© CircumPacific Council for Energy and Mineral Resources 2008 – Tectonostratigrahic
Terranes of the Circum-Pacific Region, Earth Science Series, Number 1, 1985.

Cenozoic Migration of Alaskan Terranes Indicated by Paleontologic Study

R. von Huene
G. Keller
T. R. Bruns
K. McDougall
U.S. Geological Survey
Menlo Park, California

Comparisons of microfossils from deep-sea cores, from samples of an exploratory drill hole, and from dredged rocks of the Gulf of Alaska, with coeval microfossil assemblages on the North American continent, provide constraints on the northward migration of the Yakutat block and the Prince William terrane during Tertiary time. The estimated paleolatitudes of microfauna and flora indicate that: (1) the Prince William terrane was attached to North America in its present position by middle Eocene time (40 to 42 Ma), consistent with models derived from paleomagnetic data, and (2) the adjacent Yakutat block was 30 ± 5° south of its present position in early Eocene (50 Ma), 20 ± 5° south in middle Eocene (40 to 44 Ma), and 15 ± 5° south in late Eocene time (37 to 40 Ma), thus requiring a northward motion of about 30° since 50 Ma. Moreover, the Yakutat block was at least 10° south of the Prince William terrane during Eocene time. These data are consistent with migration of the Yakutat block with the Pacific and Kula plates for at least the last 50 Ma.

The collision of the Yakutat block with North America resulted in subduction of the block coincident with uplift of the Kenai Mountains. The extension of the Kenai Mountains into the Kodiak area suggests that a southwest extension of the Yakutat block collided with the Kodiak margin and was completely subducted. The subducted extension of the Yakutat block could have connected the now subducting head of Zodiak deep-sea fan to a North American source of sediment during deposition of the fan.

INTRODUCTION

A comparison of microfossils from the gulf of Alaska, with coeval assemblages from California, Oregon, and Washington, provide constraints on past positions of allochthonous terranes. We summarize the paleontologic data in a number of informal and unpublished reports of the U.S. Geological Survey (USGS), the State of Alaska, the Deep Sea Drilling Project (DSDP), and the Middleton Island exploratory well that was released to us by Tenneco Oil Company. From this biostratigraphy there emerges a paleo-oceanographic history of two terranes in the western Gulf of Alaska.

Recent geological and geophysical studies around the Gulf of Alaska indicate a Cenozoic northward drift of large crustal fragments that are now lodged in the Alaskan continent (Stone and Parker, 1979; Plumley et al, 1982; Stone et al, 1982; Bruns, 1983a; Plafker, 1983; Moore et al, 1983). The movement histories proposed are based on incomplete data, and although all schemes agree on northward drift, each is different. The major differences involve the amounts of northward motion and the timing of this motion. The biostratigraphic data presented here provide additional constraints on the northward drift history suggested by geologic and paleomagnetic data.

The Prince William terrane and Yakutat block have moved north during the Cenozoic (Jones et al, 1981; Rogers, 1977). In the Kodiak group of islands, the Prince William terrane of Jones et al (1981) includes not only some insular terrane but also the shelf adjacent to the Kodiak group of islands and Kenai Peninsula (Fig. 1). The Yakutat block, to the north and east, is bounded on the northeast by the Fairweather fault and the Chugach–Saint Elias thrust fault system, on the west by the thrust faults paralleling Kayak Island and crossing the adjacent shelf, and on the south by the base of the continental slope. The biostratigraphic and paleoclimatic records presented here set constraints independent of plate tectonic models on some positions during the Cenozoic migration of these terranes.

Our study, based on new materials from the Middleton Island well, cores and dredge samples off Kodiak Island, and on a review of original materials from studies of other investigators, is reported in a more extensive paper by Keller et al (1984). We focus here on the tectonic consequences of that study and add some speculations with regard to terranes that may have been completely subducted just as the western part of the Yakutat block is presently being subducted beneath Alaska.

BIOSTRATIGRAPHIC AND PALEO-OCEANOGRAPHIC ANALYSES

Samples from the onshore and offshore regions of the Gulf of Alaska have been examined for planktonic and benthonic foraminifers, coccoliths, and diatoms to determine their age and paleoclimatic conditions of deposition. To obtain relative paleolatitudes, faunal assemblages were correlated with onshore marine sequences of California, Oregon, and Washington in areas

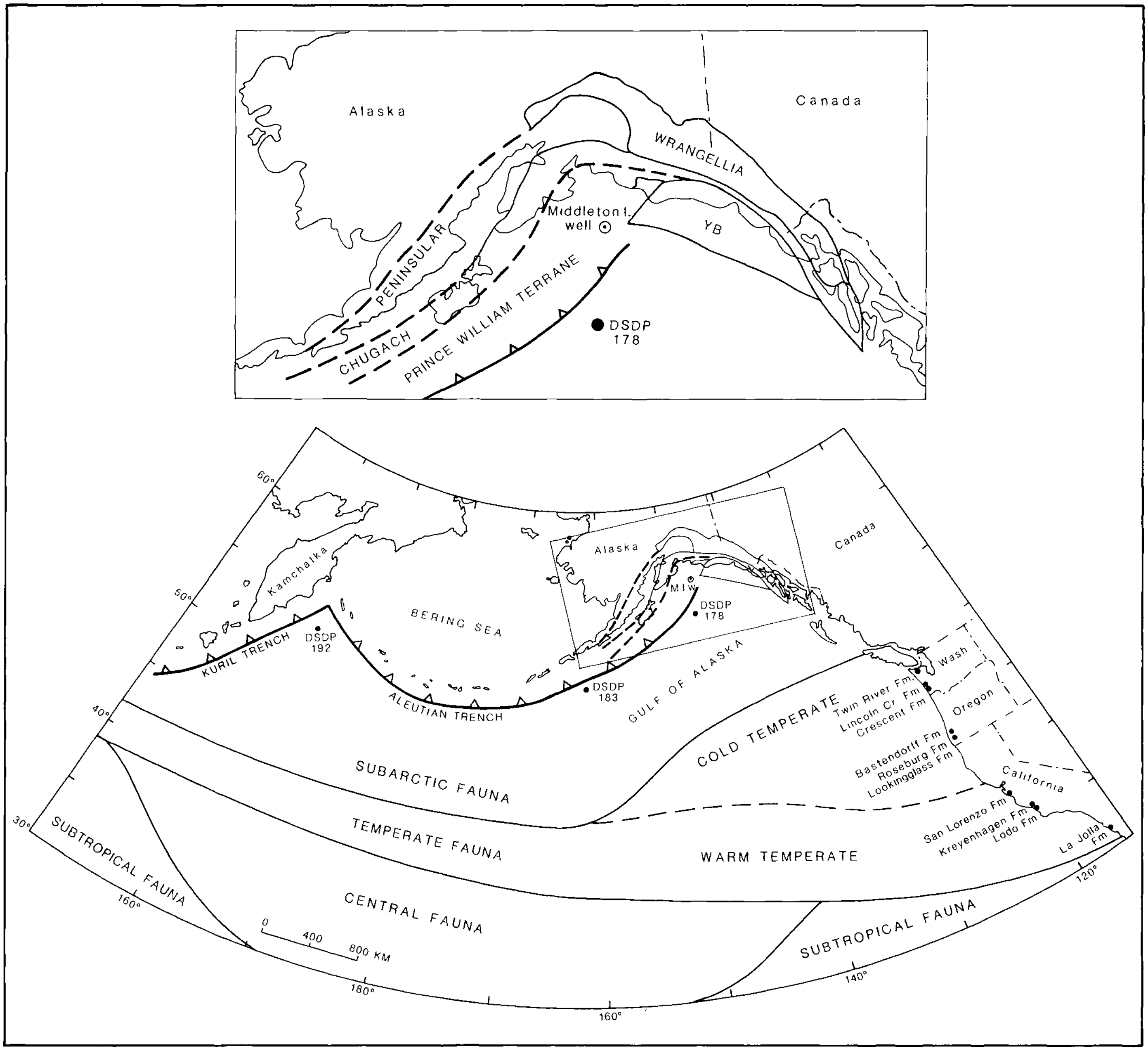

Figure 1—Location map of sites studied, terrane boundaries after Jones et al (1981), and geographic distribution of present faunal provinces. YB = Yakutat block.

that were stable since the sequences were deposited. In addition, general paleolatitudes are derived from comparison with the present distribution of planktonic faunal provinces (subtropical, temperate, subarctic; Fig. 1). The comparisons with present provinces are adjusted for the effects of major paleoclimatic changes. The main effect of globally warmer conditions, for instance, during early and middle Eocene time, was a northward shift of the faunal provinces; conversely, during globally cooler conditions of latest Eocene and Oligocene time, the subarctic fauna expanded southward. Therefore, our paleolatitude determinations based on planktonic faunal provinces may be 5 to 10° in error during times of climatic extremes.

Microfossil analyses were provided by several of our colleagues as well as from published sources. Coccoliths examined earlier and for this report were analyzed by Bukry (in Plafker et al, 1979, 1980; Poore and Bukry, 1978). Benthonic foraminifers were examined and reported by Rau (Rau et al, 1977; Rau, 1978; Plafker et al, 1979, 1980) and for this study by McDougall (Keller et al, in press). Planktonic foraminifers were reported for three dredge samples by Poore (Poore and Bukry, 1978) and were examined for this study by Keller. Diatoms originally studied by Koizumi (1973) for sites 192 and 183 and Schrader (1973) for site 178 were reexamined by Harper (1977) and by Barron (unpublished data). Paleontologic data are summarized in Figure 2 with respect to age, paleodepth and paleoenvironment; time scale is after Berggren et al (in press).

