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Chapter 12

Geology of the southern Alaska margin

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INTRODUCTION

This chapter summarizes the tectonic setting, geology, and tectonic evolution of the southern Alaska margin south of the Border Ranges fault system, which extends 2100 km from the Sanak Islands on the west to Chatham Strait on the east and seaward to the base of the continental slope (Fig. 1). Mesozoic and Cenozoic rocks that make up the southern Alaska continental margin record a complex history of subduction-related underplating, offscraping, and metamorphism, as well as transform-related large-scale strike-slip displacements. The region discussed in this chapter has an area of about 328,000 km^2, of which almost 30% is onshore. The land area includes parts or all of 26 1:250,000 scale quadrangles.

The mainland along the northern Gulf of Alaska margin consists of alluvium- and glacier-covered coastal lowlands, 0 to 40 km wide, backed by a belt as wide as 40 km of rugged foothills that rise to elevations of about 2000 m (Wahrhaftig, this volume). The foothills are bordered to the north by the exceedingly rugged Kenai, Chugach, and Saint Elias mountains. Average summit elevations are over 2000 m, and numerous peaks are over 5000 m; the highest peaks are Mt. Saint Elias in Alaska (5488 m) and nearby Mt Logan (5745 m) in Canada. All major drainages in the coastal mountains are occupied by glaciers except for the Alsek River, which drains across the Saint Elias Mountains from Canada, and the Copper River, which drains across the Chugach Mountains from the interior of Alaska. The Kodiak Islands group, the islands of Prince William Sound, and the islands within the study area between Cross Sound and Chatham Strait in the Alexander Archipelago of southeastern Alaska have moderately rugged mountains with summit altitudes between 400 and 1500 m, and generally irregular, drowned, cliffed shorelines.

The width of the continental shelf and slope averages about 110 km; it ranges from as much as 250 km off the southwestern tip of the Kenai Mountains to as little as 40 km at the southeast end of the area. Most of the topography of the shelf and slope is gently undulating, except where it is broken by seven major submarine valleys and a number of smaller valleys that were filled by glaciers to the edge of the continental shelf during the Pleistocene. East of Kayak Island, a relatively smooth and steep continental slope descends to a gentle continental rise at water depths of 2000 to 4000 m. West of Kayak Island, the slope makes up the more irregular inner wall of the eastern Aleutian Trench. The trench is as deep as 4500 m at its northeastern end and gradually deepens westward to about 6400 m off the south end of the Alaska Peninsula.

Unless otherwise indicated, age designations are based on the Decade of North American Geology geologic time scale (Palmer, 1983); metamorphic facies follow the classification of Turner (1981); plutonic rock classifications are after Streckeisen (1976); sandstone classifications are after Dickinson and Suczek (1979); terrane nomenclature follows that of Howell and others (1985); and terrane boundaries and descriptions are after Silberling and others (this volume)

TECTONIC SETTING

Included within the southern Alaska margin is a complex of highly deformed, offscraped, and accreted deep-sea rocks (Chugach, Saint Elias, Ghost Rocks, and Prince William terranes of Silberling and others [this volume]) and an allochthonous fragment of the continental margin (Yakutat terrane) (Fig. 2). The Southern Margin composite terrane includes the four accreted terranes south of the Border Ranges fault system, and the Wrangellia composite terrane includes the three terranes to the north (Peninsular, Wrangellia, and Alexander) (Plafker, 1990; Plafker and Berg, this volume, Chapter 33). The Southern Margin composite terrane boundary with the Pacific plate is the Aleutian megathrust fault system, and the Yakutat terrane boundaries with the Pacific plate are defined by the Transition and Fairweather fault systems. Boundaries between the Yakutat and Chugach terranes are the Kayak Island zone, the Chugach–Saint Elias fault system, and the Fairweather fault. In this chapter, the Saint Elias

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terrane is considered to be part of the Chugach terrane and the Ghost Rocks terrane is part of the Prince William terrane, for reasons discussed below. Present relative plate motions between the Pacific plate and the continental margin are shown in Figure 2.

Structural relations between terranes, rocks that intrude them, and overlap assemblages in the study area are shown diagrammatically in Figure 3, which also shows the inferred configuration of the subducted Pacific plate. In this overview, relations between the terranes of the study area and the major fault boundaries are discussed from north to south.

Border Ranges fault system

The Border Ranges fault system is a suture along which accreted rocks of the Chugach terrane have been juxtaposed against and beneath terranes to the north (MacKevett and Plafker, 1974). The fault system has a history of Early Jurassic through Late Cretaceous subduction manifested by ductile structures in the accreted rocks of the Chugach terrane (Nokleberg and others, 1989, Fig. 2), which were underthrust a horizontal distance of at least 40 km beneath the Wrangellia composite terrane (Plafker and others, 1989). In some areas, most notably in the northern Chugach Mountains and in the Saint Elias Mountains, the Border Ranges fault has been modified by younger, brittle and ductile strike-slip displacements along or near the fault trace (e.g., Pavlis, 1982; Pavlis and Crouse, 1989; Roeske and others, 1991); it is locally offset by Paleogene normal faults in the Matanuska Valley area east of Anchorage (Little, 1990).

Southern Margin composite terrane

The deep-marine rocks south of the Border Ranges fault system constitute one of the largest subduction-related accretionary complexes in the world and record intermittent offscraping and underplating that has occurred probably from the Late Triassic to the present. Together, these rocks make up the Southern Margin composite terrane of Plafker (1990). The accreted rocks are overlain locally by basinal deposits and are intruded extensively by Tertiary granitoid plutons. The various assemblages of the Chugach terrane were successively accreted in the interval from latest Triassic to earliest Tertiary time, but mainly from latest Cretaceous to early Paleocene time. It is believed that throughout most or all of this time, the motion of the oceanic plates relative to the North American continental margin was orthogonal to moderately transpressive (see section on tectonic evolution, Fig. 15, A–C).

The Ghost Rocks Formation was thrust relatively northward beneath the Chugach terrane along the Resurrection fault prior to about 62 Ma, and the Prince William terrane was thrust relatively northward beneath the Ghost Rocks and the Chugach terrane along the Contact fault system (Fig. 3, A–A′, B–B′) prior to about 50 Ma. Counterclockwise oroclinal bending of what is now western Alaska in the early Tertiary formed the present concave-southward margin (Coe and others, 1985), and northwestward movement of the Pacific plate relative to the continental margin since the middle Eocene has resulted in oblique to orthogonal convergence along the present northern and western Gulf of Alaska.

The deep configuration of the underthrusting oceanic crust between the Aleutian Trench and the present magmatic arc of the Aleutian Islands, Alaska Peninsula, and Wrangell Mountains (Fig. 3, C–C′, D–D′) is constrained by earthquake foci and deep seismic reflection and refraction data (Plafker and others, 1982, 1989; Plate 12, this volume; von Huene and others, 1987; Fisher and others, 1989; Page and others, 1989; Fuis and others, 1991; Fuis and Plafker, 1991; Moore and others, 1991). Along much of

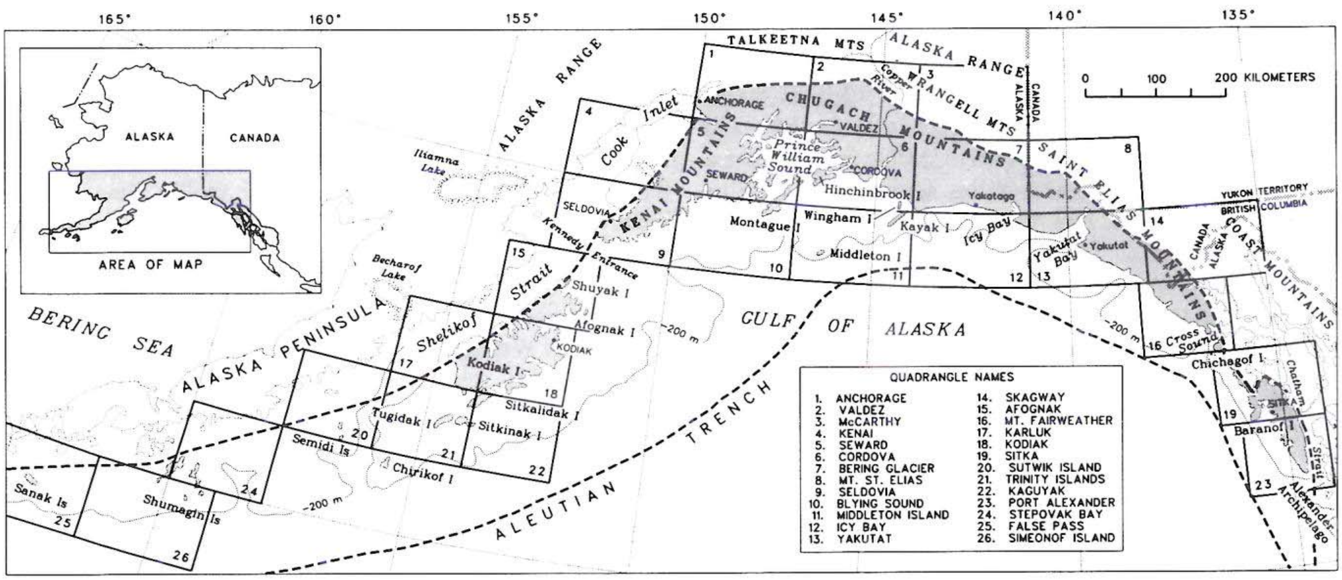


Figure 1. Index map of the southern Alaska margin (area enclosed by heavy dashed lines) showing major geographic features and areas of 1:250,000 scale quadrangles noted in text.

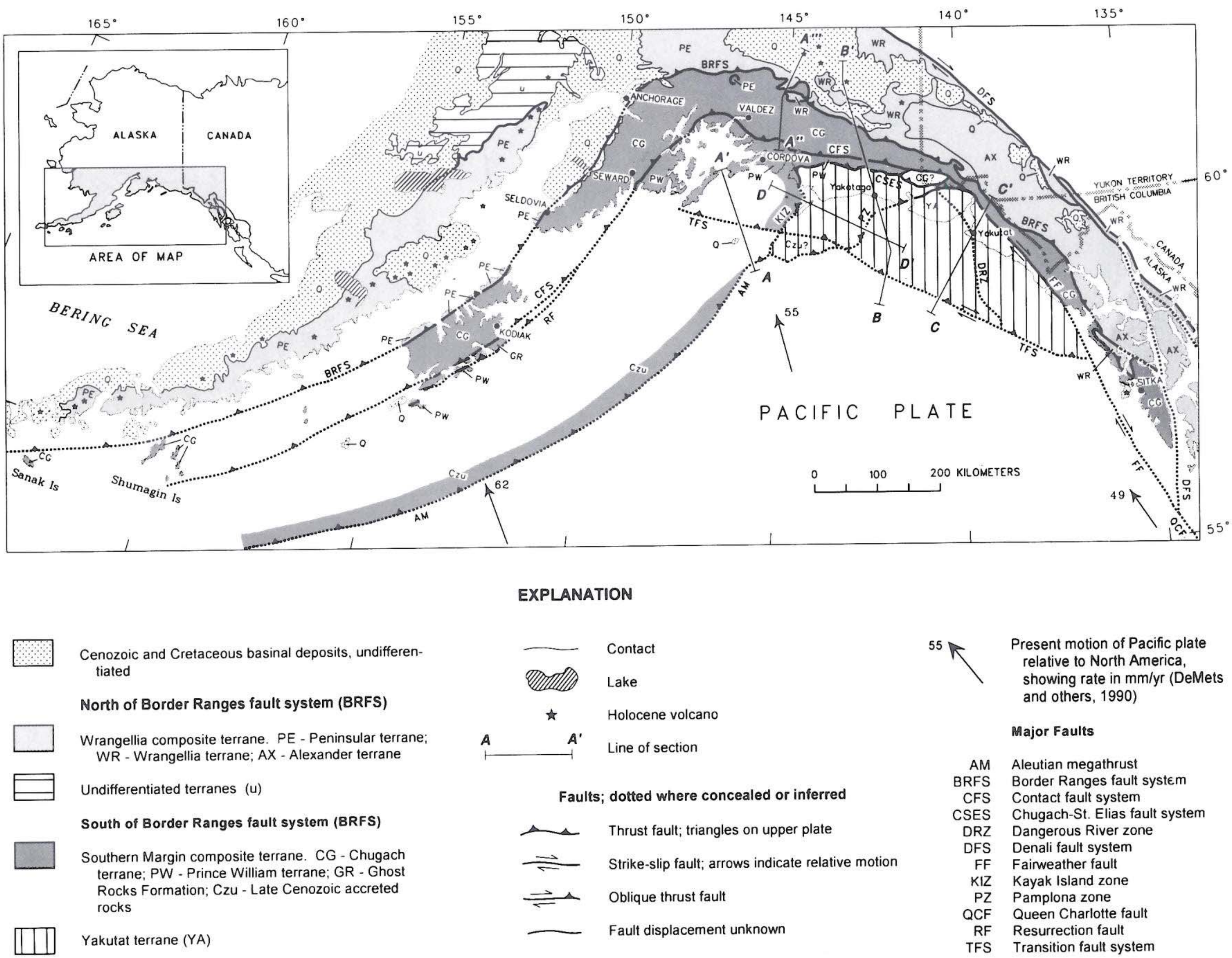


Figure 2. Major composite tectonostratigraphic terranes, terranes, and geologic units of the southern Alaska margin and adjacent areas. Modified from Silberling and others (this volume) and Plafker and Berg (this volume, Chapter 33).

