The Geology of North America
Vol. G-1, The Geology of Alaska
The Geological Society of America, 1994

Chapter 11

Geologic framework of the Aleutian arc, Alaska

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INTRODUCTION

The Aleutian arc is the arcuate arrangement of mountain ranges and flanking submerged margins that forms the northern rim of the Pacific Basin from the Kamchatka Peninsula (Russia) eastward more than 3,000 km to Cook Inlet (Fig. 1). It consists of two very different segments that meet near Unimak Pass: the Aleutian Ridge segment to the west and the Alaska Peninsula–Kodiak Island segment to the east. The Aleutian Ridge segment is a massive, mostly submerged cordillera that includes both the islands and the submerged pedestal from which they protrude. The Alaska Peninsula–Kodiak Island segment is composed of the Alaska Peninsula, its adjacent islands, and their continental and insular margins. The Bering Sea margin north of the Alaska Peninsula consists mostly of a wide continental shelf, some of which is underlain by rocks correlative with those on the Alaska Peninsula.

There is no pre-Eocene record in rocks of the Aleutian Ridge segment, whereas rare fragments of Paleozoic rocks and extensive outcrops of Mesozoic rocks occur on the Alaska Peninsula. Since the late Eocene, and possibly since the early Eocene, the two segments have evolved somewhat similarly. Major plutonic and volcanic episodes, however, are not synchronous. Furthermore, uplift of the Alaska Peninsula–Kodiak Island segment in late Cenozoic time was more extensive than uplift of the Aleutian Ridge segment. It is probable that tectonic regimes along the Aleutian arc varied during the Tertiary in response to such factors as the directions and rates of convergence, to bathymetry and age of the subducting Pacific Plate, and to the volume of sediment in the Aleutian Trench.

The Pacific and North American lithospheric plates converge along the inner wall of the Aleutian trench at about 85 to 90 mm/yr. Convergence is nearly at right angles along the Alaska Peninsula, but because of the arcuate shape of the Aleutian Ridge relative to the location of the plates' poles of rotation, the angle of convergence lessens to the west (Minster and Jordan, 1978). Along the central Aleutian Ridge, underthrusting is about 30° from normal to the volcanic axis. Motion between plates is approximately parallel along the western Aleutian Ridge.

In this paper we briefly describe and interpret the Cenozoic evolution of the Aleutian arc by focusing on the onshore and offshore geologic frameworks in four of its sectors, two sectors each from the Aleutian Ridge and Alaska Peninsula–Kodiak Island segments (Fig. 1). We compare the geologic evolution of the segments and comment on the implications of some new, previously unpublished data.

Sector 1, the Komandorsky (Russia)–Near Islands sector of the Aleutian Ridge segment, is an area along that part of the Pacific–North American plate boundary which has been virtually strike-slip in character since at least late middle Eocene time, when plate-direction and plate-velocity changes relative to the Hawaiian hot spot created the Emperor-Hawaiian seamount bend at about 43 Ma (Dalrymple and others, 1977; Clague, 1981). Sector 2, the Adak-Amlia sector, includes the large islands of Adak, Atka, and Amlia in the central Aleutians. Here, plate convergence is oblique. The third and fourth sectors constitute the Alaska Peninsula and its bordering islands. The Shumagin sector of the Alaska Peninsula, the third sector, is underthrusted by the Pacific Plate nearly normal to the arc's axis. The fourth, or Kodiak Island, sector on the east has been similarly underthrusted by the Pacific Plate.

Unpublished data incorporated in this chapter are mostly from the western part of the arc, where offshore studies in 1981 provided seismic-reflection profiles and other geophysical data, and onshore work in 1981 and 1983 yielded rock samples for stratigraphic and petrologic studies. In addition, GLORIA (Geological Long-Range Inclined Asdic) side-scan images were collected within the Exclusive Economic Zone (EEZ) of the entire arc during cruises in 1987 and 1988. Also collected during those latter cruises were single-channel seismic-reflection and bathymetric profiles, magnetics, and gravity data. Seismic-reflection

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Vallier, T. L., Scholl, D. W., Fisher, M. A., Bruns, T. R., Wilson, F. H., von Huene, R., and Stevenson, A. J., 1994, Geologic framework of the Aleutian arc, Alaska, *in* Plafker, G., and Berg, H. C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-1.

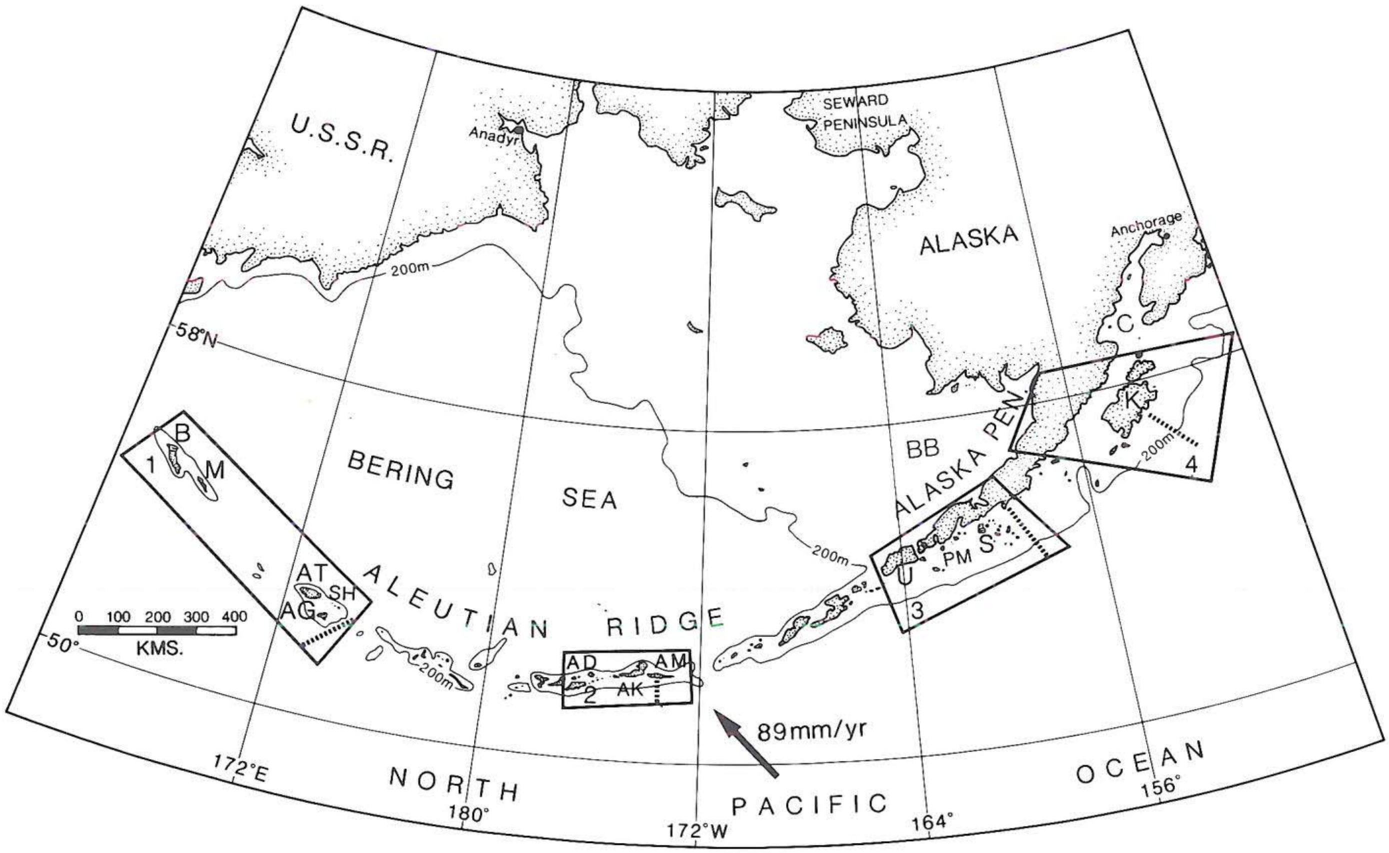


Figure 1. Index map of the North Pacific Ocean, Bering Sea, and Aleutian arc, with convergence direction (arrow) and rate shown for the central Aleutian Ridge segment (Engebretson and others, 1986). Outlined sectors: 1, Komandorsky–Near Islands sector; 2, Adak-Amlia sector; 3, Shumagin sector; and 4, Kodiak Island sector. The abbreviations (left to right) are B, Bering Island; M, Medny Island; AT, Attu Island; AG, Agattu Island; SH, Shemya Island; AD, Adak Island; AK, Atka Island; AM, Amlia Island; U, Unimak Island (Unimak Pass lies to the west of the island); BB, Bristol Bay; PM, Port Moller; S, Shumagin Islands; K, Kodiak Island; and C, Cook Inlet. Approximate locations of seismic-reflection profiles (Figs. 4, 6, 8, and 9) are shown as dashed lines within the outlined sectors.

profiles displayed in this paper were reduced photographically from migrated 24-channel records. We use the geologic time scale of Palmer (1983) throughout this chapter. Some previously unpublished stratigraphic and age data from the Alaska Peninsula also are incorporated in this chapter.

PREVIOUS STUDIES

The U.S. Geological Survey (USGS) Alaska Volcano Project focused attention on the Aleutian arc beginning in the late 1940s and continuing through the 1960s; results of those studies are published in USGS Bulletins (974 and 1028 series). Additional geologic studies preceded the nuclear tests on Amchitka Island in 1969 and 1971. In the Komandorsky Islands region, geological investigations of the major islands, Medny and Bering, were reported by Shmidt (1978) and Borsuk and Tsvetkov (1980). A regional geological and geophysical synthesis of onshore and offshore studies of the Bering Sea and Aleutian Ridge areas was written by Stone (1988).

The monumental work by Burk (1965) provided the first coherent summary of regional stratigraphy and structure of the Alaska Peninsula. Onshore studies (Fig. 2) of the Alaska Peninsula from the late 1960s to the present have been carried out in large part by several USGS geologists (e.g., Reed and Lanphere, 1969, 1973; McLean, 1979; Reed and others, 1983; Detterman and others, 1983, 1985; Detterman and Miller, 1985; Detterman, 1985, 1986; Detterman and others, 1990; Wilson, 1980, 1982, 1985; Wilson and others, 1981, 1985a, b). Stone and Packer (1977) provided important paleomagnetic data. Bordering islands, including the Kodiak and Sanak Islands, were studied by J. C. Moore and his colleagues at the University of California, Santa Cruz, and George Moore, Tor Nilsen, and others at the US Geological Survey (e.g., Moore, 1974a, b; Moore and others, 1983; Connelly, 1978; Moore, 1969; Nilsen and Moore, 1979; Nilsen and Zuffa, 1982). Particularly important to USGS studies on the Alaska Peninsula is the Alaska Mineral Resource Assessment Program (AMRAP), which began in 1974. Aleutian volcanoes have been studied during the past decade mostly by Robert Kay and Suzanne Kay and their associates at Cornell University (e.g., Kay and Kay, this volume), Thomas P. Miller at the USGS (Miller and Richter, this volume), and Bruce Marsh and his associates at Johns Hopkins University. James Myers at the University of Wyoming and James Brophy at the University of Indiana currently are studying several of the volcanoes.

Offshore geologic framework investigations along the Aleutian Ridge segment began in the early 1960s (Shor, 1964), continued with studies by Grow and Atwater (1970), the Deep Sea Drilling Project (Leg 19: Creager and others, 1973), and reached their most intense phase in the late 1970s and early 1980s when the USGS gathered multichannel seismic-reflection, seismic-refraction, gravity, and magnetic data, and rock samples (Scholl and others, 1975, 1983a, b, 1986, 1987; McCarthy and others, 1984; McCarthy and Scholl, 1985; Harbert and others, 1986; Geist and others, 1988; Ryan and Scholl, 1989). Lonsdale (1988) reported on the offshore region south of the Near Islands. Newly acquired GLORIA images and the associated geophysical data are increasing our knowledge and understanding of the Aleutian arc. Field studies complemented the offshore studies (Hein and McLean, 1980; McLean and others, 1983; Hein and others, 1984; Vallier and others, 1984).

Alaska Peninsula and Kodiak Island offshore geologic framework studies also began in the 1960s, were greatly enhanced by results from Leg 18 of the Deep Sea Drilling Project (Kulm and others, 1973), and reached their peak during the late 1970s and early 1980s. GLORIA images and associated geophysical data, collected in 1988 and 1989, are currently being studied. Interpretations of the offshore geology near Kodiak Island were given by Fisher (1980), Fisher and von Huene (1980, 1982, 1984), Fisher and others (1981, 1987), and von Huene and others (1979, 1985, 1987). Geological interpretations of the more westerly parts of the Alaska Peninsula offshore region near the Shumagin Islands were provided by Bruns and von Huene (1977), Bruns and others (1985, 1987a, b, c), and Lewis and others (1984, 1988).

GEOLOGIC FRAMEWORK OF THE ALEUTIAN RIDGE SEGMENT

Age and correlation

The Aleutian Ridge has been part of an active volcanic arc for at least 55 m.y. (Scholl and others, 1983a, b, 1986, 1987; Lonsdale, 1988; Ryan and Scholl, 1989). However, tectonic and igneous responses to subduction, as well as subduction rates and the process itself, have varied with time and location. Accordingly, large variations in lithofacies and structures are recorded in the rocks. Structural data from the islands are somewhat inconsistent because the ridge is segmented into discrete tectonic blocks, some of which have rotated (Harbert and Cox, 1984; Geist and others, 1988) in response to obliquely directed stresses that result from convergence of the Pacific and North American Plates.

