from Adak Island*

[Analyses of total organic carbon (TOC) by U. S. Geol. Survey Organic Geochemistry Laboratory. Lakewood, Colo. Analyses of chloroform extractable bitumen (EOM), vitrinite reflectance (R_o), and EOM/TOC by Mobil Oil Corp., Dallas, Tex.]

Sample No.	Location	TOC (weight percent)	EOM (ppm)	R_o	EOM/TOC (percent)
803 – 204	Andrew Lake	0.41	28.6	2.1+	0.70
803 – 206	--do -------	.04	28.7	*	7.10
810 – 302	Wedge Point	.05	44.3	*	8.90
810 – 402	--do -------	.09	40.2	*	4.50
810 – 502	--do -------	.07	29.3	*	4.20
811 – 302	--do -------	.04	26.4	*	6.60

* Insufficient organic carbon for vitrinite reflectance measurement.

Sample 803–206 has a very low TOC content, but the EOM/TOC ratio indicates that it has not been subjected to excessive heat. A low TOC content means that there probably never was a significant quantity of organic material present. Attempts to recover organic residue for measurement of R_o were unsuccessful.

YAKAK PENINSULA STRATA (WEDGE POINT AREA)

Fraser and Snyder (1959) mapped a section of sedimentary, volcanic, and volcaniclastic strata on the west side of Yakak Peninsula (fig. 3) as part of the Finger Bay Volcanics. On the basis of lithologic composition, degree of alteration and induration, and the types of secondary minerals present (see below), we propose that these strata are temporally equivalent to the Andrew Lake Formation. Study of the mineralogy and petrology of samples from two stratigraphic sections, one immediately south of and one at Wedge Point (fig. 3), complements the reconnaissance work done by Fraser and Snyder.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

The section south of Wedge Point (figs. 3 and 4) consists predominantly of interbedded sandstone, shale, and pebbly mudstone, with minor ash-flow and ash-fall tuff (including slightly welded tuff); volcanic dikes cut the section. Sandstone beds are primarily lithic arenite but include lithic to feldspathic arenite and wacke. Virtually all lithic grains are volcanic rock fragments, generally subrounded. Plagioclase, pyroxene, and locally quartz are other common framework grains. Poorly sorted rocks abound, but graded, layered, and well-sorted beds occur near the top of the section. Sandstone is commonly cemented by laumontite, yugawaralite,[3] iron oxides, or clays.

Pebbly mudstone beds contain mostly subangular grains, although a complete range of grain roundness is present. Again, the framework grains are dominantly volcanic rock fragments and, in some samples, are primarily pumiceous. These poorly sorted rocks are texturally like mudflows and are probably lahars. The mudflow units are as much as several tens of meters thick, and they include rock fragments up to 1 m in diameter.

Ash-flow tuff is purplish to gray, commonly with a green mottled surface reflecting replaced volcanic glass globules (replaced collapsed pumice lapilli?). Texturally, it appears massive to weakly flow banded. Sample 810–101 (figs. 3 and 4; table 1) is mostly glass globules and flattened pumice fragments (greater than 3 mm) replaced by yugawaralite. Sample 810–401 has pumice with an elongation ratio of 20:1. Large plagioclase and augite glomerocrysts (Carlisle, 1963, p. 58) are present. The groundmass appears to be collapsed pumice and glass shards replaced by illite or muscovite.

The section includes many porphyritic volcanic dikes altered to zeolites, quartz, and iron oxides. Vesicles and amygdules are filled with zeolites, quartz, and clays. Phenocrysts are mostly plagioclase, partly or wholly altered to albite, and pyroxene that is locally fresh.

The section at Wedge Point (figs. 3 and 4) is similar to the one to the south just described but is capped by 7 m of alternating sandstone (volcanic wacke) and shale; two pebbly sandstone beds occur in this section. Wacke makes up 93 percent of this 7-m section and consists of beds 3 to 130 cm thick (average 47 cm), whereas the 7 percent of shale consists of beds 2 to 12 cm thick (average 5.4 cm). In general, beds increase in thickness up section. Framework grains are mostly volcanie fragments, plagioclase, pyroxene, and altered volcanic glass. Samples rich in relict volcanic glass also contain abundant zeolites. The matrix is made up mostly of clays, iron oxides, and fine-grained counterparts of framework grains.