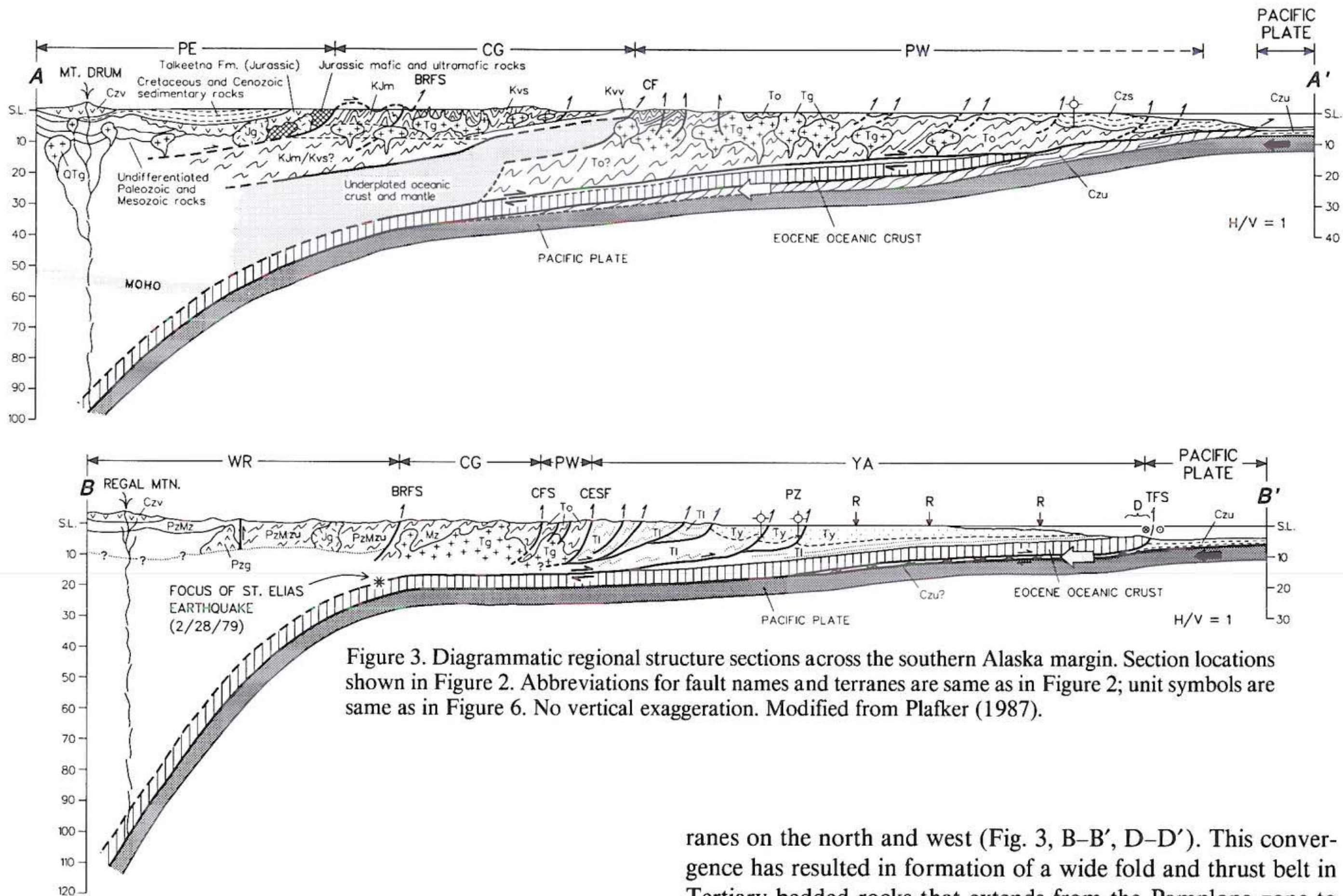


Figure 3. Diagrammatic regional structure sections across the southern Alaska margin. Section locations shown in Figure 2. Abbreviations for fault names and terranes are same as in Figure 2; unit symbols are same as in Figure 6. No vertical exaggeration. Modified from Plafker (1987).

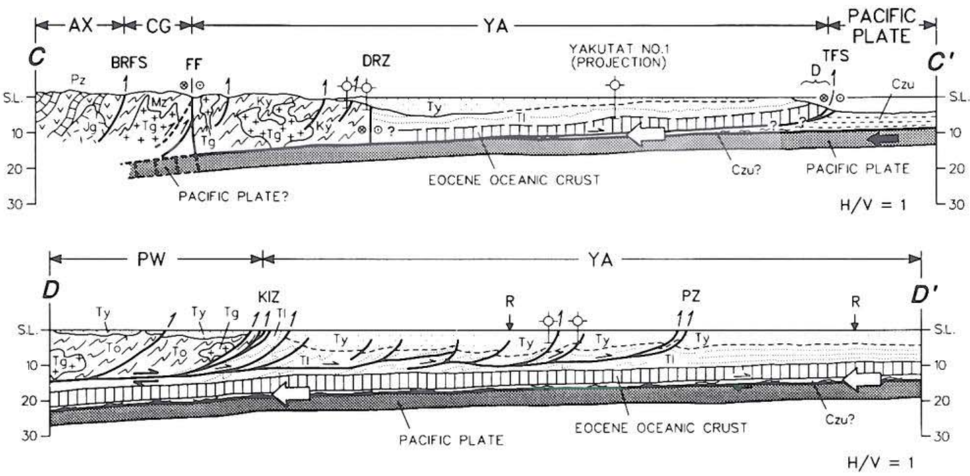
the inner wall of the Aleutian Trench, marine seismic reflection data and deep ocean drilling suggest formation of a late Cenozoic accretionary wedge (von Huene and others, 1987; Moore and others, 1991). An apparent exception is at the eastern end of the trench, where the oceanic crust and 2.5 km of sedimentary cover have apparently been subducted beneath the continental margin and there is no evidence of a post-Eocene accretionary prism in the seismic reflection data (Plafker and others, 1982).

Yakutat terrane

The Yakutat terrane consists of a thick sequence of Cenozoic clastic sedimentary rocks and minor coal underlain in part by an offset fragment of the Chugach terrane and in part by Paleogene oceanic crust (Plafker, 1987). It was displaced about 600 km northwest along the Queen Charlotte–Fairweather transform fault during the late Cenozoic (Fig. 2). Along its northwest boundary, the terrane has been underthrust at shallow depth (<15 km) for at least 200 km beneath the Prince William terrane (Fig. 3, A–A′, D–D′; Griscom and Sauer, 1990). The south boundary of the Yakutat terrane is the dextral oblique Transition fault system along which the Pacific plate has underthrust the terrane at a low angle and is carrying it northwestward relative to adjacent terranes on the north and west (Fig. 3, B–B′, D–D′). This convergence has resulted in formation of a wide fold and thrust belt in Tertiary bedded rocks that extends from the Pamplona zone to the north and west margins of the terrane.

Wrangellia composite terrane north of the Border Ranges fault system

Terranes north of the Border Ranges fault system make up the backstop against and beneath which the Mesozoic accretionary complex was emplaced (Fig. 2). These are the dominantly intraoceanic Paleozoic and Mesozoic magmatic-arc assemblages of the Peninsular, Wrangellia, and Alexander lithotectonic terranes (Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10; Silberling and others, this volume). Together with a displaced fragment of the Wrangellia terrane (northern part of the Taku terrane of Silberling and others, this volume), these terranes constitute the Wrangellia composite terrane as defined by Plafker (1990). The Wrangellia composite terrane is approximately the equivalent of Terrane II of Monger and others (1982) and the Wrangellia superterrane of Saleeby (1983). The northern part of the composite terrane, consisting of the Alaska part of the Wrangellia terrane and the Peninsular terrane, was referred to as the Talkeetna superterrane by Csejtey and others (1982). Recent data favor the interpretation that, since Paleozoic time, the Wrangellia composite terrane has been a single large disrupted terrane, rather than an amalgamation of several distinct,



EXPLANATION

QTg	Quaternary and Tertiary intrusive rocks
Czv	Late Cenozoic Wrangell Volcanics
Czu	Late Cenozoic deep marine sedimentary rocks
Czs	Cenozoic marine sedimentary rocks
Tg	Tertiary granitic rocks
To	Paleocene and Eocene Orca Group
Ty	Neogene Yakataga Fm.
Tl	Paleogene sedimentary rocks
Ky	Cretaceous Yakutat Group
Kvv	Cretaceous Valdez Group volcanic rocks
Kvs	Cretaceous Valdez Group flysch
KJm	Cretaceous and Jurassic melange and blueschist
Mz	Cretaceous metaflysch and metamelange
Jg	Jurassic granitic rocks
Pz	Paleozoic rocks, undifferentiated
Pzg	Paleozoic plutonic rocks
PzMzu	Paleozoic and Mesozoic schistose rocks
PzMz	Paleozoic and Mesozoic sedimentary and volcanic rocks
⊗	Movement away from reader
⊙	Movement toward reader
R	Refraction line

structurally bound terranes at least since the end of the Paleozoic (Plafker, 1990; Plafker, 1990; Plafker and Berg, this volume, Chapter 33; Nokleberg and others, this volume, Chapter 10).

Paleomagnetic inclination anomalies indicate that the Peninsular, Wrangellia, and Alexander terranes were about 30° south of their present latitude relative to cratonic North America during the Late Triassic (Haeussler and others, 1989; P. W. Plumley, 1990, written commun.; Hillhouse and Coe, this volume). In addition, the Alexander terrane may have undergone about 15° of northward movement relative to North America since the Pennsylvanian, assuming an origin in the Northern Hemisphere (Van der Voo and others, 1980). The composite terrane was emplaced against the North America continental margin by mid-Cretaceous time (Csejtey and others, 1982; Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10) and possibly as early as the Middle Jurassic (McClelland and others, 1992); it was at about its present position between Cenomanian and Eocene time (Hillhouse and Coe, this volume).

Magmatic arcs

The history of arc magmatism in the Wrangellia composite terrane and regions to the north of it is relevant for interpretation of the Southern Margin composite terrane accretionary complex because the magmatic arcs reflect periods of relative convergence during which rocks may have been subducted, accreted, or offscraped, and because the arcs provided much of the sediment that makes up the accretionary complex.

Rocks interpreted as arc related extend from just north of the Border Ranges fault into interior Alaska and the intermontane region of Canada (Armstrong, 1988; Dodds and Campbell, 1988; Barker, this volume; Barker and others, this volume; Brew, this volume; Miller, this volume; Miller and Richter, this volume; Moll-Stalcup, this volume; Plafker and Berg, this volume, Chapter 33). These arcs appear to have been built on the Wrangellia composite terrane (Fig. 4) prior to about mid-Cretaceous time. After emplacement of the Wrangellia com-

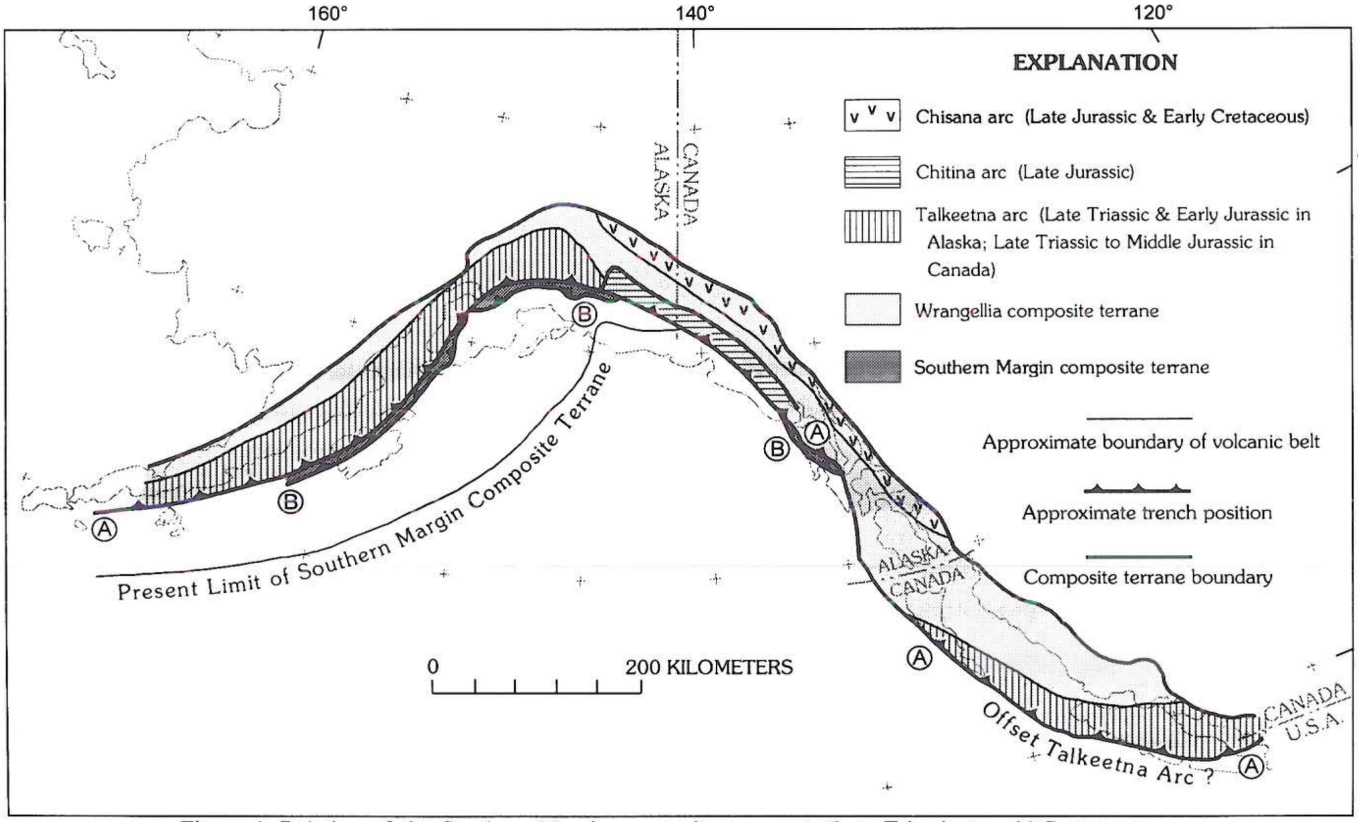


Figure 4. Relation of the Southern Margin composite terrane to Late Triassic to mid-Cretaceous magmatic arcs in the Wrangellia composite terrane. Circled letters indicate approximate positions of the associated trench at the beginning of Talkeetna arc activity (A) and at the end of Chisana arc activity (B). Trench A corresponds with present position of Border Ranges fault and trench B is at the present position of the Uganic, Chugach Bay, Eagle River, Tazlina, and related faults.