A major problem in interpreting the Cenozoic evolution of the Aleutian Ridge is the lack of reliable age data. Although older rocks are typically more altered than younger rocks, compositions and stratigraphies are not reliable for correlation purposes; similar lithologies and stratigraphic sequences occur in rocks of all ages. Some specific factors that contribute to the correlation problems are (1) an abundance of unfossiliferous, coarse-grained volcaniclastic debris; (2) abrupt lithofacies changes; (3) a long time range over which many of the flora and fauna lived, thereby making the fossils of limited value for age determinations; and (4) the arc's complex igneous history, which thermally altered preexisting rocks, thereby destroying all but the most robust fossils and making K-Ar radiometric ages suspect, especially near plutons (Delong and McDowell, 1975).

Despite age and lithologic correlation problems, rock-stratigraphic units have been mapped on some islands of the Aleutian Ridge. Gates and others (1971), for example, described rock units on Attu and Agattu Islands. Shmidt (1978) mapped units on the Komandkorsky Islands and correlated them with lithologic units on other islands of the Aleutian Ridge.

In order to correlate onshore and offshore units, we follow the example of Marlow and others (1973) and Scholl and others (1975) who informally divided the rocks into chronostratigraphic units (early, middle, and late series), which subsequently were changed (Scholl and others, 1983a, b) to lower (LS), middle (MS), and upper (US) series (Fig. 2). Rocks of these series accumulated during time intervals (early, middle, and late series time) that are associated with the ridge's evolutionary stages; they are not related directly to lithology. By dividing the rocks into chronostratigraphic units, we can examine all the rocks deposited and magmatically emplaced within a specific time interval and thereby relate them to the evolution of the ridge. A major disadvantage in using chronostratigraphic units is that they are mappable only if their ages are known (as already noted, clues are not easily found). A notable advantage is that temporally related onshore and offshore rocks can be discussed together despite large lithologic differences.

The use of chronostratigraphic units (LS, MS, US) is amenable to both the islands and the offshore in the Aleutian Ridge segment, although the smaller offshore data base has produced reliable rock ages only in certain areas (Scholl and others, 1983a, 1987). Our chronostratigraphic division for the entire ridge is based mainly on the recognition of geophysically mapped offshore rock and sedimentary units in the Adak-Amlia sector of the Aleutian Ridge. The offshore lower, middle, and upper series are dated and correlated, in part, by tracing reflecting horizons on seismic-reflection profiles to onshore outcrops, and, in part, by data obtained from submarine outcrops and drilling (Scholl and others, 1983a). Onshore units, where undated, are separated by their relative amounts of alteration and deformation; LS rocks generally are more altered and deformed than younger rocks.

We assigned an age older than 37 Ma to LS rocks along the Aleutian Ridge. The 37-Ma age is based in part on our interpretation that the major building stage of the Aleutian Ridge was completed and voluminous and widespread igneous activity had greatly decreased by about that time (Scholl and others, 1987; Ryan and Scholl, 1989). Use of the 37-Ma age is strengthened by fossils in rocks from a dredge haul located at the base of MS rocks in the Adak-Amlia sector that have an age about the same as the Eocene-Oligocene boundary (Scholl and others, 1987). Deposition of these MS beds on older igneous masses of the LS occurred after igneous activity was more restricted along the ridge crest, thereby signaling the onset of the dominance of sedimentary processes over igneous processes on the ridge's crest and sloping flanks.

On the basis of island outcrops, the LS consists dominantly of flow, hypabyssal plutonic, and volcaniclastic rocks; rare are deep-seated plutonic rocks. Included in the LS, however, are rocks that may constitute a "basement" to the stratified rocks, such as the metamorphosed mafic plutonic suite that is exposed on Attu Island (Vallier and others, 1983). LS rocks are generally metamorphosed to greenschist (or albite-epidote hornfels), prehnite-pumpellyite, and zeolite facies. In places, the grade of metamorphism in LS rocks is directly related to the proximity of younger plutons.

Rocks from the LS offshore are generally characterized by coarse and laterally discontinuous acoustic layering. In many areas, a strong and irregular upper reflector is overlain by middle series strata that exhibit laterally continuous acoustic layering. In the Aleutian Ridge back-arc region, LS rocks merge acoustically with, or overlie, probable Cretaceous igneous oceanic crust; the boundary cannot be resolved on available seismic-reflection profiles.

MS rocks are assigned an age range of 37 to 5.3 Ma (Scholl and others, 1987). We base the younger age on physical evidence for accelerated deformation and igneous activity along the present ridge axis beginning in about the early Pliocene (or possibly the latest Miocene). Mostly for convenience we place the base of the US at the Miocene-Pliocene boundary, which is 5.3 Ma according to the time scale of Palmer (1983). Island exposures of MS strata include abundant volcanic flow and volcaniclastic rocks and common plutonic rocks. Many sills, dikes, and plugs and a

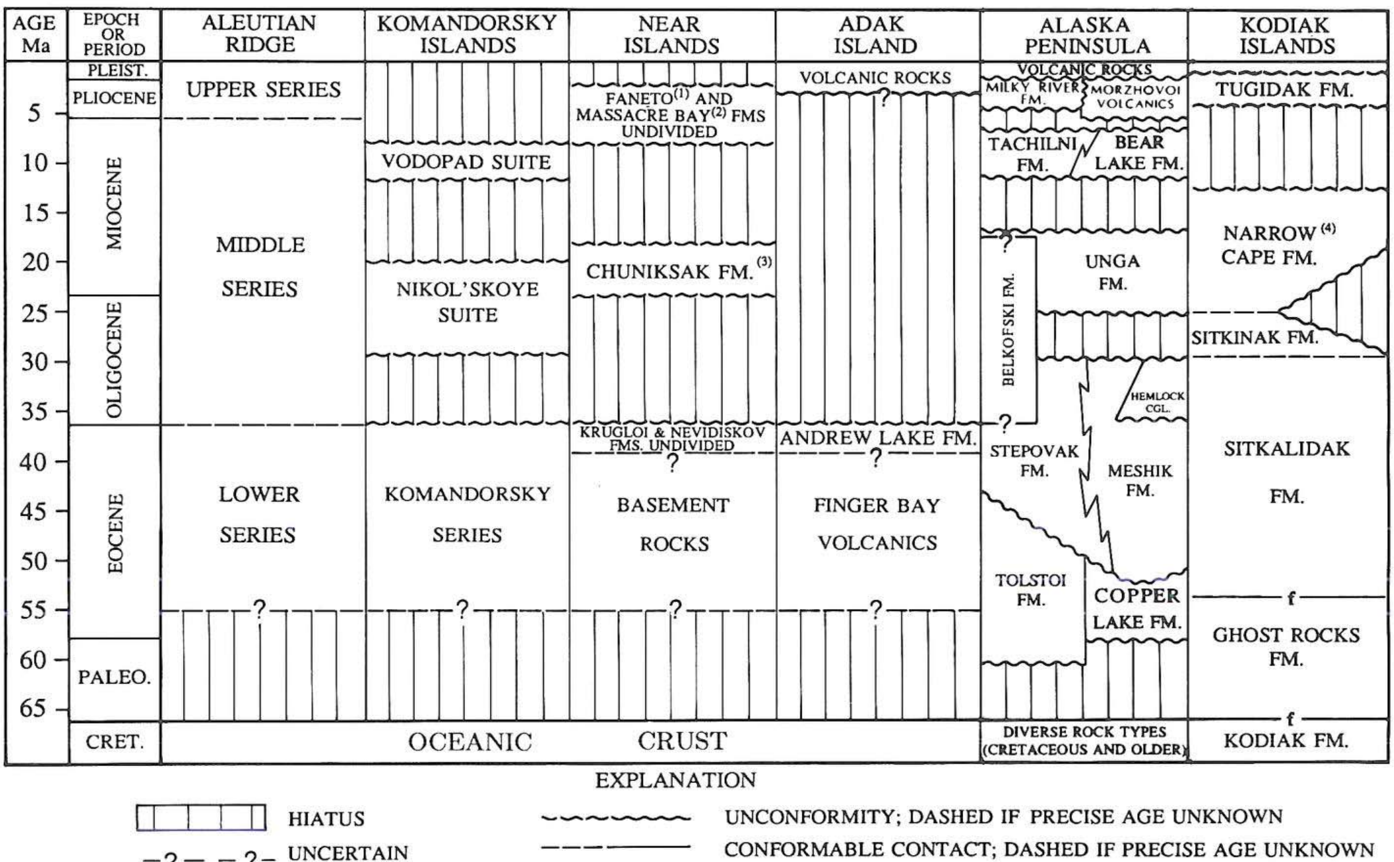


Figure 2. Correlation chart of Aleutian Ridge chronostratigraphic units and Upper Cretaceous and Tertiary rocks of the Alaska Peninsula and Kodiak Islands (compiled from Shmidt, 1978; Gates and others, 1971; Coats, 1956; Fraser and Snyder, 1959; Hein and McLean, 1980; Rubenstone, 1984; Detterman and others, 1990; G. Moore, 1969, and written communication, 1986). Time scale from Palmer (1983). Numbers signify the following: (1) age is late Tertiary or early Pleistocene; (2) age is Miocene; (3) age is Miocene (?); (4) age is late Oligocene(?) to middle Miocene.

relatively large pluton (Hidden Bay pluton on Adak Island) are of Oligocene (36 to 28 Ma) age and constitute an older plutonic phase of MS rocks (Citron and others, 1980; Pickthorn and Vallier, 1991). Large quartz diorite and granodiorite plutons, such as those exposed on Atka Island (Hein and others, 1984), constitute a younger plutonic phase and are of middle and early late Miocene (20 to 9 Ma) age (Pickthorn and others, 1984; Pickthorn and Vallier, 1991).

Middle series (MS) strata form an extensive sediment blanket on both fore-arc and back-arc slopes. Except in certain areas, the MS strata do not vary much in thickness; this indicates that slope basins were not subsiding rapidly and that, in general, local structural relief was not particularly great during the time of MS sediment deposition. Dip-slope sequences of MS strata are generally truncated along the outer edge of a very pronounced wave-planed surface of the summit platform.

Upper series (US) rocks and sediment accumulations formed approximately during the past 5.3 m.y. and include material not only from the latest stage of volcanism, but also most of the strata that fill offshore basins and mantle insular and continental slopes. These strata were deposited during a period of extensive ridge planation. Offshore, US accumulations fill fore-arc and summit basins, thinly mantle parts of the summit platform and sloping flanks of the ridge, and constitute most of the accretionary complex that underlies the landward slope of the trench. US sediments fill the Aleutian Trench.

Western Aleutian Ridge: Komandorsky–Near Islands sector

The geology of the Komandorsky Islands was reviewed by Shmidt (1978), and that of the Near Islands by Gates and others (1971), Delong and McDowell (1975), and Rubenstone (1984). Data from the corresponding offshore regions include single-channel seismic-reflection profiles and rock samples collected on a cruise of the R/V *Bartlett* (Buffington, 1973) and on Soviet cruises (e.g., Gnibidenko and others, 1980); on multichannel and single-channel seismic-reflection profiles, sonobuoy, magnetic, and gravity data collected during a 1981 cruise of the R/V *S.P. Lee* (Scholl and others, 1983a, b, 1987; McCarthy and Scholl, 1985; Ryan and Scholl, 1989); and on GLORIA side-scan images, single-channel seismic-reflection profiles, plus gravity and magnetic data collected on a cruise of the M/V *Farnella* in 1987 (unpublished).

Less than 100 km south of Attu Island the extinct Kula-Pacific Ridge intersects the Aleutian Trench (Lonsdale, 1988); a small fragment of the Kula Plate remains west of the Kula-Pacific Ridge and south of the trench. The south and west sides of the Kula Plate are terminated by Stalemate Ridge, a major transform fault that had separated Cretaceous crust of the Pacific Plate from early Tertiary crust of the Kula Plate during spreading along the Kula-Pacific Ridge. The axis of the Aleutian Trench is uplifted more than 1 km at the intersection of Stalemate Ridge and the trench. Stalemate Ridge has been partly responsible for extensive deformation along the inner trench wall of the western Aleutian Ridge as it moved westward along the arc during oblique convergence (Vallier and others, 1987).

Lower series. Rocks of the lower series (greater than 37 Ma) are well exposed on Bering and Medny Islands of the Komandorsky Islands group and on Agattu and Attu Islands of the Near Islands group (Figs. 2 and 3). The oldest unit on the Komandorsky Islands, the Komandorsky Series, is subdivided into four subunits (suites) of probable Eocene age (Shmidt, 1978). The Komandorsky Series is composed dominantly of volcaniclastic rocks and contains a relatively wide range of fossil marine faunas, including planktonic foraminifers. Radiometric ages of 35 to 28 Ma (K-Ar minimum ages of altered rocks) were obtained on samples of flows and small plutons in the Komandorsky Series (Borsuk and Tsvetkov, 1980; Pickthorn and Vallier, 1991).

On Attu Island (Fig. 3), metamorphosed mafic plutons (Vallier and others, 1983), volcanic and sedimentary rocks (the "basement rocks" unit of Gates and others, 1971), and the Chirikof and Nevidiskov Formations (Gates and others, 1971) are assigned to the lower series. LS rocks on Agattu Island consist of a "basement rocks" unit and the Krugloi Formation (Gates and others, 1971).