Relative to the section south of Wedge Point, intrusive bodies at Wedge Point are more highly altered. From 50 to 75 percent of the host volcanic rock may be altered to zeolites, quartz, and clays.

The presence of ash-flow tuff and boulder lahars and the apparent absence of microfossils suggest that the rocks at Wedge Point were deposited in a subaerial to shallow marine environment and that volcanism was active near the site of deposition. Fiske (1963) and Fiske and Matsuda (1964) have demonstrated that submarine ash-flow tuff is not welded. Rocks at Wedge Point must therefore be, in part, subaerial deposits. Further, the presence of graded lithic arenite and sequences of alternating lithic wacke and shale suggest turbidity-current deposition; if so, Wedge Point rocks are in part subaqueous deposits (probably shallow marine). No freshwater fossils or lacustrine deposits were found at Wedge Point.

[3] Yugawaralite, a rare calcium zeolite, has been reported from only one other locality in North America, near Fairbanks. Alaska (Eberlein and others, 1971). It has also been reported from Heinabergsjokull, Iceland (Barrer and Marshall, 1966) and from Japan (Sakurai and Hayashi, 1952; Seki and Okumura, 1968; Sameshima, 1969; Seki and others, 1969).

SECONDARY MINERALS

Porphyritic basaltic and andesitic rock fragments are altered to iron oxides (mostly hematite) and clay minerals (dominantly chlorite and illite). Plagioclase is altered to albite that has approximately parallel extinction and little or no relict zoning. In contrast, clinopyroxene is commonly unaltered. Much pumice is replaced by vermiculite and chlorite. Other glassy volcanic fragments are replaced dominantly by zeolites such as yugawaralite, analcime, and laumontite, and to a lesser extent by quartz, illite, chorite, celadonite, hematite, vermiculite, and smectite. The rare zeolite, yugawaralite, is the most common zeolite in these rocks on Yakak Peninsula.

Sandstone is cemented by analcime, yugawaralite, laumontite, chlorite, illite, and hematite. Thin (0.005–0.1 millimeter) clay films coat all grains in some beds of arenite. The framework grains are compact and penetrate adjacent grains, and the remaining pore spaces (commonly very small, maximum 0.4 mm^2 in cross section between grains) are filled with a zeolite such as analcime in sample 810–403 (figs. 3 and 4; table 1). These observations mean that the grains acquired their clay rim after deposition and were subsequently compacted (probably by deep burial) before cementation by zeolite. The zeolite cement is a relatively late occurrence. Galloway (1974) suggested that these diagenetic changes could occur after 300 to 1200 m of burial. He showed that the surface coatings of authigenic clay were the result of mobilization of silica and aluminum from the volcanic debris.

The groundmass of dikes and sills is replaced by quartz, laumontite, analcime, stilpnomelane, albite, iron oxides, chlorite, illite, and calcite; calcite is the latest mineral. Minerals found in vesicles and amygdules suggest the following paragenetic sequence: quartz (occasionally replaced by laumontite), granular material (unidentifiable), analcime, phyllosilicates (stilpnomelane, chloride, celadonite, rarely vermiculite or hematite), laumontite, phyllosilicates again (minor), and rarely quartz, calcite, pyrite, or epidote. The filling of an amygdule may begin any place in this sequence, and four or five different minerals may occur in one amygdule. The granular material listed above is a very fine grained, high-relief, highly birefringent mineral that may be calcite or epidote. It occurs as a thin and at places discontinuous band separating the first and second minerals formed in the vesicles. Laumontite and terminated quartz crystals more than 2 cm long suggest that these minerals formed from hydrothermal solutions.

AGE

No fossils were recovered from the strata on Yakak Peninsula. From the lithologic composition, and degree of alteration and induration, we infer that these strata are probably temporal equivalents of the Andrew Lake Formation.

HYDROCARBON POTENTIAL

Four samples from the Wedge Point area (table 4) show consistently low values of total organic carbon and are not considered to be potential source rocks for petroleum. No organic residue for determination of vitrinite reflectance was removed from any of these samples.

FINGER BAY VOLCANICS

Coats (1956) and Fraser and Snyder (1959) described the Finger Bay Volcanics as pervasively altered to chlorite, albite, epidote, and silica. We examined two samples (803–101 and 805–101) of sandstone from the Finger Bay Volcanics (fig. 2; fig. 3, inset) for comparison with sedimentary rocks of the Andrew Lake Formation and of Yakak Peninsula.