posite terrane along the southern Alaska margin, the Late Cretaceous and Paleogene arcs were built on the Wrangellia composite terrane and on terranes farther inboard in Alaska and Canada (Fig. 5). The Cenozoic Aleutian-Wrangell magmatic arc is entirely within the Wrangellia composite terrane in the Alaska Peninsula and Wrangell Mountains, and it is intraoceanic west of the Alaska Peninsula in the Aleutian Islands (Miller and Richter, this volume; Vallier and others, this volume).

Three Mesozoic arc-related magmatic sequences occur within the Wrangellia composite terrane (Fig. 4). They are (1) the latest Triassic and Early Jurassic Talkeetna arc of the Peninsular terrane and possibly the largely coeval latest Triassic to earliest Middle Jurassic arc rocks of the Bonanza Group in the British Columbia part of the Wrangellia terrane; (2) a belt of calc-alkalic plutonic rocks of Middle and Late Jurassic age (Tonsina-Chichagof belt of Hudson, 1983), which includes the Late Jurassic Chitina arc in the Wrangellia and Alexander terranes; and (3) the Late Jurassic and Early Cretaceous Chisana arc (Gravina-Nutzotin belt of Berg and others, 1972).

Three major known and inferred post–mid-Cretaceous arc sequences occur within and north of the Wrangellia composite terrane (Fig. 5). (1) The latest Cretaceous and Paleogene (mainly 77 to about 55 Ma, but locally may be as old as 93 Ma and as young as 45 Ma) Kluane arc consists of variably metamorphosed intermediate-composition plutonic rocks along and north of the northeastern margin of the Wrangellia composite terrane in the Coast Mountains of southeastern Alaska and British Columbia (Brew, this volume; Armstrong, 1988) and correlative plutonic and volcanic rocks within adjacent parts of British Columbia and Yukon Territory northeast of the Coast Mountains (Armstrong, 1988), and a broad belt of volcanic and plutonic rocks in western, central, and east-central Alaska that includes much or all of the Yukon-Tanana, Yukon-Kanuti, and Kuskokwim Mountains–Talkeetna Mountain belts of Moll-Stalcup (this volume). (2) Middle Tertiary (43 to 33 Ma) magmatism associated with the Aleutian arc forms a well-defined belt in Alaska that trends along the Alaska Peninsula and extends into central Alaska (Moll-Stalcup, this volume). (3) Neogene (<30 Ma) magmatism of the Aleutian-Wrangell magmatic arc coincides approximately with the middle Tertiary arc except for an extension eastward into the Wrangell Mountains and adjacent parts of Canada (Miller and Richter, this volume).

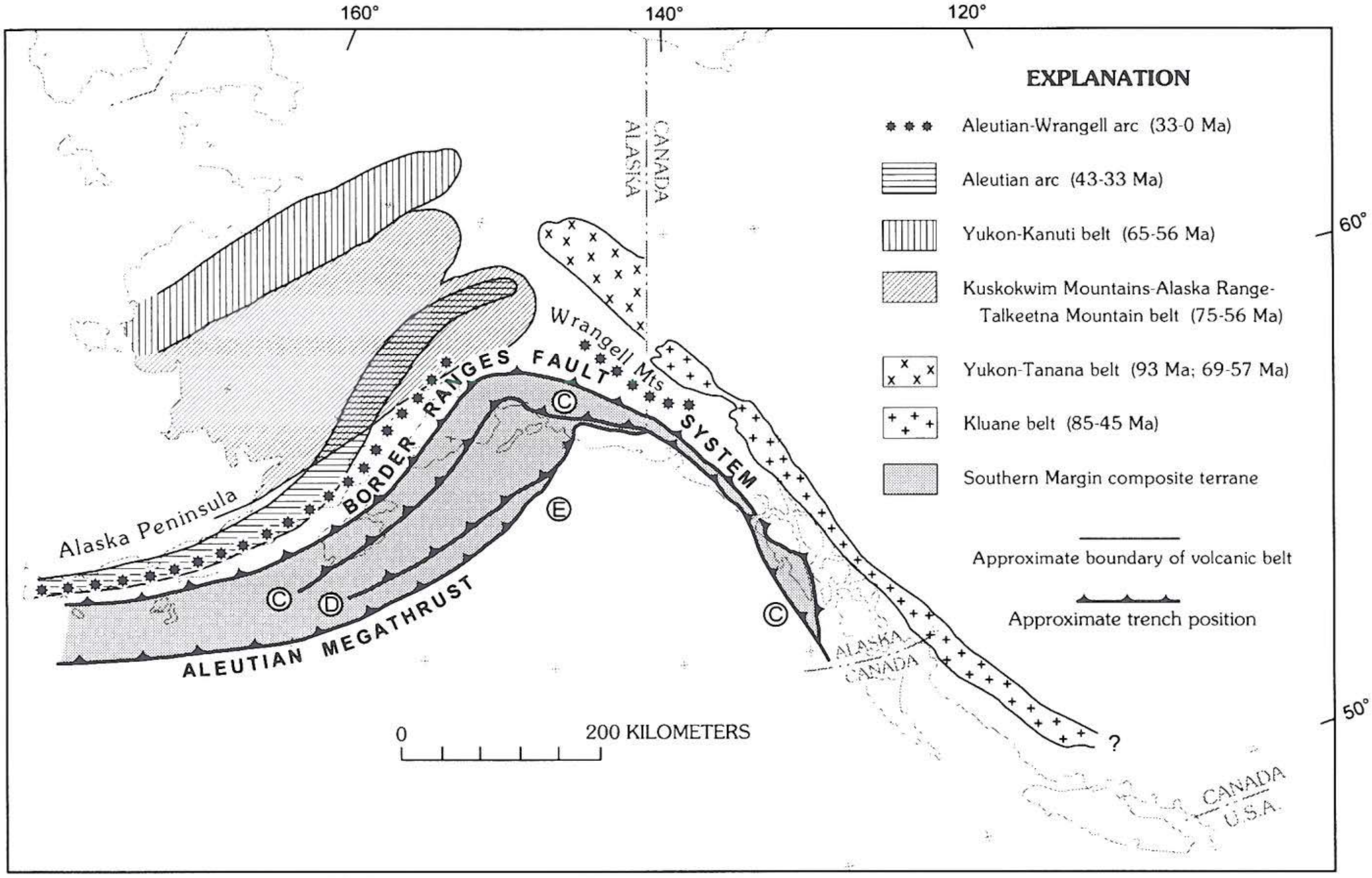


Figure 5. Relations of the Southern Margin composite terrane to Late Cretaceous and Cenozoic magmatic arcs (and belts) in Alaska. Circled letters indicate approximate positions of the associated trench at the end of the Cretaceous (C), during the middle Eocene and Oligocene(?) (D), and at present (E). Trench C corresponds with present position of the Contact fault, trench D corresponds with Chugach–Saint-Elias and Pamplona zone fault systems, and trench E corresponds with Aleutian megathrust. Magmatic belts after Moll-Stalcup (this volume) and Brew (this volume).

A mid-Cretaceous thermal event resulted in widespread plutonism and metamorphism throughout the Wrangellia composite terrane and in much of Alaska as far north as the southern Brooks Range (Miller, this volume; Dusel-Bacon, this volume). There is no evidence in Alaska that the plutonism was accompanied by arc volcanism in the Wrangellia composite terrane. During this time interval, widespread plutonism accompanied by arc volcanism was recorded in the intermontane region of Canada that extended into the eastern Yukon-Tanana belt of Alaska (Armstrong, 1988; Bacon and others, 1990).

Pacific plate

The Pacific plate oceanic crust is progressively younger from west to east along the southern Alaska margin. Its age ranges from chron 5C (about 17 Ma) off Chatham Strait, to chron 15 (about 37 Ma) at the east end of the Aleutian Trench, to chron 24 (about 58 Ma) off the Sanak Islands at the west end of the region (Atwater and Severinghaus, 1989).

The present motion of the Pacific plate relative to the North American plate is northwestward at about 66 mm/yr off the Sanak Islands, and decreases to about 50 mm/yr off southeastern Alaska (Fig. 2) (DeMets and others, 1990). Northwesterly relative motions of the Pacific and Kula plates at moderate rates have prevailed since about 55 Ma (Lonsdale, 1988). This motion is accommodated mainly by orthogonal underthrusting along the Aleutian megathrust system and the Kayak Island and Pamplona zones to the northeast, and by dextral to dextral oblique strike-slip along the Queen Charlotte–Fairweather transform fault system; lesser amounts of slip occur on faults along the south and north boundaries of the Yakutat terrane and within interior Alaska (Lahr and Plafker, 1980; Plafker and others, this volume, Plate 12).

Prior to counterclockwise rotation of what is now western Alaska in latest Cretaceous to earliest Tertiary time, the continental margin probably had a general northwest trend comparable to that of the present continental margins of British Columbia and the conterminous United States (Moore and Connelly, 1979; Plafker, 1987; Plafker and others, 1989; Hillhouse and Coe, this volume). From about 85 to 55 Ma, motion of the Kula plate relative to the continent was north-northeast at high rates (120 to 210 mm/yr), resulting in dextral transpression along the continental margin. From about 180 to 85 Ma, motion of the Farallon plate was probably east to northeast at moderate to high rates (70 to 120 mm/yr), and there was consequent orthogonal convergence or sinistral transpression along the continental margin (Engebretsen and others, 1985; Lonsdale, 1988).

SOUTHERN MARGIN COMPOSITE TERRANE

The minimum total onshore and offshore area of the Southern Margin composite terrane includes almost equal areas of Mesozoic and Cenozoic rocks covering close to 270,000 km^2 (Table 1). In general, the older Mesozoic assemblages of the Chugach terrane differ significantly from each other in age, lithology, and mode and time of emplacement, whereas differences between units in the Late Cretaceous part of the Chugach terrane and in the Paleogene Prince William terrane and related units are more subtle. These differences largely reflect the relative age spans for these rocks: greater than 100 m.y. for the Mesozoic units versus 20 m.y. for the Cenozoic units of the accretionary prism that are exposed at the surface. The more subtle differences in the younger, more voluminous sequences probably also reflect their proximity to active continental margin arcs.

Chugach terrane

Accreted rocks of Mesozoic age make up the Chugach terrane (Berg and others, 1972; Plafker and others, 1977). The terrane is 60 to 100 km wide and extends 2100 km along the Gulf of Alaska margin from the Sanak Islands to Chatham Strait (Fig. 2). The total onshore and offshore area underlain by these rocks is about 124,000 km^2. The Chugach terrane is composed of three major fault-bounded assemblages that are progressively younger from north to south and constitute about 1%, 10%, and 89%, respectively, of the total terrane area. These are (1) local coherent slabs of Late Triassic(?) and Jurassic(?) greenschist with local blueschist facies minerals closely associated with melange along the north margin of the terrane, (2) a discontinuous landward belt of Late Triassic to Early Cretaceous melange, and (3) a southern continuous belt of Late Cretaceous volcaniclastic flysch and oceanic basaltic rocks that make up most of the terrane. These three major assemblages of the Chugach terrane are referred to informally in this chapter as the glaucophanic greenschist, melange, and flysch and basalt assemblages. As thus defined, the glaucophanic greenschist assemblage includes the schist of Raspberry Strait of Roeske (1986) on the Kodiak Islands, the melange assemblage includes the Kachemak terrane of Jones and others (1987) on the southern Kenai Peninsula, and the flysch and basalt assemblage includes the Saint Elias terrane of Jones and others (1987) in the Saint Elias Mountains. Assemblages of Mesozoic melange, flysch, and mafic volcanic rocks that underlie the eastern part of the Yakutat terrane are inferred to be displaced fragments of the Chugach terrane (Plafker, 1987). The distribution of the Mesozoic accretionary assemblages is shown in Figure 6, and their lithologies, ages, and correlations are summarized in Figure 7.