The mafic metaplutonic unit on Attu Island (Vallier and others, 1983), where mapped, is in fault contact with both the stratified "basement rock" unit of Gates and others (1971) and younger rocks. It consists of small stocks, sills, and dikes of metamorphosed gabbro, diorite, diabase, and basalt. It most likely is the pedestal upon which oldest stratified rocks were magmatically emplaced and deposited. Major minerals are plagioclase, blue-green amphibole, epidote, and iron-oxide minerals. The rocks have some trace-element characteristics of the island-arc tholeiite (IAT) magma series, with low TiO_2 values, flat rare-earth patterns (normalized to chondrite-element abundances), and low values of Ni, Co, and Cr. A high $^{143}Nd/^{144}Nd$ ratio, however, suggests a mid-ocean ridge basalt (MORB) or back-arc basin basalt (BABB) affinity of these rocks (James Rubenstone, written communication, 1988). Some of the metaplutonic rocks near faults have undergone variable penetrative deformation, and are now amphibolite, actinolite-plagioclase-quartz schist, and mylonite; most rocks, however, have retained their primary igneous textures. A K-Ar radiometric age of 41.5 ± 2 Ma was determined on mineral separates of blue-green amphibole (Vallier and others, 1983; Pickthorn and Vallier, 1991). That late Eocene age marks the time of metamorphism and not of igneous crystallization.

Rocks within the oldest stratified unit on Attu Island (the "basement rocks" unit of Gates and others, 1971), include volcanic flow rocks, volcaniclastic rocks, limestone, chert, and small hypabyssal plutonic rocks. Chemically analyzed volcanic rocks range in composition from basalt to rhyolite and have trace-element signatures of island arc tholeiite (IAT) magmas. Fossil nannoplankton specimens yield a "late Eocene–early Oligocene age" (David Bukry, written communication, 1983). The Chirikof Formation (Gates and others, 1971), based on our field mapping, may be a fine-grained facies of the "basement rocks" unit. The

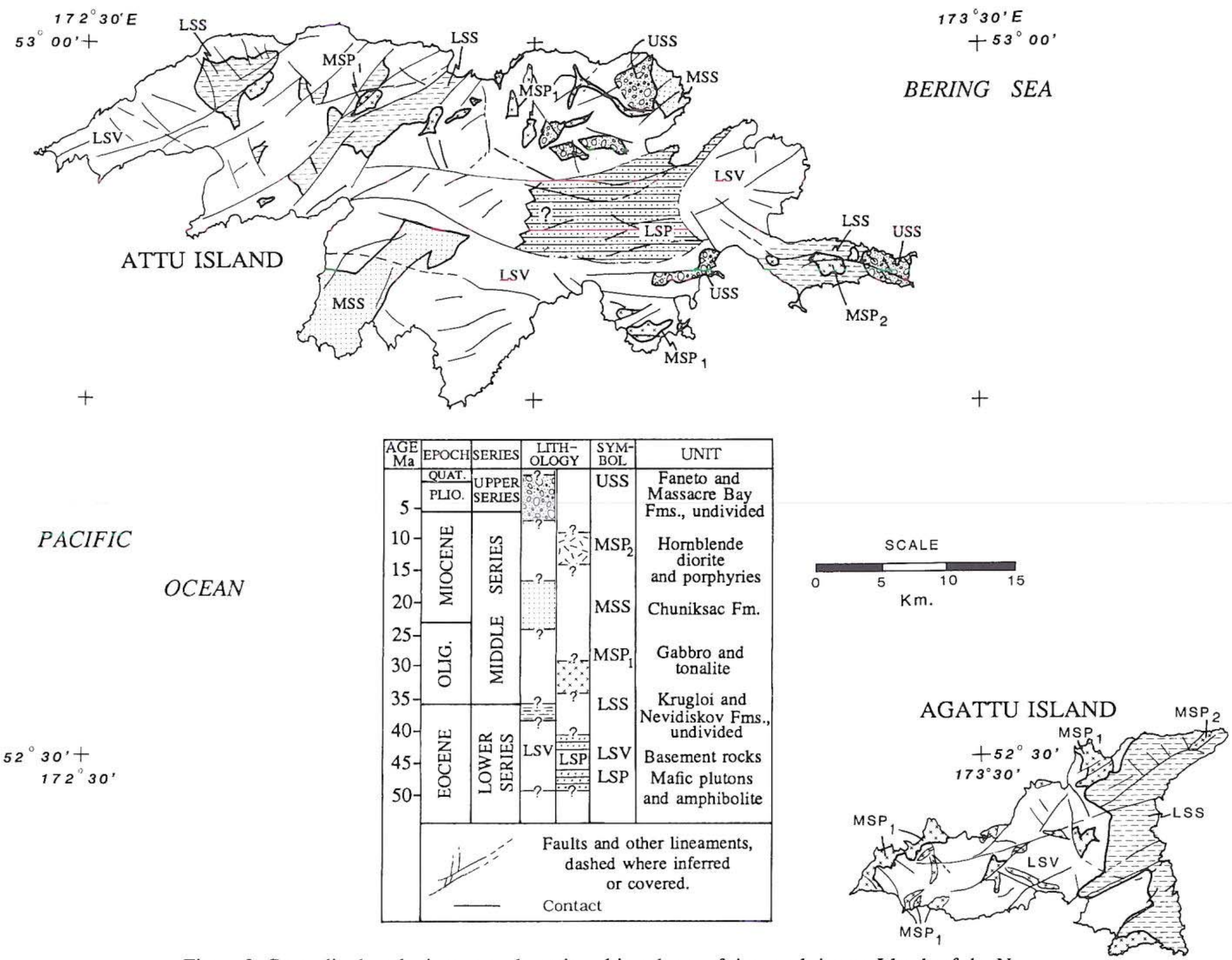


Figure 3. Generalized geologic map and stratigraphic column of Attu and Agattu Islands of the Near Islands group, sector 1 (modified from Gates and others, 1971).

Krugloi Formation on Agattu Island is well stratified and consists of flysch-like beds of sandstone, argillite, and limestone. Limestone samples within the unit have an age range of "middle Eocene to late Oligocene" based on very sparse fossil nannoplankton (Bukry, written communication, 1982). A 34-Ma K-Ar radiometric age (Pickthorn and Vallier, 1991), from altered quartz diorite that cuts the Krugloi Formation on Agattu Island, indicates that the Krugloi Formation is older than 34 Ma. The similarity between the Krugloi Formation on Agattu Island and Nevidiskov Formation (Gates and others, 1971) on Attu Island suggests that those two units are correlative.

Offshore, poorly stratified rocks of the LS underlie a prominent acoustic horizon that can be traced on a multichannel seismic profile from the summit platform seaward to an accretionary complex at the base of the inner trench wall (Fig. 4). LS rocks are truncated by the wave-cut surface of the summit platform, and can be acoustically traced northward across the insular slope, where they both merge with and overlie igneous oceanic crust.

Middle series. The middle series (Oligocene and Miocene; 37 to 5.3 Ma) rocks occur as flows, hypabyssal plutons, and volcaniclastic strata on both the Komandorsky and Near Islands groups. Offshore, on the Pacific flank of the Aleutian Ridge, the MS is characterized by relatively well-layered acoustic units (Fig. 4).

Middle series rocks on the Komandorsky Islands (Fig. 2) are the Nikol'skoye Suite, a unit that crops out mostly on Bering Island, and the Vodopad Suite of Medny Island (Shmidt, 1978). The Nikol'skoye Suite, of late Oligocene and early Miocene age, consists of flows and associated pyroclastic deposits, related volcaniclastic sedimentary rocks, conglomerate, and dolomite. Fossils include terrestrial plants and marine diatoms, mollusks, and foraminifers. Volcanic rocks of the Nikol'skoye Suite are alkalic

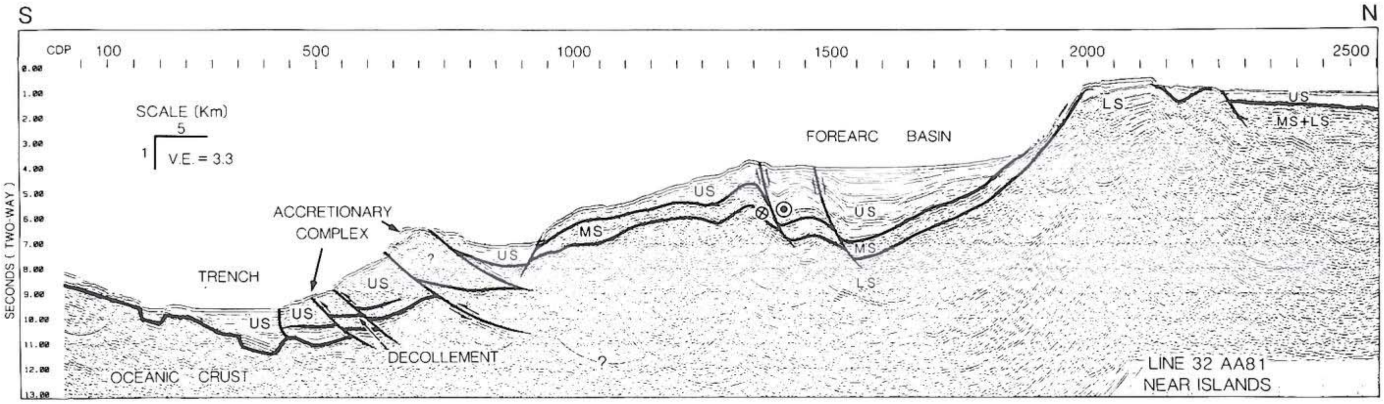


Figure 4. Migrated 24-channel seismic-reflection profile of Line 31 from the Near Islands region (see Fig. 1 for approximate location). Distance between common depth points (CDP) is about 50 m. The chronostratigraphic units are LS, lower series; MS, middle series; and US, upper series. Note the relatively small accretionary complex and the chaotic structure along the inner wall of the trench. Movement along some faults may be in part strike-slip; the fault that cuts the fore-arc basin shows suspected right-lateral displacement with circled dot (movement toward observer) and circled x (movement away from observer).

(Borsuk and Tsvetkov, 1980), as indicated by abundant ultramafic xenoliths in the basalt flows, mineralogy (titanoaugite, titanomagnetite, and barkevikite in the modes), and chemistry (relatively high Na_2O, K_2O, TiO_2, Ba, and Sr). Deeply eroded subaerial volcanoes on Medny Island make up the Vodopad Suite. The Vodopad Suite consists of lava flows and volcaniclastic rocks of basalt, andesite, and dacite compositions. Potassium-argon radiometric ages of Vodopad Suite rocks range from about 12 to 8 Ma (Borsuk and Tsvetkov, 1980; Pickthorn and Vallier, 1991).

Middle series strata on Attu Island are the Chuniksak and Massacre Bay Formations (Figs. 2 and 3). The Chuniksak Formation (Gates and others, 1971) consists of Miocene(?) siliceous fine-grained sedimentary rocks. The late Miocene (8 to 6 Ma) Massacre Bay Formation has andesitic and dacitic lavas, associated volcaniclastic sedimentary rocks, and a wide assortment of hypabyssal intrusive rocks (Gates and others, 1971; Delong and McDowell, 1975). Two major phases of MS plutonism are recognized on the Near Islands. The older phase, exposed both on Agattu and Attu Islands (Fig. 3), includes hypabyssal plutons of moderately altered gabbro, diorite, quartz diorite, and diabase. Whole-rock K-Ar radiometric ages range from about 34 to 28 Ma (Pickthorn and Vallier, 1991), indicating a probable Oligocene age of emplacement. Younger MS plutons, ranging in age from 15 to 11 Ma (Pickthorn and Vallier, 1991), are exposed on Shemya Island and along the northeastern coast of Agattu Island.

Offshore Attu and Agattu Islands, MS strata form a coherently layered and laterally continuous unit (Fig. 4). MS strata apparently mantled both the summit and the slopes of the western Aleutian Ridge before the formation of a fore-arc basin. Strata assigned to the MS are recognized beneath US strata in the fore-arc basin; they can be traced seaward on seismic-reflection profiles to the accretionary wedge. In general, acoustic layering of MS strata is not so regular and coherent as in the overlying US.

Upper series. Upper series (Pliocene and Quaternary; less than 5.3 Ma) rocks are not exposed in any large bodies on the Komandorsky Islands, but the Faneto Formation on Attu Island probably can be assigned to the upper series. The Faneto Formation is a thick sedimentary rock unit that was deposited in a fluvial environment. Gates and others (1971) stated that the age was uncertain because of an absence of fossils. However, because of the composition of the Faneto Formation, they assigned it to the late Tertiary or early Pleistocene and either syn– or post–Massacre Bay Formation in age. Based on our field work, we conclude that it is younger than the Massacre Bay Formation and assign it to the upper series (Fig. 3).

Upper series strata offshore the Near Islands are in places very thick and fill a series of discontinuous fore-arc basins (Karl and others, 1987; Vallier and others, 1987). Equivalent strata fill the Aleutian Trench (Fig. 4) and thinly mantle large parts of the summit platform. They also constitute most of the accretionary wedge that underlies the landward slope of the trench. US sediment packages are as thick as 3 km (2.8 sec) in the fore-arc basins and may be several kilometers thick in the structurally stacked accretionary wedge.

Central Aleutian Ridge: Adak-Amlia sector

Reviews of the geology of the central Aleutian Ridge in the Adak-Amlia sector are given by Marlow and others (1973), Hein and McLean (1980), Kay and others (1982), McLean and others (1983), Scholl and others (1983a, b; 1987), Hein and others (1984), Rubenstone (1984), McCarthy and others (1984), McCarthy and Scholl (1985), Geist and others (1988), Ryan and Scholl (1989), Fournelle and others (this volume), and Kay and Kay (this volume). Our offshore work in the central Aleutians was concentrated east of Adak Island near Amlia and Atka Islands (Fig. 1). New interpretations of the geologic evolution of the central Aleutian Ridge include the role of strike-slip faulting in the development of both summit and forearc basins and the tectonic rotation of discrete blocks along the ridge (Geist and others, 1988; Ryan and Scholl, 1989). Rocks on Adak Island (Fig. 5) are probably representative of the central Aleutian Ridge rock framework. All chronostratigraphic units are exposed on Adak Island.