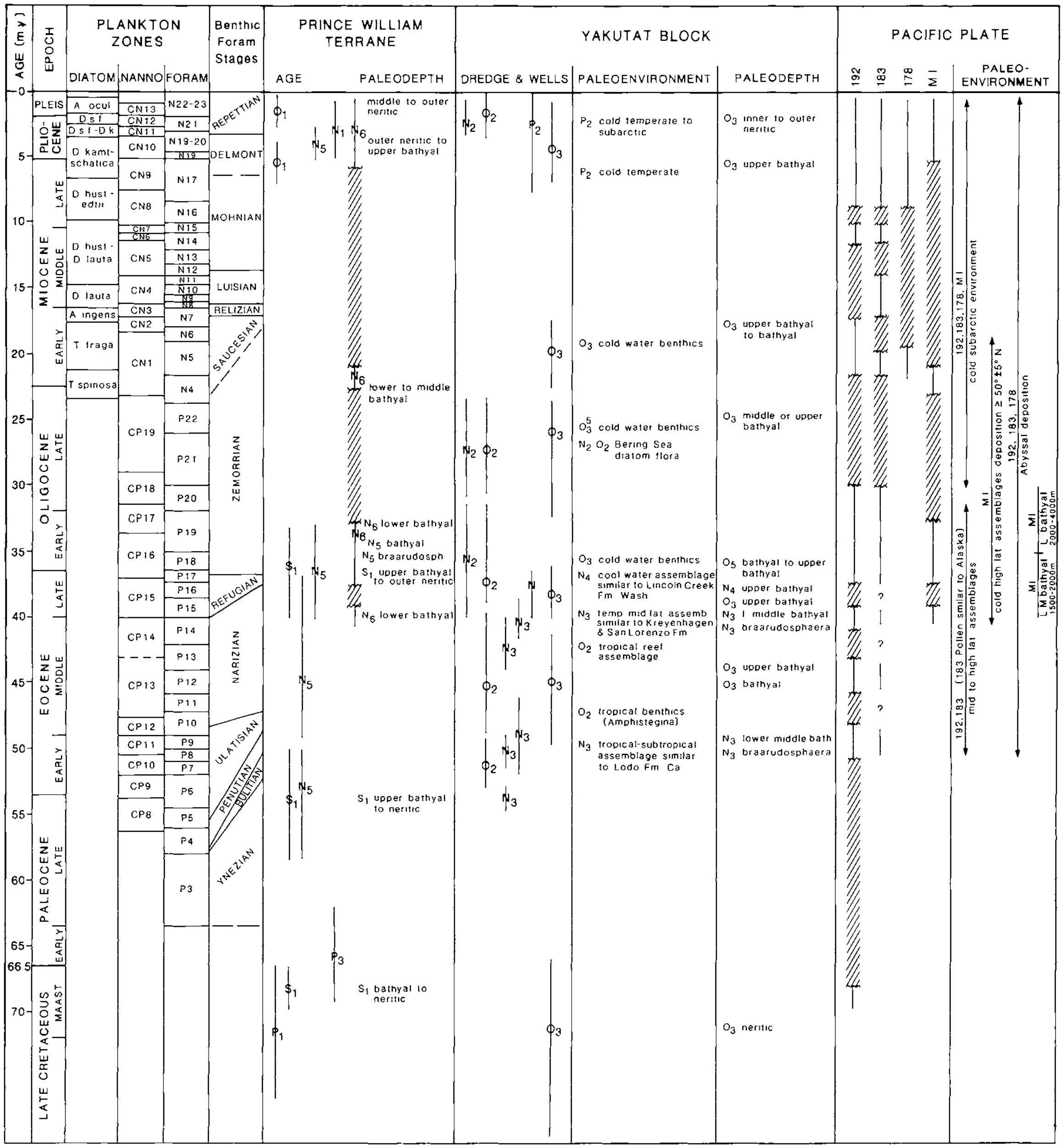

Figure 2—Biostratigraphy, age ranges, paleodepth, and paleoenvironment of samples studied for this report and/or published earlier from the Prince William terrane, Yakutat block, and Pacific plate. Absolute age scale after Berggren et al (in press), plankton zones after Barron (1980, diatoms), Okada and Bukry (1980, nannofossils), Blow (1969, foraminifera), and California benthic stages after Poore (1980). Diagonal lines mark hiatuses. Codes: N = samples studied for this report; N1 (Keller, unpublished data, Kodiak shelf), N2 (Barron, unpublished data, Eastern Gulf of Alaska), N3 and N4 (Keller, this report, samples of Plafker et al, 1979, 1980), N5 (McDougall, unpublished data, Kodiak shelf and Kodiak Island-Lower Cook Inlet outcrop samples), N6 (this report, Middleton Island well), N7 (Keller and McDougall, unpublished data, Orca Group); O = Open-File Report; O1 (80-1237), O2 (80-1089, Plafker et al, 1980), O3 (77-747, Rau et al, 1977); P = published reports, P1 (Tysdal and Plafker, 1978), P2 (Lattanzi, 1979), P3 (Byrne, 1982), S1 = State of Alaska Open-File Report 114 (Lyle and Morehouse, 1978).

YAKUTAT BLOCK

Early Eocene: 50 Ma

Diverse and well-preserved planktonic foraminiferal and coccolith assemblages are present in dredge hauls from the lower continental slope of the Yakutat block (sample locations in Plafker et al, 1979, 1980). The samples contain fossils from a subtropical to warm temperate depositional environment of late early Eocene age.

These and additional samples have been examined for coccoliths (by Bukry in Plafker et al, 1979, 1980; Poore and Bukry, 1978), and their late early Eocene age is in close agreement with the age determined from the planktic foraminifers. A late early Eocene age is also indicated by benthic foraminiferal assemblages. Deposition of benthic assemblages occurred at lower middle bathyal or deeper depths (1,500 m [4,921 ft] or deeper). Assemblages are diverse and composed of lower middle bathyal species. The bulk of the assemblages, however, is composed of species with shallower upper depth limits and indicates transport from outer shelf and upper slope environments.

The planktic foraminiferal assemblages of the Yakutat block are similar to, although more diverse and abundant than, those reported from coeval sequences of the northern Santa Lucia Range of California (present latitude 36°N) (Poore et al, 1977), the Lodo Formation of Fresno County, California (present latitude 36.5°N) (Schmidt, 1970), and the Roseburg Formation of Oregon (present latitude 42 to 45°N) (Miles, 1981). The assemblage in the Gulf of Alaska dredge samples indicates subtropical to warm temperate environments or about 20 to 30°N latitudes in Eocene times (Keller, 1983a). The comparative relation suggests that the Alaskan samples may have been slightly south of the coeval southern California onshore marine sequences (Table 1). The assemblages reported from the Roseburg Formation suggest a cooler environment than in central and southern California (Miles, 1981). Miles (1981, p. 99) observed that "planktonic foraminifera of the Umpqua Group (Roseburg, Lookinglass and Flournoy Formations) are similar to age equivalent fauna from California, but are less diverse and have a more temperate aspect." These cooler aspects of the Oregon assemblages, as compared to the dredge samples from the Yakutat block, also suggest that deposition of the latter samples occurred south of the onshore Oregon marine sequences.

Benthic foraminiferal assemblages also indicate a warm middle- to low-latitude environment. Benthic assemblages contain many of the same species reported by Mallory (1959) from the Vacaville Shale correlative with the Lodo Formation and other Ulatisian age deposits of the San Joaquin Valley, California, and Hanna's (1926) Rose Canyon Shale Member (now abandoned) of his La Jolla Formation near San Diego, California. The shelf and upper slope species of the Gulf of Alaska assemblages also resemble those of the subtropical shallow-water early to middle Eocene age assemblages of the Guyabal and Aragon Formations of Mexico (about 21°N latitude; Nuttal, 1930). The Alaskan assemblages, however, are slightly less diverse and commonly contain larger, more highly ornamented forms than the California assemblages. These differences may either show selective transport and preservation or a more southern site of deposition than the California assemblages.

Tropical species of the genus *Amphistegina* from the Olympic Peninsula of Washington are not considered equivalent to the coeval Yakutat assemblages because of the questionable age and faunal composition (see Keller et al, 1984, for a complete discussion). The benthic foraminiferal assemblages of the Yukutat block have more affinities to the tropical and subtropical assemblages of southern California and Mexico than to coeval Oregon and Washington assemblages and were probably deposited at a latitude south of, or equivalent to, La Jolla, California (present latitude 33°N).

The late early Eocene (50 Ma) planktic and benthic organisms indicate that the northern Gulf of Alaska dredge samples were originally deposited about 30° farther south than their present latitude (58°). This compares well with the coeval position for the Yakutat block (Table 2) relative to North America (Bruns, 1983a) based on the plate kinematic models of Engebretson (1982).

Middle Eocene: 40 to 44 Ma

Planktonic foraminiferal assemblages of late middle Eocene are present in dredge hauls from the lower slope of the Yakutat block (locations in Plafker et al, 1979). The assemblages are indicative of the temperate midlatitude environment of the northeast Pacific (Fig. 1).

Coccoliths examined in these samples (Bukry in Plafker et al, 1979, 1980; Poore and Bukry, 1978) also yield a late middle Eocene age, compatible with the age determination based on planktonic foraminifers. The most age diagnostic samples contain assemblages of the late middle Eocene or earliest upper Eocene (Poore and Bukry, 1978), although the assemblages lack primary index species.

A middle Eocene age is also indicated by benthic foraminifers diagnostic of the Narizian Stage that spans from the base of the middle Eocene into early late Eocene time (Fig. 2). Benthic foraminifers are common and diverse in the dredge samples. The planktonic and benthic assemblages both indicate a late middle Eocene age for these samples.

Benthic foraminiferal assemblages indicate deposition at lower middle bathyal (1,500 to 2,000 m [4,921-6,562ft]) or greater depths. These species suggest that deposition occurred below an upper-slope oxygen minimum zone.

Planktic foraminiferal assemblages in the middle Eocene rocks of the Yakutat block represent a temperate midlatitude environment similar to coeval assemblages of the Kreyenhagen Formation (present latitude 36°N; Milam, unpublished data, 1983), the San Lorenzo Formation of northern California (Poore and Brabb, 1977), and the cooler Flournoy Formation of Oregon. Abundance of the cool temperate forms in the Yakutat block samples suggest that the depositional environment of this fauna was just north of the presently onshore coeval marine sequences in California and at about the same latitude as the Flournoy Formation of Oregon, or about 20 ± 5° south of its present position (Table 1).