The Chugach terrane is bounded by major faults, both landward and seaward throughout its extent, and its three constituent assemblages also are fault bounded (Fig. 6). Along its north boundary it is faulted against and beneath the Wrangellia composite terrane. Along the south margin younger Paleogene accreted sequences of the Ghost Rocks Formation and Prince

TABLE 1. MESOZOIC AND PALEOGENE ACCRETIONARY UNITS OF THE SOUTHERN MARGIN COMPOSITE TERRANE

Terrane	Units	Area (km^2)*	Volume (km^3)†
	Ghost Rocks Formation	6100	61,000
Prince William	Orca Group (Includes Sitkalidak Formation and Resurrection Peninsula sequence)	139,300	1,393,000
	Subtotal Cenozoic	145,400	1,454,000
Chugach	Glaucophanic Greenschist Assemblage (Includes schists of Raspberry Strait, Seldovia, Iceberg Lake, Liberty Creek, and Pinta Bay)	1600	24,000
	Melange Assemblage (Includes Uyak Complex, Kachemak Bay sequence, McHugh Complex, Yakutat Group melange, and Kelp Bay Group)	13,200	198,000
	Flysch and Basalt Assemblage (Includes Shumagin Formation, Kodiak Formation, Valdez Group and its metamorphic equivalents in the Chugach Mountains, the metamorphic complex of the Saint Elias area, Sitka Graywacke, and possibly the informally named Ford Arm Formation)	108,600	1,629,000
	Subtotal Mesozoic	123,400	1,851,000
Total		268,800	3,305,000

*Includes inferred offshore areas.
†Average thicknesses based on geophysical data are 15 km for Mesozoic and 10 km for Cenozoic units. Does not include eroded material, much of which may be recycled into younger parts of the accretionary sequence.

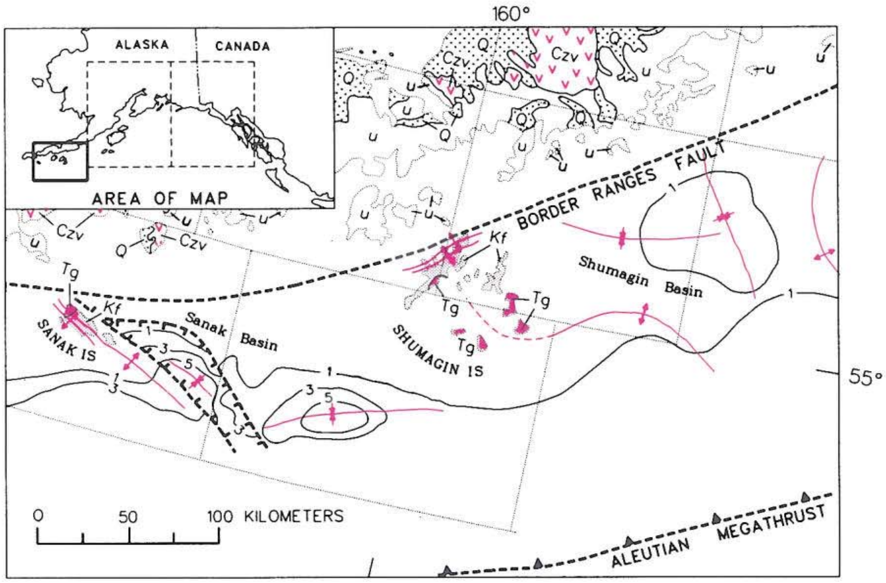


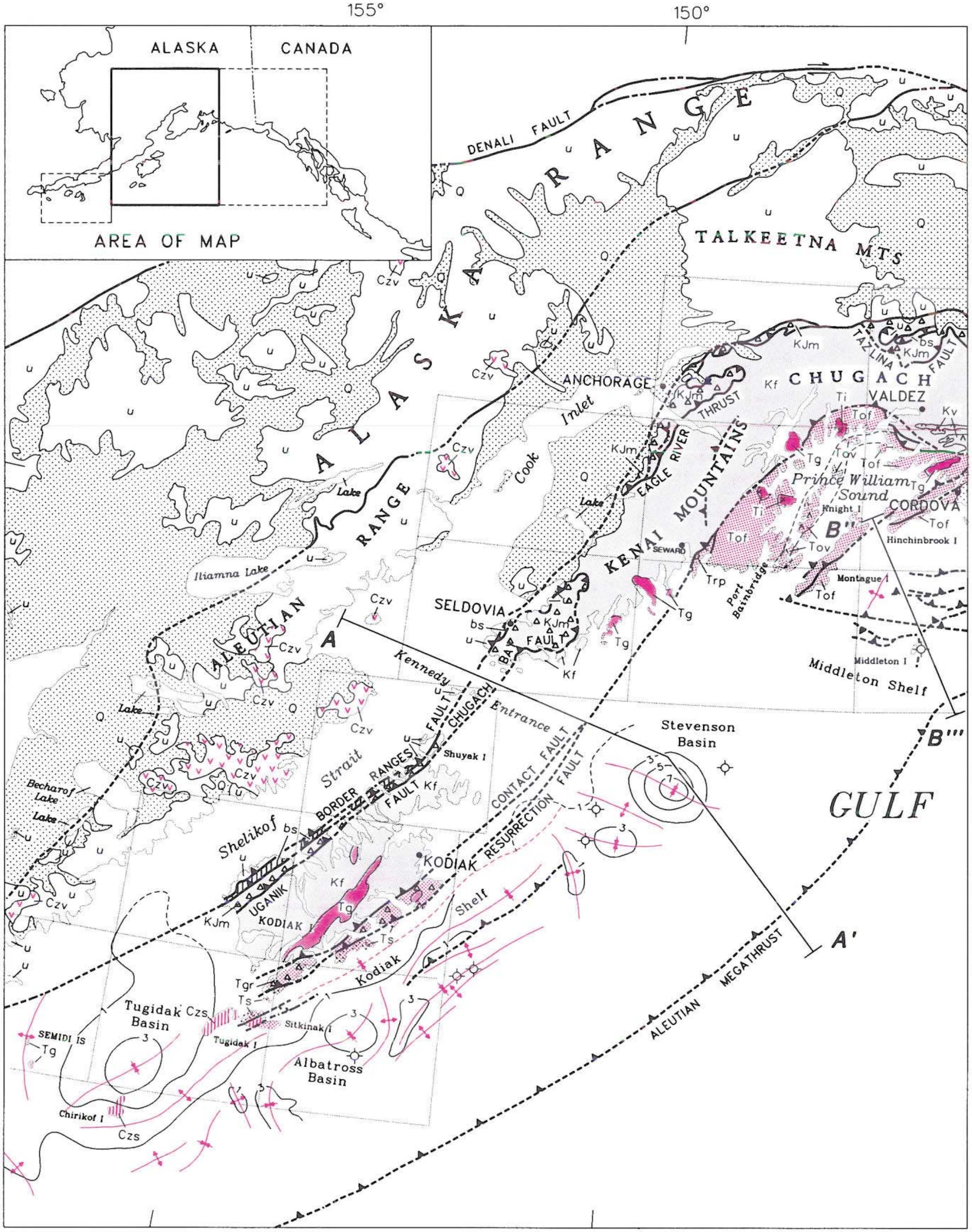
Figure 6 (on this and following three pages). Geologic map of the southern Alaska margin and adjacent regions. Geology modified from Beikman (this volume), Plafker (1987), Plafker and others (1989), and Kirschner (this volume, Plate 7).

William terrane are underthrust along the Contact fault system. In the eastern part of the Yakutat terrane (east of long 141°W), it is juxtaposed along the Fairweather dextral strike-slip fault against rocks inferred to be displaced fragments of the Chugach terrane. South of the Chatham Strait fault in southeastern Alaska, the Chugach terrane is in contact with probable oceanic crust of the Pacific plate along the Queen Charlotte dextral strike-slip fault.

We recognize that the flysch and basalt, melange, and glaucophanic greenschist assemblages could be interpreted either as subterranes of the Chugach terrane or as separate terranes. However, we prefer to retain the name "Chugach terrane" because of its extensive usage in the literature. In doing so, we have extended the original definition by Berg and others (1972) to include all Mesozoic accreted deep-sea rocks south of the Border Ranges fault. We have not attempted to define subterranes because uncertainties in dating and correlation, as well as structural complexity and metamorphism, preclude precise definition and delineation of the constituent units or of their time of accretion.

Glaucophanic greenschist assemblage. Blueschist-bearing metamorphic rocks have been recognized along and near the Border Ranges fault system from the Kodiak Islands on the west to Chatham Strait in southeastern Alaska on the east, and they underlie a total area of about 1500 km^2. Units large enough to show in Figure 6 are (1) the schist of Raspberry Strait, which comprises a discontinuous belt 2 to 8 km wide in the northern part of the Kodiak Islands (Roeske, 1986); (2) the schist of Seldovia, exposed in a small area near Seldovia in the southern Kenai Mountains (Carden and others, 1977; Seldovia schist terrane of Cowan and Boss, 1978); (3) the schist of Iceberg Lake, which occurs as a coherent tectonic slice 40 km long and up to 4 km wide as well as numerous smaller klippen that are surrounded by melange facies rocks in the western Valdez quadrangle of the northern Chugach Mountains (Winkler and others, 1981); and (4) the schist of Liberty Creek, which crops out over an area 28 km long and up to 13 km wide in the eastern Valdez quadrangle of the northern Chugach Mountains (Winkler and others, 1981; Plafker and others, 1989). The variably metamorphosed schist of Pinta Bay (Decker, 1980a) in the Chichagof Island area includes irregular fault slices containing blueschist minerals in a discontinuous belt 30 km long and 4 to 5 km wide. The presence of abundant blocks of glaucophanic greenschist in glacial moraines of the Yakutat Bay area in the Saint Elias Mountains suggests that blueschist facies rocks are present within the Chugach terrane in the rugged Saint Elias Mountains. Details of the metamorphism of the glaucophanic greenschist and other metamorphic rocks of the Chugach terrane are given by Dusel-Bacon (this volume).

Lithology. The rocks of the glaucophanic greenschist assemblage (Fig. 7) are chiefly greenschist and blueschist, but they include muscovite and actinolite schist, siliceous schist, metachert, and graphitic schist. The protolith was dominantly basaltic pillow flows, tuffs, tuff breccias, and volcaniclastic rocks with minor chert, carbonate, and argillaceous rocks. At Seldovia the schist occurs as isolated tectonic blocks of quartz-sericite schist, greenschist, and crossite-epidote blueschist immersed in a poorly exposed, completely sheared matrix of argillite (Cowan and Boss, 1978). A single large body of marble occurs with the schist of Seldovia (Forbes and Lanphere, 1973), and foliated calcareous rocks occur in the schist of Iceberg Lake (Winkler and others, 1981). Pillow structures are locally well preserved in the schist of Iceberg Lake, and faint primary structures suggestive of breccia and possible pillow breccia occur in the schist of Liberty Creek (Plafker and others, 1989).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150°
60°
ALASKA
CANADA
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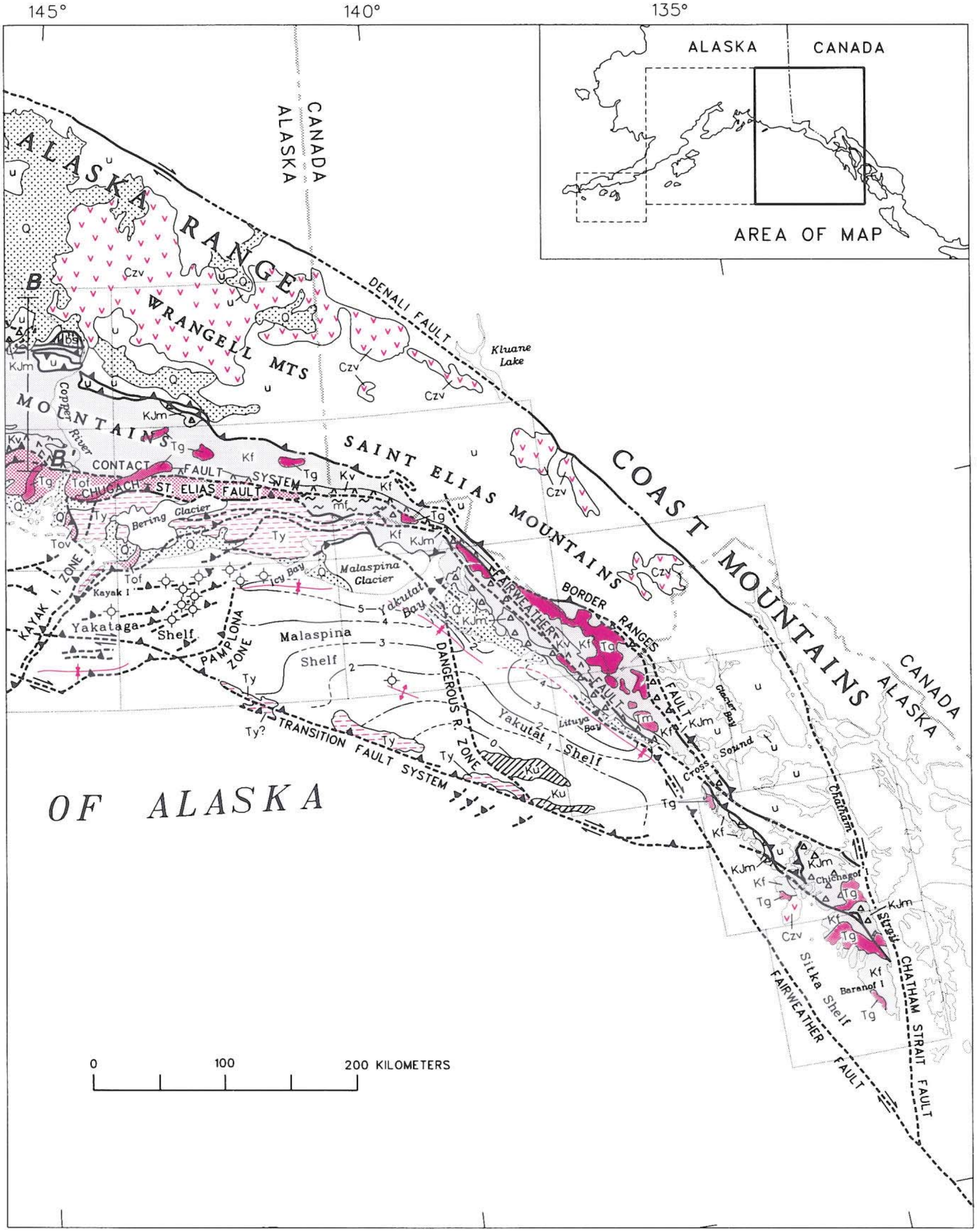
DENALI FAULT
ALASKA RANGE
TALKEETNA MTS
ALEUTIAN RANGE
ANCHORAGE
CHUGACH
VALDEZ
TAZLINA FAULT
THRUST
Cook Inlet
EAGLE RIVER
KENAI MOUNTAINS
Prince William Sound
CORDOVA
Knight I
Hinchinbrook I
SEWARD
Port Bainbridge
Montague I
Middleton I
Middleton Shelf
Iliamna Lake
SELDOVIA
BAY FAULT
Kennedy Entrance
BORDER RANGES FAULT
CHUGACH FAULT
CONTACT FAULT
RESURRECTION FAULT
Shuyak I
Shelikof Strait
Becharof Lake
Lake
Stevenson Basin
GULF
KODIAK
UGANIK
KODIAK I
Kodiak Shelf
Tugidak Basin
Tugidak I
Sitkinak I
SEMIDI IS
Albatross Basin
Chirikof I
ALEUTIAN MEGATHRUST
A
A'
B''
B'''
Q
u
Czv
KJm
Kf
bs
Ti
Tof
Tov
Tg
Kv
Trp
Ts
Tgr
Czs