Lower series (LS). The Finger Bay Volcanics, Finger Bay pluton, and Andrew Lake Formation on Adak Island (Coats, 1950, 1952, 1956; Fraser and Snyder, 1959; Scholl and others, 1970; Hein and McLean, 1980; Kay and others, 1982; Kay, 1983; Rubenstone, 1984) are all part of the lower series (Figs. 2 and 5). LS units constitute most of the rocks on Amlia Island and a large part of the flow and volcaniclastic rocks on southern Atka

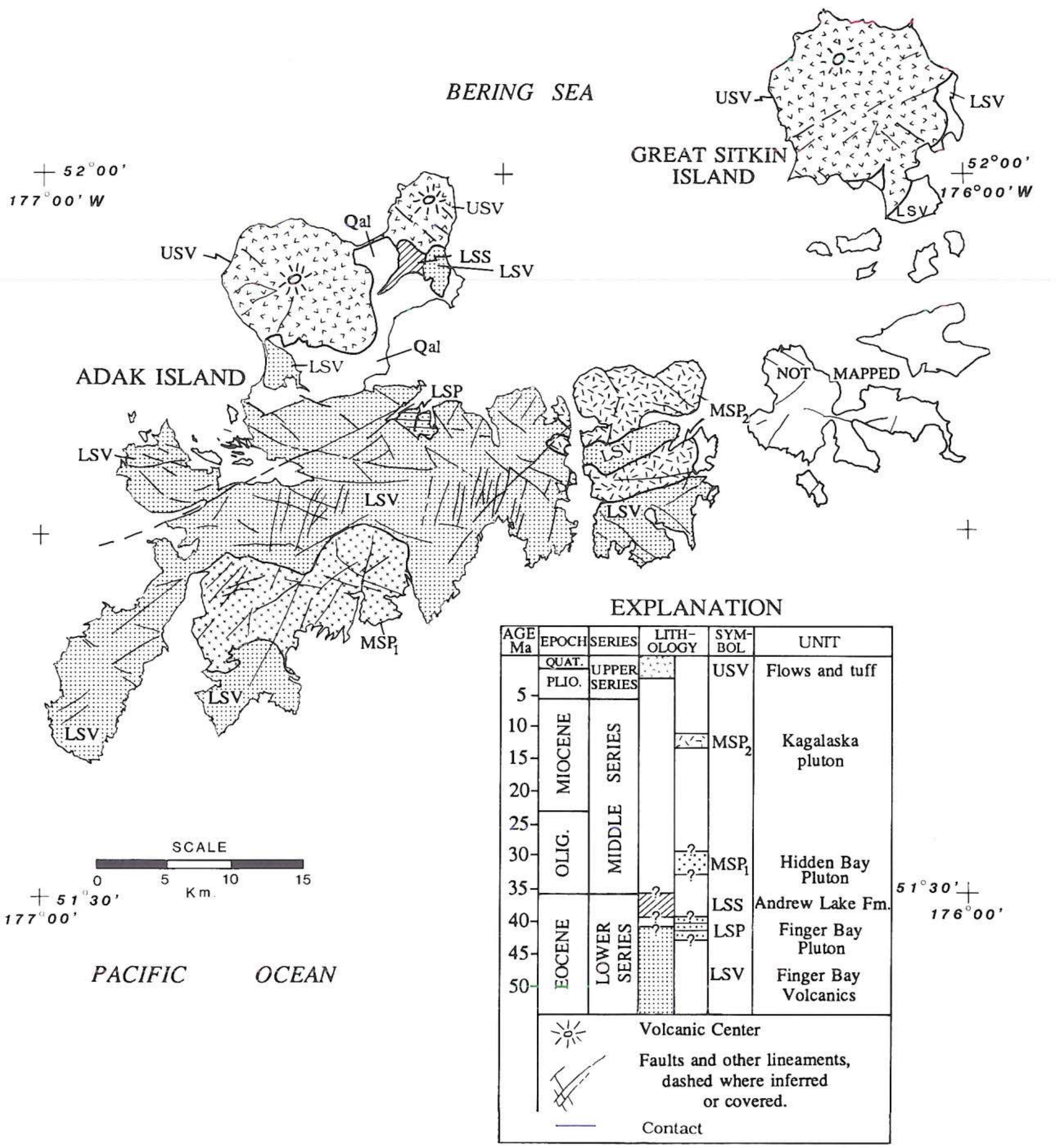


Figure 5. Generalized geologic map and stratigraphic column of Adak, Kagalaska, and Great Sitkin Islands, sector 2 (modified from Coats, 1950, 1956; Fraser and Snyder, 1959; Rubenstone, 1984).

Island (Hein and McLean, 1980; McLean and others, 1983; Hein and others, 1984).

Robust weather- and thermal-resistant fossil nannoplankton floras from calcareous rocks on Amlia Island have age ranges that extend from the "middle Eocene into the early Oligocene" (David Bukry, written communication, 1982). Somewhat altered (weathered and/or metamorphosed to the zeolite and prehnite-pumpellyite facies) gabbros and flow rocks have K-Ar radiometric ages of late Eocene (39.8 $\pm$ 1.2 Ma) and early Oligocene (32 $\pm$ 1 Ma) respectively; an altered rhyolite was dated at 24.5 $\pm$ 0.7 Ma (McLean and others, 1983). Based on the degree of alteration of radiometrically dated igneous rocks and ages of fossils in associated sedimentary rocks, we suspect that some K-Ar ages are too young and that the rocks are late Eocene and earliest(?) Oligocene in age. A $^{40}Ar/^{39}Ar$ radiometric age of about 50 Ma was determined on an altered flow rock from the Finger Bay Volcanics (Rubenstone, 1984), which suggests that rocks older than late Eocene may constitute parts of the lower series of the central Aleutian Ridge. In addition, a late Eocene faunal age is well established for the overlying(?) Andrew Lake Formation (Hein and McLean, 1980).

LS igneous rocks on islands of the Adak-Amlia sector have a broad range of compositions that are characteristic of an island-arc setting. Flow rocks of the Finger Bay Volcanics on Adak Island are calc-alkaline basalt and basaltic andesite (Rubenstone, 1984), whereas on Atka and Amlia Islands, compositions of flow rocks and hypabyssal plutonic rocks are tholeiitic, transitional, and calc-alkaline (Hein and others, 1984). Plutonic rocks of the lower series on Adak, Atka, and Amlia Islands are relatively small hypabyssal bodies of gabbro, diorite, diabase, monzodiorite, quartz diorite, and finer-grained porphyries of the same compositions (Kay and others, 1982; McLean and others, 1983; Hein and others, 1984). The Finger Bay pluton on Adak Island is the most thoroughly studied of the LS plutons (Kay, 1983; Kay and others, 1983).

LS sedimentary rocks on islands of the central Aleutians are dominantly coarse-grained volcaniclastic rocks. Finer-grained volcanic sandstone and siltstone are common components of the strata. Tuff and pyroclastic breccia are abundant locally, such as along the northeastern coast of Amlia Island, where a thick section of metamorphosed (prehnite-pumpellyite facies) silicic pyroclastic rocks is exposed.

Lower series strata offshore generally form a poorly reflective acoustic unit beneath an irregular, but persistent, strong reflector (Fig. 6; Scholl and others, 1983a, b, 1987; Ryan and Scholl, 1989). These massive accumulations form dip-slope sequences beneath the flanks of the arc. LS rocks are mostly submarine flows, hypabyssal plutons, and coarse-grained volcaniclastic rocks on islands near the ridge crest, but their lithologic characteristics are mostly unknown seaward. Based on the island outcrops and acoustic signatures of the oldest strata offshore, however, we suspect that similar rock types occur beneath the flanks of the arc.

Middle series (MS). MS rocks that crop out on large islands of the Adak-Amlia sector consist of plutons on Kagalaska and Adak Islands (Citron and others, 1980) and plutons, flows, and sedimentary rocks on Atka Island (Hein and others, 1984). On Adak and Kagalaska Islands (Fig. 5), both the Hidden Bay and Kagalaska plutons belong to the MS; K-Ar radiometric ages of about 36 to 31 Ma were determined on samples of the Hidden Bay pluton and about 14 to 12 Ma on samples from the Kagalaska pluton (Citron and others, 1980). Radiometric (K-Ar and U—Pb) ages of Tertiary plutons on Atka Island range from 24 to 9 Ma, with most dates falling in the 17- to 11-Ma interval; two flow rocks were dated at 12 to 11 Ma in the fossil-tree-bearing upper Miocene Martin Harbor section (Hein and others, 1984).

MS strata offshore form an extensive sediment blanket that drapes over the arc's Pacific (Fig. 6) and Bering Sea insular slopes. These strata unconformably overlie LS rocks in many areas and generally exhibit more coherent acoustic layering than the LS strata. MS strata are more deformed than US strata in most areas. The oldest MS sample dredged from offshore subma-

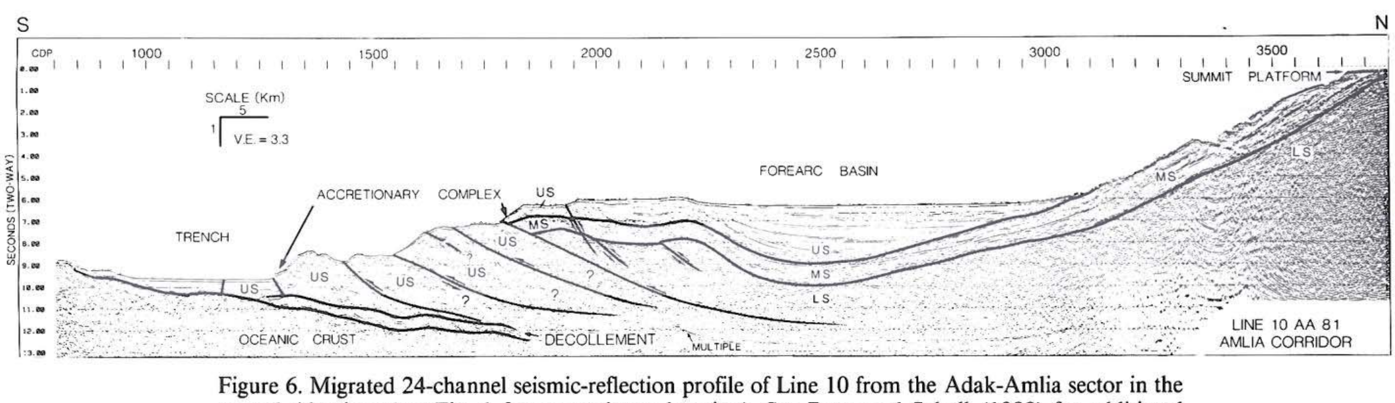


Figure 6. Migrated 24-channel seismic-reflection profile of Line 10 from the Adak-Amlia sector in the central Aleutians (see Fig. 1 for approximate location). See Ryan and Scholl (1989) for additional details of this seismic profile. Note the wide accretionary complex and the uplifted fore-arc basin sediments. Ryan and Scholl (1989) suspect that there has been some right-lateral strike-slip displacement (not shown on this profile) along a "backstop thrust" that separates the arc framework from the accretionary wedge.

rine outcrops is early Oligocene volcanic sandstone (Scholl and others, 1983a, b, 1987). The strata maintain a roughly uniform thickness beneath the fore-arc terrace (about 1.2 sec), and they can be traced seaward to the structural high that borders the seaward edge of the terrace.

Upper series (US). The Atka volcanic center (Marsh, 1976, and written communication, 1985) forms a large part of exposed US rocks on Atka Island. On Adak Island (Figs. 2 and 5), rocks of Pliocene and Quaternary age of the US include the volcanic flow and volcaniclastic rocks of Moffett and Adagdak volcanoes. Other active and dormant volcanoes in the Amlia-Adak sector (e.g., Seguam volcanic cones, Koniuji, Kasatochi, Great Sitkin, Kanaga, and Tanaga) are also part of the US.

Offshore, US strata are characterized acoustically by coherent and laterally continuous reflectors (Fig. 6). The strata typically are thin over the higher parts of the summit platform, but fill summit basins (i.e., Amukta and Amlia basins) to a thickness of 2 to 5 km (Scholl and others, 1983a; Geist and others, 1988). US strata also fill the fore-arc basin (Atka basin) beneath the Aleutian Terrace (Fig. 6) to a thickness of about 4 km and are uplifted across Hawley ridge, a prominent fore-arc structural antiform (Scholl and others, 1983a; Ryan and Scholl, 1989). US beds in Atka basin unconformably onlap south-dipping MS strata that underlie the arc's southern insular slope. In addition, equivalent sediment fills the Aleutian Trench to an average thickness of about 1.5 km (Fig. 6), but the trench fill is as thick as 3 to 4 km a short distance away near the intersection of the trench and the Amlia Fracture Zone at about 173° W (Scholl and others, 1982). US strata constitute the bulk of the accretionary complex, which is 6 to 8 km thick (4.6 sec.) along Line 10 (Fig. 6); the age of these offscraped deposits is poorly known, but based on regional relations, they are interpreted to be latest Miocene or Pliocene and younger (McCarthy and Scholl, 1985; Scholl and others, 1987; Ryan and Scholl, 1989).

