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Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex

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ABSTRACT

The Uyak Complex is a chaotic assemblage of gray chert and argillite, wacke, greenstone, radiolarian chert, and gabbroic and ultramafic rocks. The simplest interpretation of these rocks is that the gabbroic and ultramafic rocks and greenstone represent basal oceanic crust upon which the radiolarian chert, gray chert and argillite, and wacke were deposited, respectively, at a mid-ocean rise, on the abyssal ocean floor, and in an oceanic trench. Fossils are scarce in the complex and range in age from mid-Permian to mid–Early Cretaceous. The Uyak Complex was emplaced by underthrusting to the northwest beneath lower Mesozoic metamorphic, igneous, and sedimentary rocks. During underthrusting, brittle rock types were broken into phacoids of all sizes and suspended in the less competent matrix of gray chert and argillite with their longest dimensions aligned subparallel to cataclastic foliation. Prehnite and pumpellyite developed extensively in lithologies of suitable composition.

The Uyak Complex correlates to the northeast with a similar assemblage of deep-sea rocks on the Barren Islands and with the McHugh Complex on the Kenai Peninsula and near Anchorage. The Uyak-McHugh belt defines a probable subduction complex trending northeast for at least 600 km along the margin of southwestern Alaska. The time of emplacement of this mélange is uncertain, but fossils present indicate that it occurred after mid–Early Cretaceous time. To the southeast, the Uyak is underthrust by deformed turbidites of the Kodiak Formation, which are interpreted to have been deposited in an oceanic trench and accreted to the Alaskan margin in Late Cretaceous time. The relationship between the Uyak Complex and Kodiak Formation is uncertain, but they may represent two phases, or two facies, of Late Cretaceous accretion.

Two large bodies of schist, referred to as the Kodiak Islands schist terrane, occur along the northwest border of the Uyak. The Kodiak Islands schist terrane is a blueschist-bearing metamorphic belt that has yielded mainly Early Jurassic K-Ar mineral ages. Similarities in K-Ar ages, metamorphism, and tectonic setting support a correlation between the Kodiak Islands schists and the Seldovia schist terrane on southern Kenai Peninsula. The Upper Triassic Shuyak Formation structurally overlies the Kodiak Islands schist terrane and Uyak Complex but is separated from them by a long, narrow pluton emplaced in Early Jurassic time. The Shuyak is a little-deformed formation of volcanic and volcaniclastic rocks. It correlates with similar rocks on the Alaska and Kenai Peninsulas, which together outline a lower Mesozoic forearc basin; K-Ar ages show that much of the Alaska-Aleutian Range batholith was intruded coeval with deposition in this forearc basin. A likely interpretation of these rocks is that the Kodiak-Seldovia schists are the only vestige of a subduction complex emplaced along the margin of southwestern Alaska during the prominent early Mesozoic volcanoplutonic activity recorded on the Alaska and Kenai Peninsulas and the Kodiak Islands.

INTRODUCTION

Plate-tectonic theory is now on firm ground and is providing the genetic concepts necessary to unravel the complex geology of ancient continental margins. Geophysical and geological studies of modern plate margins indicate that oceanic trenches are the site of large-scale underthrusting of oceanic lithosphere (Isacks and Molnar, 1971) and that deep-sea sediments are scraped from the downgoing plate and accreted to the overlying plate in the process (Kulm and others, 1973). Seismic profiles across these convergent margins suggest that the thick wedges of sediment making up the trench inner wall are structured by compressional folds and landward-dipping thrust faults (Seely and others, 1974; Silver, 1971). Although these sediments are complexly deformed, they often are compositionally identical or similar to those at the trench axis (Kulm and others, 1973; von Huene, 1972; Fisher and Engle, 1969). However, because acoustic methods cannot resolve the deep internal structures of subduction complexes and because drilling and dredge hauls are capable of sampling only the uppermost part of these belts, it is informative to study ancient uplifted subduction complexes.

The margin of southwestern Alaska has been the site of accretion of several belts of deep-sea deposits since early Mesozoic time. These accretionary belts are well exposed along the fiord-indented coastlines of the Kodiak Islands (Fig. 1) and apparently have not been affected by subsequent strike-slip faulting. To better understand the nature of subduction complexes in general and to clarify the geology of this little-studied region, Casey Moore, Malcolm Hill, Betsy Hill, James Gill, and myself have conducted an integrated study of the Uyak Complex. This paper deals primarily with the sedimentary geology of the Uyak and a sedimentation model to explain its origin.

The Uyak is interpreted here as a subduction complex because of rock types present, style of deformation, grade of metamorphism, and tectonic setting. Rock types included in the Uyak are similar to lithologies that occur in typical deep-sea sequences. Deformation of these rocks is intense, but structural analyses indicate that deformation occurred in a shear-couple consistent with emplacement by underthrusting to the northwest beneath an existing continental margin (Moore and Wheeler, 1975). Prehnite-pumpellyite–facies

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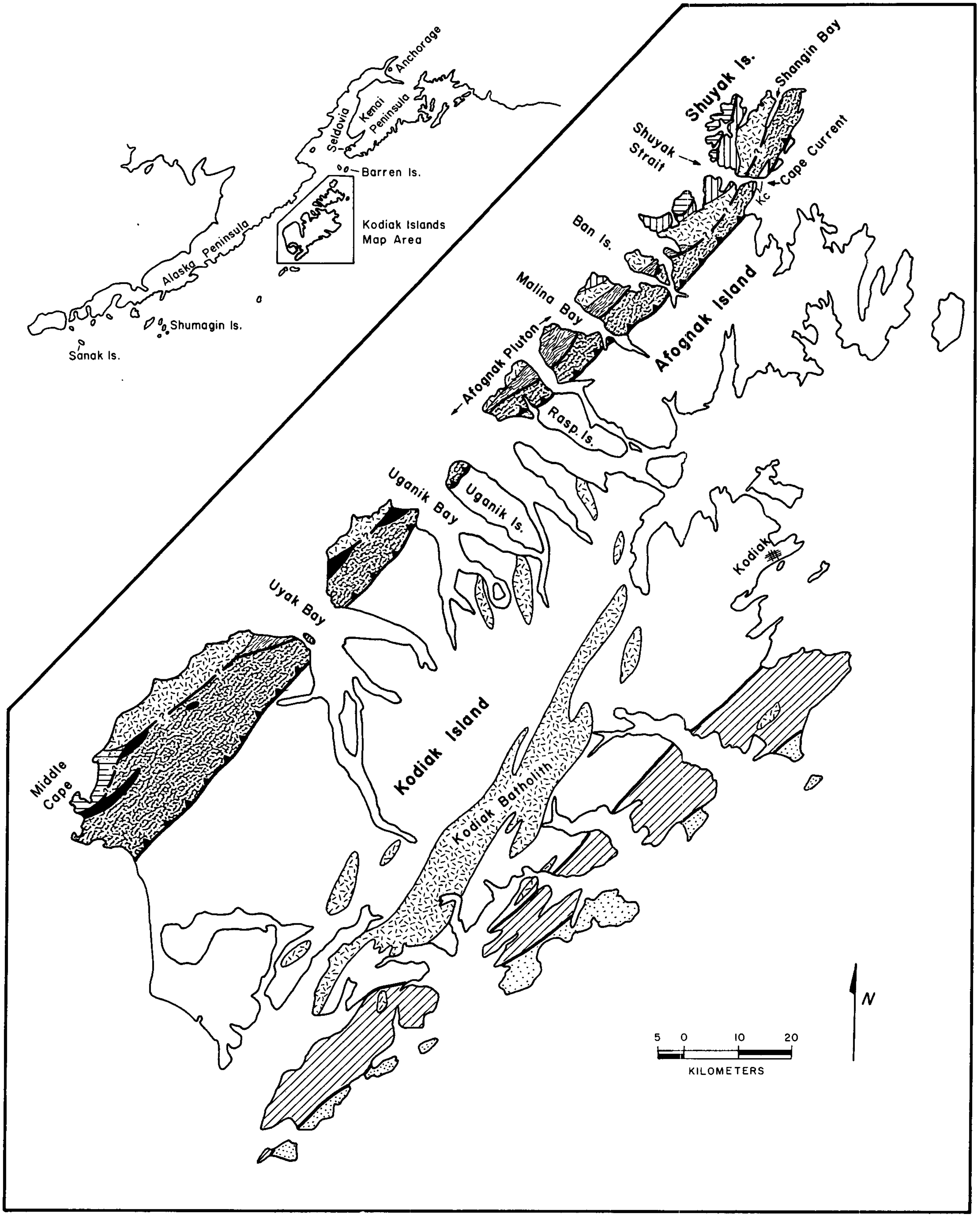


Figure 1. Generalized geologic map of Kodiak Islands; after Connelly and Moore (1977), Moore (1967), and Capps (1937).

metamorphism of the Uyak could have occurred in a pressure-temperature regime thought to exist in subduction zones. Finally, the Uyak Complex and correlative McHugh Complex define a long, narrow outcrop belt along the margin of southwestern Alaska that is sandwiched between a younger belt of deep-sea rocks seaward and an older belt landward, suggesting a long history of seaward accretion by subduction.

GEOLOGIC SETTING

The oldest rock unit on the Kodiak Islands is a sequence of vesicular pillow lava and openly folded volcaniclastic turbidites at least 7 km thick (Fig. 1). This previously unmapped volcanogenic section is here named the Shuyak Formation after the type section in western Shuyak Strait (see Connelly and Moore, 1977). The Shuyak Formation is divided into a lower volcanic member and an upper sedimentary member (discussed below); the Late Triassic pelecypod *Halobia* cf. *H. halorica* (N. J. Silberling, 1976, written commun.) has been collected from several localities in the sedimentary member. It is likely that a lithologically similar unit of rocks in the Middle Cape area on westernmost Kodiak Island is an isolated remnant of the Shuyak Formation, but no fossils were found there. The Shuyak Formation correlates to the northeast with lithologically and biostratigraphically equivalent unnamed rocks on the Barren Islands (Cowan and Boss, 1978) and near Seldovia on southern Kenai Peninsula (Martin, 1915), and to the northwest with similar rocks on the Alaska Peninsula at Puale Bay and in the Lake Iliamna–Kamishak Bay area (Burk, 1965; Detterman and Hartsock, 1966).