145°
140°
135°
60°
55°
ALASKA
CANADA
AREA OF MAP
CANADA
ALASKA
ALASKA RANGE
WRANGELL MTS
DENALI FAULT
Kluane Lake
COAST MOUNTAINS
SAINT ELIAS MOUNTAINS
CHUGACH MOUNTAINS
Copper River
CONTACT FAULT SYSTEM
CHUGACH-ST. ELIAS FAULT
Bering Glacier
Malaspina Glacier
Icy Bay
Kayak I
KAYAK I. ZONE
Yakataga Shelf
PAMPLONA ZONE
Malaspina Shelf
Yakutat Bay
DANGEROUS R. ZONE
FAIRWEATHER FAULT
BORDER RANGES FAULT
Lituya Bay
Yakutat Shelf
TRANSITION FAULT SYSTEM
Glacier Bay
Cross Sound
Chatham
Chichagof
Strait
Baranof I
Sitka Shelf
FAIRWEATHER FAULT
CHATHAM STRAIT FAULT
OF ALASKA
0
100
200 KILOMETERS
B
B'
Czv
Q
u
KJm
Kv
Kf
Tg
Tof
Tov
Ty
Ty?
Tm
Ku
mf
0
1
2
3
4
5

EXPLANATION

OVERLAP AND SUTURE ASSEMBLAGES

Q	Surficial deposits	Holocene and Pleistocene
Czv / Czs	Volcanic rocks; Sedimentary rocks	Holocene, Pleistocene, Pliocene, and Miocene
Ti / Tm	Ti – granitic rocks; Tm – gabbro and ultramafic rocks	Lower Oligocene and upper Eocene
Tg	Granitic rocks	Middle and lower Eocene and Paleocene

YAKUTAT TERRANE

Ty	Marine and continental siliciclastic rocks and coal. Neogene overlap assemblage (Yakataga Fm.) is not differentiated	Lower Miocene to upper Paleocene

PRINCE WILLIAM TERRANE

Tof / Tov	Orca Group – Tof, flysch; Tov, basalt	Middle Eocene to upper Paleocene
Trp	Resurrection Peninsula sequence – ophiolite	Middle Eocene to upper Paleocene
Ts	Sitkalidak Fm. – flysch	Middle Eocene to upper Paleocene
Tgr	Ghost Rocks Formation – basalt, oceanic sedimentary rocks, melange	Paleocene and Upper Cretaceous

CHUGACH TERRANE (INCLUDING EASTERN YAKUTAT TERRANE)

Kf / Kv / Ku	Kf – flysch; Kv – basalt; Ku – undifferentiated	Upper Cretaceous Campanian (?) and lower Maastrichtian
mf	Metaflysch and metavolcanic rocks of the Saint Elias complex	Cretaceous and Upper Jurassic (?)
KJm	Melange assemblage – basalt and oceanic sedimentary rocks	Middle Cretaceous to Middle Triassic
bs	Glaucophanic greenschist assemblage – blueschist and greenschist	Middle Cretaceous and Lower Jurassic to Upper Triassic (?)

UNDIFFERENTIATED ROCKS NORTH OF BORDER RANGES FAULT

u	Undifferentiated rocks

FAULTS
dashed where concealed

High angle fault

Thrust or reverse fault; sawteeth on upper plate

Strike-slip fault; arrows indicate direction of relative movement

A — A'

Line of section; Figs. 11 and 12

FOLDS
dashed where approximately located

Anticline or structural high

Syncline or structural low

3

Structure contour – In kilometers; dashed where control is poor. Contours are on approximate base of Neogene overlap sequence (Yakataga Formation) on Yakataga, Malaspina and Yakutat shelves, and at the base of Neogene and Paleogene overlap sequence on Kodiak shelf.

Contact

Dry well

Geochemically analyzed metabasalts from the schists of Liberty Creek and Iceberg Lake have variable major element composition, but stable minor element and rare earth element (REE) compositions that closely match average normal mid-ocean ridge basalt (N-type MORB) at about 7 to 19 times chondrites with slight depletion of light REEs (LREE) over heavy REEs (HREE) (Plafker and others, 1989).

Metamorphic grade is transitional greenschist-blueschist facies in most areas. However, it ranges from prehnite-pumpellyite and lawsonite-albite through lower greenschist and blueschist, to transitional blueschist-epidote-amphibolite facies. The characteristic blue amphibole in the rocks is crossite; glaucophane has been identified only in the schist of Raspberry Strait (Roeske, 1986). Lawsonite occurs in the schist of Raspberry Strait (Roeske, 1986) and rarely in the schists of Iceberg Lake and Liberty Creek (Winkler and others, 1981). Peak metamorphism for the schist of Raspberry Strait was 4.5 to 8 kbar and 350 to 500 °C, and for the schists of Iceberg Lake and Liberty Creek it was 6.2 ± 2 kbar and 350 to 375 °C (Roeske, 1986; Sisson and Onstott, 1986).

Structure. The schist is deformed into chevron and isoclinal folds that commonly verge south. All rocks are pervasively sheared and locally mylonitic. The schist of Raspberry Strait has undergone at least three regional deformations: one or two ductile deformations associated with the high-pressure metamorphism; a brittle crenulation; and a late brittle-shearing event that locally juxtaposes rocks of differing metamorphic facies (Roeske, 1986). This latest deformation formed a pervasive system of anastomosing faults ranging in width from a few centimeters to >100 m. In the schist of Liberty Creek, at least two generations of regional ductile deformations include an earlier south-verging set of folds that is overprinted by younger, north-verging folds (Fig. 8; Nokleberg and others, 1989) and a later brittle-shearing event of mid-Cretaceous or younger age.

Age. Isotopic dating of metamorphic minerals in the glaucophanic greenschist assemblage indicates Late Triassic to mid-Cretaceous crystallization ages (Fig. 7); crystallization presumably occurred during deep subduction of the rocks. The data indicate at least two episodes of subduction-related transitional blueschist facies metamorphism along the north margin of the Chugach terrane. The early episode is Early to Middle(?) Jurassic in age in the Kodiak Islands, southern Kenai Mountains, and Chugach Mountains. The younger episode in southeastern Alaska is considered by Decker and others (1980) to be mid-Cretaceous (91 to 106 Ma), on the basis of ^{40}Ar ages on white mica and actinolite in rocks associated with the blueschist minerals. The possibility of postemplacement resetting of these mineral ages by shearing and/or extensive Tertiary plutonism cannot be discounted.

The protolith age of the schist is conjectural. Its position in the accretionary complex indicates only that it is probably as old as, or older than, the less metamorphosed Late Triassic to mid-Cretaceous McHugh Complex, which borders the schist on the south. In the western Valdez quadrangle (Winkler and others, 1981) and in the Seldovia area (Forbes and Lanphere, 1973; Carden and others, 1977; Jones and others, 1987), glaucophanic greenschist rocks having Early to Middle Jurassic metamorphic ages occur in close proximity to Late Triassic oceanic rocks, which include paleontologically dated radiolarian chert. This association suggests that the glaucophanic greenschist in those areas may be a more deeply subducted part of the Late Triassic oceanic assemblage (Plafker and others, 1989; Bradley and Kusky, 1992). Emplacement age within the accretionary complex is considered to be close to the recrystallization age of the schist, or Early Jurassic for all but the schist of Pinta Bay in southeastern Alaska, which may have been emplaced in the mid-Cretaceous. Glaucophanic blueschist that occurs as erratic blocks in the Yakutat terrane is undated.

Interpretation. The combination of lithology of the sequence and the geochemistry and relict textures of the metavolcanic rocks suggests that the glaucophanic greenschist is an oceanic assemblage of basalt and associated marine sedimentary rocks. Metamorphism to glaucophanic greenschist indicates underthrusting to a depth of 12 to 25 km beneath a convergent margin followed by rapid uplift and retrograde metamorphism. Metamorphic ages indicate subduction during the Early Jurassic in the Kodiak Islands and the Chugach Mountains and during the mid-Cretaceous in southeastern Alaska. Because convergence and deep underthrusting probably occurred during much of the Mesozoic Era (see section on tectonic evolution), blueschist facies metamorphic rocks with ages other than Early to Middle(?) Jurassic and mid-Cretaceous will probably be discovered within the Chugach terrane.

Glaucophanic greenschist and the Talkeetna magmatic arc. Glaucophanic greenschist along and near the Border Ranges fault system occurs in close proximity to almost coeval Late Triassic to early Middle Jurassic volcanic and plutonic rocks along the south margin of the Peninsular terrane, including the informally named Border Ranges ultramafic and mafic complex of Burns (1985), the Kodiak-Kenai plutonic belt of Hudson (1983), and the Talkeetna Formation. Plafker and others (1989) interpreted this relation to indicate that both the glaucophanic blueschist of the Chugach terrane and the magmatic rocks of the Peninsular terrane are related to the Talkeetna arc (Fig. 4) and that together they record a Late Triassic, Early Jurassic, and possibly early Middle Jurassic history of northward to eastward subduction relative to the Wrangellia composite terrane. The close proximity of the high-pressure–low-temperature schists to high-temperature plutonic rocks suggests major post–Early Jurassic structural disruption of the Talkeetna arc margin, most probably by tectonic shortening and subsequent modification by extension (Plafker and others, 1989; Fuis and Plafker, 1991).

Melange assemblage. The melange facies of the Chugach terrane occurs in an area of about 13,000 km^2, mainly in a discontinuous belt 0 to 20 km wide along the north margin of the Chugach terrane and locally as slices that are structurally interleaved with the blueschist and flysch facies (Fig. 6). The melange facies includes (1) the Uyak Complex and terrane of Cape Current in the Kodiak Islands, (2) the McHugh Complex in the

Kenai and Chugach mountains, and (3) the Kelp Bay Group on Chichagof Island and rocks that extend northwestward through Cross Sound to Glacier Bay to the Tarr Inlet area along the northern Saint Elias Mountains (Fig. 7). The melange unit of the Yakutat Group of the eastern Yakutat terrane is inferred to correlate with the melange of the Chugach terrane and is discussed in this section.