GEOLOGIC FRAMEWORK OF THE ALASKA PENINSULA-KODIAK ISLAND SEGMENT

Age and correlation

The Alaska Peninsula and adjacent islands are composed predominantly of northeast-trending rock masses ranging in age from Permian to Holocene (Burk, 1965; Moore, 1974b; von Huene and others, 1979, 1987; Detterman and Reed, 1980; Detterman and others, 1981, 1983; Detterman, 1985; Wilson and others, 1985a; Fisher and others, 1987; Bruns and others, 1987b; Detterman and others, 1994). A complete discussion of the pre-Cenozoic rocks is beyond the purpose of this chapter; the most up-to-date review is given by Detterman and others (1994). Exposed rocks on the Alaska Peninsula, northern part of Kodiak Island, and inner Shumagin Islands include mostly arc-related Paleozoic to Holocene volcanic and plutonic rocks as well as shallow marine and continental deposits rich in volcanic and plutonic detritus (Fig. 7). In contrast, most rocks on the islands of Sanak, outer Shumagin, and the southern part of Kodiak are thick, flysch-like deposits of Late Cretaceous and Paleogene ages. The Cretaceous strata are intruded by Paleocene (about 60 Ma) plutons.

An understanding of the geologic evolution of the Alaska Peninsula and companion island groups was enhanced by the recognition of discrete, fault-bounded tectonostratigraphic terranes (e.g., Stone and Packer, 1977; Berg and others, 1978; Jones and others, 1981; Plumley and others, 1983; Silberling and others, this volume). In the study area, these terranes—initially named the Peninsular, Chugach, and Prince William terranes by Jones and Silberling (1979)—are believed to be allochthonous to southern Alaska (Hillhouse, 1987; Hillhouse and Coe, this volume). The Peninsular terrane was renamed Alaska Peninsula terrane by Wilson and others (1985a) who subdivided it into Iliamna and Chignik subterranes (Wilson and others, 1985a).

In this paper we refer to the Chugach and Prince William terranes south of the Alaska Peninsula as the Chugach–Prince William terrane. The contact between the mostly shallow-marine and continental rocks of the Alaska Peninsula terrane and the deep-water Shumagin and Kodiak Formations of the Chugach–Prince William terrane is the Border Ranges fault (Plafker and others, 1977; Plafker and others, this volume, Chapter 12; Fisher and von Huene, 1984). This structure is inferred (Fig. 7) to strike southwest and to lie between the inner and outer Shumagin Islands. Wilson and others (1985b) suggested that the Border Ranges fault in the Port Moller area may lie instead along the south coast of the Alaska Peninsula.

Western Alaska Peninsula: Shumagin sector

Onshore Shumagin sector. Stratigraphy of Cenozoic rock units on the Alaska Peninsula was discussed by Burk (1965), McLean (1979), Wilson (1980, 1985), Wilson and others (1981, 1985b), Detterman (1985), Detterman and Reed (1980), Detterman and others (1981, 1983, 1985), and Detterman and Miller (1985). Revisions in stratigraphic nomenclature, ages, and geologic interpretations will continue as work progresses. Detterman (1985) and his co-workers (Detterman and others, 1994), for example, have modified some stratigraphic and age assignments, and we use them in this short review (Fig. 2).

Five major stratigraphic packages of Cenozoic age are recognized on the Alaska Peninsula. The oldest consists of the Paleocene and Eocene Tolstoi and Copper Lake Formations, which unconformably overlie Upper Jurassic to Upper Cretaceous rocks; these early Tertiary formations consist predominantly of nonmarine, volcaniclastic, and carbonaceous sedimentary rocks. In places, the Tolstoi Formation is as thick as 1,500 m.

Unconformably overlying the Tolstoi and Copper Lake Formations, and making up the second package, are the Stepovak Formation and Meshik Volcanics of late Eocene and early Oligocene age and correlative volcanic rocks in the Katmai region and the informally defined Popof volcanic rocks of the Shumagin Islands (Fig. 2). These constitute most of the Meshik arc as defined by Wilson (1985). The Stepovak Formation consists mostly of arc-related sedimentary rocks, whereas the Meshik Volcanics are composed of a full range of volcanic rocks, including abun-

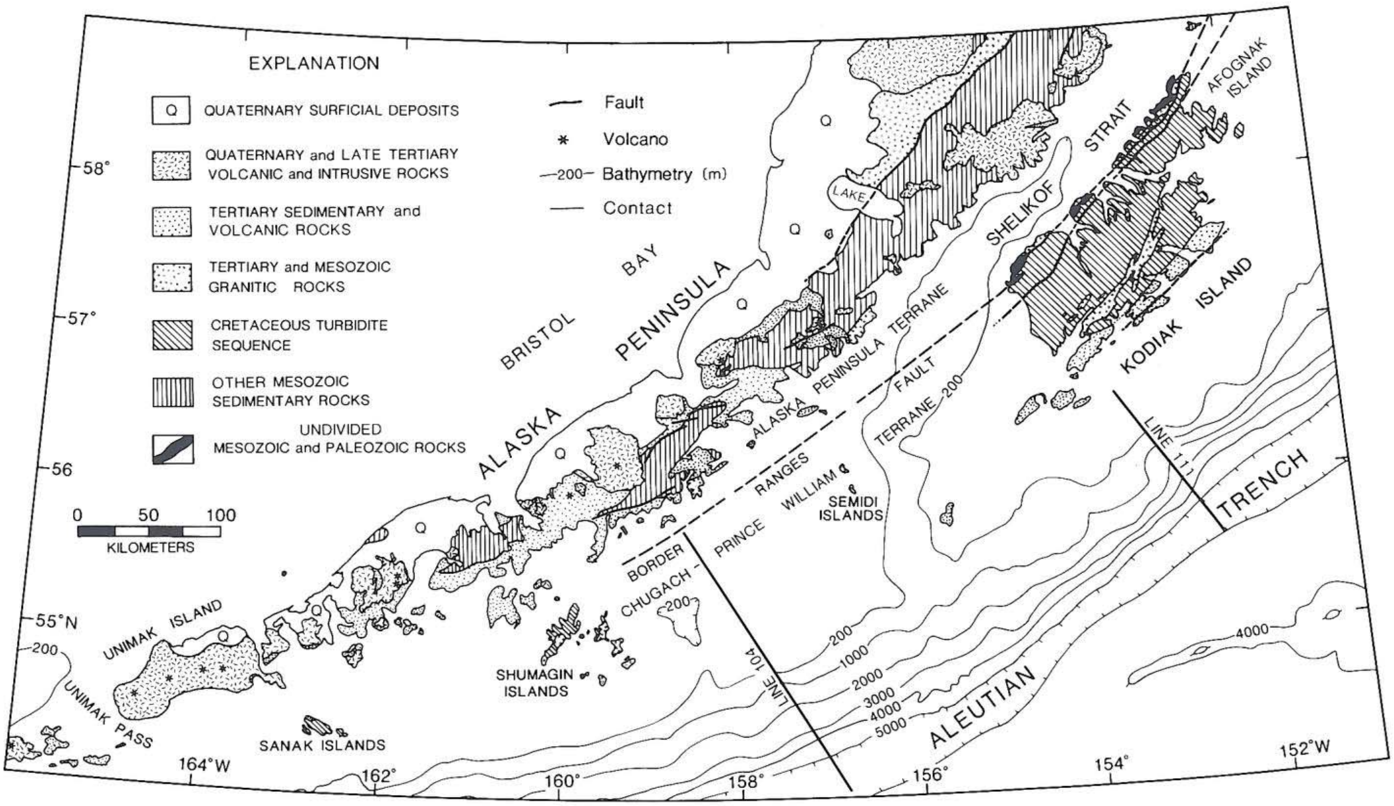


Figure 7 Generalized geologic map of the Alaska Peninsula, Kodiak Island, and adjacent island groups, sectors 3 and 4 (modified from Beikman, this volume; Bruns and others, 1985). Approximate locations of Lines 104 (Fig. 8) and 111 (Fig. 9) are shown.

dant andesite and dacite, along with their associated volcaniclastic rocks. A third package is the Oligocene and lower Miocene Belkofski Formation, the early Oligocene Hemlock Conglomerate, and the late Oligocene and early Miocene Unga Formation. The preferred interpretation is that the Unga and Belkofski Formations are at least in part correlative. The fourth package is the unconformably overlying upper Miocene Tachilni and Bear Lake Formations. These two formations were shown by Marincovich (1983) to be correlative. They consist of shallow-water marine and nonmarine units including sandstone, conglomerate, siltstone, shale, and thin coal beds. The Pliocene Milky River Formation and Morzhovoi Volcanics unconformably overlie the Bear Lake and Tachilni Formations. These units, as well as the unnamed Pliocene and Quaternary rocks and sediments, are the youngest in the region and constitute the fifth stratigraphic package of Cenozoic age.

The Upper Cretaceous Shumagin Formation is exposed on the outer islands of the Shumagin sector and is the major stratigraphic unit of the Chugach–Prince William terrane. These deep-water sedimentary rocks, and those of the partly equivalent Kodiak Formation, were probably deposited in slope basins and/or a trench (Moore, 1974a; Nilsen and Moore, 1979; Nilsen and Zuffa, 1982). Upper Cretaceous flysch-like rocks mapped on the Alaska Peninsula, the Kaguyak Formation in the Katmai region, and the Hoodoo Formation in the Port Moller area, are equivalent in age and lithologically similar to the Shumagin and Kodiak Formations (Detterman and Miller, 1985).

Igneous activity on the Alaska Peninsula was discussed by Reed and Lanphere (1969, 1973) for the plutons east of the Shumagin sector and by Wilson and others (1981) and Wilson (1985) for the volcanic rocks. Reed and Lanphere (1973) concluded that Jurassic plutons, ranging in age from about 175 to 155 Ma, compose most of the Alaska-Aleutian Range batholith. In addition, another period of plutonism occurred nearly continuously beginning in the Late Cretaceous, about 74 Ma, and ending in the early Tertiary, about 58 Ma and possibly as late as 55 Ma. In the Meshik arc (Wilson, 1985), ages of the volcanic flows and associated hypabyssal plutons range from 48 to 22 Ma; most fall within the interval from 40 to 30 Ma. Ages of volcanic rocks that make up the present regime on the Alaska Peninsula range in age from about 10 Ma (possibly as old as 15 Ma) to the present (Wilson and others, 1981; Wilson, 1982; Wilson and others, this volume).

Offshore Shumagin sector. The Shumagin margin (Bruns and others, 1985, 1987a, b, c; Lewis and others, 1988) has five major structural elements: (1) Shumagin basin, (2) Sanak basin,

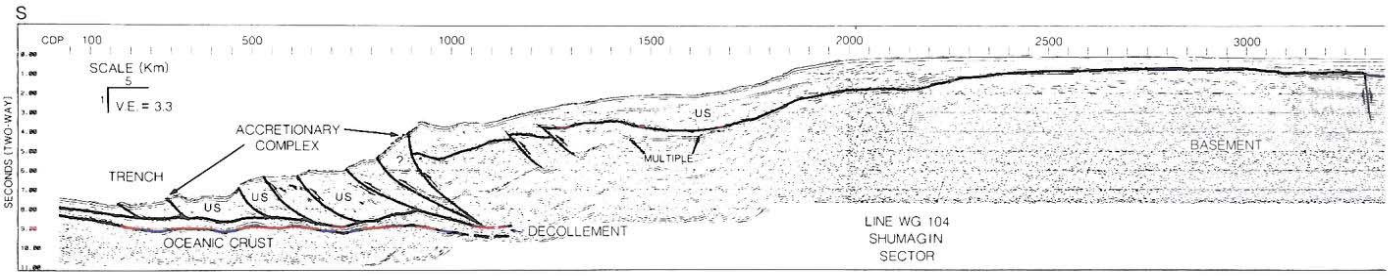


Figure 8. Migrated 24-channel seismic-reflection profile of Line 104 of the Shumagin sector. See Bruns and others (1987a, b) for additional interpretations on the region. The upper series (US) is the only chronostratigraphic unit shown; older units are difficult to correlate with Aleutian Ridge units. Note the thick upper series sequences and the wide accretionary complex.

(3) shelf edge and upper slope sedimentary wedges, (4) a mid-slope structural trend that includes Unimak ridge, and (5) a lower-slope accretionary complex. A multichannel seismic-reflection profile that crosses the margin near the Shumagin Islands, reveals a 35-km-wide accretionary complex beneath the landward trench slope and a sediment-filled Shumagin basin beneath the shelf (Fig. 8).

The difficulty in correlating chronostratigraphic units of the Aleutian Ridge with units of the Alaska Peninsula and Kodiak Island is their very different pre-Eocene histories. Furthermore, very few submarine outcrops have been sampled for age determinations. Therefore, only the upper series and "basement" designations are used for offshore regions of the Alaska Peninsula–Kodiak Island segment in the figures, where "basement" refers to acoustic basement and may be of any age older than late Cenozoic (e.g., probably late Miocene or Pliocene).

Shumagin basin (Fig. 8) has a relatively thin (about 2.5 km) sediment fill, whereas the sediment fill of nearby Sanak basin is as thick as 8 km (Bruns and others, 1985, 1987a, b). These basin-filling sedimentary units possibly include rocks as old as Oligocene, but most are probably of latest Miocene to Holocene age. They overlie an acoustic basement that probably consists of the same rock assemblages that compose older parts of the Chugach–Prince William terrane onshore. The sedimentary cover that drapes the shelf edge and upper slope ranges in thickness from 2 to 4 km; seismic-refraction data suggest that the thickness locally may be as great as 6 km.

An accretionary complex on the lower slope is nearly 35 km wide and several kilometers thick (Fig. 8). A decollement at the base of the accretionary complex can be traced for the entire width of the accretionary complex and, in places, for an additional 10 km beneath the margin's bedrock framework. We believe that most sediment in the accretionary complex is of Pliocene and Quaternary age.