To the southeast, the Shuyak Formation is structurally underlain by the Kodiak Islands schist terrane along the inferred Shuyak fault (Fig. 1). The Kodiak Islands schist terrane consists of thinly layered and intricately folded quartz-mica schist, greenschist, blueschist, and epidote amphibolite, and it has yielded mainly Early Jurassic K-Ar mineral ages. Similarities in K-Ar ages, metamorphism, and tectonic setting support a correlation between the Kodiak Islands schists and the Seldovia schist terrane on southern Kenai Peninsula (Carden and others, 1977). The inferred Shuyak fault is now intruded by the dioritic Early Jurassic Afognak pluton.

The Uyak Complex structurally underlies the Kodiak Islands schist terrane and Afognak pluton along the Raspberry fault (Fig. 1). The Uyak Formation of G. W. Moore (1969) is here modified to the Uyak Complex (see Berkland and others, 1972). The term "complex" is used in recognition of the highly complicated internal structural relations of the Uyak rocks and is in accordance with the American Commission on Stratigraphic Nomenclature (1970, art. 6, p. 6–7). Similarities in lithology, style of deformation, degree of metamorphism, and tectonic setting suggest a correlation of the Uyak Complex with an unnamed unit on the Barren Islands and with rocks on the southern Kenai Peninsula presumed to be an extension of the McHugh Complex of the Anchorage area (Clark, 1973; Moore and Connelly, 1976; Magoon and others, 1976; Cowan and Boss, 1978).

The highly deformed turbidites of the Kodiak Formation underthrust the southeast side of the Uyak along the Uganik thrust (Capps, 1937; Moore, 1967, 1969). The Kodiak Formation is part of an extensive turbidite sequence that is interpreted to have been deposited in an oceanic trench along the margin of southwestern Alaska in Late Cretaceous time (Burk, 1965; Moore, 1972, 1973a, 1973b; Jones and Clark, 1973; Budnik, 1974).

The Paleocene(?) to Eocene Ghost Rocks Formation is faulted against the seaward side of the Kodiak Formation (Fig. 1). The Ghost Rocks Formation consists primarily of tightly folded thin- to medium-bedded argillite and wacke with occasional occurrences of nonvesicular pillowed greenstone and agglomerate (Moore, 1969); intense localized shearing has produced many zones of tectonic mélange. The only fossils recovered from the Ghost Rocks Formation are Eocene planktonic foraminifera (J. L. Thompson, 1975, written commun.) collected by me from a pelagic limestone at Ghost Rocks, Sitkalidak Strait, Kodiak Island. The metamorphic grade of the Ghost Rocks Formation locally reaches the prehnite-pumpellyite facies. The oceanic lithologies and style of deformation

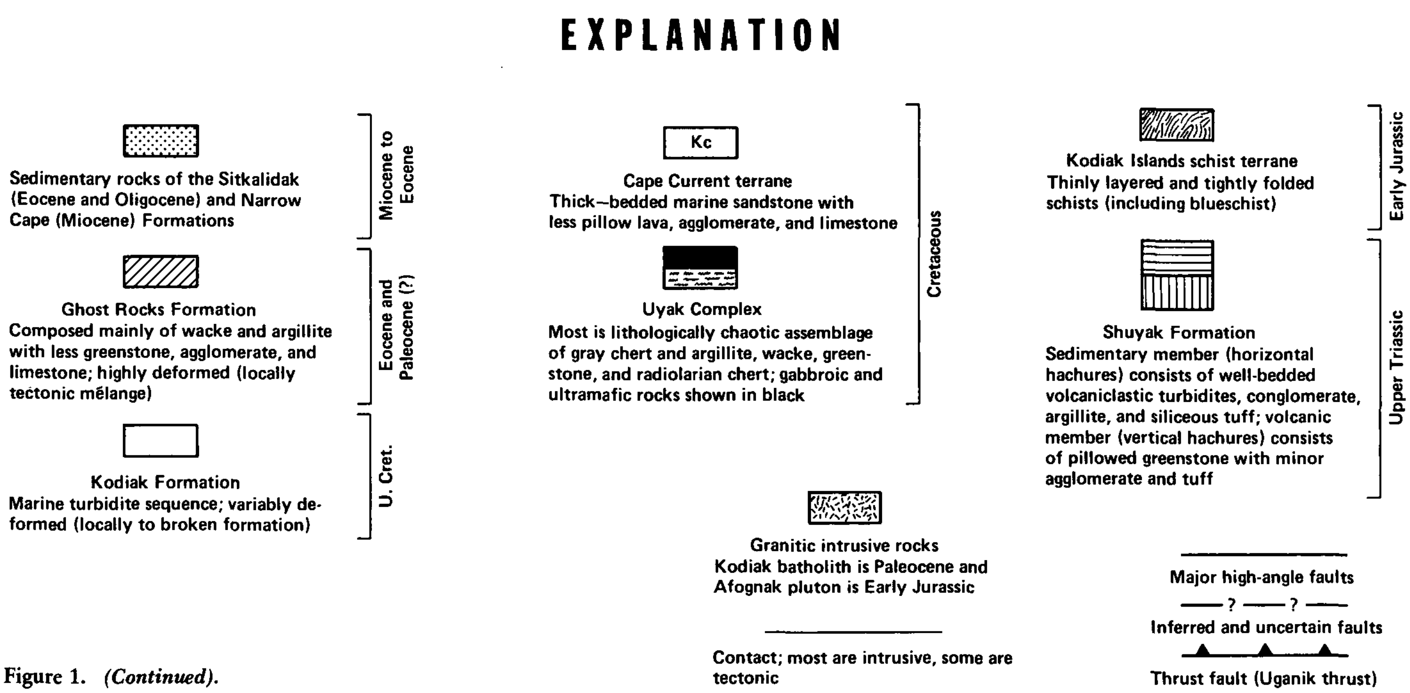


Figure 1. *(Continued).*

of the Ghost Rocks suggest that it is a subduction complex. Younger accreted deep-sea sequences occur seaward of the Kodiak Islands (von Huene, 1972) and indicate that this region has been the site of continual accretion up to Holocene time.

In the Alaska Peninsula are exposed volcanic and plutonic rocks with ages that apparently coincide with phases of accretion on the Kodiak Islands (Burk, 1965; Detterman and Hartsock, 1966; Reed and Lanphere, 1973). In addition, in the Kodiak Islands, two anomalously seaward plutonic belts are exposed: (1) the Early Jurassic Afognak pluton, which intrudes between the Shuyak Formation and Kodiak Islands schist terrane, and (2) the Paleocene Kodiak batholith, which intrudes the Kodiak Formation in central Kodiak Island (Burk, 1965; Moore, 1969; Hill and Morris, 1977).

LITHOLOGY OF UYAK COMPLEX

Intense shearing in the Uyak has destroyed most stratal continuity and tectonically juxtaposed different lithologies. Nevertheless, isolated clues and modern analogs suggest a sedimentation model based on plate tectonics to explain the relationships between the diverse deep-sea lithologies included in this mélange (Fig. 2).

Ultramafic, Gabbroic, and Basaltic Rocks

Gabbroic and ultramafic rocks occur as kilometre-sized slabs in the northwesternmost exposures of the Uyak (Fig. 1) and constitute about 6% of the mélange. These slabs contain layered gabbro, clinopyroxenite, dunite, and plagioclase peridotite; no harzburgite or sheeted-dike complexes have been observed (Hill, 1975). The bodies are always fault bounded, and serpentinization is pronounced near their margins. On the basis of mode of occurrence and mineralogy, these rocks tentatively are interpreted as fragments of dismembered oceanic crust (Hill and Brannon, 1976).

Greenstones generally occur as fault-bounded blocks tens to hundreds of metres in size and constitute about 20% of the complex. Nonvesicular pillowed greenstone with a thin chloritic interpillow matrix is most common, but massive greenstone occurs locally. The greenstones are partially altered to chlorite, albite, pumpellyite, and calcite, but relict phenocrysts of plagioclase and clinopyroxene locally are recognizable (M. Hill, 1976, personal commun.). Quench textures, variolitic structures, and nonvesicularity suggest extrusion in relatively deep water (Jones, 1969; Moore, 1970; Furnes, 1973). Major- and trace-element analyses suggest that the greenstones are ocean-floor basalts (Hill and Gill, 1976). Thus, the greenstones also appear to be fragments of dismembered oceanic crust.

Radiolarian Chert

Small tectonic blocks of rhythmically bedded radiolarian chert are scattered throughout the Uyak and account for about 2% of the mélange. Unsheared sedimentary contacts between radiolarian chert and underlying pillow basalt occur only at a few localities, but blocks of these two rock types are commonly in close proximity. The chert typically is red (although sometimes green or mottled) and occurs as homogeneous contorted sequences of 2- to 7-cm-thick beds separated by thin shaly partings. Individual chert beds locally contain small-scale laminations (Fig. 3), and X-ray diffraction of the shaly partings between beds indicates the presence of hematite and probably palagonite (see Nisbet and Price, 1974). Petrographic examination of this chert reveals abundant quartz-filled radiolaria in various stages of preservation set in a very fine-grained matrix of microcyrstalline quartz.

E. A. Pessagno (1976, written commun.) has examined radiolaria extracted from Uyak chert collected at five localities by myself and by G. W. Moore, and has identified (1) cryptoceptic Nassellariina forms of probable Paleozoic age; (2) *Archaeodictyomitra* sp. of probable Late Jurassic or Early Cretaceous age; (3) *Parvicingula boesi, Thanarla conica,* and *Archaeodictyomitra* cf. *A. vulgaris,* of late Valanginian age; (4) *Thanarla conica, Parvicingula*?, and *Pseudodictyomitra*?, of late Valanginian to Aptian age; and (5) *Thanarla conica* and *Archaeodictyomitra* sp. of late Valanginian to late Aptian age.