On its north margin, the melange assemblage is faulted against rocks of the glaucophanic blueschist assemblage along a strand of the Border Ranges fault system in the Kodiak Islands (Roeske, 1986), along the Port Graham fault in the southern Kenai Mountains (Kelley, 1985), and along the near-vertical Second Lake fault zone in the Chugach Mountains (Fig. 8). Elsewhere in the Kenai and Chugach mountains, the melange is

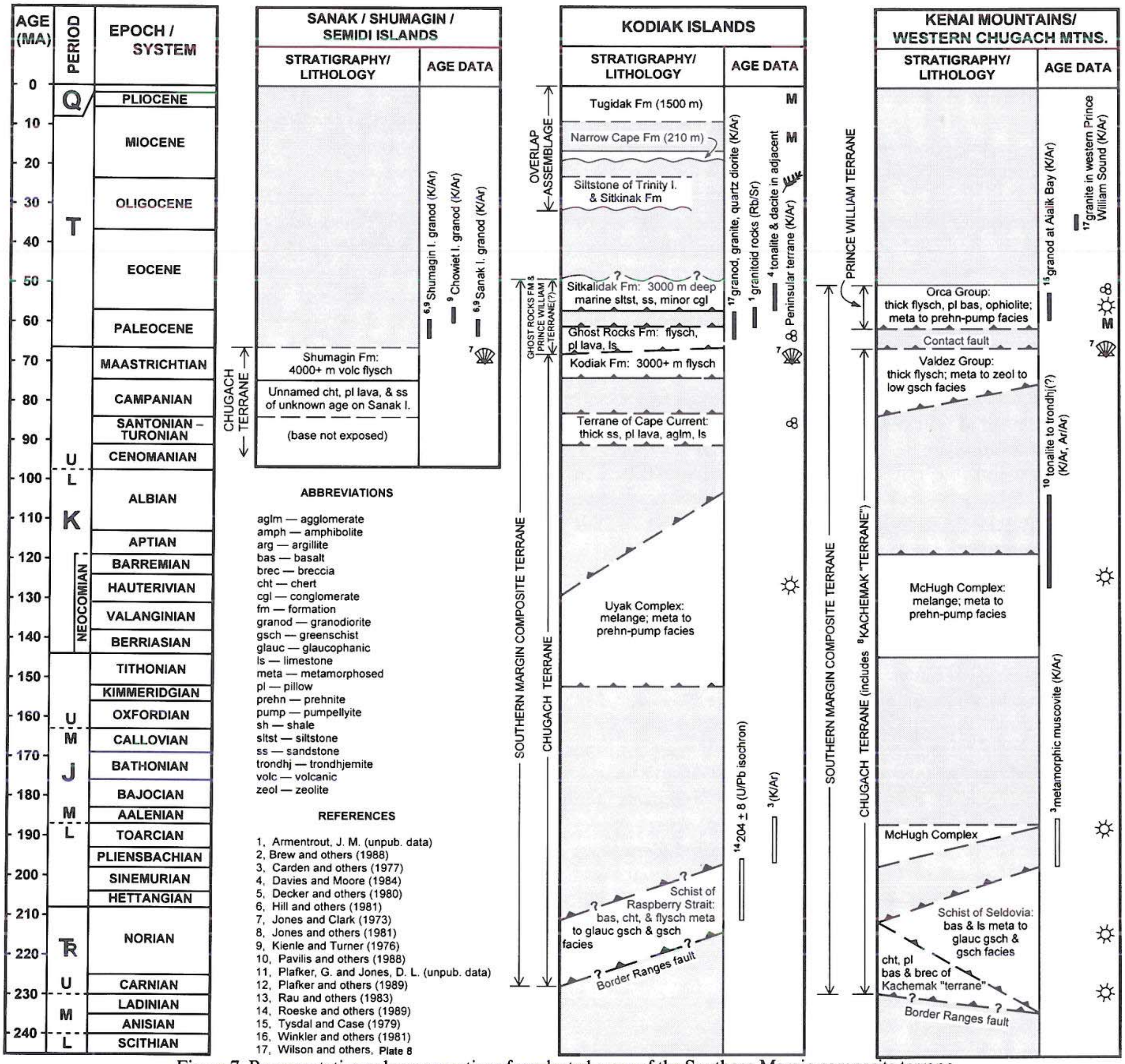
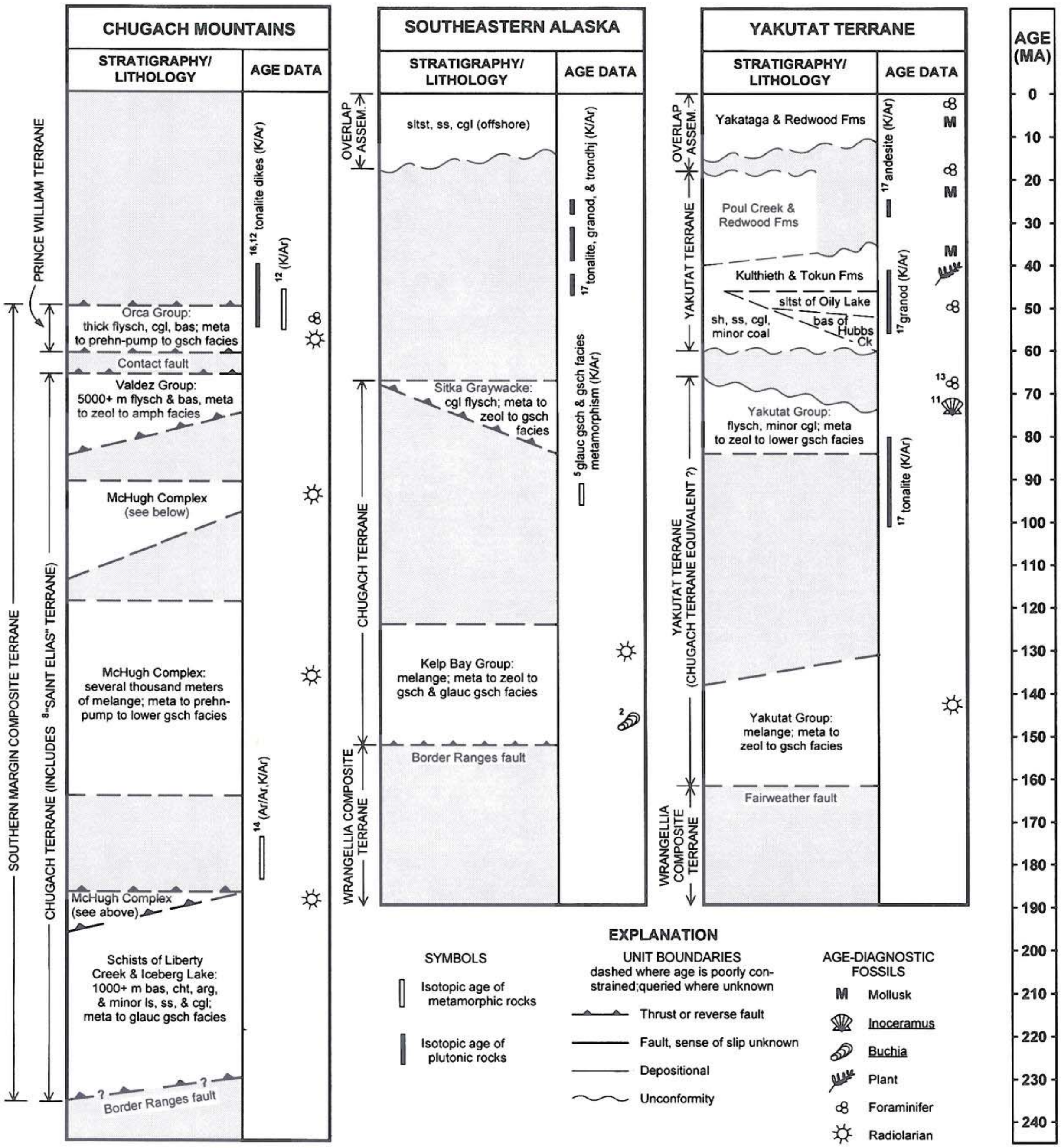


Figure 7. Representative columnar sections for selected areas of the Southern Margin composite terrane and Yakutat terrane. Selected data sources keyed by numbers to references; see text for unit descriptions. More detailed stratigraphic columns for Cenozoic basinal strata and Cenozoic strata of Yakutat terrane are shown in Figures 10 and 13, respectively.

juxtaposed against rocks of the Peninsular or Wrangellia terranes along the Border Ranges fault system. These faults are commonly marked by lenses of serpentinized ultramafic rocks and broad shear zones. In southeastern Alaska and in the Yakutat terrane, contact relations are commonly obscured by pervasive postemplacement disruption along strike-slip faults. In those areas, the melange may be intercalated with rocks of the glaucophanic schist and turbidite facies or they may be juxtaposed against the Wrangellia and Alexander terranes along the Border Ranges fault system (Plafker and Campbell, 1979; Decker and Plafker, 1982; Karl and others, 1982; Roeske and others, 1991).

Lithology. The melange typically consists of pervasively disrupted and variably metamorphosed broken formations that originally consisted mainly of dark greenish-black tholeiitic pillowed basalt and related fragmental volcanic rocks, subordinate amounts of black argillite, green tuff, tuffaceous argillite, and siliceous argillite, and minor lenticular bodies of radiolarian ribbon chert and gray carbonate rocks. Characteristic lithologic associations include (1) massive to weakly foliated green calcareous and glassy-appearing tuff and metavolcanic rocks in crudely discontinuous layers from a few millimeters to several tens of meters thick, together with volcaniclastic graywacke and rare dark-gray



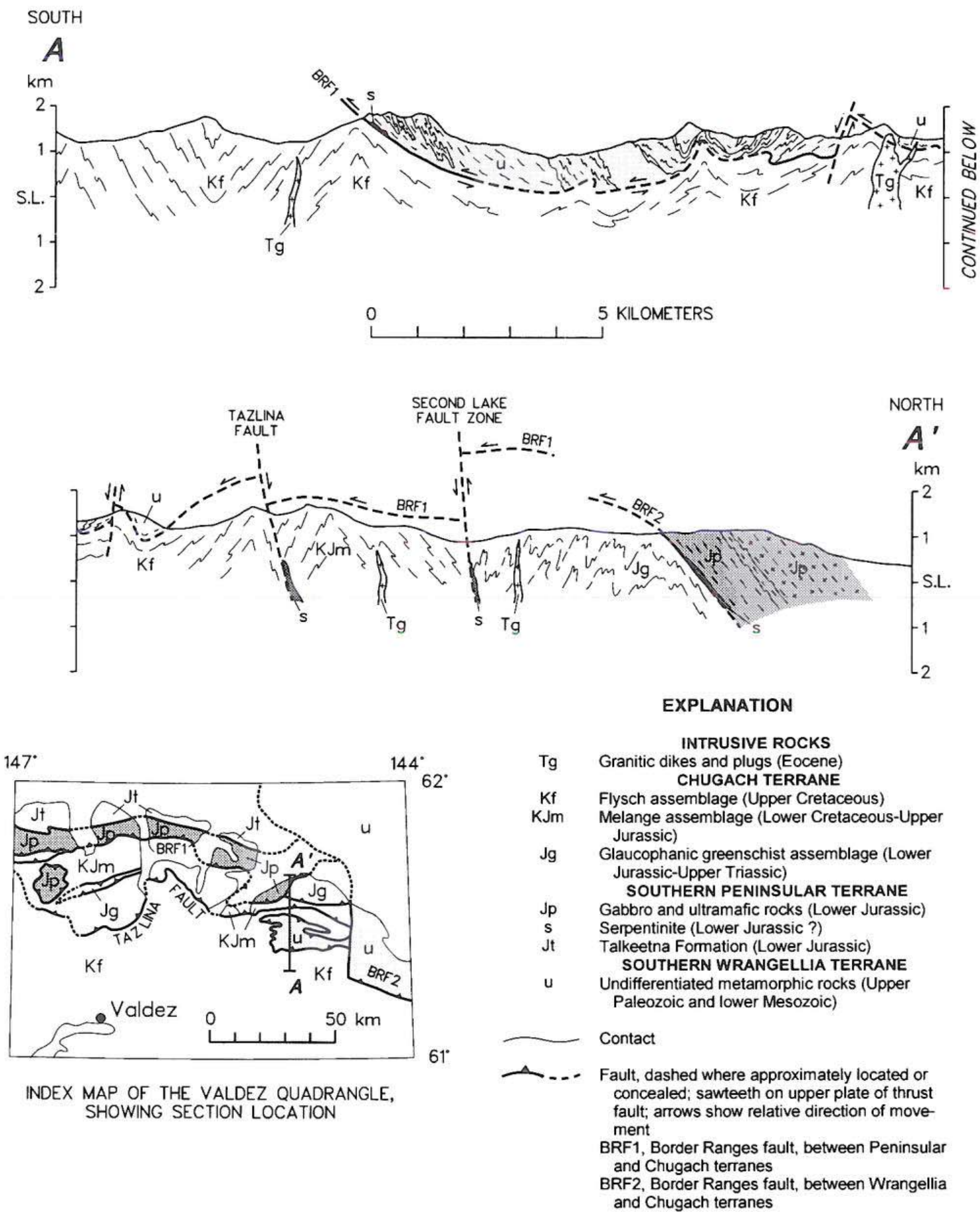


Figure 8. Structure section across the northern Chugach terrane and southern Peninsular and Wrangellia terranes along the Trans-Alaska Crustal Transect (modified from Plafker and others, 1989).

argillite; (2) thinly interlaminated green metatuff and recrystallized dark gray argillite with light green radiolarian chert; (3) greenish-gray volcaniclastic graywacke, with rare mudstone rip-ups, and lenses of pebble-cobble conglomerate, pebbly mudstone, and green chert; (4) chaotically intermixed green tuff and dark gray to black argillite that enclose blocks of bedded chert, graywacke, massive green metavolcanic rocks, recrystallized carbonate rocks, argillite, slaty argillite, and phyllitic green metatuff, which is locally interlayered with recrystallized gray phyllitic argillite; and (5) massive, red-weathering, green and greenish-gray metavolcanic rocks enclosing blocks of red ribbon chert, and associated with greenish-gray graywacke.