Benthic foraminiferal assemblages also indicate a temperate to middle latitude fauna. Assemblages similar to those of the Yakutat block are common in the Kreyenhagen Formation in southern California (Cushman and Hanna, 1927; Jeffries, unpublished investigation. Most of the species are also found in other Narizian assemblages in California (Mallory, 1959) but less commonly in Washington and Oregon assemblages (Rau, 1966; McDougall, 1980); they are nearly absent in Alaskan assemblages (Rau et al, 1977). Narizian age benthic foraminiferal assemblages from the Pacific Northwest are present in the Coaledo Formation (present latitude 43°30'N; Roth, 1974), the "sedimentary rocks of late Eocene age" from the Cowlitz and McIntosh Formations (present latitude 46 to 47°N; Beck, 1943; Rau, 1958, 1966, 1981; Armentrout et al, 1980; McDougall, 1980), and the Lyre Formation and lower part of the Twin River Formation (now revised to Twin River Group; present latitude 48°N; Rau, 1964). These assemblages, however, contain more upper-slope and shelf species than either the Yakutat block dredge samples or the Kreyenhagen

Table 1

Age	Zone	Samples	Paleobathymetry	Correlations (*partial)	Present Latitude
Early Eocene 50 Ma	P8 or P9 CP11 Ulatisian	S5-EG-43E, 43F Chan-79-41B, 43	lower middle bathyal or deeper ≥1,500 m downslope transport	Santa Lucia Range, CA Lodo Fm.*, CA La Jolla Fm. of Hanna, (1926), CA Guyabal Fm. and Aragon Fm., Mexico	subtropical to warm temperate 30 ± 5° N
Middle Eocene 44-40 Ma	P13 or P14 CP14b or CP15a Narizian	S5-78-44E-44F, 44D, Chan-79-36A, 36C, 41A, 43A 37C	lower middle bathyal or deeper ≥1,500-2,000 m lower bathyal, abyssal	Kreyenhagen Fm.*, CA San Lorenzo Fm.*, CA Lincoln Creek Fm.*, WA	temperate 40 ± 5° N
Late Eocene 40-36 Ma	P16-P17 P15 L. Narizian to Refugian	W-79-45 72-APR-112 70A, 106E, 52A S2-77-E6 Chan-10A, 24B 39F, 39G, 38A	middle bathyal <1,500 m (Narizian) upper slope-shelf transport in Refugian	Lincoln Creek Fm.* Twin River Gp.*, WA Bastendorff Fm.*, OR	cool temperate 45 ± 5° N
Middle Eocene 42-40 Ma	P15 or P14? CP14b or CP15a Narizian	Middleton Is. 3,658-3,642 m, 3,639-3,642 m	lower bathyal 2,000-4,000 m	S5-78-EG-44 Chan-79-36, 37	cold subarctic 50 ± 5° N
Late Eocene 38-36 Ma	P16-P17	3,495-3,432 m	lower bathyal 2,000-4,000 m	W-79-45	cold subarctic 50 ± 5° N
Late Eocene and early Oligo (undifferent) 38-34? Ma	P17 or P18-P19 Narizian to Refugian	3,347-3,207 m, to 2,347 m 3,246-1,329 m	lower bathyal 2,000-4,000 m downslope transport	Lincoln Creek Fm.*, WA, DSDP site 192	cold subarctic north of 50 ± 5° N
Oligocene 36?-32 Ma	Zemorrian	1,469-1,213 m	lower to middle bathyal >1,500 m downslope transport	Lincoln Creek Fm.*, WA	present latitude
Early Miocene	Saucesian	1,469-1,213 m	lower to middle bathyal >1,500 m		present latitude
Late Miocene to Pleistocene		701-219 m	shelf, neritic		present latitude

Table 1—Summary of chronostratigraphy, paleobathymetry, onshore correlations, and paleolatitude determinations relative to present latitude of assemblages or Pacific faunal zones of key samples from the Yakutat block and Prince William (Middleton Island well) terrane.

Table 2

	Yakutat Block		Prince William Terrane		Pacific Plate	
Age	Faunal	Tectonic	Faunal	Tectonic	Faunal	Tectonic
Late Oligocene to early Miocene 20-30 Ma	north of 50 ± 5° N	50-53° N	north of 50 ± 5°	present	north of 50 ± 5°	44-47° N
Late Eocene to early Oligocene 34-36 Ma	north of 50 ± 5° N	49-50° N	north of 50 ± 5°	present	north of 50 ± 5°	43° N
Late Eocene 36-40 Ma	48 ± 5° N	48-49° N	50 ± 5° N	present	(192) 45 ± 5° N	42° N
Middle Eocene 40-44 Ma	44 ± 5° N	46-48° N	50 ± 5° N	present	(192) 40 ± 5° N	40-42° N
Early Eocene 50 Ma	35 ± 5° N	37° N			(192) 30 ± 5° N	37° N
Paleocene 62 Ma			paleomagnetic position of the Ghost Rocks Fm. 40 ± 9° N.			
Late Cretaceous					(192) 15 ± 5° N	26° N

Table 2—Comparison of absolute paleolatitude positions determined from faunal data and plate tectonic models for the Yakutat block, Prince William terrane, and Pacific plate; onshore correlations corrected for southward drift of North America during the Cenozoic.

Formation. Important, however, in these Pacific Northwest onshore sections is the successive northward decrease in abundance of the species common to both the Kreyenhagen and Yakutat dredge samples, indicating an apparent temperature gradient from north to south. The middle Eocene assemblages in Yakutat dredge samples suggest that deposition occurred at about 40° ± 5°N present latitude. The middle Eocene 44°N (present latitude) position of the Yakutat block predicted by the plate tectonic reconstruction of Bruns (1983a) is in good agreement with the faunal paleolatitude determination (Table 2).

Late Eocene: 38 to 40 Ma, 36 to 38 Ma

Late Eocene (38 to 40 Ma) planktonic foraminiferal faunas were found in Yakutat block dredge samples and a sample from Kayak Island (locations in Rau et al, 1977; Plafker et al, 1979). The Kayak Island samples contain sparse late Eocene assemblages, although the zonal index marker is missing. The faunal assemblage suggests a cool temperate midlatitude environment.

One dredge sample also contains a cool-water assemblage that first appears in the latest Eocene (Keller, 1983a, 1983b), and some of the common forms suggest that this sample is no older than 36.3 to 38 Ma but may be as young as early Oligocene.

A late Eocene age (Refugian Stage) is also indicated by benthic foraminifers in both the dredge and the samples from Kayak Island (Rau et al, 1977). These benthic assemblages are similar to those observed by Rau et al (1977) in the Cape St. Peters and Kayak Island sections. The late Eocene faunas indicate deposition at middle bathyal depth (<1,500 m[4,921 ft]). However, a faunal change suggests either a gradual shallowing or increased sediment transport from shallower biofacies.

The generally cool temperate faunas of the Yakutat block late Eocene assemblages are similar to those examined from coeval onshore marine sequences in the Bastendorff Formation of Oregon (present latitude 45°N; Warren and Newell, 1981) and in the Sapsop and Little River sections of the Lincoln Creek Formation of southwest Washington (Keller, unpublished data). However, the lower species diversity of coeval assemblages from the Lincoln Creek Formation indicate deposition in a cooler environment than assemblages from the Yakutat block. The late Eocene and early Oligocene depositional environment of the Yakutat block was probably slightly south of the southwestern Washington and at a similar paleolatitude to that of the Bastendorff Formation of Oregon, or about 45° ± 5°N present latitude (Table 1). The same paleolatitude is predicted for the Yakutat block based on the plate tectonic reconstruction by Bruns (1983) (Table 2).

The late Eocene (36 to 38 Ma) benthic foraminiferal assemblages of the Yakutat block are most similar to the cold-water late Eocene assemblages of the Lincoln Creek Formation (Rau, 1966; McDougall, 1980), and the shallow-water facies of the Twin River Group of Washington (Rau, 1964). Benthic assemblages similar to the Twin River Group of Washington (Rau, 1964) are found in various upper Eocene onshore sections around the Gulf of Alaska

(Rau et al, 1977) and in the Middleton Island well, but these assemblages are commonly dominated by arenaceous forms characteristic of cooler shelf and slope faunas. Late Eocene assemblages from California (Mallory, 1959) and Japan (Ujie and Watanabe, 1960) also contain many of the same species as found in rocks of the Yakutat block; however, these more southern assemblages also contain warmer water species not present in Alaskan latitudes. These faunal comparisons suggest that the late Eocene to early Oligocene Yakutat block samples were deposited in an environment similar to samples from southwestern Washington and Oregon, or about 45 ± 5°N present latitude, in agreement with the latitude of deposition indicated by planktonic foraminifers and by plate tectonic reconstruction (Table 2).

PRINCE WILLIAM TERRANE: MIDDLETON ISLAND WELL

Microfossil assemblages from the Middleton Island well (present latitude 59°25′N) are generally sparse and poorly preserved in the upper part of the well; however, in the lower part definite age assignments could be made. Sixty-six samples were examined for coccolith and foraminifers. Twenty of these contained coccoliths, but only four samples have diagnostic or diverse assemblages adequate for good age correlations. Planktonic foraminifers are also poorly represented, whereas benthic foraminifers are more common. The Middleton Island well was studied earlier by Rau for benthic foraminifers (Rau et al, 1977) with the few samples available at that time. Correlations and faunal comparisons were made between the Middleton Island well and sediments of the Yakutat block described in Plafker et al (1979, 1980), Rau et al (1977), and Poore and Bukry (1978). All the samples were reexamined for planktonic foraminifers by Keller et al (1984).

Late Middle Eocene: 40 to 42 Ma

The basal sample of the Middleton Island well (3,658 to 3,642 m [12,001-11,949 ft]) contains the coccolith index species for the early late Eocene (38.5 to 40 Ma). Coccolith assemblages of sample 3,639 to 3,642 m (11,939-11,949 ft) contain forms that suggest the late middle Eocene. The overlying sample (3,633 to 3,637 m [11,919-11,932 ft]) contains forms that suggest a late Eocene age in agreement with the age determined from planktonic foraminifers. Coccolith stratigraphy therefore indicates that the middle to late Eocene boundary falls between sample 3,642 m (11,949 ft) and 3,636 m (11,929 ft) with a possible hiatus. Therefore, at its greatest depth the Middleton Island well penetrated late middle Eocene or earliest late Eocene sediment (40 to 42 Ma).

Benthic foraminifers are rare in the lower part of the Middleton Island well (3,658 to 3,258 m [12,001-10,689 ft]), but they also suggest a middle to late Eocene age. Rau et al (1977) reported a more diverse benthic fauna of questionable early to middle Eocene age, which could not be confirmed by Keller et al (1984).

The low-diversity microfossil assemblages in the Middleton Island well, as compared to coeval assemblages from dredge hauls from the continental slope of the Yakutat block, indicate that the Middleton Island assemblages were deposited in a significantly cooler water environment. This relation suggests that the Middleton Island late middle to early late Eocene fauna probably accumulated north of coeval sequences dredged from the Yakutat block.

Late Eocene: 36 to 38 Ma

Planktic foraminiferal assemblages in samples between 3,495 and 3,423 m (11,467 and 11,260 ft) are indicative of the late Eocene (36.5 to 38 Ma), although in the absence of the index species, it could be as young as early Oligocene. Coccolith assemblages are determinate late Eocene to early Oligocene. This sample is coeval with a dredge sample from the Yakutat block, as discussed earlier. The low faunal diversity and absence of warm-water species in both the Middleton Island well and the Yakutat sample suggest a similar cool environment indicative of high northern latitudes.

Latest Eocene and Early Oligocene: 34? to 38 Ma

Middleton Island well samples between 3,347 and 3,207 m (10,981 and 10,522 ft) contain planktonic foraminiferal assemblages indicative of late Eocene or early Oligocene age. Coccolith assemblages between 3,505 and 3,613 m (11,499 and 11,854 ft) can, at best, be assigned a late Eocene to early Oligocene age. This age is in good agreement with age determinations based on planktonic foraminifers.