Sedimentary structures such as graded bedding, cross-bedding, parallel laminations, and sole marks have been described in radiolarian chert beds at many localities (Nisbet and Price, 1974; Garrison, 1974; Imoto and Saito, 1973). One interpretation of these structures is that they formed by redeposition of the radiolaria and their matrix by turbidity currents flowing down the tectonically active slopes of mid-ocean rises (Fig. 2). These currents may have flowed directly over exposed oceanic basalt and finally ponded as lenticular deposits between fault blocks along the rise. The model therefore explains the characteristic but enigmatic thin bedding and lenticularity of radiolarian chert deposits the world over. The presence of palagonite in the shaly partings between chert beds that is quite similar to palagonite of weathered submarine basalts (Matthews, 1971; Nisbet and Price, 1974) supports this interpretation.

I have adopted this general model for the Uyak radiolarian chert and suggest that it was deposited directly on pillow basalt of oceanic crust along the flanks of a mid-ocean spreading center, both as redeposited radiolarian turbidites and as primary pelagic sediments. Deposition on an elevated mid-ocean rise rather than

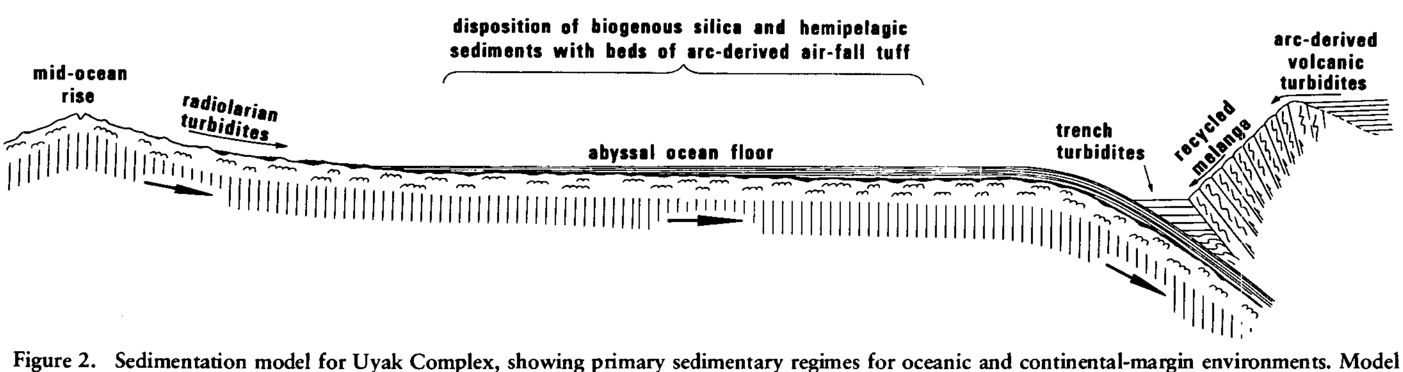


Figure 2. Sedimentation model for Uyak Complex, showing primary sedimentary regimes for oceanic and continental-margin environments. Model portrays sedimentary environments preceding Jurassic and Cretaceous proliferations of pelagic calcareous micro-organisms.

the abyssal ocean floor is supported by the lack of clastic sediments and air-fall tuff in the chert deposits. Furthermore, deposition directly on the pillow basalt would place the chert at the base of the ocean sediment column and therefore explain why some of the included radiolaria are among the oldest fossils from the complex.

Gray Chert and Argillite

Rocks included in our mapping unit "gray chert and argillite" account for about 45% of the Uyak Complex. This is an intensely deformed, thinly layered unit typically containing 55% to 65% gray chert, 25% to 35% black argillite, and 0% to 10% green tuff or limestone; a similar lithology containing more than 40% tuff accounts for about 6% of the mélange. Deformation has caused the more competent chert layers to become folded, boudinaged, or thoroughly shattered and suspended in the argillaceous matrix (Fig. 4). The green tuff occurs in these deformed sections as discontinuous layers generally less than 2 cm thick, but locally greater than 10 cm thick. At outcrop and map scale, the gray chert and argillite unit comprises the mélange matrix in which phacoids of more competent rock types are enclosed (Fig. 5).

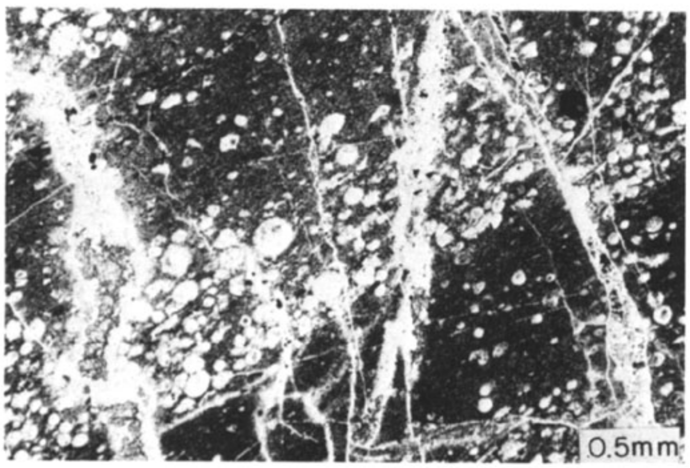


Figure 3. Photomicrograph of sample from radiolarian chert bed, collected from east Uganik Bay. Note how radiolaria define small-scale laminations.

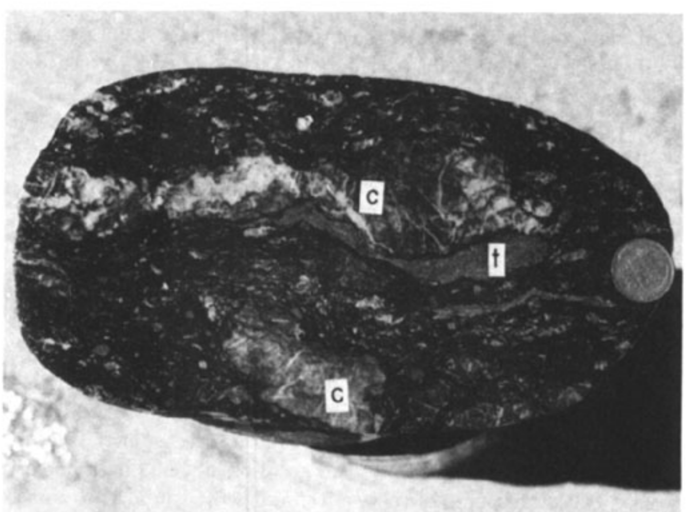


Figure 4. Cut slab of highly deformed "gray chert and argillite" from Malina Bay, showing how individual chert layers (c) are shattered and suspended in argillaceous matrix; note thin layer of green tuff (t).

The gray chert is highly recrystallized and cut by abundant quartz-filled fracture veinlets. No traces of volcanic debris such as shards, clasts, or phenocrysts have been observed in chert layers, and ghosts of radiolaria occur only rarely. X-ray diffraction analyses indicate that this chert is composed entirely of quartz. The argillite and tuff in this unit are highly altered to pumpellyite, prehnite, and chlorite. The green tuff is petrographically distinct from the argillite because of its green color and greater abundance of plagioclase and volcanic fragments.

The Deep Sea Drilling Project has found that "bedded cherts," especially of Eocene age, are a volumetrically important rock type in abyssal sequences of most deep-ocean basins (see Davies and Supko, 1973). These cherts generally are devoid of biogenous remains and are thinly interbedded with pelagic sediment types such as abyssal clay and air-fall tuff (Heath and Moberly, 1971; Davies and Supko, 1973). These abyssal "bedded cherts" are lithologically similar to the Uyak gray chert and represent a probable Eocene analog. However, calcareous sediments often are important constituents in Tertiary abyssal sequences but are lacking in the ancient counterpart, perhaps because pelagic calcareous organisms did not proliferate and diversify until late Mesozoic and early Cenozoic

Figure 5. "Gray chert and argillite" at Uyak Bay; note phacoid of wacke (w). Scale bar = 15 cm.

time, whereas deposition of most of the Uyak sediments may have occurred before this time.

In the North Pacific, layers of air-fall tuff as much as 6 cm thick often occur interbedded with normal abyssal sediments more than 1,000 km seaward of the nearest volcanic arc, and the percentage of tuff increases toward the arc (Ninkovich and Robertson, 1975; Scheidegger and Kulm, 1975). This relation suggests that the green tuff interlayered with the Uyak gray chert and argillite was blown seaward from a volcanic arc and deposited with other deep-sea sediments. The absence of tuff interbedded with the radiolarian chert implies that the tuff did not originate as an aquagene tuff at a mid-ocean spreading center.

The distinctly different characteristics of radiolarian chert and gray chert in the Uyak Complex raise interesting questions in regard to their origin and diagenesis. The abundant radiolaria preserved in the radiolarian chert clearly attest to its biogenic origin. However, the scarcity of biogenous remains in the Uyak gray chert and the "bedded cherts" of modern ocean basins leaves their origin less clear. Wise and Weaver (1974) reviewed the many hypotheses proposed for the origin of silica in deep-sea chert deposits and concluded that most silica was originally deposited as the opaline skeletal material of microplankton (Berger and von Rad, 1972; von Rad and Rosch, 1974; Garrison, 1974). If both forms of chert are biogenic, why then are radiolaria preserved in one, while in the other occasional ghosts and molds of radiolaria are the only remaining biogenous traces? The answer is not clear, but it may reflect significant differences in diagenetic processes on a mid-ocean rise and on the abyssal ocean floor. Perhaps the high heat flow at a mid-ocean rise favors preservation of the forms of siliceous microfossils by increasing the rate of diagenetic reactions as the biogenic opaline remains are converted to opal-CT and subsequently to quartz (see Ernst and Calvert, 1969; Heath and Moberly, 1971). Preservation may also be enhanced by the addition of secondary silica to pore water from the diagenetic and hydrothermal alteration of underlying ocean–floor basalt (Garrison, 1974; Hart, 1973; Fein, 1973). Alternatively, it may be that certain sediments interbedded with the "bedded cherts" and the Uyak gray chert contain unstable silicate minerals that have low silicon/aluminum ratios and readily react with silica released from microfossils. Johnson (1976) reported that regions in the deep ocean with anomalously poorly preserved siliceous microfossils approximately correspond to regions with a high input of hemipelagic sediments; this suggests that the sediments are a potential "silica sink" that lowers interstitial silica concentrations, thereby favoring the solution of siliceous remains.