Sample 803–101, collected from a quarry southeast of Andrew Lake, is a compact, poorly sorted feldspathic arenite. The main framework grain is plagioclase with accessory quartz, biotite, volcanic rock fragments, and chert. Silica and less abundant clays cement the rock. Abundant epidote, quartz, and actinolite-tremolite replace pyroxene (?) and feldspar grains and fill veins (table 1). Plagioclase is altered to albite. Chlorite, vermiculite, and hematite are less abundant secondary minerals.

Quartz sandstone, quartzite, and minor epidosite are found at Gannet Cove on the west coast of Adak Island (sample 805–101, fig. 3, inset). Quartz, epidote, and muscovite are secondary minerals that now compose the bulk of the rocks. Piemontite, calcite, chlorite, iron oxides, and illite are minor secondary minerals. Granular quartz and deeply corroded and replaced plagioclase are probably the only primary grains remaining. Faint structures are reminiscent of glass shards, collapsed pumice, and microfossils. Rare chlorite spherulites occur. Although the Finger Bay Volcanics is highly altered, it is not penetratively deformed. Open folds with dips generally less than 40° occur (Fraser and Snyder, 1959).

METAMORPHISM

Secondary mineral assemblages (Fraser and Snyder, 1959) suggest that the Finger Bay Volcanic~was subjected to regional greenschist-facies metamorphism. The diagnostic mineral assemblages range from actinolite- or tremolite-epidote-chlorite-albite-quartz to epidote-quartz-muscovite-chlorite-albite (table 1). Prehnite and pumpellyite mineral assemblages, indicative of lower temperature grades than actinolite-greenschist facies (Coombs, 1953; Seki, 1969, Coombs and others, 1970), appear in the Finger Bay Volcanics (Fraser and Snyder, 1959), although the reconaissance nature of the work by Fraser and Snyder precludes delineation of a coherent regional pattern of metamorphic facies. Certainly, the actinolite and epidote greenschist assemblages appear to be dominant on Adak Island.

It is not clear whether emplacement of granodiorite plutons contributed significantly to metamorphism (contact metamorphism) of the Finger Bay Volcanics or whether metamorphism was dominated by a regional thermal event. Fraser and Snyder (1959) described only a thin zone of contact-metamorphic hornfels adjacent to the plutons. It is worth noting, however, that although some outcrops of the Finger Bay Volcanics and the Andrew Lake Formation are equidistant from exposed plutonic rocks, these formations show significant differences in metamorphic mineral assemblages. More fieldwork is needed to fully distinguish regional patterns from contact metamorphism.

In contrast to the Finger Bay Volcanics, sedimentary and pyroclastic rocks on Yakak Peninsula and the Andrew Lake Formation at Andrew Lake have not been subjected to greenschist- or even zeolite-facies regional metamorphism. These rocks have been moderately altered by low-temperature supergene and hydrothermal processes of the zeolite facies and nowhere show greenschist-facies metamorphism. Thermal metamorphism associated with emplacement of dikes and sills, together with the supergene and hypogene mineralization, has created a complex milieu of secondary minerals.

AGE

Except for sedimentary rocks of the Andrew Lake Formation, Paleogene rocks of Adak Island are apparently devoid of fossils. Fossil findings indicate that the Andrew Lake Formation accumulated during the late Eocene (37.5–43 m.y. ago; Scholl and others, 1970; table 2). The Finger Bay Volcanics is estimated to be as old as the initial formation of the Aleutian ridge and no younger than the overlying Andrew Lake Formation. The Finger Bay Volcanics therefore formed sometime before the late Eocene (before about 40 m.y. ago) but probably after latest Cretaceous (about 65 m.y. ago) (Marlow and others, 1973; Scholl and others, 1975). The Finger Bay Volcanic~and associated sedimentary rocks evolved through a sequence of deposition, burial, regional greenschist-facies metamorphism, uplift, and erosion before the Andrew Lake Formation was deposited. We therefore favor an age representative of the older part of this (40–65 m.y.) timespan, perhaps late Paleocene or early Eocene (about 50 m.y. ago), but rocks may be as old as early Paleocene (60 m.y.). Certainly the episode of regional metamorphism must have ended at least 45 m.y. ago. Unfortunately, it may not be possible to obtain reliable radiometric dates from the Finger Bay Volcanic because of the thermal effects associated with the intrusion of plutonic rocks. The granodiorite on adjacent Kagalaska Island is Miocene (dated as 13.2 and 13.7 m.y.; Marlow and others, 1973; DeLong and others, 1978), approximately the same age as an andesite sill (table 3) cutting the Andrew Lake Formation, and is probably the same age as plutons on Adak.