Planktic microfossils are rare between 3,240 and 2,347 m (10,630 and 7,700 ft) but suggest that this interval is also of late Eocene or early Oligocene age. No planktonic microfossils are present between 2,347 and 890 m (7,700 and 2,920 ft); the latter sample contains latest Oligocene or early Miocene planktonic foraminifers.

Benthic foraminifers of late Eocene age are also observed between 3,246 and 1,329 m (10,650 and 4,360 ft). Mixed assemblages of Narizian and Refugian Stage species are present between 3,222 and 2,682 m (10,571 and 8,799 ft) with Refugian Stage species more common in the upper part. Similar mixed Narizian and Refugian Stage species assemblages were observed in coeval sediments of Washington and Oregon (McDougall, 1980). The late Eocene and early Oligocene age of the well section (Narizian to Refugian; Poore, 1980) agrees well with the age determinations based on planktonic microfossils. The benthic foraminiferal assemblages between 3,246 and 2,673 m (10,650 and 8,770 ft) contain many species characteristic of middle to lower bathyal depths with an influx of transported material from a nearby slope and shelf region.

The long-ranging, low-diversity planktic foraminifers from the late Eocene and early Oligocene section of the Middleton Island well (present latitude 59°25′N) are indicative of a cold water environment similar to coeval assemblages of the Lincoln Creek Formation of southwest Washington at 47°N present latitude. The cooler assemblages at the Middleton Island well, however, appear to have lived at a somewhat higher latitude than those of the Lincoln Creek Formation. We think the Middleton Island late Eocene sediment was deposited in an environment north of 50 ± 5°N present latitude (Table 1).

Coccolith assemblages also indicate a cold-water environment as suggested by poor diversity and by the lack of tropical taxa. These cold-water assemblages are most similar to coeval assemblages from DSDP site 192 in the western North Pacific and also indicate that deposition occurred in colder waters than assemblages from southwestern Washington.

Oligocene (32? to 36 Ma)

Benthic species diagnostic of the Oligocene are present between 6,289 and 5,193 m (20,633 and 17,037 ft) (see also Rau et al, 1977). No planktonic microfossils are present. Benthic assemblages indicate deposition at middle to lower bathyal depths with continued transport from shelf and upper-slope regions.

Miocene to Pleistocene

Rare early Miocene species occur in sample 5,193–5,219 m (17,037–17,123 ft) and more commonly in sample 3,810–3,836 m (12,500–12,585 ft). Planktic foraminifers in sample 3,810–3,836 also suggest an early Miocene or very latest Oligocene age. Deposition continued in a lower to middle bathyal environment.

The upper part of the Middleton Island well, 3,001 to 939 m (9,846–3,081 ft), is of late Miocene to Pleistocene age (undifferentiated). Thus, a hiatus is present between the early and late Miocene deposits, a circumstance also observed in the nearby deep-ocean DSDP site 178 and noted by Lagoe (1983) in samples from Cape Yakataga. The presence of shallow-water benthic species, including numerous *Elphidiums*, suggest deposition at shelf depths or transport from inner shelf regions.

PACIFIC PLATE

DSDP cored sequences provide sufficient continuity to show the chronostratigraphic and paleoclimatic record and variations in the sedimentation patterns that result from large-scale changes in oceanographic conditions. Figure 3 illustrates the chronostratigraphic and lithologic records of deep-sea sequences of DSDP sites 192, 183, and 178, which are presently at high northern latitudes, and the Middleton Island well. The Yakutat block is not included because no similar cored sequence is available. The DSDP sites are on the Pacific plate and hence, during their northward migration, their relative positions on the plate remained constant through time. The related position of the Middleton Island well located on the Prince William terrane is less well known. Because of similar faunal and floral records (Fig. 3), the sediment at the Middleton Island well was probably deposited within the same general paleo-oceanographic and paleoclimatic regime as those of the DSDP sites.

Late Cretaceous

The oldest sediment overlying basement at site 192 (Hole A) is of Maestrichtian age (70 to 68 Ma). Coccolith assemblages indicate a tropical to subtropical environment; however, absence of siliceous microfossils suggest that deposition occurred north of the high productivity equatorial region (Worsley, 1973), or about 15 ± 5°N present latitude. This position is in good agreement with the predicted position of 19°N latitude based on plate tectonic reconstructions by Engebretson (1982, Table 2).

Sediment recovered from the Ghost Rocks Formation of the Kodiak Islands was considered to be of Late Cretaceous and Paleocene age by Byrne (1982). Based on paleomagnetic data, Plumley et al (1982) infer a Paleocene (62 Ma) paleolatitude of the Kodiak Islands about 17 ± 6° south of their present latitude. No sediment of Paleocene age was recovered in the north Pacific DSDP sites. At site 192 a hiatus marks the position of the uppermost Cretaceous, the Paleocene, and part of the early Eocene (68 to 51 Ma), and at site 183 early Eocene sediments rest on basement basalt (Fig. 3).

Eocene

Eocene sedimentation is disrupted by hiatuses at the early-middle Eocene boundary (49 to 46 Ma), middle-late Eocene boundary (43 to 41 Ma), and during late Eocene (39 to 37.5 Ma, Figs. 2,3). Early Eocene (51 to 49 Ma) coccolith assemblages at site 192 suggest that deposition occurred in the low-productivity central water mass (Fig. 1, Worsley, 1973), or at about 30 ± 5°N latitude and hence at a similar latitude to coeval assemblages of the Yakutat block. Plate tectonic reconstructions place site 192 and the Yakutat block at 31°N present latitude (Table 2), in agreement with the latitudinal limits determined from faunal evidence.

Middle Eocene sediment at site 192 indicates deposition within the central to temperate water masses, or about 40 ± 5°N latitude, as compared to 36°N latitude determined by plate reconstruction (Table 2). Late Eocene assemblages (37 to 40 Ma) are indicative of a cold subarctic environment, or about 45 ± 5°N latitude. Plate tectonic reconstruction suggests a somewhat lower position of 38°N present latitude (Table 2).

Cold subarctic assemblages are also present in the late Eocene sediment of site 183, although preservations of microfossils is poor. Wolfe (1977) reports pollen assemblages dominated by conifers, similar to coeval assemblages from the Alaskan mainland and cooler than coeval assemblages from Washington and Oregon. It was also observed earlier that foraminifers from the Middleton Island well indicated a position north of the Lincoln Creek Formation of Washington (i.e., north of 50°N latitude).

Thus, late Eocene to early Oligocene assemblages (34 to 37 Ma) from the Pacific (site 192), Prince William terrane (Middleton Island well), and the Yakutat block contain assemblages from the subarctic faunal province or about 50 ± 5°N present latitude. In contrast, plate tectonic reconstruction indicates that the late Eocene and early Oligocene position of sites 192 and 183 was about 10° further south, and the Yakutat block was about 12° further south (Bruns, 1983a; Table 2). This discrepancy may be explained by a southward expansion of the subarctic fauna in the latest Eocene and Oligocene resulting from initiation of polar glaciation (Keller, 1983a, 1983b; Keigwin and Keller, 1984). Therefore, the effect on faunal paleolatitude determinations would be a bias towards cooler, that is, higher latitudes at this time.

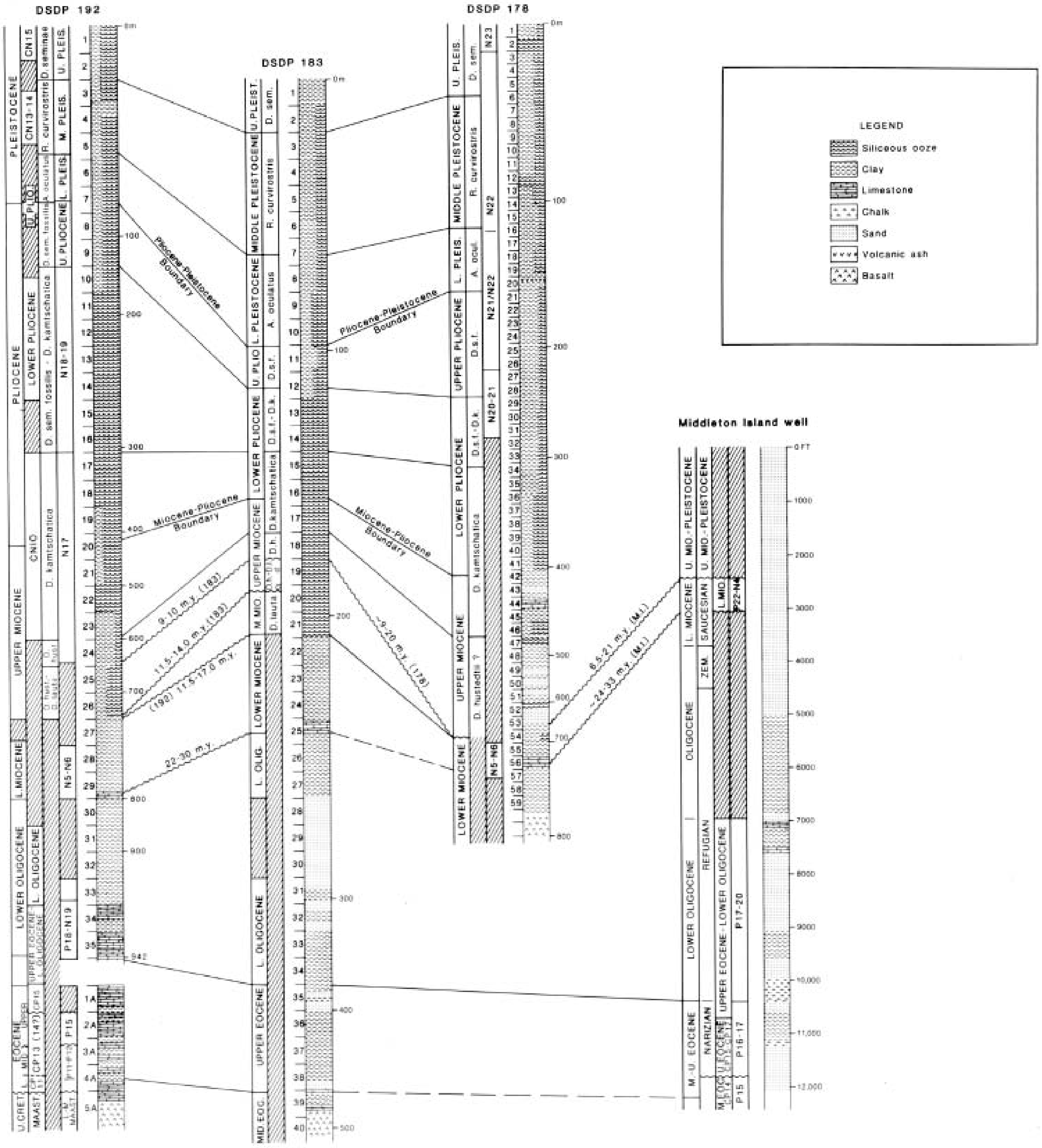

Figure 3—Biostratigraphic correlation and lithologies of sediments in DSDP sites 192, 183, and 178 and the Middleton Island well. Dashed zigzag lines mark hiatuses. Diagonal lines mark dissolution in sediments. The biostratigraphy at DSDP sites has been previously studied: nannofossils by Worsley (1983), diatoms for sites 192 and 183 by Koizumi (1973), Harper (1977), and Barron (unpublished data), foraminifers by Echols (1973) for sites 192 and 183 and by Keller (this report) and for site 178 by Ingle (1973). Absolute age scale after Berggren et al (in press).