Limestone

Limestone is uncommon in the Uyak and generally occurs as small recrystallized phacoids in gray chert and argillite; mappable bodies were encountered at only three localities (see Connelly and Moore, 1977) and constitute about 1% of the mélange. The limestones exposed on southeastern Ban Island (a body 0.2 by 2.4 km) and on the northeastern tip of Shuyak Island (0.3 km thick) consist of contorted sequences of thin-bedded white limestone separated by thin layers of black argillite. This limestone is recrystallized and lacks preserved fossils.

The third mappable body is exposed on the northeast shore of Uyak Bay. This tectonic block contains a sequence of thick-bedded, variably recrystallized grainstone with occasional thin layers of tuff and tuffaceous limestone. Fusulinids collected from this block were identified by G. Wilde (1975, written commun.) as *Neoschwagerina* sp.; crinoid stems are also present. In a second sample of fossiliferous limestone (micritic-skeletal wackestone), which was collected from a small phacoid in gray chert and argillite on the northeast shore of Uganik Bay, G. Wilde identified the fusulinids *Neoschwagerina* sp., *Cancellina*? sp., and *Codonofusiella* sp. and the foraminifers *Colaniella, Pachyphloria,* and *Nodosinella,* as well as Dasyclad alga?. These fusulinids are mid-Permian in age (pre-middle Guadalupian) and of the Verbeckinid association; this association indicates a Tethyan affinity (Ross, 1967).

G. W. Moore (1969) located an additional phacoid of fossiliferous limestone on the west shore of Uyak Bay that yielded fragments of gastropods, pelecypods, echinoderms, a solitary coral, and the hydrozoan *Spongiomorpha* (N. J. Silberling, 1966, 1976, written communs.). Most fossil material here is of indeterminate age, but the *Spongiomorpha* is a form strikingly similar to a Late Triassic (Norian) hydrozoan on the Alaska Peninsula.

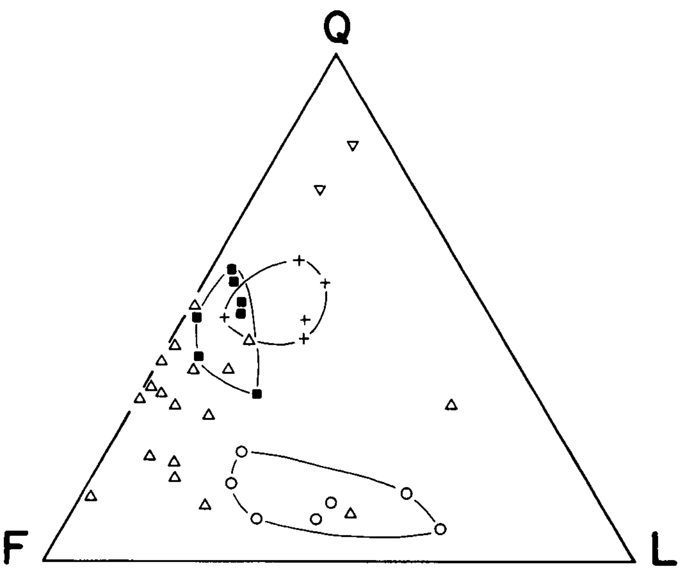
Perhaps limestone is rare in the Uyak Complex because most of the sediments were deposited in late Paleozoic and early Mesozoic time before the appearance of pelagic calcareous organisms: the proliferation of Coccolithophorids occurred in Jurassic time, and the first appearance of planktonic Foraminifera was not until the Cretaceous (Garrison and Fisher, 1969; Bosellini and Winterer, 1975). Alternatively, Uyak sediments may have been deposited after the proliferation of pelagic calcareous organisms, but below the carbonate compensation depth; thus they could be deep-water upper Mesozoic rocks. The thin-bedded limestone and argillite sequences described on Ban and Shuyak Islands are probable examples of Uyak sediments deposited after the appearance of pelagic calcareous organisms. The significance of the Tethyan affinity of the fusulinid limestone is not clear, but it may indicate that the limestone was conveyed to the Uyak plate margin from warmer latitudes, or perhaps that it formed as carbonate banks or reefs along the Alaskan margin in fairly shallow water (see Monger and Ross, 1971). The *Spongiomorpha* limestone may have originated on the Alaska Peninsula and then been introduced subsequently into the Uyak trench as a slide block.

Wacke

Massive wacke and contorted thinly interbedded wacke and argillite make up about 20% of the Uyak Complex and occur as variously sized tectonic blocks. Primary sedimentary structures are no longer recognizable in either variety. Wispy shear planes and white shatter veinlets of prehnite and/or calcite commonly are visible in hand specimens.

The two varieties of wacke are petrographically quite similar. They typically are medium grained, poorly sorted, and have diffuse grain boundaries surrounded by fine-grained matrices of phyllosilicates (mostly chlorite), prehnite, and/or pumpellyite. In thin section, fabrics of unsheared domains are isotropic to slightly flattened but locally are semischistose. These relatively well-preserved domains are separated by narrow anastomosing shear zones, which generally are 1 or 2 mm wide but which may make up an entire thin section or hand specimen. Movement along these shear fractures has cataclastically reduced grain size and produced a high percentage of granulated matrix (now recrystallized); rounded to augen-shaped relict grains and rock fragments are suspended in the mylonitic matrix. Point counting of 20 samples of Uyak wacke indicates that fine-grained matrix averages 28%, but this ranges from 16% to 41%. Secondary prehnite and pumpellyite are abundant and occur in veinlets and as replacement of matrix and plagioclase.

The determination of the modal mineralogy by point counting is hampered by the low-grade metamorphism and internal shearing. An average of 600 counts each was made on 20 samples and plotted on a standard quartz-feldspar-lithic diagram (Fig. 6), following the techniques of Dickinson (1970). Samples group into a more abundant arkosic wacke and a less abundant chert-clast wacke. Potassium feldspar accounts for less than 1.0% of all samples, so the ratio of plagioclase to total feldspar (P/F) is always near unity. The presence or absence of potassium feldspar is independent of the occurrence of secondary prehnite or pumpellyite, so its deficiency cannot be explained by its loss during low-grade metamorphic reactions. Unstable rock fragments consist almost entirely of andesitic clasts in the arkosic wacke and of both andesitic and basaltic clasts in the chert-clast wacke, giving rise to a ratio of volcanic rock fragments to total unstable lithic fragments (V/L) of about 1.0 in both. The ratio of chert to total chert plus quartz (C/Q) is low in the arkosic wacke and high in the chert-clast wacke. Quartz grains in all samples generally are monocrystalline, have nonundulatory extinction, and are cut by simple fractures; these characteristics suggest a volcanic parent rock (Blatt and others, 1972, p. 270–278). Clasts of radiolarian chert and variolitic greenstone are sparsely present in the arkosic wacke, whereas in the chert-clast wacke they are the main constituents. In addition to an almost complete lack of metamorphic and sedimentary rock fragments,



		C/Q	P/F	V/L
△	Uyak Arkosic Wacke	0.3	1.0	1.0
▽	Uyak Chert-Clast Wacke	0.9	1.0	1.0
○	Cape Current Sandstone	0.2	1.0	1.0
+	Kodiak Fm. Wacke	0.3	1.0	–
■	Sliver Wacke	0.2	1.0	–

Figure 6. Modal mineralogies of various clastic detrital rocks from northwest Kodiak Islands plotted on Q-F-L diagram; Q includes quartz and chert, F includes plagioclase and potassium feldspar, and L includes unstable lithic fragments.

secondary indicators of metamorphic and sedimentary provenance such as primary mica, gneissose or undulatory quartz grains, and well-rounded multicycled grains also are lacking. It is clear, then, that these clastic rocks were derived predominantly from an andesitic terrane. I interpret the Uyak wacke as having been deposited in an oceanic trench adjacent to an active volcanic arc.

The occurrence of radiolarian chert and greenstone fragments in the wacke may indicate some recycling of Uyak rocks whereby the deformed and uplifted "sea-floor scrapings" forming the trench inner wall were syntectonically eroded and redeposited with normal trench turbidites (Fig. 2). This mechanism of recycling was invoked by Cowan and Page (1975) to explain the occurrence of blueschist cobbles in a conglomerate of the Franciscan Complex which has only a prehnite-pumpellyite–facies background metamorphism. They believed that the most likely source for these cobbles was the syntectonic uplift and subaqueous erosion of landward wedges of the subduction complex. Cobbles such as radiolarian chert and greenstone are also present in this Franciscan conglomerate but are not as clearly exotic as the blueschist. Nothing as dramatic as this Franciscan example has been recognized in the Uyak Complex, but a similar origin is suggested for the chert-clast wacke and for the sparse clasts of greenstone and radiolarian chert in the more typical arkosic wacke.