Available published data (Fraser and Barnett, 1959; Powers and others, 1960; Lewis and others, 1960; Carr and others, 1970 and 1971; Gates and others, 1971) suggest that the oldest exposed rocks on the western Aleutian Islands (Attu, Agattu, Shemya, Amchitka, Rat, Amatignak, Ulak, Tanaga, Kanaga) have undergone variable but mild alteration. Variability of alteration, presence of fresh calcic plagioclase, only weakly altered volcanic glass, and the occurrence of a variety of temperature-sensitive zeolites argue against regional greenschist-facies metamorphisms of the exposed rocks on these islands. Accordingly, the Finger Bay Volcanics on Adak Island appears to be unique among the rocks that crop out on the western Aleutian Islands and may represent the oldest rocks described to date from these areas. Alternatively, the basement rocks of other Aleutian islands may be the same age as, but were not as deeply buried as the Finger Bay Volcanics on Adak Island.

DISCUSSION

PALEOCENE SEDIMENTATION

Fraser and Snyder (1959) estimated that the exposed section of the Finger Bay Volcanics includes about 70 percent pyroclastic, 20 percent flow, and 10 percent sedimentary rocks and that most of this 2400-m-thick section was deposited in a marine environment. We infer that this occurred in the late Paleocene or early Eocene. Coats (1956) provided evidence for a minimum thickness of about 600 m and speculated that the maximum is 4600 m. These observations suggest that the Finger Bay Volcanics is part of the initial series rocks, the Aleutian ridge basement complex (See Jake and White, 1969; Mitchell and Bell, 1973; Marlow and others, 1973.)

SOURCE OF SEDIMENT

The Finger Bay Volcanics was deposited and metamorphosed before deposition of the next recognizably younger strata, the Andrew Lake Formation. Probably by middle Eocene time, the growing Aleutian ridge had nearly reached sea level, and subaerial volcanoes contributed debris to surrounding basins. At times, the Finger Bay Volcanics may have contributed sediment to the Andrew Lake Formation, as clasts in some samples (samples 802–201, 802–202, table 1) are lithologically similar, but the overall amount of sediment derived from the Finger Bay Volcanics appears to be relatively small. The main source of Andrew Lake detritus was most likely contemporaneous volcanism. The host volcanic centers were eventually deeply eroded and perhaps in part covered by younger debris.

Because hydrothermal silicification of the Andrew Lake Formation was intense, it is difficult to identify the origin of the silica in the chert beds. It is not clear whether the silica in the chert-porcelanite section of the Andrew Lake Formation is released by the dissolution of siliceous biogenic debris, deposition from hydrothermal solutions, or both. Diatoms and minor radiolarians from the quartz chert occur in all states of preservation, from ghosts to specimens that retain frustule ornamentation. This suggests that at least part of the silica was derived from dissolution of siliceous microfossils. The calcite in this section is probably redeposited carbonate released when foraminifers were replaced by quartz.

DEPOSITIONAL BASIN

The dimensions of the depositional basin of the Andrew Lake Formation are not known. Scholl and others (1970) speculated that the Andrew Lake strata accumulated in a fairly deep (500 m) basin along an early Tertiary Aleutian ridge. If the Yakak Peninsula strata (Wedge Point) are temporally equivalent to the Andrew Lake Formation, then they possibly represent the subaerial and shallow-marine facies of the deeper water Andrew Lake strata. The basin seems to have been no deeper than 500 m (fossils suggest 200–500 m), a situation very much like the present Aleutian Islands and the adjacent 200-m-deep Aleutian ridge platform. We infer that these rocks were deposited on the subaerial flanks of a volcanic complex and in adjacent offshore shelf and slope environments. The presence of a small enclosed basin, one isolated from turbidity-current deposition, is evident in the laminated chert and porcelanite of the Andrew Lake Formation.