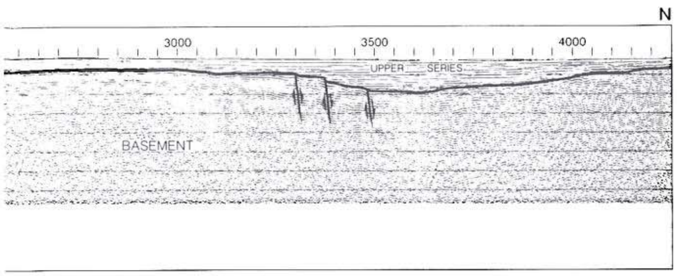
Geophysical and regional geological studies indicate that the offshore structural fabric swings northwestward from the Sanak Islands region and merges with the outer part of the Beringian margin (Pratt and others, 1972; Lewis and others, 1984, 1988). This structural continuity strengthens the hypothesis that there was a tectonic link between the Alaska Peninsula and the Beringian margin before the growth of the Aleutian Ridge.

Eastern Alaska Peninsula: Kodiak Island sector

Onshore Kodiak Island sectors. The Kodiak Island sector (Fig. 7) includes parts of both the Alaska Peninsula and Chugach–Prince William terranes and has a relatively well known, though complex, geologic history (Moore, 1969; Reed and Lanphere, 1973; Connelly, 1978; Reed and others, 1983; Wilson and others, 1985a, von Huene and others, 1985, 1987; Fisher and others, 1987; Detterman and others, 1994). The Alaska Peninsula terrane portion of the sector is divided into the Chignik and the Iliamna subterranes by the Bruin Bay fault. On Kodiak Island the Alaska Peninsula and Chugach–Prince William terranes are separated by the Border Ranges fault.

Isolated exposures of possibly early Mesozoic and Paleozoic(?) quartzite, greenstone and other metavolcanic rocks, schist, and Triassic(?) limestone that occur as roof pendants in the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973) in the Iliamna subterrane may be the oldest rocks of the Alaska Peninsula terrane. In the Chignik subterrane, Triassic volcanic rocks and a sequence of Permian to Late Cretaceous arc-derived sedimentary units occur in the Kodiak Island sector. A small part of the Alaska Peninsula terrane is also exposed on the northwest coasts of the Kodiak Island group; it consists of a complex assemblage of Late Triassic volcanic rocks, Early Jurassic schist, and Early Jurassic diorite and quartz diorite plutons. A plausible explanation for geologic relations in the Kodiak Islands is that the Chignik subterrane and rocks of the Alaska Peninsula terrane represent a back-arc region of the Iliamna subterrane Jurassic magmatic arc. This arc may have been constructed on the Wrangellia terrane (Jones and others, 1977); the Triassic and Permian rocks of the Chignik subterrane correlate well with Wrangellia rocks of the same age.

Tertiary rocks overlying the Alaska Peninsula terrane in the Kodiak Island sector are much thinner than in the Shumagin sector. The Copper Lake Formation in the Katmai area has a total thickness of about 1,000 m and consists of thick conglomer-



ate at the top and bottom and sandstone and siltstone with considerable carbonaceous debris and minor coal in the middle. Fossil megaflora suggest an age of early Eocene for the Copper Lake Formation, approximately the same as the Tolstoi Formation on the southern part of the Alaska Peninsula. The Copper Lake Formation, like the Tolstoi Formation, is dominantly nonmarine with some nearshore marine beds. The overlying Hemlock Conglomerate is a fluvial sandstone and conglomerate with interbedded siltstone, shale, and coal of presumably early Oligocene age on the basis of megaflora. The Hemlock Conglomerate was largely derived from erosion of Mesozoic sedimentary and granitic rocks; the proportion of volcanic debris in the unit increases southward toward the Katmai area.

Southwest of the Alaska Peninsula terrane, the combined Chugach–Prince William terrane rims the entire south side of the Alaska Peninsula. It is composed of Late Cretaceous and early Tertiary subduction complexes. The dominant geologic units are the Kodiak (Moore, 1969) and Shumagin (Moore, 1974b) Formations that consist of Cretaceous flysch. The Uyak Complex (Connelly, 1978), bounded on the northwest by the Border Ranges fault, structurally overlies the flysch unit on Kodiak, Afognak, and nearby islands. The Uyak Complex is a chaotic melange-like unit consisting of blocks of sandstone, greenstone, radiolarian chert, and limestone in a chert and argillite matrix. Early Tertiary granitic plutons (63 to 58 Ma; Wilson and others, this volume) intrude the flysch.

Nearer the Aleutian trench, the Ghost Rocks and Sitkalidak Formations (Moore, 1969; Nilsen and Moore, 1979) of Paleocene to Oligocene age may form a similar subduction complex, which is equivalent to the Orca Group of Prince William Sound. The Ghost Rocks Formation is an isoclinally folded, faulted, and sheared unit that is distinguished by its pillow basalt or greenstone, hard and black claystone, thin limestone beds, and locally prominent zeolite-bearing tuffaceous sandstone. It is lithologically similar to the Uyak Complex more so than to the structurally adjacent Kodiak Formation. The Sitalidak Formation, according to Moore (1969, p. 32), is ". . . a rather uniform sequence of sandstone and siltstone graded beds about 3,000 m thick . . ." and has many lithologic characteristics similar to the Kodiak Formation.

Overlap sequences of the Chugach–Prince William terrane are the Sitkinak, Narrow Cape, and Tugidak Formations of the Kodiak Islands. The Sitkinak Formation, of middle or late Oligocene age, stratigraphically overlies the Sitkalidak Formation. The Sitkinak Formation consists of 1,500 m of dominantly nonmarine coal-bearing siltstone, sandstone, and conglomerate and lesser amounts of marine sandstone and siltstone. The late Oligocene and Miocene Narrow Cape Formation is a richly fossiliferous marine sandstone and siltstone unit 700 m thick that conformably overlies the Sitkinak Formation. Its rocks record a quiet shallow marine environment. The youngest rock unit in the Kodiak Island sector is the Tugidak Formation. It consists of 1,500 m of richly fossiliferous Pliocene sandstone and siltstone with randomly distributed pebbles and cobbles. Correlation with the Yakataga Formation by Moore (1969) suggests by inference that the Tugidak Formation was deposited in a glaciomarine environment (Molnia, 1986).

Offshore Kodiak Island sector. The offshore deep-water (more than 1 sec water depth) framework of the Kodiak Island sector, in part shown in Figure 9, is well documented by several profiles shown in von Huene and others (1987). The older rocks have been deformed, and large structures (e.g., Albatross bank; not shown on Fig. 9) underlie extensive bathymetric highs.

Few rock samples have been collected from the submerged parts of the margin, although upper Miocene through Quaternary rocks and sediments were recovered from the top of Albatross bank. From studies of the seismic stratigraphy and drill hole data, the fill in Albatross Basin (a shelf basin) is considered to be late Miocene and younger in age (Fisher and von Huene, 1980; von Huene and others, 1987; Fisher and others, 1987) and to overlie a regional unconformity similar to that in the Shumagin sector. The nature of the underlying rocks can be interpreted from outcrops on Kodiak Island and from drill-hole samples. A drill hole near the shelf edge north of the Kodiak Island sector, near Middleton Island, which is located about 150 km northeast of Kodiak Island, penetrated this regional unconformity and bottomed in lower Eocene rocks (Rau and others, 1977; Keller and others, 1984); a drill hole near the edge of the shelf on the flank of Albatross bank bottomed in rocks of Eocene age (Herrera, 1978). The Middleton Island drill hole has sedimentary rocks and sediment of late middle Eocene (42 to 40 Ma), late Eocene and early Oligocene (38 to 34 Ma), early Miocene (23 to 22 Ma), and late Miocene to Pleistocene (younger than 6 Ma) ages (Keller and others, 1984). Structural variations within the Chugach–Prince Williams terrane and the distance between the Middleton Island well and the Kodiak Island sector suggest, however, that correlations between the two areas remain tentative.

The lower slope of the margin is underlain by an accretionary complex that is divided into two parts along a prominent decollement. The upper part, mostly trench and abyssal-plain sequences, was accreted along steeply dipping thrust faults; the lower half is being subducted (Fig. 9). On the Pacific Plate, the sediment sequence is probably similar to that penetrated at DSDP Site 178 (Kulm and others, 1973) where 730 m of Miocene to Quaternary hemipelagic and terrigenous sedimentary rocks and sediments overlie older pelagic sedimentary rocks and Eocene basalt.

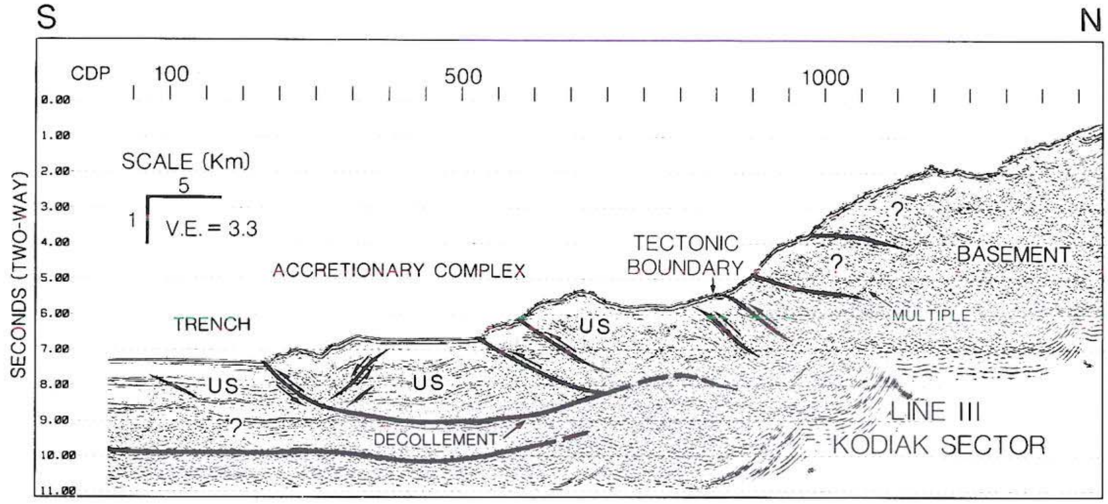


Figure 9. Migrated 24-channel seismic-reflection profile of the deeper parts in the Kodiak Island sector. Approximate location shown in Figure 1. See von Huene and others (1987) for a more complete interpretation of the Kodiak Islands sector. Similar to Figure 8, only upper series strata are designated. Note the relatively thick accumulation of trench sediments and thick section underlying the prominent decollement.

COMPARISON OF FORE-ARC SEISMIC REFLECTION PROFILES

Comparisons of seismic-reflection profiles along the Pacific margin of the Aleutian arc show distinct differences among the four sectors (Table 1). In the Komandorsky–Near Islands sector southeast of Agattu Island (Fig. 4), a relatively narrow fore arc is about 70 km wide between common depth points (CDP) 400 and 2000 (calculated by considering the 30° angle between the line of profile and the present axis of the ridge crest). Although the vector sum of Pacific and North American Plate motions is nearly parallel to the plate boundary, earthquake analyses indicate some reverse faulting beneath the ridge (Newberry, 1984; Newberry and others, 1986); compressional stress is confirmed by several high-angle reverse faults on the seismic profile. These faults, in places, offset the sea floor. We strongly suspect that movement along some of these faults is predominantly oblique-slip. The accretionary complex is narrow and thin if only the deformed sedimentary pile is considered. However, oceanic crust probably is involved, which may not be the case along other profiles (Figs. 6, 8, and 9). A poorly developed decollement can be traced on the profile (Fig. 4) for a maximum of only about 8 to 10 km. LS rocks, which make up the lithologic basement of a large part of the Aleutian Ridge, merge acoustically with the Pacific oceanic crust beneath the outer structural high that separates the accretionary complex from the arc's framework. The fore-arc basin is well developed; the sedimentary section is thick (the US alone has a thickness of about 3 to 4 km), and the basin is narrow (about 20 km).

The Adak-Amlia sector has the greatest number of multichannel seismic-reflection profiles in the Aleutian Ridge segment (e.g., Scholl and others, 1983a, b, 1987; McCarthy and others, 1984; McCarthy and Scholl, 1985; Harbert and others, 1986; Geist and others, 1988; Ryan and Scholl, 1989). There are some major differences between seismic-reflection profiles from the Komandorsky–Near Islands and Adak-Amlia sectors (Table 1). In the Amlia region (Fig. 6), for example, the accretionary complex, fore-arc basin, and decollement are about twice as wide as they are along the Near Islands profile (Fig. 4), and the accretionary complex is much thicker. However, sediment thicknesses are about the same in the trench, fore-arc basin, and subdecollement sequences. Not far from Line 10 (Fig. 6), near the intersection of the Amlia Fracture Zone and the Aleutian Ridge, the thickness of trench sediments is 3 to 4 km (Scholl and others, 1982). An antiform (Hawley Ridge; Ryan and Scholl, 1989) upwarped the sediment sequence along the seaward side of the fore-arc basin (at about CDP 2200 on Fig. 6).

In contrast to fore-arc regions of the Aleutian Ridge, the Pacific margin of the Alaska Peninsula in the Shumagin sector (Line 104, Fig. 8; Table 1) has no well-developed fore-arc terrace. Instead, the sea floor descends gradually from shelf depths to the Aleutian Trench. The depth to the trench floor is about 1,400 m shallower along Line 104 compared to depths in the Amlia corridor and Near Islands regions. A major thrust fault (at about CDP 1800, Fig. 8) structurally separates an accretionary complex from the margin's framework. Shelf basins (shallow fore-arc basins) have formed (Bruns and others, 1985, 1987a, b; Lewis and others, 1988); particularly well developed is Sanak basin. Thicknesses of the trench sediments, the accretionary complex, and the subdecollement sequence are about the same in the Shumagin sector as in the Amlia corridor region (Table 1).