Table 1 includes chemical analyses of ten samples of arkosic wacke and one sample of chert-clast wacke collected from widely spaced localities in the Uyak. Crook (1974) and Schwab (1975) postulated a correlation between the composition of wacke (framework components and volatile-free chemistry) and the geotectonic setting of the continental margin at which the wacke accumulates. There are two primary source areas for continental-margin wackes: quartz-rich sediments from a craton and quartz-poor sediments from a volcanic arc. Thus, on the basis of framework quartz, total SiO_2, and K_2O/Na_2O ratio, wacke should group into categories corresponding to Atlantic-type rifted margins, Andean-type consumptive margins (adjacent to a craton), and western Pacific-type consumptive margins (adjacent to an island arc). Atlantic-type margins are characterized by >65% quartz, average 70% SiO_2, and K_2O/Na_2O greater than 1.0; Andean-type margins have 15% to 65% quartz, average 68% to 74% SiO_2, and K_2O/Na_2O less than 1.0; and west Pacific–type margins have <15% quartz, average 58% SiO_2, and K_2O/Na_2O much less than 1.0 (Crook, 1974; Schwab, 1975). Uyak wacke has an average of 17% framework quartz, 66% SiO_2, and K_2O/Na_2O of 0.25, and therefore it appears to be an Andean-type wacke. The composition of Uyak wacke verges on the characteristics of a west Pacific–type wacke, possibly reflecting the primitive nature of the southwestern Alaskan craton in Uyak time. Note that the composition of the Upper Cretaceous Kodiak Formation (average 36% quartz, 73% SiO_2, K_2O/Na_2O = 0.26) reflects a greater contribution of cratonic sediment.

METAMORPHISM OF UYAK COMPLEX

Wacke in the Uyak Complex characteristically contains the metamorphic assemblage quartz-albite-chlorite-prehnite-pumpellyite-sphene ± calcite, pyrite, and celadonite. Relict detrital minerals in these rocks include hornblende, clinopyroxene, epidote, potassium feldspar, biotite, zircon, and apatite. Greenstone is characterized by the assemblage albite-pumpellyite-chlorite-sphene ± calcite, prehnite, quartz, pyrite, and epidote, commonly with rel-

TABLE 1. ANALYTICAL DATA FOR SOME KODIAK ISLANDS ROCKS

Sample	Location	SiO_2	TiO_2	Al_2O_3	$Fe2O_3$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	K_2O/Na_2	Framework quartz (%)
Uyak Complex															
S13c	North Cape Current Narrows	59.00	0.77	19.42	6.59	0.17	2.32	5.86	3.79	1.85	0.21	6.97	98.75	0.49	8
B16c	Southeast Foul Bay	66.66	0.66	15.14	5.92	0.11	2.87	3.79	3.91	0.84	0.11	3.75	99.91	0.22	16
M10c	Northeast Malina Bay	63.28	0.93	16.39	7.26	0.16	3.43	3.04	4.12	1.20	0.18	3.66	99.10	0.29	14
R10c	South Raspberry Island	69.58	0.30	15.04	4.15	0.12	1.97	2.05	6.07	0.61	0.10	2.88	97.88	0.10	37
N17c*	Noisy Island, Uganik Bay	74.59	0.38	8.06	4.07	0.10	1.63	8.52	1.79	0.71	0.16	7.70	97.83	0.40	6
U10a	Harvester Island, Uyak Bay	61.16	0.61	19.19	7.27	0.16	3.16	2.85	4.15	1.28	0.18	3.88	97.84	0.31	13
U14c	Southwest Uyak Bay	66.13	0.71	14.81	7.49	0.12	3.10	2.58	3.50	1.32	0.24	4.51	97.39	0.38	21
U15a	Southwest Uyak Bay	62.23	0.64	17.63	7.76	0.19	3.15	3.61	3.66	0.97	0.17	5.03	96.89	0.27	17
G4a	Bumble Bay, west Kodiak Island	68.05	0.55	14.46	5.66	0.14	2.22	4.30	4.12	0.34	0.17	3.52	97.88	0.08	22
G4b	Bumble Bay, west Kodiak Island	66.40	0.56	15.56	5.78	0.12	2.31	3.95	4.58	0.54	0.20	2.60	97.39	0.12	17
G4e	Bumble Bay, west Kodiak Island	71.00	0.48	12.83	5.60	0.12	2.00	4.03	3.67	0.14	0.15	3.29	98.06	0.04	32
Avg		66.19	0.60	15.32	6.14	0.14	2.56	4.05	3.94	0.89	0.17	4.34	98.08	0.25	
Cape Current															
S9a	Southeast Shuyak Island	63.48	0.72	17.39	5.73	0.11	2.42	3.34	5.40	1.20	0.20	3.51	98.34	0.22	6
S9d	Southeast Shuyak Island	63.32	0.79	18.14	5.83	0.11	2.41	1.94	5.17	2.10	0.21	2.87	97.91	0.41	7
S13a	Southeast Shuyak Island	63.26	0.74	17.71	5.99	0.14	3.18	3.37	4.18	1.21	0.25	4.31	97.24	0.29	7
S14b	Southeast Shuyak Island	63.74	1.06	16.77	7.69	0.13	2.80	2.03	4.82	0.84	0.14	4.18	98.26	0.17	19
Avg		63.45	0.83	17.50	6.31	0.12	2.70	2.67	4.88	1.33	0.20	3.72	97.94	0.23	
Kodiak Formation															
U9b	Northeast Uyak Bay	73.39	0.57	13.74	5.07	0.05	1.66	0.74	3.56	1.07	0.16	3.21	97.11	0.30	38
U13a	Southwest Uyak Bay	74.06	0.62	12.73	4.82	0.05	1.69	1.42	3.44	1.00	0.17	3.63	97.51	0.29	32
N14m	Southwest Uganik Island	70.91	0.63	11.38	7.79	0.21	2.00	3.91	2.74	0.30	0.13	5.65	97.52	0.11	44
R12f	Onion Bay, Raspberry Island	73.33	0.60	11.29	5.22	0.12	1.54	3.88	2.85	0.97	0.20	5.26	97.29	0.34	27
Avg		72.92	0.61	12.29	5.73	0.11	1.72	2.49	3.15	0.83	0.17	4.43	97.36	0.26	
Kodiak Slivers															
U6d	Northeast Uyak Bay	62.35	0.86	18.93	8.07	0.07	1.49	1.41	3.76	2.82	0.24	4.32	97.09	0.75	18
U7b	Chief Island, Uyak Bay	74.31	0.44	12.11	4.16	0.13	1.37	2.78	4.04	0.57	0.09	4.00	97.57	0.14	43
U7d	Chief Island, Uyak Bay	69.19	0.57	14.84	7.01	0.18	2.71	0.83	3.62	0.91	0.14	3.76	97.48	0.25	39
U15d	Southwest Uyak Bay	70.62	0.47	11.81	7.34	0.10	2.10	4.05	2.80	0.55	0.17	4.65	97.04	0.20	39
Avg		69.12	0.58	14.42	6.65	0.12	1.92	2.26	3.56	1.21	0.16	4.18	97.30	0.34	

Note: X-ray fluorescence analyses listed are anhydrous equivalents corrected to 100%. Totals consistently are low even though replicability is generally quite good; I believe this is because LOI at 1100 °C was not sufficiently hot to remove all structural water.

* Chert-clast wacke.

ict phenocrysts of clinopyroxene and plagioclase. Many of these metamorphic minerals are fine grained and petrographically evasive, so X-ray diffraction analyses of heavy-mineral separates were conducted on 24 samples to confirm identifications.

Prehnite is nearly ubiquitous in wacke but is absent in most greenstone. It occurs as fanning or intergrown idioblastic laths in veinlets with quartz or albite, as spongy amoeboid porphyroblasts replacing the sheared matrix, or as intergrown laths replacing plagioclase grains (Fig. 7). Single crystals commonly exceed 0.5 mm in length, and clusters of crystals may exceed 2.0 cm. Prehnite is often a major component in wacke and may constitute more than 13% of a sample.

Pumpellyite occurs in most samples of wacke and greenstone. It usually is colorless and occurs as very fine-grained acicular gray aggregates in sheared matrix and in plagioclase. In addition, greenstone sometimes contains small needles of green pleochroic pumpellyite in veinlets with albite.

Sphene also occurs as fine-grained mats and is often distinguishable from pumpellyite only by X-ray diffraction. Chlorite typically occurs as tiny plates in the matrix of wacke or as an alteration product of detrital biotite; pseudomorphs of chlorite after clinopyroxene are common in greenstone. Plagioclase has been albitized and has a characteristic cloudy appearance; secondary albite commonly fills shatter veinlets. Secondary epidote is quite rare in wacke and greenstone, but rounded detrital clasts are not uncommon in wacke.

The metamorphic mineral assemblages in these rocks are characteristic of the prehnite-pumpellyite facies; conditions did not exceed the prehnite-out isograd that marks the lower limit of the pumpellyite-actinolite facies (Coombs and others, 1970; Liou, 1971; Bishop, 1972; Surdam, 1973). The pressure and temperature conditions for the prehnite-pumpellyite facies are not well known and are influenced by variations in activities of components such as H_2O, CO_2, SiO_2, Ca^{++}, and H^+ (Coombs and others, 1970; Bishop, 1972), but estimates range from 200 to 350 °C and 3 to 5 kb.