ALTERATION OF SEDIMENTARY ROCKS

Burial diagenesis, local thermal metamorphism by dikes and sills, and hydrothermal activity contributed to the alteration of Eocene rocks. Burial diagenesis was an important process in the early stages of alteration of these rocks, primarily because they contain a large fraction of unstable mafic to intermediate volcanic rock fragments. Burial caused the transformation of the glassy parts of volcanic rock fragments to clays. These structurally weak rock fragments, upon further burial, decomposed to form a sedimentary rock consisting of framework grains of plagioclase, pyroxene, and rock fragments in a clay matrix. All the original glass shards and glass globules were altered or replaced during burial.

After uplift and some erosion, two additional stages of alteration strongly affected the character of the sedimentary rocks:

1. Numerous late Tertiary dikes and sills intruded and thermally metamorphosed adjacent wallrock. Sedimentary rocks adjacent to dikes were baked, and locally epidote and prehnite formed. More commonly chlorite, hematite, quartz, and vermiculite mixed-layer clay phases formed next to dikes.
2. A more significant episode of alteration occurred in conjunction with the intrusion of Miocene plutonic rocks, when extensive formation of zeolites occurred.

Many observations favor hydrothermal fluids rather than zeolite-grade regional or burial metamorphism as the mechanism of alteration of the Andrew Lake and the Yakak Peninsula rocks:

1. At Andrew Lake, wairakite, the highest temperature zeolite, stratigraphically overlies laumontite and clinoptilolite, minerals characteristic of *a* relatively lower temperature metamorphic facies (Coombs, 1961; Harada, 1969; Seki and others, 1969).
2. Nonequilibrium mineral assemblages are common; for example, smectite is associated with laumontite. Low-temperature zeolites occur in close association with higher-temperature forms; for example, laumontite, clinoptilolite, and wairakite at Andrew Lake and laumontite, analcime, and yugawaralite at Wedge Point. (See Coombs and others, 1959; Seki, 1969; Kossovskaya, 1975.)
3. There is no apparent stratigraphic or spatial variation in the metamorphic grade of zeolites. The distribution of zeolites does not show zonal relations.
4. A wide variety of secondary minerals is associated with the zeolites.
5. Calcium zeolites (yugawaralite, laumontite, and wairakite) greatly predominate over sodium varieties (analcime; Kossovskaya, 1975).
6. Some crystals of quartz and laumontite are more than 2 cm long.

Less diagnostic but supporting evidence is that (1) ubiquitous quartz silicification suggests deposition from circulating hydrothermal fluids (Fournier, 1973; Coombs, and others, 1959), (2) mixed-layer clays, for example vermiculite-smectite-chlorite in our samples, commonly form in hydrothermal deposits (Bundy and Murray, 1959; Lovering and Shepard, 1960; Heystek, 1963; Steiner, 1968), (3) secondary mineral assemblages (except in the biogenic chert-porcelanite section) are independent of original rock type (Sigvaldason and White, 1961), and (4) reported occurrences of yugawaralite (and at most locations, wairakite) are from geothermal areas (Sakurai and Hayashi, 1952; Barrer and Marshall, 1965; Harada and others, 1969).

Hydrothermal solutions associated with emplacement of plutons and with the contemporaneous volcanic activity apparently permeated the Paleocene rocks and sealed any available pore space by deposition of secondary minerals. Rocks close to the main thoroughfares of circulating fluids were 50–75 percent replaced. Deposition of secondary minerals in vesicles probably resulted from several different passes of hydrothermal solutions during which time the temperature decreased and the chemistry of fluids changed. Analysis for iron yielded 3.8, 5.6, and 6.8 weight percent Fe for samples 810–201, 810–301, and 811–201b, respectively, values that are similar to those found for mafic and intermediate volcanic rocks (Turner and Verhoogen, 1960). Circulating fluids apparently did not add much iron to the system; rather, the iron in the volcanic rocks was mobilized to form iron oxides and hydroxides, chlorite, celadonite, and stilpnomelane. Alteration of plagioclase and ferromagnesian minerals and ions from the circulating hydrothermal solutions provided abundant calcium for formation of laumontite, yugawaralite, wairakite, and minor calcite. Solutions were silica saturated with respect to quartz. Eberlein and others (1971) stated that the conditions for yugawaralite formation include low fluid pressure, 200–300°C, and alkaline solutions with silica saturated with respect to quartz.