The ratio of argillite to tuff in the matrix commonly varies from 1:10 to 10:1, but locally may be nearly pure argillite or nearly pure tuff. Contacts among these rock types are rarely depositional, but more commonly have been disrupted by brittle shear fractures subparallel to bedding. Bedding is generally completely disrupted where argillite is most abundant.

The brittle rocks occur as angular phacoids or lenses from millimeters to kilometers in maximum dimension; in thin section, they show cataclastic fabrics overprinted by solution seams. They may be either enclosed in sheared argillite or streaky tuff and tuffaceous argillite, or juxtaposed against other phacoids. Some inclusions display pinch-and-swell structure, necking, and boudinage. All are oriented parallel to the foliation in the argillite matrix. These blocks and slabs include both (1) disrupted brittle basalt, sandstone, and chert beds within the original stratigraphic sequence and (2) exotic olistostromal blocks of variable age and lithology derived mainly from the Wrangellia composite terrane to the north. The proportion of matrix and blocks varies markedly along regional strike of the unit. In the Anchorage area, Clark (1973) delineated both predominantly metaclastic sequences of metamorphosed graywacke, argillite, and conglomerate and predominantly metavolcanic sequences of metamorphosed greenstone, including pillow basalt, radiolarian chert, and argillite.

The intraformational basaltic rocks characteristically occur in masses from a few meters to several hundred meters thick with variable amounts of chaotically intermixed maroon ribbon chert, green tuff, and black argillite. They are thoroughly altered to greenstone but locally retain textures and structures indicating derivation from massive flows, pillow lavas, and pillow breccia. Geochemically, the metavolcanic rocks are basalts with fairly consistent major and minor element compositions; minor variations are probably due to alteration and the presence of fine veinlets of quartz and calcite (Nelson and Blome, 1991; Barker, this volume). The rocks are predominantly N-MORB on the basis of their REE contents and most discrimination plots, but they include some samples from the Yakutat Group melange that may represent ocean-island or plateau basalt types. Metavolcanic rocks of the McHugh Complex are geochemically indistinguishable from those of the glaucophanic blueschist assemblage, except that average REE contents are slightly higher.

Greenish-gray metasandstone and metasiltstone occur in units as thick as a few tens of meters, mainly in association with the argillite and metatuff. Chaotic structures attributed to local soft-sediment deformation are common. Rarely, massive bodies of graywacke more than 1 km thick are surrounded by incipiently to pervasively sheared rocks. The graywacke is fine to medium grained and is massive to weakly schistose; its bedding-plane foliation is defined by flattened lithic grains. The metasiltstone, which may exhibit a spaced cleavage, occurs as laminae in argillite and as couplets graded with metasandstone. The metasandstone is mainly volcanogenic metagraywacke consisting of plagioclase and mafic to intermediate volcanic grains in variable amounts of carbonate matrix. The metasandstone commonly contains metamorphic pumpellyite and prehnite; veins and patches of prehnite, calcite, and quartz are abundant.

In the Kodiak Islands, large fault-bounded slabs of lithofeldspathic sandstone with minor pillow lava, pillow breccia, and pelagic limestone are incorporated along a fault that separates the melange from the flysch and basalt assemblage. These slabs, named the terrane of Cape Current by Connelly and Moore (1979), are discussed here because they are similar to the melange facies in lithology and structural style. The Cape Current rocks, however, differ in that they contain Turonian to Santonian foraminifers that are one or two stages younger than any other dated rocks of the melange assemblage.

Slabs and blocks as large as a few kilometers in maximum dimension occur within the melange; many are of probable or suspected extraformational origin. These include a wide variety of gabbroic, ultramafic, and schistose rocks, Paleozoic and Triassic marble, some pillowed and massive greenstone that is in part Late Triassic, Early Jurassic shallow-water sandstone, and Jurassic granitoid rocks of intermediate composition (Clark, 1973; Connelly, 1978; Decker, 1980a; Winkler and others, 1984; Plafker, 1987). At outcrop scale these slabs and blocks, together with those of intraformational origin, are commonly lensoid in shape and form a macroscopic melange foliation that strikes parallel to the faults that bound the assemblage. Fault-bounded pods and lenses of schistose to massive serpentinite as much as 250 m wide by 1600 m long occur locally in the Yakutat melange both east and west of Yakutat Bay (Plafker, unpublished data) and within the Kelp Bay Group at 28 or more localities on Baranof Island in southeastern Alaska (Loney and others, 1975).

Metamorphic grade of the melange assemblage is primarily prehnite-pumpellyite facies in the region west of the Richardson Highway, indicating that it was subducted to depths of about 10 to 22 km at temperatures below 400 °C (Dusel-Bacon, this volume). The pervasively sheared, partly mylonitic character of the melange assemblage makes it difficult to establish a clear chronology between metamorphism and deformation. In the Uyak Complex, the first-generation folds and associated axial-planar foliation formed before the peak prehnite-pumpellyite metamorphism of the melange (Moore and Wheeler, 1978). In the Chugach and Kenai mountains, prehnite occurs both in deformed patches and in veinlets that cut the foliation in the enclosing rocks, indicating that metamorphism may have been both syntectonic and post-tectonic (Winkler and others, 1984). In the western Valdez quadrangle in the northern Chugach Mountains and in the Yakutat Group in the Saint Elias Mountains, the melange has been overprinted by Paleogene greenschist facies metamorphism (Plafker and others, 1989). In southeastern Alaska the metamorphic grade commonly ranges from greenschist to amphibolite facies near Eocene plutons (Loney and others, 1975).

Structure. Structural style in this commonly massive-appearing unit consists of sparse south-verging structures (Fig. 8) and numerous, closely spaced zones of intense cataclasis. Within the assemblage, broad zones of intense shearing lack any stratal continuity and innumerable shears of unknown offset have juxtaposed contrasting rocks. The penetrative fabric of these chaotic rocks clearly records an overall ductile behavior during deformation. The occurrence of disrupted brittle phacoids at all scales in a foliated and sheared ductile argillite and tuff matrix imparts the characteristic appearance of a blocks-in-argillite melange to the unit.

Detailed fabric analysis of the Uyak Complex in the Kodiak Islands by Moore and Wheeler (1978) indicates that the melange is geometrically coherent, that it shows two generations of folds and related axial-plane foliations formed during emplacement into the hanging wall of a subduction zone, and that the tectonic transport direction is approximately perpendicular to the trend of the outcrop belt (N 38° ± 11° W). In most areas, the outcrop-scale planar fabric defined by slabs and blocks in the melange parallels a penetrative foliation in the rocks. In some areas, such as the northern Chugach Mountains, the fabric is locally chaotic or mylonitic (Nokleberg and others, 1989). The thickness of the melange assemblage is unknown because of the prevailing structural complexity and an absence of stratigraphic marker horizons; maximum structural thickness is estimated to be about 20 km in the Chugach Mountains (Winkler and others, 1981; Plafker and others, 1989).

Age. The most reliable depositional age for this melange of oceanic basalt and overlying sediment is from radiolarians in chert, which were presumably deposited as pelagic ooze on the sea floor. Radiolarians from numerous chert samples include Middle to Late Triassic (Ladinian, Carnian, Norian), Early Jurassic (Hettangian, Pleinsbachian, Toarcian), Late(?) Jurassic, Late Jurassic to Early Cretaceous (Tithonian to Albian), and early Late Cretaceous (Cenomanian) assemblages (Fig. 7; Yao and others, 1982; Winkler and others, 1981; Nelson and others, 1987; C. D. Blome, unpublished data). Where the radiolarian data are adequate to determine age progression, strata in the melange are generally younger toward the south despite their prevailing structural complexity (Plafker and others, 1989).

In the northern Kodiak Islands, the terrane of Cape Current, which occurs along the south margin of the melange unit, contains planktonic foraminifers of Turonian to Santonian age that appear to have been deposited on a seamount of pillow basalt. Early Cretaceous foraminifers occur in the Yakutat Group melange in the subsurface near Yakutat (Yakutat #3 well; Rau and others, 1983) but it is not known whether they are from pelagic sediment or exotic blocks.

The only age-diagnostic megafossils from sedimentary rocks of the melange assemblage are Tithonian *Buchia* from two localities in the Kelp Bay Group, including *Buchia fischeriana* (D'Orbigny) of late Tithonian age (Connelly, *in* Decker, 1980a; Brew and others, 1988). In addition, *Buchia* were collected from several other Kelp Bay Group sites where they occur in blocks several meters to tens of meters wide consisting of medium-grained calcareous sandstone with shallow-marine trace fossils. These blocks which are surrounded by distal turbidites and pelagic mudstone with deep-marine trace fossils, are clearly foreign to the deep-marine deposits and were probably redeposited by submarine landsliding (Decker, 1980a). The blocks include *Buchia* cf. *B. fischeriana* and *B. piochii*(?) of Tithonian age and *B. subokensis* and *B. okensis* of Berriasian age (Loney and others, 1975; D. L. Jones, 1978, written commun., cited *in* Decker, 1980a).

Interpretation. The melange assemblage is interpreted as oceanic crustal rocks and pelagic chert, carbonate rocks, and shale that were mixed with arc-derived sediments and fragments of older rocks at the south margin of the Wrangellia composite terrane. Volcanogenic sandstone and local andesitic green tuff in the sedimentary units indicate that much of the sediment was probably derived from an active arc source. The abundance of slump structures in the siliciclastic rocks reflects deposition on relatively steep slopes such as the inner wall of a trench or a continental margin. The structural style of the assemblage indicates that oceanic rocks were probably accreted, disrupted, and mixed with terrigenous sediments at a convergent plate margin (Clark, 1973; Connelly, 1978; Moore and Connelly, 1979). The serpentinite could represent altered fragments of ultramafic rocks incorporated in the melange from deep levels of the oceanic crust; suitable sources in adjacent terranes to the north are not known.

Fisher and Byrne (1987) interpreted the melange in the Kodiak Islands as having formed as shear zones at the top of a deeply subducted layer immediately below a major decollement in zones of concentrated fluid flow and fracture-dominated permeability. Evidence of relative landward underthrusting and dominantly prehnite-pumpellyite facies metamorphism argue for underplating and substantial burial of this assemblage (Moore and Wheeler, 1978).

Pavlis (1982) suggested that mid-Cretaceous trondhjemitic plutonic rocks in the McHugh Complex in the Anchorage quadrangle were emplaced during a single episode of accelerated accretion. A comparable hornblende K-Ar age (96 ± 4.5 Ma) was obtained for lithologically similar tonalite in coeval melange of the Yakutat Group in the Yakutat quadrangle (Wilson and others, this volume). Decker and others (1980) postulated that a minimum age for the correlative Kelp Bay Group on Chichagof Island is given by mid-Cretaceous K-Ar ages (109 to 91 Ma) from low-temperature–high-pressure regional metamorphic mineral assemblages, which they suggested formed during subduction and accretion of the group.

Data indicating that plate convergence occurred along the southwest boundary of the Wrangellia composite terrane during much or all of the Jurassic and Cretaceous (Engebretsen and others, 1985), together with the apparent southward decrease in age, suggest that the melange was probably accreted over a long time span and that the mid-Cretaceous accretion differed only in the local occurrence of near-trench plutonism. Accretion of melange facies rocks may have begun with inception of the Talkeetna magmatic arc in the Late Triassic and it may have been simultaneous with glaucophanic-greenschist facies metamorphism. The main phase of melange accretion postdates Early to early Middle Jurassic glaucophane-greenschist facies metamorphism, and the youngest accretion was coeval with, or postdated, the early Late Cretaceous rocks of the terrane of Cape Current.

Structural relations and paleontologic data suggest that the melange assemblage predates deposition and accretion of the adjacent flysch and basalt assemblage of the Chugach terrane. In areas affected by postemplacement structural interleaving along strike-slip faults, such as the Yakutat terrane and southeastern Alaska, we recognize that some turbidites of the flysch and basalt assemblage may be indistinguishable from comparable facies in the melange.