The pervasively sheared nature of these rocks makes it difficult to establish a relationship between metamorphism and deformation. Shatter veinlets containing prehnite commonly cut foliation and are therefore posttectonic. However some veinlets cutting foliation are in turn truncated by later brittle fractures, indicating some postmetamorphic deformation. Prehnite growing in the sheared matrix in wacke generally is undeformed and therefore posttectonic, but the local occurrence of deformed prehnite in shear zones suggests that metamorphism was syntectonic as well. In a subduction

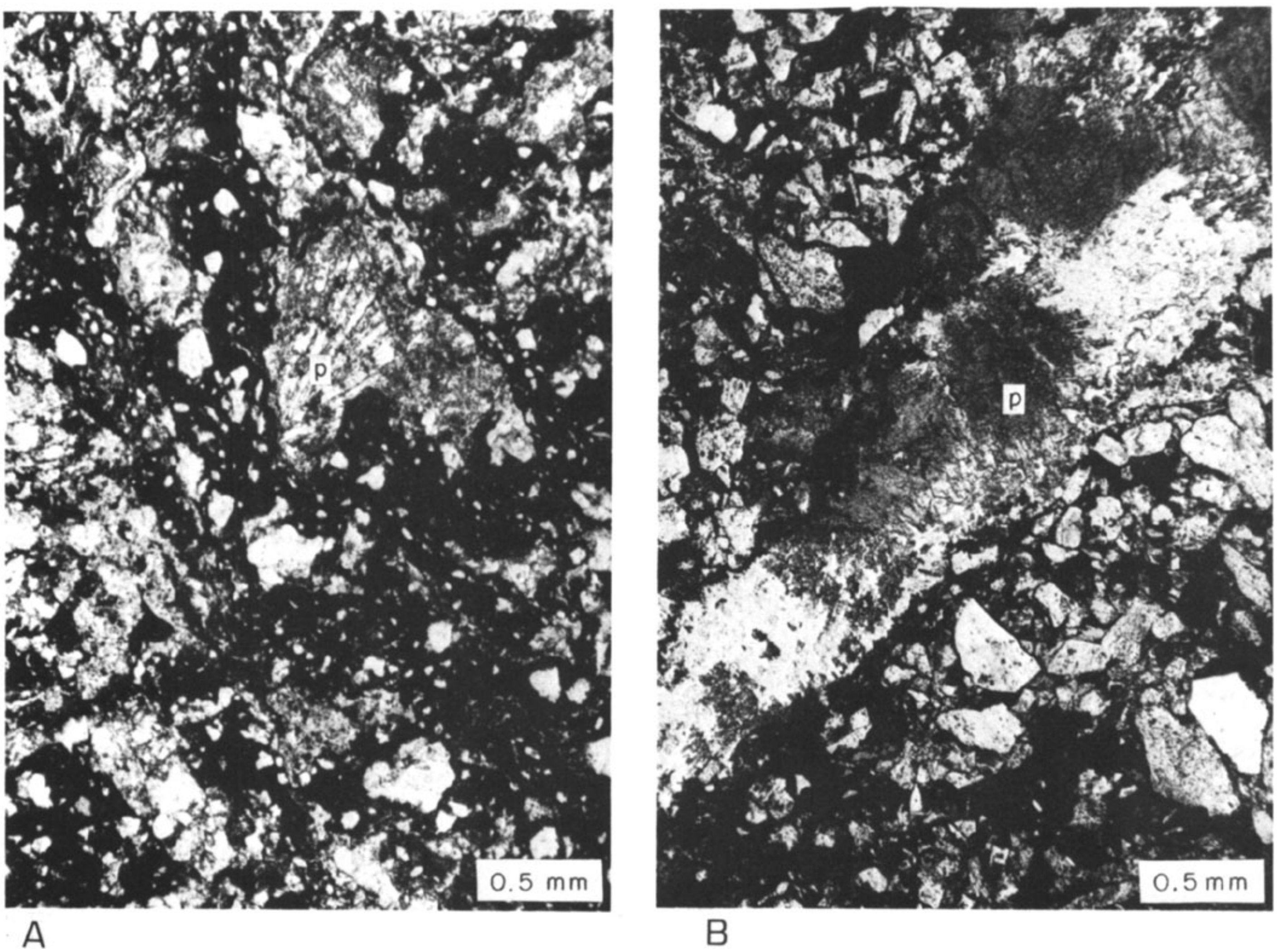


Figure 7. Photomicrographs of well-developed prehnite (p) in Uyak wacke collected from Gurney Bay area, (A) replacing matrix with fanning laths, and (B) filling shatter veinlet with quartz.

model, this may indicate that metamorphism occurred during active underthrusting (syntectonic metamorphism), continued after accretion of the subduction wedge onto the overthrust plate (posttectonic metamorphism), and was followed by late fracturing and cataclasis during uplift of the subduction complex (postmetamorphic deformation). A similar progression of deformation was suggested by Glassley and Cowan (1975) for Franciscan rocks.

LITHOLOGY AND METAMORPHISM OF RELATED ROCKS

Kodiak Islands Schist Terrane

A 40 by 3 km belt of schists borders the northwest side of the Uyak Complex through Raspberry, Afognak, and Ban Islands, and a smaller body is exposed at the mouth of Uyak Bay (Fig. 1; Martin, 1913; Capps, 1937; Carden and others, 1977). This metamorphic terrane consists mainly of thinly layered and complexly folded quartz-mica schist (quartz–white mica ± garnet), greenschist (chlorite-epidote-albite), crossite-epidote schist (crossite-epidote-albite-chlorite ± white mica, sphene, calcite, and quartz), and epidote amphibolite (blue-green amphibole-plagioclase-epidote ± chlorite, sphene or rutile, white mica, calcite, quartz, and rarely crossite). Lawsonite has been identified from one schist sample at the Uyak Bay locality, but elsewhere the blueschist-facies index minerals lawsonite, jadeitic pyroxene, and aragonite have not been recognized. These schists were metamorphosed under relatively high pressure-temperature conditions (Carden, 1977; Ernst, 1973; Maresch, 1973).

The most complete sections of the schist belt occur at Malina and Paramanof Bays. Our limited sampling from this belt suggests that the metamorphic grade increases toward the northwest from blueschists in the southeast to epidote amphibolites in the northwest, although it is not known if the belt is internally imbricated. This schist terrane is juxtaposed against the structurally underlying Uyak Complex along the Raspberry fault (Fig. 1) and is separated from the structurally overlying Shuyak Formation by the Afognak pluton and inferred Shuyak fault (discussed below).

K-Ar age determinations from blueschists are 170.0 ± 5.5 and 187.6 ± 5.6 m.y. from, respectively, coexisting crossite and white mica at east Malina Bay, and 161.4 ± 19.4 m.y. from crossite at west Uyak Bay; because the lattice structure of crossite may leak argon and therefore produce anomalously young ages, the white mica age is considered most reliable (Carden and others, 1977). Similarities in lithology, mineral ages, and tectonic setting indicate that the Kodiak Islands schists are the southwestern extension of the blueschist-bearing Seldovia schist terrane on southern Kenai Peninsula (Forbes and Lanphere, 1973). Carden and others (1977) interpreted the Kodiak-Seldovia schist terrane as a subduction complex emplaced in part during Early Jurassic time simultaneous with blueschist metamorphism (discussed below). It is not known why this subduction complex is represented only by schists or why the belt is discontinuous.

The Afognak pluton usually separates the Kodiak Islands schist terrane from the Shuyak Formation. It locally diverges from this position, and sections of Shuyak Formation pillow lava may be preserved on the southeast side of the intrusion along the west shores of Malina and Shangin Bays. This long narrow pluton consists of foliated and massive diorite and quartz diorite containing abundant hornblende and little or no biotite. K-Ar hornblende ages from the pluton are 183.7 ± 5.5 and 188.4 ± 5.7 m.y. at north Raspberry Island and 192.7 ± 5.8 m.y. at Afognak Island (Carden and others, 1977). Zones bordering both sides of the pluton are thermally metamorphosed, and migmatites and aplitic dikes locally are prominent. Most of the contact-metamorphosed rocks are amphibolites (hornblende-plagioclase ± biotite, chlorite, epidote, muscovite, and quartz) with crudely schistose textures, but hornfelsic textures also are present. Pillow structures occasionally are preserved in Shuyak Formation amphibolites, and the interpillow limestone is metamorphosed to calc-silicate rock (garnet-calcite ± plagioclase, diopside, talc, chlorite, and hornblende). On the basis of the limited distribution of collected samples, it appears that the width of the thermally overprinted border zone is less than 1.0 km.

The relationship between the blueschist-bearing Kodiak Islands schists and the apparently coeval Afognak pluton is uncertain, but field relations and metamorphic facies suggest that the pluton was synkinematically intruded between the schists and the Shuyak Formation and that rocks adjacent to the pluton were upgraded in the process. Alternatively, it may be that the Afognak pluton and its thermally metamorphosed aureole were structurally juxtaposed against the blueschist-bearing schist terrane, or that the schists are older than the pluton and that the intrusion of the pluton reset the radiometric ages of the schists.

Shuyak Formation

On the northwest side of Afognak and Shuyak Islands are exposed previously unmapped sections of pillowed greenstone and volcaniclastic turbidites of the Upper Triassic Shuyak Formation; the unfossiliferous volcanogenic rocks exposed at the Middle Cape area of westernmost Kodiak Island are probably an isolated remnant of the Shuyak Formation (J. C. Moore and others, in prep.). The Shuyak Formation structurally overlies the Kodiak Islands schist terrane and Uyak Complex but generally is separated from them by the Afognak pluton (Fig. 1). The Shuyak Formation consists of a lower volcanic member and an upper sedimentary member. Although major outcrops of the two members are in fault contact, local sedimentary intercalations in the upper parts of the volcanic member suggest that it is succeeded by the sedimentary unit. Moreover, the sense of displacement along fracture cleavages adjacent to the fault contact indicates that the sedimentary member has been dropped down relative to the volcanic member.

The volcanic member occupies a narrow belt bounded on the southeast by the Afognak pluton and on the northwest by a fault juxtaposing it with the sedimentary member. It is a coherent unit consisting mainly of vesicular pillowed greenstone with interpillow limestone, but locally containing beds of pillow breccia, agglomerate, tuff, and argillite. No fossils have been recovered from these rocks. Major- and trace-element analyses of the greenstone suggest that most is volcanic-arc tholeiitic basalt (Hill and Gill, 1976).

The sedimentary member of the Shuyak Formation consists of well-bedded volcanic turbidites, conglomerate, siliceous tuff, and argillite, either broadly folded or homoclinally dipping to the southeast (Fig. 8). Graded beds with sole markings and complete Bouma sequences indicate deposition by density currents. The pelecypod *Halobia* cf. *H. halorica* (N. J. Silberling, 1976, written commun.) was collected from three localities and indicates a Late Triassic (early to middle Norian) age. Preliminary petrographic examination of Shuyak sandstone indicates that it is rich in andesitic rock fragments and plagioclase, with less quartz and clinopyroxene (J. C. Moore, 1977, personal commun.). The metamorphism has not been studied in detail, but secondary prehnite and/or pumpellyite are present in many samples.