Oligocene

Microfossil preservation in Oligocene sediment is poor, and a hiatus appears to represent the late Oligocene (30 to 20 Ma, Fig. 2). In addition, late Eocene to early Oligocene assemblages are commonly indistinguishable and indicate cold subarctic conditions. This circumstance suggests that by Oligocene time deposition at the North Pacific DSDP sites, the Prince William terrane, and the Yakutat block occurred in cold water north of Washington, or north of 50 ± 5°N present latitude.

Miocene to Pleistocene

Early Miocene sediment (23 to 20 Ma) is present at all North Pacific DSDP sites and the Middleton Island well (Fig. 2). Early Miocene assemblages are found in a limestone layer at sites 192, 183, and 178 and sediment enriched in carbonate at the Middleton Island well. Hiatuses are present throughout the Miocene sequences at sites 192 and 183, in the late Miocene (10 to 9 Ma), middle Miocene (14 to 11.5 Ma), and early Miocene (20 to 15 Ma). At site 178 and Middleton Island well, hiatuses occur between 9 to 20 Ma and 6.5 to 20 Ma, respectively.

Biostratigraphic control in the late Miocene to Pleistocene sequences is excellent, except for the Middleton Island well where correlation is more tenuous because of poor preservation of microfossils. Faunal and floral assemblages are typical of a subarctic to arctic environment.

Terrane Kinematics

The concept that the Prince William terrane and Yakutat block migrated northward *during the Cenozoic* has been addressed in paleomagnetic studies and plate tectonic reconstructions (Stone et al, 1982; Plumley et al, 1983; Moore et al, 1983; Bruns, 1983a) and are illustrated in Figures 4 and 5 with positions from our faunal data. Paleomagnetic data from the Prince William terrane (Plumley et al, 1983; Moore et al, 1983) show that early Paleocene (about 62 Ma) volcanic rocks of the Ghost Rocks Formation of Kodiak Island were emplaced at 25 ± 9° south of their present position (Figs. 4, 5). Moore et al (1983) present three models for movement of the Prince William terrane. Paleontologic data are consistent with these models but do not aid in differentiating between them. The Ghost Rocks Formation and the Middleton Island well are on the same terrane (Jones et al, 1981) and thus migrated northward together. Our paleontologic data indicate that the Middleton Island middle Eocene sediment was deposited about 8 ± 5° south of its current location.

Paleontological data indicate that the Yakutat block moved into the Gulf of Alaska after the Prince William terrane. The foraminiferal fauna of the Yakutat block are similar to coeval late early Eocene fauna of California at 36°N present latitude, to middle Eocene fauna of northern California at 40°N present latitude, and to late Eocene fauna of southwest Washington (Table 1) at about 45°N present latitude. Oligocene fauna (about 34 Ma) suggest a high-latitude depositional environment north of about 50 ± 5°N present latitude. Fauna of equivalent ages from the Prince William terrane and Yakutat block show that the Yakutat block was at least 10° south of the Prince William terrane during middle Eocene time and reached a similar latitude no earlier than middle Oligocene time.

Recent geological and geophysical studies of the Yakutat block indicate that it is currently colliding with, and accreting to, southern Alaska (Plafker et al, 1978; von Huene et al, 1979b; Bruns, 1979; Perez and Jacob, 1979; Lahr and Plafker, 1980; Bruns and Schwab, 1983) and that it has moved with the Pacific plate for at least Pliocene and Quaternary time (Schwab et al, 1980; Bruns, 1983a). One plate tectonic model for the movement history of the Yakutat block, which suggests that it moved with the Pacific and Kula plates since the Eocene (Fig. 5; Bruns, 1983a), agrees with the predicted position of the Yakutat block and the Eocene and Oligocene positions indicated by this study. Thus, within the limits of uncertainty in the latitude determinations, the paleontological data and terrane path reconstruction are consistent.

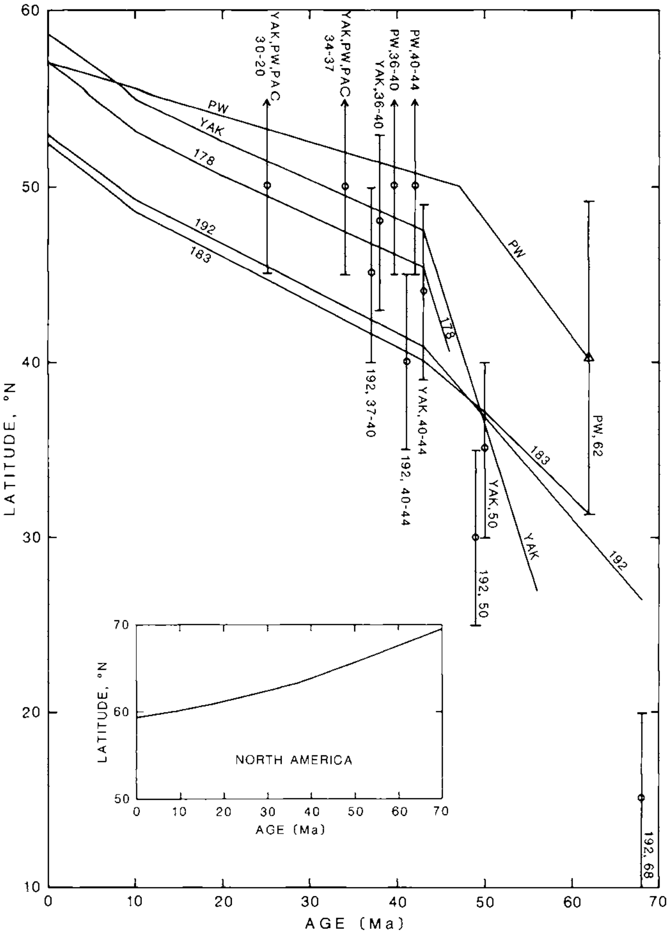

Figure 4—Plot of absolute paleolatitude versus age of sites studied in this report. All paleolatitudes have been adjusted for motion of Pacific and North America plates based on the movement of these plates relative to the fixed hotspot reference of Engebretson (1982). Travel paths relative to a fixed North America reference frame are shown in Figure 5. Circles with error bars indicate best estimate of paleolatitude positions determined from faunal data. Triangle with error bar marks paleomagnetic data of Plumley et al (1982, 1983). Labeled lines indicate latitude positions of indicated terranes and DSDP sites according to plate tectonic reconstructions of Engebretson (1982), Moore et al (1983), and Bruns (1983a). Inset shows southward drift of North America plate during last 70 Ma. Total closure between northward-moving terranes and North America plate can be determined by subtracting paleolatitudes of equivalent ages.

In summary, paleolatitudes determined from microfaunas and floras in the Gulf of Alaska coastal and offshore areas provide three main tectonic constraints: (1) The Prince William terrane was at a high northerly latitude near its present position by 40 to 42 Ma. This observation is consistent with paleomagnetic data from Kodiak Island (Plumley et al, 1983), provided the Prince William terrane traveled northward with the fast-moving Kula plate from 62 to 45 Ma and was incorporated into Alaska by about 45 Ma. (2) Fossil assemblages from the Yakutat block require northward motion of about 30° relative to a North American point of origin and also require that the Yakutat block was about 10° south of the Prince William terrane through Eocene and Oligocene time. These data are

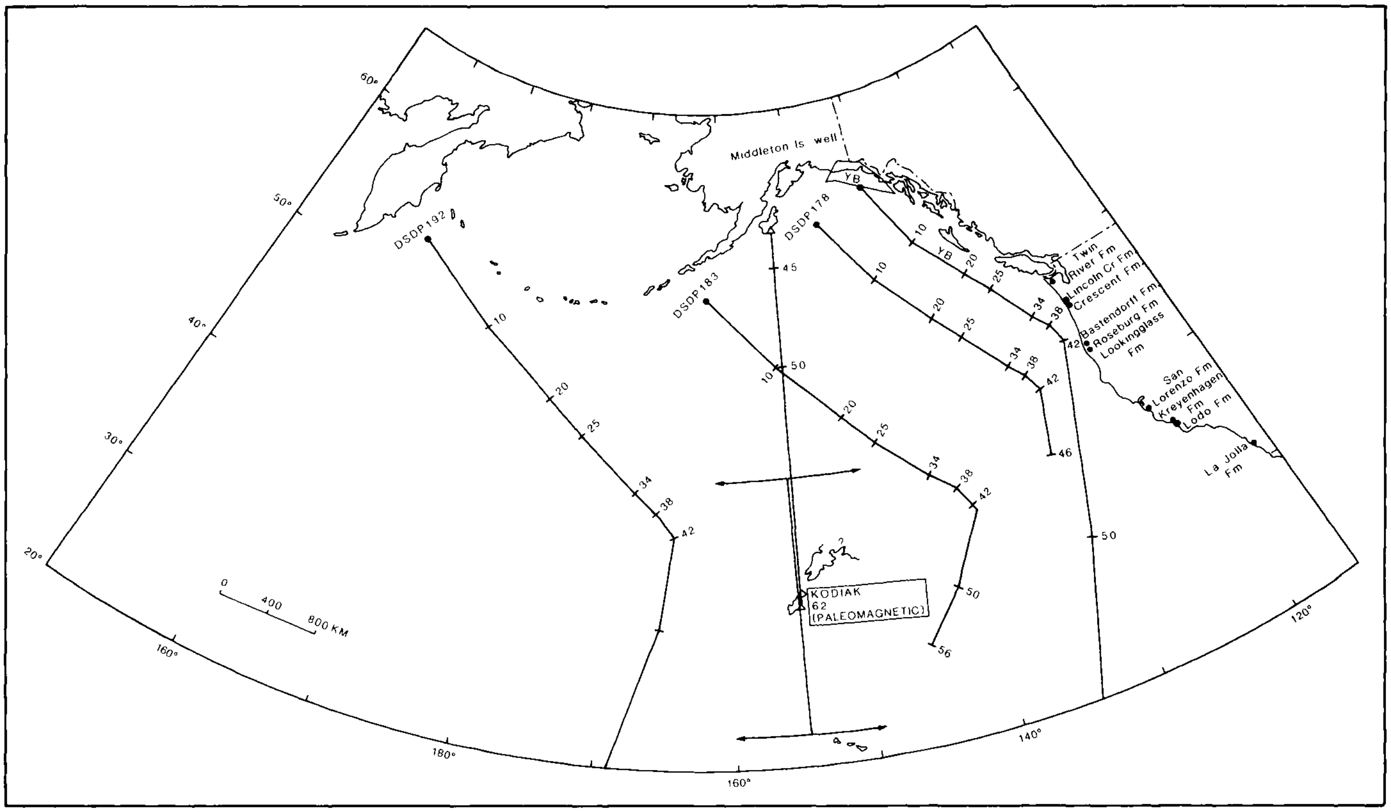

Figure 5—Backtrack positions of sample localities described in this paper (relative to a North America plate fixed in its current position). Heavy solid lines show movement paths according to Pacific-North America poles of Engebretson (1982), and models for Prince William terrane of Moore et al (1983) and for the Yakutat block (YB) of Bruns (1983a). Numbers along lines indicate positions in million years. Latitude position of Kodiak Island at 62 Ma based on paleomagnetic data of Plumley et al (1982, 1983).