REGIONAL TECTONICS

In recent years, there has been much speculation about what effect the subduction of an active oceanic ridge (spreading center) has on an island-arc complex (for example, Atwater, 1970; Grow and Atwater, 1970; Uyeda and Miyashiro, 1974; DeLong and Fox, 1977; DeLong and others, 1978). It has been proposed by some workers (Atwater, 1970; Hayes and Pitman, 1970; Marlow and others, 1973; among others) that subduction of a ridge will terminate ridge spreading. Uyeda and Miyashiro (1974) believed that spreading can continue long after subduction of the spreading center. They also suggested that widespread volcanism accompanies subduction of ridges. Grow and Atwater (1970) equated middle and late Tertiary orogeny in the Aleutian Islands and Alaska to subduction of the Kula ridge beneath the Aleutian-Alaskan part of the North American plate. DeLong and others (1978) speculated that regional greenschist-facies metamorphism in the Aleutian Islands resulted from subduction of the Kula ridge beneath the Aleutian island arc.

By the interpretation of Grow and Atwater (1970) and DeLong and others (1978), the Kula ridge entered the Aleutian trench between 20 and 35 m.y. ago (favored age is 30 m.y.). Our results, however, suggest that the 30-m.y. K-Ar ages on which DeLong and McDowell (1975) and DeLong and others (1978) base their conclusions are initial cooling ages of Aleutian island volcanic rocks and not metamorphic ages. If ridge subduction produces an episode of regional lowgrade metamorphism, as DeLong and others speculate, then because the Andrew Lake and probably correlative sedimentary rocks on Adak Island are not regionally metamorphosed, subduction of the Kula ridge must have occured before the late Eocene, about 50 m.y. ago. Models for North Pacific plate motion allow subduction of the Kula ridge at 50 m.y. or 35 m.y. ago depending on whether relative motions have been discontinuous or continuous, respectively (Cooper and others, 1976, fig. 4). Although the plate models are approximations, there is increasing evidence of discontinuous motion with faster rates of convergence in early Cenozoic time and slower rates during the middle and late Cenozoic; this evidence, then, favors subduction of the Kula ridge 50 m.y. ago (Hayes and Pitman, 1970; Hein, 1973; Hamilton, 1973; Scholl and others, 1977; also, see Francheteau and others, 1970; Larson and Pitman, 1972). Therefore, evidence for the timing and the effects of ridge subduction as proposed by DeLong and others (1978) can be interpreted variously. More likely, early Tertiary (Paleocene or Eocene) metamorphism resulted from the depositional burial and tectonic uplift of more than 4000 m of volcanic and sedimentary rocks. Emplacement of plutonic rocks at depth during early development of the arc complex may have contributed to the observed metamorphism.

CONCLUDING REMARKS

We suggest that sedimentary and volcanogenic rocks in the Wedge Point area are temporally equivalent to the upper Eocene, Andrew Lake Formation. However, despite the similarity in lithologic composition, degree of alteration, and induration, age-diagnostic fossils must be found in rocks in the Wedge Point area to justify including them as part of the Andrew Lake Formation. These rocks accumulated approximately 40 m.y. ago on the flanks of an active volcanic complex. Subaerial and marine (maximum 200–500 m deep) rocks are represented. Deposits underwent burial diagenesis that significantly reduced porosity and produced authigenic clay minerals, iron oxides, and possibly quartz. Additional alteration occurred in conjunction with intrusion of sills, dikes, and especially granodiorite plutons. Secondary minerals formed during these late-stage thermal and hydrothermal events are primarily zeolites (yugawaralite, laumontite, analcime, wairakite), clays, iron oxides, and quartz. Most pore spaces that remained after burial diagenesis were filled during this episode, essentially eliminating any reservoir potential these strata may have had. Organic matter was either initially very low in these rocks, or if present was in places subsequently "cooked" by the heat of igneous intrusions. Consequently, these strata are unlikely sources of hydrocarbons.

The Finger Bay Volcanics was regionally metamorphosed to the greenschist facies some time before the late Eocene (possibly 50–55 m.y. ago). These rocks represent the oldest rocks exposed in the western Aleutian Islands. DeLong and McDowell (1975) and DeLong and others (1978) inferred from K-Ar ages that subduction of the Kula ridge spreading center resulted in a regional greenschist metamorphic event along the Aleutian are about 35 m.y. ago (Oligocene). The absence of regional metamorphism in the Andrew Lake Formation suggests other interpretations. If Adak is typical of other Aleutian islands, either the Kula ridge was subducted about 50 m.y. ago or greenschist metamorphism need not accompany subduction of a spreading center.

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