I tentatively interpret the pillowed greenstone of the Shuyak Formation as volcanic-arc tholeiites (see Jakeš and Gill, 1970) that were generated during the initial phase of volcanism accompanying early Mesozoic subduction. The apparent stratigraphic position beneath the Norian sedimentary member and the geochemistry of this greenstone suggest that it correlates with the Nikolai Greenstone of south-central Alaska (MacKevett, 1970). The overlying sedimentary member of the Shuyak Formation is interpreted as the seaward margin of the early Mesozoic forearc basin that existed during emplacement of the Kodiak-Seldovia schist terrane. These volcaniclastic rocks correlate with sections of similar lithology and age on the Barren Islands and on the Kenai and Alaska Peninsulas, which together outline the extent of this forearc basin in southwestern Alaska. Furthermore, lithologic and biostratigraphic equivalents of the Shuyak Formation occur in southeastern Alaska, suggesting that the magmatic arc was continuous around the Alaska orocline during early Mesozoic time (Moore and Connelly, 1977; Connelly, 1976).

Cape Current Terrane

In the Cape Current area of southeastern Shuyak Island and northernmost Afognak Island, a narrow belt of atypical sedimentary and igneous rocks is exposed which I informally shall call the Cape Current terrane (Fig. 1). This moderately deformed and slightly metamorphosed terrane is composed of bedded sandstone with minor pillow lava, pillow breccia, and pelagic limestone. It occupies a structural position between the Uyak Complex and Kodiak Formation but is distinct from both.

Sandstone of the Cape Current terrane occurs as coherent sequences of medium- to thick-bedded turbidites that dip steeply to the northwest. Sedimentary structures such as sole marks and Bouma sequences sometimes are recognizable and indicate deposition by density currents. Cape Current sandstone is texturally distinct from sheared Uyak wacke but similar to Kodiak wacke: it is medium-grained, poorly sorted, and lacks penetrative deformation. The quartz/feldspar/lithic ratios of this sandstone are distinct from those of both the Uyak and Kodiak wackes, whereas the secondary parameters of all three rocks are similar (Fig. 6). The abundance of andesitic clasts, plagioclase, and hornblende in the Cape Current sandstone indicates derivation from a volcanic source area.

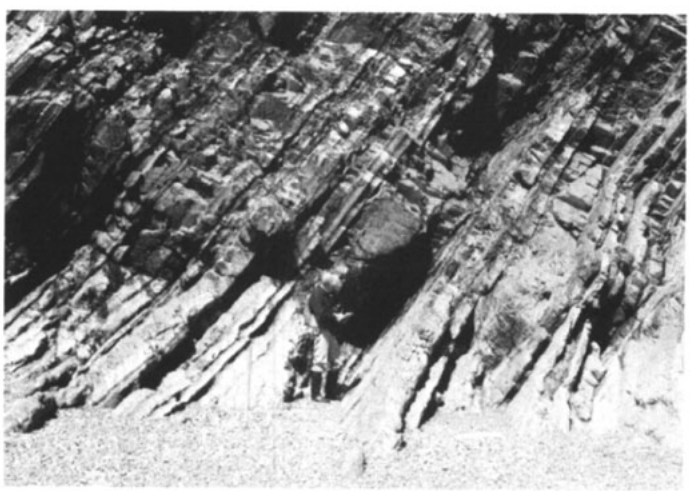


Figure 8. Sedimentary member of Shuyak Formation near Black Cape, Afognak Island. Note well-preserved bedding in volcaniclastic turbidites.

X-ray diffraction analyses of both heavy- and light-mineral separates from seven sandstone samples reveal no prehnite, pumpellyite, or zeolites. Secondary minerals observed include chlorite, calcite, sphene, and pyrite, and relict detrital minerals include hornblende, biotite, and epidote.

Sections of vesicular pillow lava and pillow breccia locally occur in the Cape Current terrane. They are coherent units and are closely associated with the bedded sandstone. In the few samples I have investigated, these rocks appear only slightly altered and contain abundant plagioclase and clinopyroxene. Petrographically these appear to be basaltic rocks, but no chemical analyses are available.

The Cape Current terrane includes two bodies of red pelagic limestone along the southeast shore of Shuyak Island. These rocks are tightly folded and thin bedded and include many siliceous layers. Small-scale laminations are preserved in many of the individual beds. The limestone contains poorly preserved planktonic foraminifers of Late Cretaceous age (approximately Turonian to early Santonian; W. V. Sliter, 1976, written commun.). Transmission electron microscopy of the limestone reveals occasional coccoliths, which are too poorly preserved for dating (S. Horan, 1976, personal commun.).

Kodiak Formation and Extraformational "Slivers"

The Kodiak Formation underlies most of the Kodiak Islands (Fig. 1). It is juxtaposed on the northwest against the Uyak Complex by the Uganik thrust, and on the southeast against the Ghost Rocks Formation by an unnamed fault. The Kodiak Formation consists of steeply dipping medium- to thick-bedded arkosic wacke and shale with occasional beds of pebbly conglomerate (Moore, 1969) that are deformed into tight large-scale folds and locally into broken formation. X-ray diffraction analyses of heavy-mineral separates from four wacke samples reveal no prehnite or pumpellyite. The Kodiak Formation correlates with the Shumagin Formation to the southwest on the Shumagin and Sanak Islands (Burk, 1965; Moore, 1972) and with at least part of the Valdez Group to the northeast on the Kenai Peninsula (Clark, 1973). Jones and Clark (1973) have documented the occurrence of Late Cretaceous (Maestrichtian) *Inoceramus kusiroensis* at scattered localities in the Shumagin-Kodiak-Valdez belt.

A number of kilometre-thick "slivers" of coherently bedded wacke having tectonic contacts occur within the Uyak Complex. These slivers in all respects resemble the Kodiak Formation but occur as far as 3 km structurally above the major thrust fault (Uganik thrust) juxtaposing the Kodiak Formation with the Uyak Complex. Figure 6 illustrates how sliver wacke resembles Kodiak wacke in modal mineralogy, and Table 1 shows their geochemical similarities. In contrast to most Uyak wacke, sliver wacke and Kodiak wacke are not internally sheared and do not contain secondary phrenite or pumpellyite. Moreover, *Inoceramus* fragments were collected from a sliver locality on east Shuyak Island; these offer convincing evidence of their faunal association with the Kodiak Formation.

On the basis of paleocurrent patterns, style of deformation, stratigraphy, and regional geology, the Kodiak Formation and correlative rocks have been interpreted as a trench and associated deep-sea sequence that was accreted to the southwestern Alaska margin during Late Cretaceous subduction (Plafker, 1972; Moore, 1973a, 1973b; Jones and Clark, 1973; Budnik, 1974). Because of the small amount of structural data available at most sliver localities, I have not determined the mechanism of their insertion. However it is likely that they were emplaced during Late Cretaceous underthrusting of the Kodiak Formation beneath the Uyak Complex.

STRUCTURAL GEOLOGY

Uyak Complex

The Uyak Complex is a chaotically dislocated and pervasively sheared assemblage of deep-sea lithologies. Mesoscopic shear fractures and innumerable faults of unknown magnitude have disrupted stratal continuity and juxtaposed contrasting sedimentary and igneous rocks. Shear surfaces contain slickensides and occur both as subparallel anastomosing fractures in competent lithologies such as wacke and greenstone and as more closely spaced fractures in the less competent argillaceous rocks (Fig. 9). The more brittle rock types are broken into angular phacoids and either juxtaposed against other tectonic blocks or enclosed in the highly deformed gray chert and argillite matrix. These tectonic inclusions range from millimetres to kilometres in size and are aligned with their longest dimensions subparallel to foliation. The structural style of this terrane is best described as *tectonic mélange* (Cowan, 1974; Hsu, 1974). Although lithologically chaotic, the fabric of this mélange is surprisingly orderly (Moore and Wheeler, 1975).

The orientation of fracture cleavages and faults in the complex define a foliation that trends consistently northeast and dips steeply northwest (Connelly and Moore, 1977). This foliation dips much more steeply than the inclination of modern Benioff zones at shallow depths. This apparent anomaly may be explained by Seely and others' (1974) model for accretion at convergent plate margins whereby thin wedge-shaped slices of deep-sea sediments are progressively inserted along landward-dipping thrust surfaces at the foot of the trench inner wall, causing the progressive landward rotation of the subduction complex (Fig. 2).

A detailed structural analysis of the Uyak indicates that the mean direction of slip during deformation was N38° ± 11°W and that structural transport was southeast under northwest (Moore and Wheeler, 1975). Thus, it appears that the Uyak was thrust beneath the early Mesozoic rocks on the northwest side of the Kodiak Islands; this underthrusting was toward the presumably coeval volcanoplutonic arc to the northwest on the Alaska Peninsula.

Major Faults

The contrasting characteristics of the Kodiak Islands schist terrane and the Shuyak Formation indicate that a major fault must separate them, but this fault is now obscured by the Afognak pluton that occurs between the two units (Fig. 1). I believe that this fault is a major early Mesozoic thrust; I shall call it the Shuyak fault. The Shuyak fault correlates with the Port Graham fault on southern Kenai Peninsula which juxtaposes Upper Triassic and Lower Jurassic volcanogenic rocks on the northwest against blueschist-bearing metamorphic rocks of the Seldovia schist terrane (Carden and others, 1977; Magoon and others, 1976; Forbes and Lanphere, 1973). The combined Shuyak–Port Graham fault may represent a trace of the early Mesozoic plate boundary along the margin of southwestern Alaska.

The Uyak Complex is bounded on the northwest by a fault juxtaposing it with either the Kodiak Islands schist terrane or the Afognak pluton; this is named the Raspberry fault. The Raspberry fault marks the southeastern extent of early Mesozoic rocks along this margin and may therefore be the trace of the continental margin at the time of Uyak accretion.