consistent with motion of the Yakutat block with the Pacific and Kula plates during the past 50 Ma, as suggested by Bruns (1983a). (3) Data from the Pacific plate require about 40° of northward motion and are consistent with the plate tectonic reconstruction of Engebretson (1982) for Pacific plate motion based on hot-spot tracks.

IMPLICATIONS OF THE YAKUTAT BLOCK HISTORY

The 30° northward transport of the Yakutat block suggested by paleontologic data and the interaction of the block with the Alaskan continent are dynamic examples of processes inferred from ancient inactive terrane sutures. The Yakutat block has collided with Alaska on the north and has been subducting beneath Alaska on the west for the past 4 m.y. (Bruns, 1983a). Subduction of the block is shown by a distinctive magnetic anomaly that extends along the seaward margin of the Yakutat block and then continues about 280 km (174 mi) across the shelf west of the zone where the block is subducted. The anomaly reaches the Kenai Peninsula (Schwab et al, 1980), but its full extent has not been determined by magnetic surveying on land. Where the magnetic anomaly crosses the shelf, the amplitude decreases, indicating an increase in depth of the causative body. The increased depth indicates subduction of the Yakutat block. Thus, we infer a minimum length of the block now subducted beneath the late Mesozoic and early Tertiary rocks of the continent (Schwab et al, 1980; Bruns, 1983b). The minimum length of the subducted anomaly in the direction of plate convergence (258 km [160 mi]) divided by the rate of Pacific-North American relative plate convergence (6.6 cm/year [2.6 in./year]) gives a nearly 4 m.y. minimum age for initial subduction of the west end of the anomaly.

Another possible sign of subduction of a terrane is seen about 40 km (25 mi) west and 60 km (37 mi) south of the end of the magnetic anomaly in the passage that separates the Kenai from the Kodiak Mountains. Fisher et al (1983) have pointed out a 30 km (19 mi) long sequence of reflections that plunge from a depth of 11 km to 23 km (6.8–14 mi) in an arch that parallels the top of the Benioff zone (Fig. 6). Using their suggested velocities and the time interval from top to bottom of the reflective sequence indicates a layer from 2 to 5 km (1.2–3.1 mi) thick. One cause these authors suggest for the reflections is a sedimentary rock sequence that could have been detached from the subducting plate. We believe that sediment sequence of this thickness might represent part of a subducted terrane.

Subduction of the westernmost end of the Yakutat block at least 4 m.y. ago corresponds roughly with the initial uplift of the present Kenai Mountains. This uplift is marked in Cook Inlet by the introduction of detritus from the mountain range and the end of a sediment supply from the interior of the continent during the Pliocene, or about 5 m.y. ago (Kirschner and Lyon, 1973). Prior to the mountain-building phase, the Kenai area was an eroded

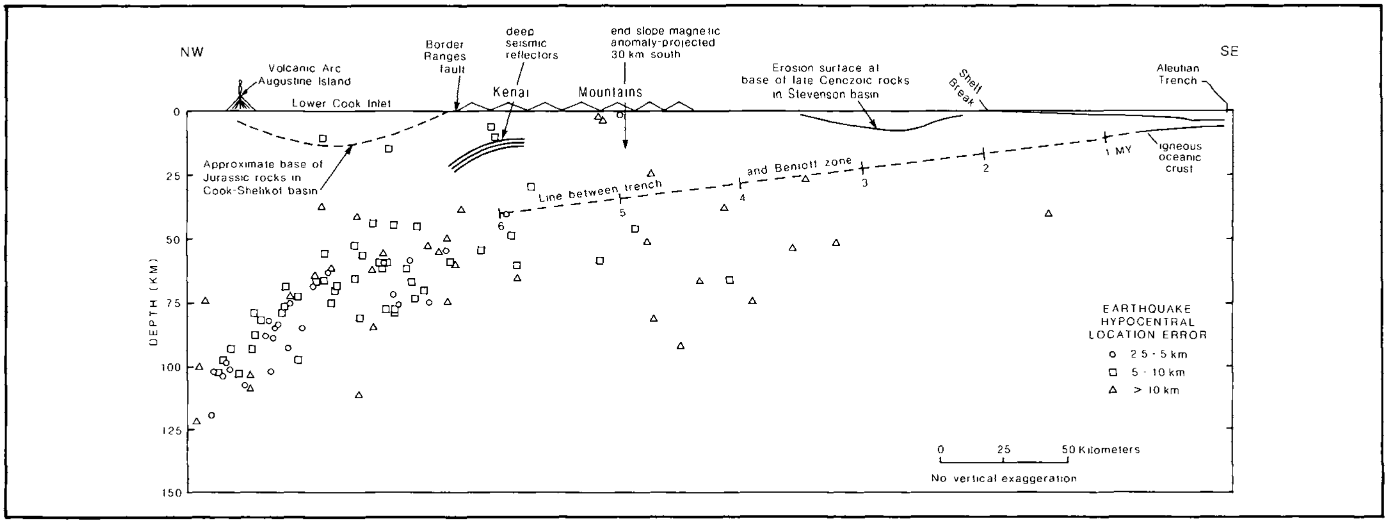

Figure 6—Diagrammatic section through the waterway between the Kenai Peninsula and Kodiak group of islands and normal to the trench showing some tectonic features of the Prince William terrane, the extent of the subducted continuation of the Yakutat block slope magnetic anomaly, and the deep layered seismic reflections. The component of convergence along the line of section is 4.7 cm/year (1.9 in/year), and the time in Ma since introduction of a point on the oceanic plate is shown by numbers along the line between the trench and the Benioff zone. Earthquake hypocenters located from records of a local network during the period 1971 to 1980 are projected from 20 km (12 mi) on either side of the line of section.

lowland. The concordant summits of the Kenai Mountains reflect a pre-Pliocene erosional surface that extended across the present mountainous areas. On the adjacent continental shelf a regional erosional surface forms the base of a reflective sequence in most seismic reflection records (Fisher and von Huene, 1980; Bruns, 1979). This extensive erosion surface was disrupted by mountain building and subsidence in the present land and continental shelf areas, respectively.

The Kenai-Kodiak Mountains are in a peculiar position and have no counterpart in the rest of the Aleutian arc-trench system. Forearc areas are generally not the sites of high mountains. Furthermore, the Benioff zone beneath the Kenai-Kodiak area has an anomalous shallow dip (4 to 5°) and the distance between the trench and arc (almost 400 km [249 mi]) is unusually great (Jacob et al, 1977). Thus, some process in addition to normal subduction of ocean crust might be considered.

The deep crustal mechanism by which subduction of a block causes the uplift of mountains is conjectural; however, the concurrent uplift of the Kenai Mountains, depression of the shelf, and the subduction of the Yakutat block suggest a genetic relation. If the Kenai Mountains were indeed formed by the collision and subduction of the Yakutat block, this relation could provide an explanation for some unresolved tectonic problems along the western Gulf of Alaska, and we present these ideas to stimulate further consideration.

If uplift of the Kenai Mountains is related to the collision and subduction of the Yakutat block, then it begs the question of the origin of the Kodiak Mountains, which are the southwest continuation of the Kenai Mountains. The Kodiak area has the unusually great arc-trench separation and the shallow-dipping Benioff zone noted beneath the Kenai Peninsula and Prince William Sound (von Huene et al, 1979a). Did the Yakutat block once extend southwest of its present boundaries on part of the ocean crust now subducted beneath the Kodiak group of islands? Could the subduction of a southern continuation of the Yakutat block be responsible for the Kodiak Mountains? Not only does the anomalous position of the Kodiak Mountains suggest such a subducted continuation of the block, but so does the Zodiak Fan.

The Zodiak Fan has been an unexplained feature of the western Gulf of Alaska since its discovery by Hamilton (1967). Stevenson et al (1983) have defined the extent of this huge fan complex and show that its proximal part is subducting just south of the Kodiak group of islands (Fig. 7). Thus, the feeder channel and associated continental margin are on the now subducted Pacific plate beneath the Kodiak area. Stevenson et al (1983) considered several models to connect Zodiak Fan to a North American source of sediment, but these remained equivocal.

We reconstruct a terrane convergence history using the plate motion model of Engebretson (1983). The subducted leading or northwest edge of the Yakutat block and its extension are positioned beneath the Kenai-Kodiak mountains at the time mountain building started. The present position is then derived by moving the leading edge with the Pacific plate during the past 5 m.y. (Fig. 7). The trailing edge position of the subducted block beneath the Kodiak area is poorly constrained by geophysical data but can be estimated from the position of the head of Zodiak fan, assuming its apex was at the base of the extension of the Yakutat block. This position also corresponds to the southwest end of the Kenai-Kodiak mountains. The shape of the Yakutat block extension was diagrammed based on these assumptions (Fig. 7).