Several seismic-reflection profiles, in addition to that shown here (Fig. 9) are displayed and discussed in detail by Fisher and von Huene (1980) and von Huene and others (1987). For example, an adjacent profile across the Kodiak Island margin (line 509; von Huene and others, 1987) shows a well-developed shelf basin (Albatross basin) that contains a thick (about 4 km) sequence of relatively young (late Miocene and younger, mostly correlative to upper series) sediments. Line 111 (Fig. 9) shows significant differences from the other profiles we selected for this chapter (Table 1; Figs. 4, 6, and 8). Particularly evident is the shallower depth of the trench floor and the greater volume of sediments in the trench. The subdecollement sedimentary sequence also is much thicker than in any of the other profiles (Figs. 4, 6, and 8).

GEOLOGIC EVOLUTION OF THE ALEUTIAN ARC

General discussion

The Aleutian arc formed along zones of convergence between the North American Plate and various oceanic plates, including the modern Pacific Plate and extinct Kula Plate. As a structural entity, the Aleutian arc has been an elongate structural feature, rimming the North Pacific Ocean, since at least the early Eocene. The geologic evolution of the western (Aleutian Ridge) segment was very different from that of the eastern (Alaska Peninsula–Kodiak Island) segment during the Mesozoic and early Tertiary with regards to dominant geologic processes. Since the early Eocene, however, the entire arc has had a similar history, although igneous episodes have not been synchronous and we believe that the western part of the arc is being translated westward along major strike-slip faults.

The Alaska Peninsula–Kodiak Island segment evolved along a zone of plate convergence since at least the Jurassic. Arc polarity may have changed after Jurassic plutonism (Reed and others, 1983), but the igneous rocks are clearly characteristic of a convergent, subduction-related margin. Parts of the Alaska Peninsula and Chugach–Prince William terranes apparently originated far to the south of their present position (Stone and Packer, 1977; Plumley and others, 1983; Hillhouse, 1987; Hillhouse and Coe, this volume) and were accreted onto nuclear Alaska during the Late Cretaceous and earliest Tertiary. Paleomagnetic data from the southern part of the Chugach–Prince William terrane indicate that some latitudinal displacement occurred until at least the Oligocene (Plumley and others, 1983).

Aleutian Ridge segment

Some broad, general interpretations can be made regarding the geological evolution of the Aleutian Ridge: (1) the major volumetric growth of the ridge occurred after a rotational change in Kula Plate motion (about 56 to 55 Ma; Lonsdale, 1988) and before the time of the Emperor-Hawaiian seamount bend (about 43 Ma; Dalrymple and others, 1977; Clague, 1981); (2) major arc-building volcanism had waned, but had not entirely ceased, by about 37 Ma; (3) the ridge subsequently was irregularly uplifted and fragmented by shearing and block rotation, eroded, and affected by volcanism during the ensuing approximately 30 m.y., and was intruded by plutons in episodes that occurred at about 36 to 28 Ma and 20 to 9 Ma; (4) the ridge has been rejuvenated volcanically since about 5 or 6 Ma; (5) the fore-arc and modern shelf (or summit) basins and the subduction complex have developed mostly since the Pliocene; and (6) the ridge is being translated westward along major strike-slip faults in reponse to oblique convergence between the Pacific and North American Plates.

Lower series rocks, erupted and deposited from about 55 to 37 Ma, are dominantly arc-type igneous rocks and derivative coarse-grained volcaniclastic rocks. Arc volcanism most likely began at the start of oceanic intraplate subduction, probably along a transform fault that resulted from the buckling of the extinct Kula Plate (now mostly subducted), with subsequent formation of the Aleutian subduction zone (Scholl and others, 1987; Lonsdale, 1988). Underthrusting during the arc's early stage of rapid growth was roughly due north, possibly at a relatively high rate (Engebretson and others, 1986). Resultant intraplate subduction and volcanism caused rapid growth of the ridge's igneous framework across a width of 150 to 200 km and along the entire length of the arc. At about 43 Ma (age of the Emperor-Hawaiian

TABLE 1. DEPTHS TO AND DIMENSIONS OF MAJOR FEATURES ALONG THE PACIFIC MARGIN OF THE ALEUTIAN ARC*

Line No.		Trench		Accretionary Complex		Decollement†		Forearc Basin				Shelf Basin	
		D	T	W	T	W	T	W	D	T(MS)	T(US)	D	T
32	(Fig. 4)	9.6	1.4	12	2.4	10	0.5	20	4.0	1.0	2.8	1.0	0.8
10	(Fig. 6)	9.6	1.1	26	5.0	25	0.6	50	6.2	1.2	2.0	....	....
104	(Fig. 8)	7.8	1.2	35	5.0	30	0.5	....	....	....	....	0.2	1.6
111	(Fig. 9)	7.2	2.8	32	4.5	27	1.1	....	....	....	....	0.2	3.0§

*Locations of lines and seismic-reflection profiles are shown in Figure 1. Widths are in kilometers; depths and thicknesses are two-way travel time in seconds. D = depth; T = thickness; W = width; MS = middle series; US = upper series.
†Thickness is measured between the decollement upper surface and oceanic crust.
§Data are from adjoining Line 509; R. von Huene's files.

seamount bend), the rate of convergence decreased and the oceanic plate rotated counterclockwise to travel in a west-northwest direction, thereby generally oblique to the trend of the curvilinear Aleutian Ridge. This change in plate vectors led to widespread extension along the arc and to strike-slip faulting that, with time, fragmented the arc into blocks that rotated in a clockwise sense and initiated extensive westward dispersion of the fore-arc regions, particularly in the central and western sectors.

The end of lower series time marks the waning of voluminous arc volcanism and the beginning dominance of tectonic erosion and sedimentation over volcanic processes. However, volcanic and plutonic episodes continued sporadically along the magmatic axis of the ridge. The lower slope (trench wall) of the ridge probably was sediment starved during the early growth of the ridge, similar to the insular lower slopes of the present-day Tonga and Mariana volcanic arcs.

The mafic metaplutonic suite on Attu Island is a significant LS unit because its metamorphic age indicates a thermal event at about 42 Ma (near the time of the Emperor-Hawaiian seamount bend and the shutdown of the Kula-Pacific Ridge). The metamorphic amphibole age (41.5 ± 2 Ma) indicates that the magmatic crystallization age of the igneous rocks is older; that age has not yet been determined. These metamorphosed mafic plutons compose the only large exposure of high-grade (amphibolite facies) metamorphic rocks known on the Aleutian Ridge. Some trace-element contents suggest island-arc tholeiite chemical affinities. A high $^{143}Nd/^{144}Nd$ ratio, however, suggests oceanic (or back-arc basin) MORB affinities (J. Rubenstone, written communication, 1988).

Other LS igneous rocks from the Aleutian Ridge are typical of island arcs and have calc-alkaline, tholeiitic, and transitional chemical affinities. No progression from tholeiitic to calc-alkaline affinities with time and/or space is apparent in LS rocks.

Lower series sedimentary rocks accumulated mostly as debris and turbidite flows (unsorted, mostly coarse-grained volcaniclastic rocks and size-graded breccia and sandstone associations). Finer-grained sedimentary rocks of the Krugloi (Agattu Island), Nevidiskov (Attu Island), and Andrew Lake (Adak Island) Formations probably are lithofacies of the coarser-grained units. Lower series rocks identified offshore of the islands can be traced acoustically on many seismic-reflection profiles to the outer structural high that borders the accretionary complex.

The Oligocene through Miocene middle series (37 to 5.3 Ma) had a beginning that was marked by virtual cessation of igneous activity on the ridge flanks and the beginning of their burial by sediments. Igneous activity did continue along the crestal area where plutons were emplaced during the intervals from 36 to 28 and 20 to 9 Ma. During MS time, terrigenous debris eroded from the arc covered LS rocks with a sedimentary blanket as thick as 2 to 3 km.

Most volcanism along the Aleutian Ridge during middle series time was of island-arc character; calc-alkaline volcanic rocks are prevalent. The Nikol'skoye Suite on Bering Island (the westernmost island in the arc) is the only known pre-Quaternary volcanic rock unit of alkalic character on the Aleutian Ridge. These late Oligocene and early Miocene alkalic rocks erupted in a tectonic regime that may have been different from the rest of the Aleutian Ridge at that time.

The apparent episodic plutonism and change in chemical affinities (tholeiitic to calc-alkaline) of plutonic rocks may be related to significant changes in either tectonic patterns or tectonic processes. After the buildup of LS rocks, for example, the first phase of plutonism occurred during the Oligocene (36 to 28 Ma). On the Agattu, Amatignak (small island southwest of Adak), and Umnak Islands, this phase is characterized by large (up to 100 m thick) sills and dikes that have island-arc tholeiite affinities on the basis of high FeO/MgO ratios, flat rare earth patterns, and low contents of compatible trace elements. Only on Adak Island has a relatively large calc-alkaline pluton (Hidden Bay pluton) of that age been recognized. The second phase (20 to 9 Ma; mostly 17 to 11 Ma) is characterized by large calc-alkaline plutons. Above about 52 percent SiO_2, these plutonic rocks have relatively constant FeO/MgO ratios and rare earth element patterns that are enriched in lighter elements and depleted in heavier elements. The pulses or phases of plutonism may be related to tectonic events such as greater extension of the ridge, changes of plate convergent vectors, crustal thickening related to underplating of subducted sediment, and the subduction of hotter (younger) sea floor. Much more information is needed, however, before pluton episodes and compositions can be related to tectonic patterns and processes in volcanic arcs.

Near the end of the Miocene the last major plutonic phase waned. During the past 5 to 6 m.y. the arc's summit area began to undergo significant erosion, synchronous with the formation of large offshore fore-arc and summit basins and to the beveling of the summit platform. Renewed volcanism has not been sufficient to offset the combined effects of subsidence and erosion. Since the Eocene, the Aleutian Ridge segment apparently has not traveled far latitudinally (Harbert and Cox, 1984).

Alaska Peninsula–Kodiak Island segment

The Alaska Peninsula–Kodiak Island segment of the Aleutian arc records a longer geologic history than the Aleutian Ridge segment, and its Cenozoic history more generally reflects a continental margin, rather than an island arc, response to the subduction environment. The Mesozoic history reflects the migration of terranes northward since the Triassic from near equatorial latitudes to near the present latitude. The Paleozoic history of the Alaska Peninsula is poorly known and poorly constrained by present data.

In early Mesozoic time, the Alaska Peninsula may have been an island arc located far to the south of its present position (Stone and Packer, 1977; Hillhouse and Coe, this volume). The backbone of the Alaska Peninsula, the Alaska-Aleutian Range batholith, was emplaced during Jurassic time, and magmatically associated volcanic rocks were erupted. Reed and others (1983) suggested that the Jurassic arc had a reverse polarity to the present arc. The Jurassic and Early Cretaceous sedimentary sequence in the Chignik subterrane records erosion of this arc and unroofing of the batholith.

Early Late Cretaceous rocks are generally unknown on the Alaska Peninsula; however, Late Cretaceous rocks of the Peninsula terrane and, in part, the Chugach–Prince William terrane, reflect continued erosion of the Jurassic arc and sedimentary recycling of earlier Mesozoic sedimentary rocks. Transport of some debris into the paleo-Aleutian trench, which was the locus of deposition for sediments of the Kodiak and Shumagin Formations, is shown by thin section analysis of the rocks from the Shumagin Islands (John Decker, oral communication to F. H. Wilson, 1985). Late Cretaceous plutons in the northwestern part of the Alaska-Aleutian Range batholith may indicate the presence of a Late Cretaceous magmatic arc. However, rocks of the Alaska Peninsula contain no evidence for significant Late Cretaceous volcanism.

The Border Ranges fault, the present boundary between the Chugach–Prince William and Alaska Peninsula terranes, was formed in Late Cretaceous or early Tertiary time. Foreshortening of the continental margin and accretion of the Chugach–Prince William terrane occurred soon afterward. In the Shumagin Islands region, Eocene and Oligocene volcanic and volcaniclastic sedimentary rocks may overlap the possible extension of the Border Ranges fault.

In contrast to the three recognized rock series (LS, MS, and US) of the Aleutian Ridge segment, Cenozoic rocks of the Alaska Peninsula–Kodiak Islands segment are not separated into chronostratigraphic units (Fig. 2). If they were, however, then the Tolstoi and Copper Lake Formations, and possibly parts of the Stepovak Formation and Meshik Volcanics, are correlative with the LS. The Belkofski, Unga, Tachilni, and Bear Lake Formations, plus the Hemlock Conglomerate, would be correlated with the MS. Furthermore, the Milky River Formation, Morzhovoi Volcanics, and younger volcanic rocks and sediments would be assigned to the US.

The first clear evidence of post-Jurassic volcanism on the Alaska Peninsula occurs in rocks of the Meshik arc. In contrast to the Aleutian Ridge segment, after the time of the Emperor-Hawaiian seamount bend, volcanism increased significantly on the Alaska Peninsula. The vast majority of these volcanic rocks yield K-Ar ages in the range from 42 to 30 Ma. However, at the southwest end of the Alaska Peninsula, ages of 54.8 ± 1.8 and 51.7 ± 5.5 Ma (Wilson and others, this volume) have been determined on basaltic volcanic rocks that crop out in a limited area on the mainland just northwest of the Shumagin Islands. Volcanic rocks of similar age are not known elsewhere on the Alaska Peninsula. These rocks may either be the earliest evidence for the formation of the Aleutian arc or be part of the ancient Beringian margin arc (Davis and others, 1989). On the north end of the Alaska Peninsula, plutons of late Eocene and Oligocene age overlap the age range of plutons in the lower series (e.g., the Finger Bay pluton on Adak Island) and the oldest of the middle series plutons (Hidden Bay pluton on Adak Island and sills on Attu, Agattu, and Umnak Islands). Farther south on the Alaska Peninsula, coeval volcanic rocks of the Meshik arc are exposed. The youngest rocks that are clearly part of the Meshik arc are sparsely distributed late Oligocene and earliest Miocene volcanic rocks. However, hypabyssal plutons and volcanic rocks correlative with the second phase of the middle series (20 to 9 Ma) are known from the inner Shumagin Islands and offshore islands west of the Shumagin Islands at the southwest end of the Alaska Peninsula.