The Uyak Complex is underthrust by the Kodiak Formation along a steeply northwest-dipping thrust fault, here named the Uganik thrust (Fig. 1; Moore and Connelly, 1977). The Uyak and Kodiak rocks responded differently to the faulting that juxtaposed them. The underthrust turbidite sequence was transformed into a 1-km-thick broken formation adjacent to the thrust contact, whereas deformation in the more rigid Uyak rocks was concentrated in a zone 1 to 500 m wide and is expressed by an overprinted fracture cleavage but no remobilization of layering. This broken formation is identical in structural style to those occurring throughout the Kodiak Formation, and it apparently developed during underthrusting. Tectonic mixing in the Uganik thrust zone inserted kilometre-sized "slivers" of Kodiak Formation lithology into the Uyak as far as 3 km structurally above the thrust contact, and mixed smaller blocks of Uyak lithology as far as 0.5 km into the Kodiak broken formation. The local occurrence of well-bedded Kodiak turbidites separated from the Uyak by a simple fault trace suggests some recent reactivation of this fault surface.

The Uganik thrust correlates with the Chugach Bay fault on southern Kenai Peninsula (Cowan and Boss, 1978) and the Eagle

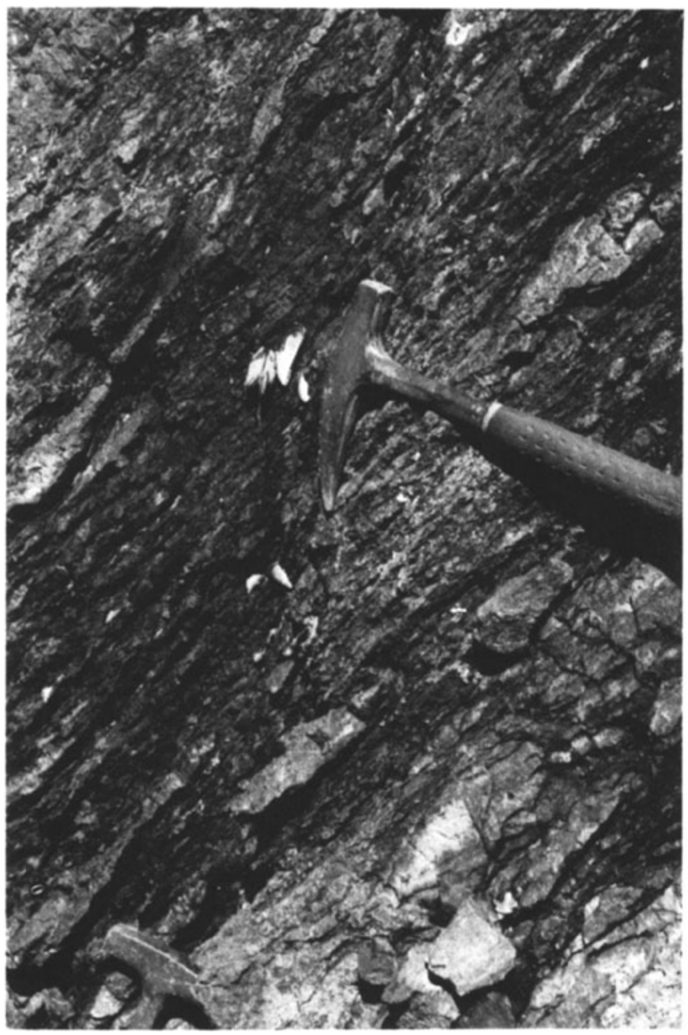


Figure 9. Foliated, matrix-rich fabric characteristic of most Uyak mélange.

River thrust in the Anchorage area (Clark, 1972), where it juxtaposes the McHugh Complex against the Valdez Group. Because of uncertainties as to the age of emplacement of the Uyak-McHugh belt (discussed below), the significance of the Uganik–Eagle River thrust is unclear. If the Uyak-McHugh belt was emplaced in late Early Cretaceous time, then these rocks are older than the Upper Cretaceous Kodiak-Valdez trench deposits, and the thrust must mark a trace of the Late Cretaceous plate boundary. However if the Uyak-McHugh belt was emplaced in Late Cretaceous time and is genetically related to the Kodiak-Valdez (preferred model), then the thrust juxtaposes the more deeply subducted and more highly metamorphosed Uyak-McHugh rocks against the Kodiak-Valdez trench deposits. The occurrence of more highly metamorphosed rocks along the arcward side of subduction complexes has been noted at other convergent margins (see, for example, Suppe, 1972; Cowan, 1974) and may be attributed to differential uplift of the subduction complex from continued underplating of deep-sea sediments at the foot of the trench inner wall (Ernst, 1975; Seely and others, 1974).

AGE OF EMPLACEMENT

Limits on the age of emplacement of a subduction complex may be determined from its incorporated fossils. However these include pelagic fossils such as radiolaria, coccoliths, and foraminifera, which are deposited with abyssal sediments on oceanic crust before being offscraped and accreted at a consuming plate margin, and fossils interbedded with trench turbidites that accumulate during subduction. The former provide only a lower limit on the age of emplacement, whereas the latter closely approximates that age. Either fossil type may occur in structurally coherent offscraped packages that young seaward, or in extraformational slivers that are inserted into previously accreted packages. More definitive evidence for the time of active subduction may be obtained from (1) radiometric ages of high-pressure subduction-zone metamorphic rocks, (2) biostratigraphic ages from the associated forearc-basin deposits, and (3) radiometric ages from the associated magmatic arc.

Mainly Early Jurassic K-Ar ages from blueschists of the Kodiak-Seldovia schist terrane apparently provide a reliable measure for its age of emplacement (Fig. 10). This estimate approximately coincides with the prominent Late Triassic to Middle Jurassic andesitic volcanism recorded in the rocks of the arc and forearc basin on the Alaska and Kenai Peninsulas (Burk, 1965; Detterman and Hartsock, 1966; Martin, 1915) and on the Kodiak and Barren Islands (Cowan and Boss, 1978; Moore and Connelly, 1976); and with the 176 to 154 m.y. B.P. phase of plutonism in the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973).

The age of emplacement of the Uyak-McHugh complex is problematical. Radiolaria from Uyak cherts range in age from Paleozoic to mid–Early Cretaceous (Valanginian to Aptian) and provide a lower limit for the age of accretion (Fig. 10). The Permian fusulinid limestone and Upper Triassic *Spongiomorpha* limestone also provide lower limits. The youngest fossils included in the complex are *Inoceramus* prisms from an extraformational "sliver" of probable Kodiak Formation. Thus fossil evidence alone can limit the age of emplacement only to post-Valanginian. It is therefore useful to identify the associated magmatic arc and attempt to indirectly determine the age of emplacement.

The early Mesozoic phase of magamtism on the Alaska Peninsula was followed by the uplift and erosion of pre-existing plutons and deposition of Upper Jurassic (Oxfordian) to Lower Cretaceous (Valanginian) nonvolcanic plutoniclastic beds (Burk, 1965; Detterman and Hartsock, 1966). These rocks are truncated upsection by a strong unconformity that locally is succeeded by uppermost Cretaceous (Campanian and Maestrichtian) volcanic-rich strata. Similarly, early Mesozoic plutonism on the Alaska Peninsula was succeeded by a hiatus, which in turn was succeeded by a Late Cretaceous to Paleocene event yielding K-Ar ages of 83 to 58 m.y. (Reed and Lanphere, 1973).

I suggest that the Uyak-McHugh complex was emplaced during Late Cretaceous subduction coincident with magmatism on the Alaska Peninsula. The only likely alternative is Early to middle Cretaceous (post-Valanginian) emplacement, but if such an event occurred, it produced insignificant magnatism.

The Kodiak Formation and Valdez Group are interpreted as

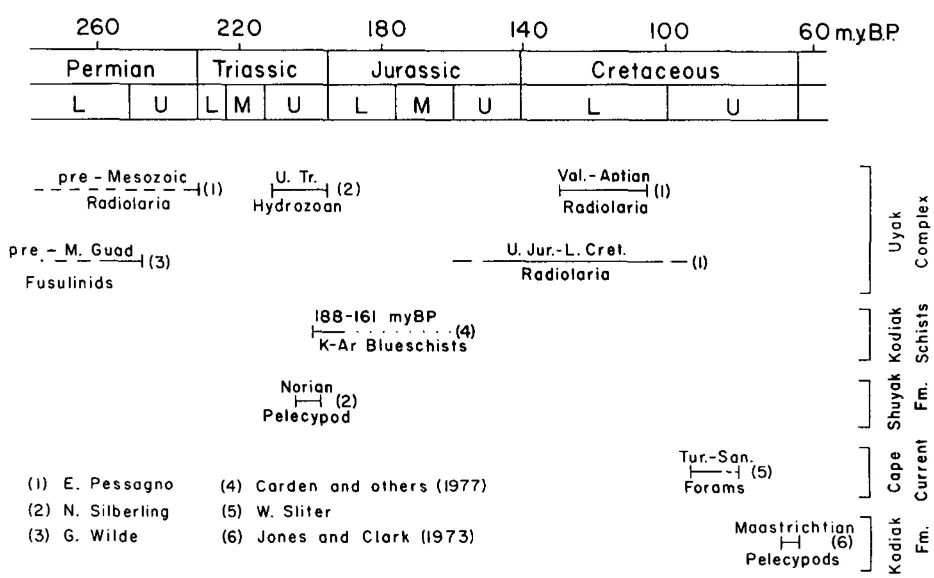


Figure 10. Summary of age data from Uyak Complex, Kodiak Islands schist terrane, Shuyak Formation, Cape Current terrane, and Kodiak Formation.

trench turbidites, so the Upper Cretaceous (Maestrichtian) pelecypods in these rocks presumably provide a close estimate for the time of active subduction and accretion. This estimate coincides with the Late Cretaceous magmatism on the Alaska Peninsula. Therefore, the relationship between the Uyak-McHugh and Kodiak-Valdez rocks is unclear. Perhaps they represent two phases of Late Cretaceous accretion, or perhaps the Uyak-McHugh is a more deeply subducted abyssal facies and the Kodiak-Valdez a late-stage trench-fill facies of the same Late Cretaceous accretionary event.

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