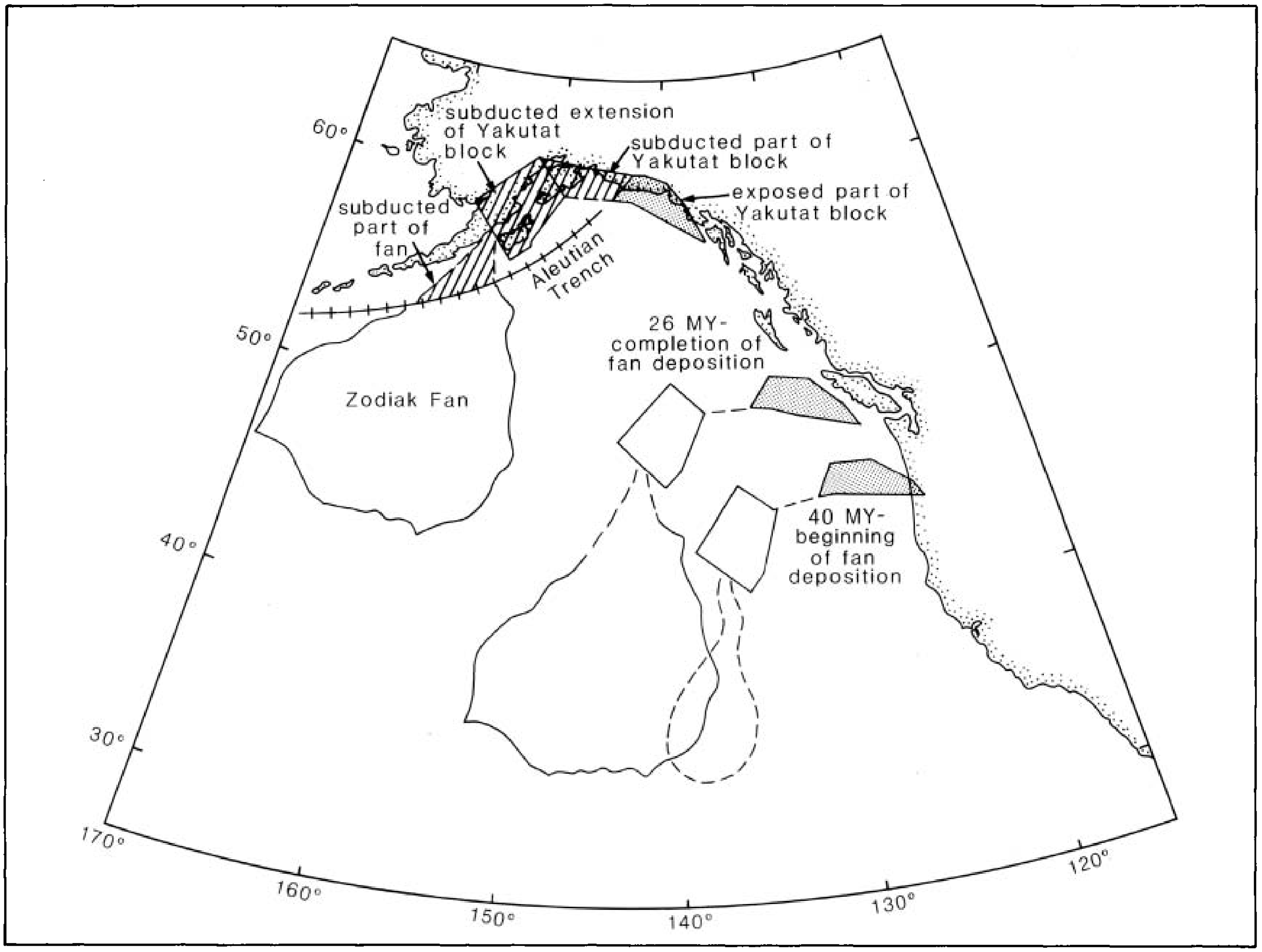

Figure 7—Reconstruction of a possible subducted extension of the Yakutat block beneath the Kodiak area. The area of the Pacific plate that subducted between 1 and 8 m.y. ago and may have extended between Zodiak Fan and the Yakutat block is indicated by hatchurs. Position of the Yakutat block, its possible southwest extention, and Zodiak Fan are shown when the fan first began to develop (40 Ma), when fan sedimentation ended (26? Ma), and in its present position (subducted parts hatchured). Migration of the Yakutat block and its subducted continuation along the magnetic anomaly marking the slope of the block is after Bruns (1983a).

Zodiak fan began to receive sediment about 40 m.y. ago, and construction of the fan ended about 26 m.y. ago (Stevenson et al, 1983). If the reconstructed Yakutat block and Zodiak fan are rotated back to the 40 m.y. and 26 m.y. positions, they are near the North American continent. Therefore, during deposition the fan might have been connected by the Yakutat block to drainages from Washington State and British Columbia (Fig. 7). A North American sediment source for the large amount of material in Zodiak fan is very appealing, but not without some possible problems. Stevenson has pointed out the possibility of a spreading ridge separating the Yakutat block from our postulated Yakutat block extension about 40 m.y. ago or the alternate possibility of a transform fault terminating the spreading ridge similar to the scheme of Bruns (1983a).

Our restoration is consistent with present plate motion models and we consider it an attractive working hypothesis because it involves an adequate source of sediment for Zodiak fan. It also provides an explanation for the episodic tectonic history of the Kodiak area (Fisher and von Huene, 1980) during a period of constant plate convergence. The Kodiak shelf was subaerially eroded in mid-Miocene time as shown by the widespread erosion surface in seismic records and the regional hiatus (Fig. 2). In contrast to the erosion surface are the basins and mountains of the present tectonic regime that began to develop in late Miocene time. Plate tectonic models show no change in relative motion since Oligocene time (Engebretson, 1983) and thus in this subduction-dominated tectonic system the collision and subduction of a terrane may have caused the change in tectonic regime.

REFERENCES

Armentrout, J. M., et al, 1980, Cenozoic stratigraphy and late Eocene paleoecology of southwestern Washington, *in* Geologic field trips in western Oregon and southwestern Washington: Oregon Department of Geology and Mineral Industries Bulletin 101, p. 79–120.

Bandy, O. L., 1956, Ecology of foraminifera in northeastern Gulf of Mexico: U.S. Geological Survey Professional Paper 274-G, p. 179–204.

Barron, J. A., 1980, Lower Miocene to Quaternary diatom biostratigraphy of Leg 57, off northeastern Japan, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 56–57, p. 641–685.

Beck, Jr., M. E., 1980, Paleomagnetic record of plate-margin tectonic processes along the western edge of North America: Journal of Geophysical Research, v. 85, p. 7115–7131.

Beck, R. S., 1943, Eocene foraminifera from Cowlitz River, Lewis County, Washington: Journal of Paleontology, v. 17, p. 584–614.

Berggren, W. A., et al, in press, Paleogene geochronology and chronostratigraphy, *in* Geochronology and the geological record: Geological Society of London Special Paper.

Blondeau, A., and E. E. Brabb, 1983, Large foraminifers of Eocene age from the coast ranges of California, *in* E. E. Brabb, ed., Studies in Tertiary stratigraphy of the California Coast Ranges: U.S. Geological Survey Professional Paper 1213, p. 41–48.

Blow, W. H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy, *in* P. Bronnimann and H. H. Renz, eds., First international conference on planktonic foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad: U.S. National Museum Bulletin 215, p. 97–123.

Bruns, T. R., 1979, Late Cenozoic structure of the continental margin, northern Gulf of Alaska, *in* A. Sisson, ed., The relationship of plate tectonics to Alaska geology and resources: Anchorage, Proceedings of the Alaska Geological Society Symposium, 1977, p. 11–130.

______, 1983a, A model for the origin of the Yakutat block, an accreting terrane in the northern Gulf of Alaska: Geology, v. 11, p. 718–721.

______, 1983b, Structure and petroleum potential of the Yakutat segment of the northern Gulf of Alaska continental margin: U.S. Geological Survey Miscellaneous Field Studies Map MF-1430, 22 p. and 3 sheets, scale 1:5000,000.

______, and W. C. Schwab, 1983, Structure maps and seismic stratigraphy of the Yakataga segment of the continental margin, northern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1424, 3 sheets scale 1:250,000.

Byrne, T., 1982, Structural geology of coherent terranes in the Ghost Rocks Formation, Kodiak Islands, Alaska, *in* J. K. Leggett, and O. Blackwell, eds., Trench-forearc geology; sedimentation and tectonics on modern and ancient active plate margins: Geological Society of London, p. 229–242.

Chase, C. G., 1978, Plate kinematics: The Americas, East Africa, and the rest of the world: Earth and Planetary Science Letters, v. 37, p. 355–368.

Cushman, J. A., and G. D. Hanna, 1927, Foraminifera from the Eocene near Coalinga, California: California Academy of Science Proceedings 4th Series, v. 16, p. 205–228.

Drugg, W. S., 1959, Eocene stratigraphy of the Hoko River area, Olympic Peninsula, Washington: Master's Thesis, University of Washington, 192 p.

Echols, R. J., 1973, Foraminifera, Leg 19, Deep Sea Drilling Project, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 19, p. 721–736.

Engebretson, D. C., 1982, Relative motion between oceanic and continental plates in the Pacific basin: PhD Dissertation, Stanford University, p. 1–211.

Fisher, M. A., and R. von Huene, 1980, Structure of Upper Cenozoic strata beneath Kodiak shelf, Alaska: Bulletin of the American Association of Petroleum Geologists, v. 64, n. 7, p. 1014–1033.

______, et al, 1983, Possible seismic reflections from the downgoing Pacific plate, 275 km arcward from the eastern Aleutian Trench: Journal of Geophysical Research, v. 88, p. 5835–5849.

Hamilton, E. L., 1967, Marine geology of abyssal plains in the Gulf of Alaska: Journal of Geophysical Research, v. 72, p. 4189–4213.

Hanna, M. A., 1926, Geology of the La Jolla quadrangle, California: California University Publications, Department of Geological Sciences Bulletin, v. 16, p. 187–246.

Harper, H. E., 1977, Diatom biostratigraphy of the Miocene/Pliocene boundary in marine strata of the circum North Pacific: PhD Dissertation, Harvard University, p. 1–112.

Ingle, Jr., J. C., 1973, Neogene foraminifera from the northeastern Pacific Ocean, Leg 18, Deep Sea Drilling Project, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 18, p. 517–567.

Jacob, K. H., et al, 1977, Trench-volcanic gap along the Alaskan-Aleutian arc: facts and speculations on the role of terrigenous sediments, *in* M. Talwani and W. C. Pitman, III, eds., Island arcs, deep-sea trenches, and back-arc basins: American Geophysical Union, M. Ewing Series 1, p. 243–258.

Jones, D. L., et al, 1981, Map showing tectonostratigraphic terranes of Alaska, columnar sections, and summary description of terranes: U.S. Geological Survey Open-File Report 81-792, 2 p.

______, et al, 1983, Recognition, character and analysis of tectonostratigraphic terranes in western North America, *in* M. Hashimoto and S. Uyeda, eds., Accretion tectonics in the circum-Pacific regions: Tokyo, Advances in Earth and Planetary Sciences, Terra Scientific Publishing Company, p. 21–36.