A second episode of magmatism on the Pacific coast of the Alaska Peninsula was apparently initiated in late Miocene time (about 15 Ma). Since that time, the active volcanic front has migrated to the northwest, and rapid uplift and erosion have exposed large plutons as young as Pliocene. Late Miocene sedimentary rocks on the northwest side of the Peninsula (the Bear Lake Formation) record the continued erosion and sedimentary recycling of debris from the Mesozoic magmatic arc and are conspicuous because of the small portion of volcanic clasts compared to most other Tertiary sedimentary rocks on the Alaska Peninsula. In contrast, on the Pacific Ocean side of the Peninsula, the age equivalent late Miocene Tachilni Formation is composed dominantly of clasts derived from a volcanic terrane. By Pliocene time, volcanic rocks and volcanic debris were the major components of the section. The Quaternary rocks record a complex interaction between glacial, volcanic, and shallow-marine sedimentary processes. The glacial accumulation zone on the southwest half of the Alaska Peninsula was on the continental shelf and glaciers traveled across the peninsula to the Bering Sea, leaving well-developed morainal deposits that record successive ice advances across the Alaska Peninsula (Weber, 1985; Detterman, 1986).

Outboard of the Alaska Peninsula on Kodiak Island, Cenozoic rocks record an early Tertiary subduction event; Miocene sedimentary units record a progressive tectonic uplift and a progressive decrease in the proportion of volcanic lithic fragments (Nilsen and Moore, 1979). This decrease in volcanic lithic fragments is in stark contrast to the development of the modern Aleutian volcanic arc farther inland. Pliocene and later rocks on the shelf and offshore islands show an increasing dominance of glaciomarine processes with time.

In the Aleutian magmatic arc (including the Paleogene Meshik arc) of the Alaska Peninsula, calc-alkaline andesite and dacite are the dominant volcanic products. However, rocks of tholeiitic affinity are common, particularly on the south half of the Alaska Peninsula. Available data suggests no apparent relation between age and chemical affinity. In the modern (Holocene) volcanic arc, only some of the westernmost volcanic centers are tholeiitic (Miller and Richter, this volume).

Rocks as young as Oligocene are involved in folding that produced a series of northeast-trending en echelon anticlines on the central Alaska Peninsula, and rocks as young as late Miocene are overthrust by Mesozoic rocks at the south end of the Peninsula.

SUMMARY AND CONCLUSIONS

The Aleutian arc forms most of the northern boundary of the Pacific Ocean. It is separated near Unimak Pass into an Aleutian Ridge segment on the west and an Alaska Peninsula–Kodiak Island segment on the east. The Aleutian Ridge segment is an early(?) Eocene to Holocene intraoceanic island arc, whereas the Alaska Peninsula–Kodiak segment is composed of tectonostratigraphic terranes of Mesozoic and Cenozoic age that incorporate fragments of even older rocks, upon which a Cenozoic volcanic arc has evolved. The curvature of the Aleutian structural arc is such that it is underthrust at about 90° by the Pacific Plate in the east; in the far western part, the North American and Pacific Plate motions are nearly parallel.

Rocks of the Aleutian Ridge segment are divided into three chronostratigraphic units as a convenient method for correlating offshore and onshore rocks. These units are informally called the lower (middle early through late Eocene rocks, older than 37 Ma), middle (early Oligocene through late Miocene rocks, 37 to 5.3 Ma), and upper series (early Pliocene through Quaternary rocks, younger than 5.3 Ma).

The Aleutian Ridge segment is also divided into two geographic sectors: the Komandorsky–Near Islands sector in the extreme western part of the arc and the Adak-Amlia sector in the central part. The Komandorsky–Near Islands sector shows a wide range of strike-slip and extensional structures and arc-type rock compositions; the Pacific margin is narrow, but a well-developed fore-arc basin and a relatively small accretionary complex occur in some areas. A large mafic metaplutonic suite on Attu Island was metamorphosed to the amphibolite facies about 42 Ma. In the central part of the structural arc, the Adak-Amlia sector, plate convergence is about 30° west of a perpendicular line drawn to the axis of the arc. Here, the arc has a relatively wide fore-arc basin and accretionary complex.

The Aleutian Ridge developed on Early(?) Cretaceous oceanic crust, apparently beginning in the early Eocene about 55 Ma. Growth of the ridge waned in the 40 to 37 Ma interval, which corresponds to the end of lower series time. During middle series time (37 to 5.3 Ma) volcanism continued, but at a diminished rate; plutonic activity was particularly dominant during the intervals from 36 to 28 Ma and 20 to 9 Ma. A major summit-cutting erosional event took place in the latest Miocene and early Pliocene interval. During the past approximately 5.3 m.y. (upper series time), offshore fore-arc and summit basins formed, the Aleutian Trench filled with sediments, a broad accretionary complex formed, and the latest phase of arc magmatic activity commenced.

The Alaska Peninsula–Kodiak Island segment is converging with the Pacific Plate at about 90°. Two discrete tectonostratigraphic terranes, recognized on land, are separated by the Border Ranges fault: the Alaska Peninsula terrane on the north and the Chugach–Prince William terrane on the south. Most rocks in the Alaska Peninsula terrane are Middle Jurassic to Late Cretaceous in age. The Chugach–Prince William terrane contains mostly Late Cretaceous and younger rocks, many of which were deposited in trench and other deep marine basin settings. The terranes were juxtaposed during the Late Cretaceous and major activity on the Border Ranges fault ceased sometime in the Late Cretaceous and early Tertiary interval prior to 60 Ma. Early Tertiary to Holocene volcanic rocks, their associated plutonic rocks, and marine and nonmarine sedimentary rocks constitute the Cenozoic geologic column on the Alaska Peninsula.

Offshore along the Alaska Peninsula–Kodiak Island segment, Cenozoic sediments were deposited in shelf and slope basins and in the Aleutian Trench. A regional offshore unconformity of either early or middle Miocene age separates the older framework of the margin from acoustically well-stratified basinal sequences. A thick accretionary complex beneath the lower slope is late Miocene(?) to Holocene in age. Offshore structures and regional geologic data indicate that the structural fabric of the Alaska Peninsula–Kodiak Island segment changes from a southwest to a northwest trend near Unimak Pass and forms part of the margin of the Bering Sea.

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MANUSCRIPT ACCEPTED BY THE SOCIETY MAY 9, 1990

ACKNOWLEDGMENTS

We greatly appreciate the critical reviews of Hugh McLean, Henry Berg, and John Armentrout. In addition, Michael Garrison, Sean Stone, and James R. Le Compte gave valuable technical help with the manuscript. We thank George Moore for assistance with the stratigraphic column of Kodiak Island. Andre Tsvetkov sent samples from the Komandorsky Islands. Jill McCarthy, Dennis Mann, Jon Childs, and John Miller processed the seismic-reflection profiles. Robin Frisch helped map lineaments on Attu, Agattu, and Adak Islands. Leda Beth Pickthorn determined K-Ar radiometric ages of several samples. William Harbert and Robert O'Connor provided stimulating discussions while mapping parts of Attu, Shemya, Amlia, and Atka Islands during the 1983 field season. Hugh McLean and James Hein worked with us on Amlia Island in 1979.

NOTES ADDED IN PROOF

Significant studies have been completed since this manuscript was accepted for publication. Some interpretations have changed, particularly in the Alaska Peninsula segment, and new data have been collected. Suggested changes in the stratigraphy of the Komandorsky Islands are summarized by Tsvetkov and others (1990). In the Gulf of Alaska and Kodiak regions, the Trans-Alaska Crustal Transect (TACT) and EDGE projects (Fisher and others, 1989; Fuis and others, 1991; Moore and others, 1991; and Page and others, 1989) added new data for interpretations of the deep crust beneath the Alaskan margin and of the crustal structure of accreted terranes in southern Alaska. Preliminary data from section balancing of EDGE and other seismic profiles in the Aleutian trench region east of the Kodiak Islands, in fact, suggest that the accretionary wedge is younger than previously thought, possibly no more than 1 m.y. old.

GLORIA (Geological LOng-Range Inclined Asdic) side-scan and complementary geophysical surveys in 1986, 1987, and 1988, along both sides of the Aleutian arc and as far west as the international border between the United States and Russia, contributed a large amount of marine data within 200 nautical miles of the coastlines. Those cruises gathered side-scan images, single-channel seismic profiles, and magnetic and gravity data. Information from the Bering Sea (north) side of the Aleutian arc is published in an atlas (EEZ-SCAN Scientific Staff, 1991) and data from the Pacific Ocean (south) side of the arc will be published in a similar atlas in late 1995 or 1996.

Interpretations of Aleutian GLORIA surveys, to be published in the near future, deal with sedimentation in the Aleutian fore-arc region (M. R. Dobson, written communications, 1993) and with a small remnant of Kula plate that occurs offshore the Near Islands that was discovered by Lonsdale (1988). Extreme obliquity of collision between the western Aleutian arc and the oceanic plate resulted in the formation of extensive wrench faults that have fragmented the Near Islands and Komandorsky Islands regions into elongate slivers. The Aleutian arc is moving west along those wrench faults and is headed for a rendezvous with the Kamchatka Peninsula (E. Geist, written communications, 1993). One of the wrench faults, the Agattu fault, cuts the fore-arc region from south of Amchitka Island to west of the Near Islands. At the intersections of the Agattu fault with northeast-trending wrench faults, deep sediment basins have developed along the narrow Aleutian terrace.

The present-day Kula plate is a small fragment of a major oceanic plate that has been mostly consumed beneath the Aleutian arc. The plate is bounded on the south and west by Stalemate ridge and on the north by the Aleutian trench. The Kula-Pacific ridge, a relict spreading center, trends nearly north-south and intersects the Aleutian trench at about long 172°E. Spreading along that ridge ended ~42 m.y. ago, close to the same time as the bend of the Hawaii-Emperor seamount chains.

The Alaska Peninsula–Kodiak Island segment has a coherent and nearly complete stratigraphic sequence dating from Permian time. We now recognize that past reports giving Silurian and Devonian ages to some carbonate rocks on the Alaska Peninsula are in error (Detterman and others, 1994); those carbonates are Triassic in age. Some of the early rocks of the Alaska Peninsula record the rapid development and deep erosion of a Jurassic island arc developed on a carbonate and greenstone terrane that has Wrangellia affinities. Recent analyses (Wilson and others, 1993) suggest that the oldest rocks in the Kodiak Islands, which lie adjacent to the Border Ranges fault system, are not part of the Alaska Peninsula terrane. Their lithology and geologic history are distinctly different from rocks of equivalent age on the Alaska mainland. They in part represent a metamorphosed early Mesozoic accretionary complex (Roeske and others, 1989) and may be a sliver of an undefined terrane. These rocks are unknown in outcrop southwest of the Kodiak Islands; however, Fisher (1981) correlated a series of magnetic anomalies thought to be associated with plutonic and ultramafic rocks in this complex to near Sutwik Island, which does lie southwest of the Kodiak Islands. Late Cretaceous rocks consist of a subduction complex that includes fluvial and flyschoid deposits on the mainland and extensive flyschoid trench deposits on the offshore islands. The coherent Late Cretaceous stratigraphy and facies relationships, as originally reported by Mancini and others (1978), across the Alaska Peninsula and Chugach terrane suggest that at the southwest end of this segment rocks of the Chugach terrane were deposited adjacent to the Alaska Peninsula terrane and not rafted in from elsewhere.

Alaska Peninsula Tertiary rocks include the deposits of the Meshik arc, age-equivalent to the early part of the middle series in the Aleutian arc, and deposits from late Miocene to Holocene magmatic activity along the arc, age-equivalent to late middle series and upper series rocks of the Aleutian Ridge segment. The only rocks on the Alaska Peninsula that are now believed to be age-equivalent to lower series rocks in the Aleutian arc are the Tolstoi and Copper Lake formations. However, neither of these units provides evidence for the initiation of volcanism along the Aleutian arc; both have batholithic and sedimentary rock provenances. In the Kodiak Islands, Tertiary rocks include very early Tertiary plutons emplaced into Late Cretaceous trench deposits. In the eastern part of the islands, a Paleogene subduction complex (Ghost Rocks) equivalent to the Orca Group of Prince William Sound is overlapped by nonmarine and shallow-water marine clastic rocks as young as Pliocene. Southwest of the Kodiak Islands, rocks neither equivalent to the Ghost Rocks nor to the clastics are known onshore.

Migration of the Alaska Peninsula terrane as part of the larger Peninsula-Alexander-Wrangellia (PAW) composite terrane (see Nokleberg and others, this volume, Chapter 10) from southerly latitudes was largely complete by the end of Mesozoic time. The outboard composite Chugach and Prince William terranes are in part depositional on the PAW terrane and in part juxtaposed against it. The magmatic arc, subdivided into two components in this segment, is emplaced through the older rocks. The older component, called the Meshik arc, is primarily exposed on the southern Alaska Peninsula. The younger component extends the length of the segment and shows clear evidence for migration of the volcanic front to the northwest from the Pacific coast with time.

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Printed in U.S.A.