Keigwin, L. D., and G. Keller, 1984, Middle Oligocene climatic change from equatorial Pacific DSDP Site 77B: Geology, v. 12, p. 1–16.

Keller, G., 1983a, Biochronology and paleoclimatic implications of middle Eocene to Oligocene planktonic foraminiferal faunas: Marine Micropaleontology, v. 7, p. 463-486.

______, 1983b, Paleoclimatic analyses of middle Eocene through Oligocene planktonic foraminiferal faunas: Paleogeography, Paleoclimatology, and Paleoecology, v. 42, p. 73-94.

______, et al, 1984, Paleoclimatic evidence for Cenozoic migration of Alaskan terranes: Tectonics, v. 3, n. 4, p. 473-495.

Kirschner, C. E., and C. A. Lyon, 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province: American Association of Petroleum Geologists Memoir 19, p. 346-407.

Koizumi, I., 1973, The late Cenozoic diatoms of Sites 183-193, Leg 19, Deep Sea Drilling Project, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 19, p. 805-856.

Lagoe, M. B., 1983, Oligocene to Pliocene foraminifera from the Yakutat Reef section, Gulf of Alaska Tertiary Province, Alaska: Micropaleontology, v. 29, p. 202-222.

Lahr, J. C., and G. Plafker, 1980, Holocene Pacific-North America plate interaction in southern Alaska: implications for the Yakutaga seismic gap: Geology, v. 8, p. 483-486.

Lattanzi, R. D., 1979, Planktonic foraminiferal biostratigraphy of Exxon Company USA wells drilled in the Gulf of Alaska during 1977 and 1978: Journal of the Alaska Geological Society, p. 48-49.

Lyle, W., and J. Morehouse, 1978, Tertiary formations in the Kodiak Island area, Alaska, and their petroleum reservoir and source—rock potential: Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Alaska Open-File Report 114, 47 p.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: Tulsa, OK, American Association of Petroleum Geologists, 416 p.

McDougall, K., 1980, Paleoecological evaluation of late Eocene biostratigraphic zonations of the Pacific coast of North America: Journal of Paleontology, v. 54, Society of Economic Paleontologists and Mineralogists Paleontology Monograph 2, 75 p.

Miles, G. A., 1977, Planktonic foraminifera of the Lower Tertiary Roseburg, Lookingglass and Flournoy Formations, southwest Oregon: PhD Dissertation, University of Oregon, Eugene, 359 p.

______, 1981, Planktonic foraminifers of the lower Tertiary Looking-glass and Flournoy Formations (Umpqua Group), southwest Oregon; Pacific Northwest Cenozoic Biostratigraphy, J. M. Armentrout, ed.: Geological Society of America Special Paper 184, p. 185-204.

Molnar, P., and T. Atwater, 1973, Relative motion of hot spots in the mantle: Nature, v. 246, p. 288-291.

Moore, J. C., et al, 1983, Paleogene evolution of the Kodiak Islands, Alaska: Consequences of Ridge-Trench Interaction in a more southerly latitude: Tectonics, v. 2, p. 265-294.

Murry, J. W., 1973, Distribution and ecology of living benthic foraminiferids: New York, Crane, Russak, and Company, Inc., 274 p.

Nuttall, W. L., 1930, Eocene foraminifera from Mexico: Journal of Paleontology, v. 4, p. 271-293.

Okada, H., and D. Bukry, 1980, Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973, 1975): Marine Micropaleontology, v. 5, p. 321-325.

Perez, O. J., and K. H. Jacob, 1979, Tectonic model and seismic potential of the eastern Gulf of Alaska and Yakataga seismic gap: Journal of Geophysical Research, v. 85, no. B12, p. 7132-7150.

Phleger, F. B, 1960, Ecology and distribution of recent foraminifera: Baltimore, Johns Hopkins Press, 297 p.

Plafker, G., 1983, The Yakutat block: an actively accreting tectonostratigraphic terrane in southern Alaska: Geological Society of America Abstracts with Programs, v. 15, p. 406.

______, et al, 1979, Geologic implications of 1978 outcrop sample data from the continental slope: U.S. Geological Survey, Circular 804-B, p. 143-146.

______, et al, 1980, Preliminary geology of the continental slope adjacent to OCS Lease sale 55, eastern Gulf of Alaska, petroleum resource implications: U.S. Geological Survey Open-File Report 80-1089, 72 p.

Plumley, P. W., et al, 1982, Paleomagnetism of volcanic rocks of the Kodiak Islands indicates northward latitudinal displacement: Nature, v. 300, p. 50-52.

______, 1983, Paleomagnetism of the Paleocene Ghost Rocks Formation, Prince William Terrane, Alaska: Tectonics, v. 2, p. 295-314.

Poore, R. Z., 1980, Age and correlation of California Paleogene benthic foraminiferal stages: U.S. Geological Survey Professional Paper 1162-C, 8 p.

______, and E. E. Brabb, 1977, Eocene and Oligocene planktonic foraminifera from the upper Butano sandstone and type San Lorenzo Formation, Santa Cruz Mountains, California: Journal of Foraminiferal Research, v. 7, p. 249-272.

______, and D. Bukry, 1978, Preliminary report on Eocene calcareous plankton from the eastern Gulf of Alaska continental slope: U.S. Geological Survey Circular 804-B, p. 141-142.

______, et al, 1977, Lower Tertiary biostratigraphy of the northern Santa Lucia Range, California: U.S. Geological Survey Journal Research, v. 5, p. 735-745.

Rau, W. W., 1948, Foraminifera from the Porter Shale (Lincoln Formation), Grays Harbor County, Washington: Journal of Paleontology, v. 22, p. 152-174.

______, 1958, Stratigraphy and foraminiferal zonation in some of the Tertiary rocks of southwestern Washington: U.S. Geological Survey Oil and Gas Investigations Chart OC-57, 2 sheets.

______, 1964, Foraminifera from the northern Olympic Peninsula, Washington: U.S. Geological Survey Professional Paper 374-G, p. G1-G33.

______, 1966, Stratigraphy and foraminifera of the Satsop River area, southern Olympic Peninsula, Washington: Washington Division of Mines and Geology Bulletin 53, 66 p.

———, 1978, Unusually well preserved and diverse Eocene foraminifers in dredge samples from the eastern Gulf of Alaska continental slope: U.S. Geological Survey Circular 804-B, p. 139

———, 1981, Pacific Northwest Tertiary benthic foraminiferal biostratigraphic framework—An overview; *in* J. M. Armentrout, ed., Pacific Northwest Cenozoic biostratigraphy: Geological Society of America Special Paper 184, p. 67-84.

———, et al, 1977, Preliminary foraminiferal biostratigraphy and correlation of selected stratigraphic sections and wells in the Gulf of Alaska Tertiary Province: U.S. Geological Survey Open-File Report 77-747, 54 p.

Rogers, J. F., 1977, Implications of plate tectonics for offshore Gulf of Alaska petroleum exploration: Proceedings of the 9th Annual Offshore Technology Conference, p. 11-16.

Roth, G. H., 1974, Biostratigraphy and paleoecology of the Coaledo and Bastendorff Formations, southwestern Oregon: PhD Dissertation, Oregon State University, 270 p.

Schmidt, R. R., 1970, Planktonic foraminifera from the lower Tertiary of California: PhD Dissertation, University of Southern California, 339, p.

Schrader, H. J., 1973, Cenozoic diatoms from the northeast Pacific, Leg 18, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 18, p. 673-798.

Schwab, W. C., et al, 1980, Maps showing structural interpretation of magnetic lineaments in the northern Gulf of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1245.

Serova, M. Y., 1976, The *Caucasina eocaenica kamchatica* Zone and the Eocene-Oligocene boundary in the northwestern Pacific *in* Progress in micropaleontology: New York, Special Publication Micropaleontology Press, p. 314-328.

Snavely, Jr., P. D., et al, 1978, Twin River Group (upper Eocene to lower Miocene)—defined to include the Hoko River, Makah, and Pysht Formations, Clallam County, Washington: U.S. Geological Survey Bulletin 1457-A, p. 111-120.

Stevenson, A. J., et al, 1983, Tectonic and geologic implications of the Zodiak fan, Aleutian Abyssal Plain, northeast Pacific: Geological Society of America Bulletin, v. 94, p. 259-273.

Stock, J. M., and P. Molnar, 1983, Some geometrical aspects of uncertainties in combined plate reconstructions: Geology, v. 11, p. 697-701.

Stone, D. B., and D. R. Parker, 1979, Paleomagnetic data from the Alaska Peninsula: Geological Society of America Bulletin, v. 90, p. 545-560.

———, et al, 1982, Paleolatitude versus time for southern Alaska: Journal of Geophysical Research, v. 87, p. 3697-3707.

Thoms, R. E., 1965, Biostratigraphy of the Umpqua Formation, southwestern Oregon: PhD Dissertation, University of California, Los Angeles, 219 p.

Tysdal, R. G., and G. Plafker, 1978, Age and continuity of the Valdez Group, southern Alaska, *in* N.F. Sohl and W. B. Wright, eds., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1977: U.S. Geological Survey Bulletin, 1457-A, p. A120-A124.

Ujie, B. H., and H. Watanabe, 1960, The Poronai foraminifera of the northern Ishikari Coal field, Hokkaido: Science Reports of the Tokyo University, v. 7, p. 117-136.

Vedder, J. G., et al, 1983, Stratigraphy, sedimentation and tectonic accretion of exotic terranes, southern Coast Ranges, California, *in* J. S. Watkins and S. L. Drake, eds., Studies in continental margin geology: American Association of Petroleum Geologists Memoir 34, p. 471-498.

von Huene, R. E., et al, 1979a, Cross section, Alaska Peninsula-Kodiak Island-Aleutian Trench: Geological Society of America Map and Chart Series MC-28A, scale 1:250,000.

———, 1979b, Continental margins of the eastern Gulf of Alaska and boundaries of tectonic plates, *in* J. S. Watkins and L. Montadert, eds., Geological and geophysical investigations of continental margins: American Association of Petroleum Geologists Memoir 29, p. 273-290.

Warren, A. D., and J. H. Newell, 1981, Calcareous plankton biostratigraphy of the type Bastendorff Formation, southwest Oregon, *in* J. M. Armentrout, ed., Pacific Northwest Cenozoic biostratigraphy: Geological Society of America Special Paper 184, p. 105-112.

Wolfe, J. A., 1977, Paleogene floras from the Gulf of Alaska region: U.S. Geological Survey Professional Paper 997, 100 p.

Worsley, T. R., 1973, Calcareous nannofossils, Leg 19 of the Deep Sea Drilling Project, *in* Initial reports of the Deep Sea Drilling Project: Washington, DC, U.S. Gov't. Printing Office, v. 19, p. 741-750.