Provenance of exotic blocks. The age and lithology of distinctive exotic blocks and conglomerate clasts in the melange assemblage indicate a dominant provenance from the adjacent Peninsular and Wrangellia terranes. The distribution of most of these exotic rocks suggests modest relative strike-slip displacement following deposition; however, the Yakutat Group melange is interpreted to be displaced with the Yakutat terrane about 600 km from the continental margin south of Chatham Strait (see section on Yakutat terrane displacement history). At least six kinds of exotic clasts are included in these blocks. (1) Limestone phacoids in the Uyak Complex contain Permian Tethyan fusulinids (Connelly, 1978) and remnants of the probable Late Triassic hydrozoan Spongiomorpha, both of which are known from adjacent areas of the western Peninsular terrane (N. J. Silberling, cited *in* Connelly, 1978). (2) A carbonate cobble in the McHugh Complex near Anchorage contains a distinctive Early Pennsylvanian conodont fauna (Nelson and others, 1986) that is identical in age and lithology to carbonate rocks from the western part of the Strelna metamorphics of Plafker and others (1985a) near the south margin of the Wrangellia terrane. (3) Limestone blocks in the McHugh Complex near Anchorage contain Early Permian Tethyan fusulinids of the type found in nearby parts of the Peninsular terrane (Clark, 1972). (4) Abundant large blocks of Middle Jurassic quartz diorite (165 to 175 Ma) in the McHugh Complex in the Anchorage and western Valdez quadrangles were probably derived from nearby parts of the Peninsular terrane (G. R. Winkler, 1988, unpublished data). (5) Exotic blocks in the correlative Yakutat Group melange (and probably the Kelp Bay Group), include Permian marble, Late Triassic carbonate rocks with associated greenstone, Sinemurian ammonite-bearing volcanogenic sandstone, and Middle Jurassic quartz diorite; suitable sources for these rocks are present in the Wrangellia terrane south of Chatham Strait (see discussion of Yakutat terrane displacement history). (6) Blocks of Late Triassic marble with associated greenstone in the Kelp Bay Group in southeastern Alaska are best correlated with the Whitestripe Marble and Goon Dip Greenstone in nearby outcrops of the Wrangellia terrane (Karl and others, 1990). In addition, kilometer-scale slabs and blocks of mafic and ultramafic plutonic rocks near the north margins of the Uyak and McHugh complexes (Moore and Wheeler, 1978; Winkler and others, 1981; Kelley, 1985) are lithologically similar to rocks of the informally named Border Ranges ultramafic and mafic complex of Burns (1985) along the south margin of the Peninsular terrane. These larger exotic bodies are interpreted as klippen of the Peninsular terrane that were structurally interleaved with the Chugach terrane during Late Cretaceous or younger folding and/or displacement along steeply dipping faults (Plafker and others, 1989).

Melange assemblage and the Chitina and Chisana arcs. The volcanogenic sandstone and andesitic tuff that make up much of the melange assemblage are arc derived and appear to be mainly of Late Jurassic and Early Cretaceous age (Tithonian to Valanginian). The most likely sediment sources for the volcanogenic deposits are the Late Jurassic Chitina arc and Early Cretaceous Chisana arc in the Wrangellia terrane (Plafker and others, 1989) and their possible westward continuations in the Peninsular terrane (Fig. 4). It is likely that at least part of the volcanogenic sediment may also have been derived from the Late Triassic and Early Jurassic Talkeetna arc, which is widely distributed in the Peninsular terrane part of the Wrangellia composite terrane in Alaska and its inferred offset continuation in the British Columbia segment of the Wrangellia terrane (Plafker and others, 1989; Plafker, 1990).

Flysch and basalt assemblage. The flysch and basalt assemblage is an extremely thick, lithologically monotonous sequence that crops out in a continuous belt as wide as 80 km, extending the full length of the Chugach terrane (Fig. 6), and that underlies about 110,000 km^2. Volcanic rocks make up only a small percentage of the assemblage west of the Chugach Mountains, but they increase in relative abundance and thickness in the eastern Chugach Mountains and Saint Elias Mountains from Prince William Sound to Cross Sound. The assemblage consists of the Shumagin Formation (Moore, 1973, 1974), the Kodiak Formation (Moore, 1969; Moore, 1973), the Valdez Group (Tysdal and Plafker, 1978), the Sitka Graywacke (Decker and Plafker, 1982), and the flysch facies of the Yakutat Group (Fig. 7).

Lithology of flyschoid rocks. The flysch consists of slope, fan, and basin-plain turbidites, with volumetrically minor intercalations of volcanic tholeiite. Primary sedimentary features are commonly well preserved in the Sanak, Shumagin, and Kodiak islands. In most areas east of the Kodiak Islands, however, primary sedimentary features other than graded bedding are commonly obliterated by shearing along bedding planes and by development of a penetrative foliation. The rocks include gradational sequences of argillaceous mudstone containing sporadic thin beds of sandstone, sequences of rhythmically alternating thin beds of argillite and fine-grained sandstone, and medium- to thick-bedded sandstone with minor thin beds of argillite. Graded beds are common, and thicker sandstone beds locally contain small chips of phyllite and thin layers of granule-sized clasts. The sandstone is generally quartzofeldspathic, and grains are typically surrounded by a very fine grained matrix of recrystallized phyllosilicate minerals.

Petrographic studies indicate that the sandstone is dominantly volcaniclastic graywacke but contains sedimentary and metamorphic lithic grains from a broad spectrum of rock types, including some that may have been derived from both inside and outside the Chugach terrane (Decker, 1980a; Zuffa and others, 1980; Winkler and Plafker, 1981a; Winkler and others, 1981, 1984; Lull and Plafker, 1985; Dumoulin, 1987). Although most sandstone of the flysch and basalt assemblage is lithic rich, Connelly (1978) reported that samples from the Kodiak Formation are more feldspathic than those from correlative rocks to the southwest and northeast. Most sandstone is compositionally graywacke (percent lithic grains > percent feldspar grains) but is not texturally graywacke (matrix less than 15%). Lithic clasts are dominantly volcanic in origin, but the ratio of volcanic to total lithics (Lv/Lt) seems, in general, to decrease eastward across the Chugach terrane (Zuffa and others, 1980). The volcanic detritus is primarily andesitic (Moore, 1973; Winkler, *in* Nilsen and Moore, 1979; Zuffa and others, 1980), although Mitchell (1979) and Decker (1980a) suggested that the volcanic suite in southeastern Alaska is bimodal, with rhyolitic and dacitic compositions dominant over basaltic. A subordinate plutonic source for these sedimentary rocks is indicated by the occurrence of sericitized feldspars, microcline, micas, and plutonic rock fragments. Thus, the primary source for the sedimentary rocks of the Chugach terrane appears to have been an evolved arc with an increasing degree of dissection to the east (Zuffa and others, 1980). In Prince William Sound, the Valdez Group compositions that change systematically from west to east (and probably from older to younger) indicate derivation from progressively deeper levels of a magmatic arc (Dumoulin, 1987).

Turbidite facies associations have been delineated for several areas in flyschoid rocks of the Chugach terrane—particularly in the Shumagin Islands (Moore, 1973), the Kodiak Islands (Nilsen and Bouma, 1977; Nilsen and Moore, 1979), the Kenai Peninsula (Budnik, 1974; Mitchell, 1979), Chichagof Island (Decker, 1980a), and the Yakutat terrane (Nilsen and others, 1984). Nilsen and Zuffa (1982) summarized the regional facies associations as inboard slope facies and outboard inner fan and basin-plain facies, the more proximal facies being to the southeast. However, many, if not all, of the slope facies rocks discussed by Nilsen and Zuffa (1982) are probably part of the melange assemblage and predate deposition of the flysch and basalt assemblage. The facies relations suggest a prograding fan system in a narrow trough (probably a trench) with a principal source at the southeast end (Nilsen and Zuffa, 1982). This interpretation is consistent with general coarsening of the flysch from west to east along the length of the belt.

Goechemical analyses of seven samples of metagraywacke (67.3% to 70.5% SiO_2, 0.8% to 2.1% K_2O) and eight samples of metapelite (58.2% to 72.0% SiO_2, 1.6% to 3.6% K_2O) from the Valdez Group in the western Chugach Mountains are remarkably uniform in major and minor element concentrations (Plafker and others, 1989). LREEs are moderately enriched relative to HREEs, and REE concentrations are comparable with that of Andean-type andesite. Discrimination plots using the immobile trace elements La, Th, and Sc suggest a continental margin arc provenance, in agreement with the data from sandstone provenance studies elsewhere in the Chugach terrane.

Lithology of volcanic rocks. Volcanic rocks are present along the south margin of the flysch and basalt assemblage, mainly in the region east of Prince William Sound (Fig. 6). They are dominantly tholeiitic basalt, pillowed basalt, and basalt breccia with minor associated diabase intrusive rocks. The volcanic rocks occur in a belt as wide as 8 km that can be traced discontinuously from the Prince William Sound area to southeastern Alaska for a distance of 600 km (Lull and Plafker, 1990; Barker and others, this volume). In much of this region their positions correlate closely with highs on aeromagnetic maps (Godson, this volume) and in a general way with a discontinuous 60 to 100 mGal isostatic gravity anomaly (Barnes and others, this volume). Minor green basaltic to andesitic metatuff in lenticular beds from a few centimeters to about 15 m thick and up to 4 km long is locally interbedded with metasedimentary rocks overlying the massive basalt unit. Decker's (1980a) correlation of the metavolcanic rocks of the Valdez Group with the metavolcanic rocks near the westernmost exposures of the Ford Arm Formation of Decker (1980b) on Chichagof Island was based on the continuity of the magnetic anomaly associated with these rocks and on their similarity in structural position, sandstone petrography, and turbidite facies.

The mafic igneous rocks of the flysch and basalt assemblage are geochemically similar to LREE-depleted basalt (Lull and Plafker, 1990). They plot as tholeiites with an iron enrichment trend on the AFL diagram, and they straddle the tholeiite–calc-alkalic compositional boundary on a plot of FeO^*/MgO vs. SiO_2. On discrimination diagrams for Th-Hf-Ta, Ti-Zr-Y, and Ti-Zr, the metabasalts and the comagmatic basaltic tuff within the Valdez Group plot mostly within island-arc tholeiite fields. REE patterns have moderate negative slopes and primitive chondritic compositions and show moderate depletion of LREEs relative to HREEs (La 1 to 7 × chondrite, Lu 9 to 20 × chondrite). REE abundances of the intrusive rocks are systematically lower than those of the greenstones. Geochemical data suggest that the Valdez Group metabasalts could be transitional between island-arc tholeiite and MORB, but with a strong island-arc tholeiite signature. Together with the field relations, however, the data favor an island-arc petrogenetic setting, but close enough to the continental margin to be within reach of deep-sea fan deposits (Lull and Plafker, 1990).

Metamorphism. The flysch and basalt assemblage is variably metamorphosed to zeolite facies west of the Chugach Mountains, to zeolite and low-greenschist facies in the western Chugach Mountains, to greenschist and amphibolite facies in the eastern Chugach Mountains and Saint Elias Mountains, and to zeolite and low-greenschist facies in southeastern Alaska and in the Yakutat Group; local areas show contact metamorphism (Dusel-Bacon, this volume).

Detailed studies in the Kodiak Islands indicate that the Kodiak Formation was underthrust to significant depths and then underplated to the Chugach terrane (Sample and Moore, 1987). Both mesoscopic and regional structural trends indicate that underplating probably occurred by duplex accretion. Metamorphic mineralogy, vitrinite-reflectance data (Sample and Moore, 1987), and fluid-inclusion data (Vrolijk and others, 1988) indicate that deformation related to underthrusting occurred at a depth of 10 to 12 km at temperatures of 200 to 250 °C.

In the Chugach Mountains east of the Copper River, metamorphic grade increases along strike, culminating in the eastern

Chugach Mountains in a schist and gneiss complex with sillimanite-grade migmatitic rocks (the informally named Chugach metamorphic complex of Hudson and Plafker, 1982). Epidote-amphibolite and greenschist facies metamorphism characterizes the sequence throughout the Saint Elias Mountains to Cross Sound. The superimposition of progressive metamorphism across regional structural trends and the typical granoblastic textures indicate that metamorphism occurred after the Valdez Group part of the flysch and basalt assemblage was deformed against and amalgamated with the melange assemblage to the north. Rocks of the Chugach metamorphic complex record a regional Paleogene thermal event characterized by very high temperature at low pressure (Sisson and others, 1989). A minimum age for metamorphism of the group is given by K-Ar whole-rock and mineral ages that range from 53.5 to 47.9 ± 2 Ma in the Chugach and Saint Elias Mountains (Fig. 7). This age of metamorphism overlaps the age of anatectic plutonism in the region (Hudson and others, 1979; Hudson, this volume; Barker and others, 1992), which culminated about 50 m.y. ago (Fig. 7). Numerous felsic dikes, sills, and plugs of this age that intrude the Valdez Group throughout the full width of its outcrop belt in the central Chugach Mountains were formed during the anatectic melting event (Plafker and others, 1989).

Thickness. Estimated minimum stratigraphic thicknesses from outcrop data are 3 to 4 km for the Shumagin Formation (Moore, 1973) and 3 km or more for the Kodiak Formation (Nilsen and Moore, 1979). Deep-marine reflection data indicate a vertical structural thickness of as much as 30 km for the Kodiak Formation and thick, probably younger, underplated sedimentary sequences or intercalations of oceanic crust and sedimentary rocks (Moore and others, 1991). The vertical thickness of the Valdez Group, based on geophysical data, is between 10 and 20 km beneath the central Chugach Mountains (Fuis and Plafker, 1991); the outcrop thickness of the basaltic sequence is 3 to 5 km along the southern margin of the Chugach terrane near the Contact fault system east of Prince William Sound.

Structure. In the Kodiak Islands, and the Kenai, Chugach, and Saint Elias mountains, the flysch and basalt assemblage is faulted against and relatively beneath either the melange assemblage (along the Uganik, Chugach Bay, Eagle River, Tazlina, and related thrust faults), or it is juxtaposed against the Wrangellia composite terrane along the Border Ranges fault system (Fig. 6).

Detailed study of the structures and fabric of the Kodiak Formation (Fig. 9) indicates that (1) the unit can be divided structurally into a northwestern belt of moderate strain with steeply dipping structures, a high-strain central belt with shal-

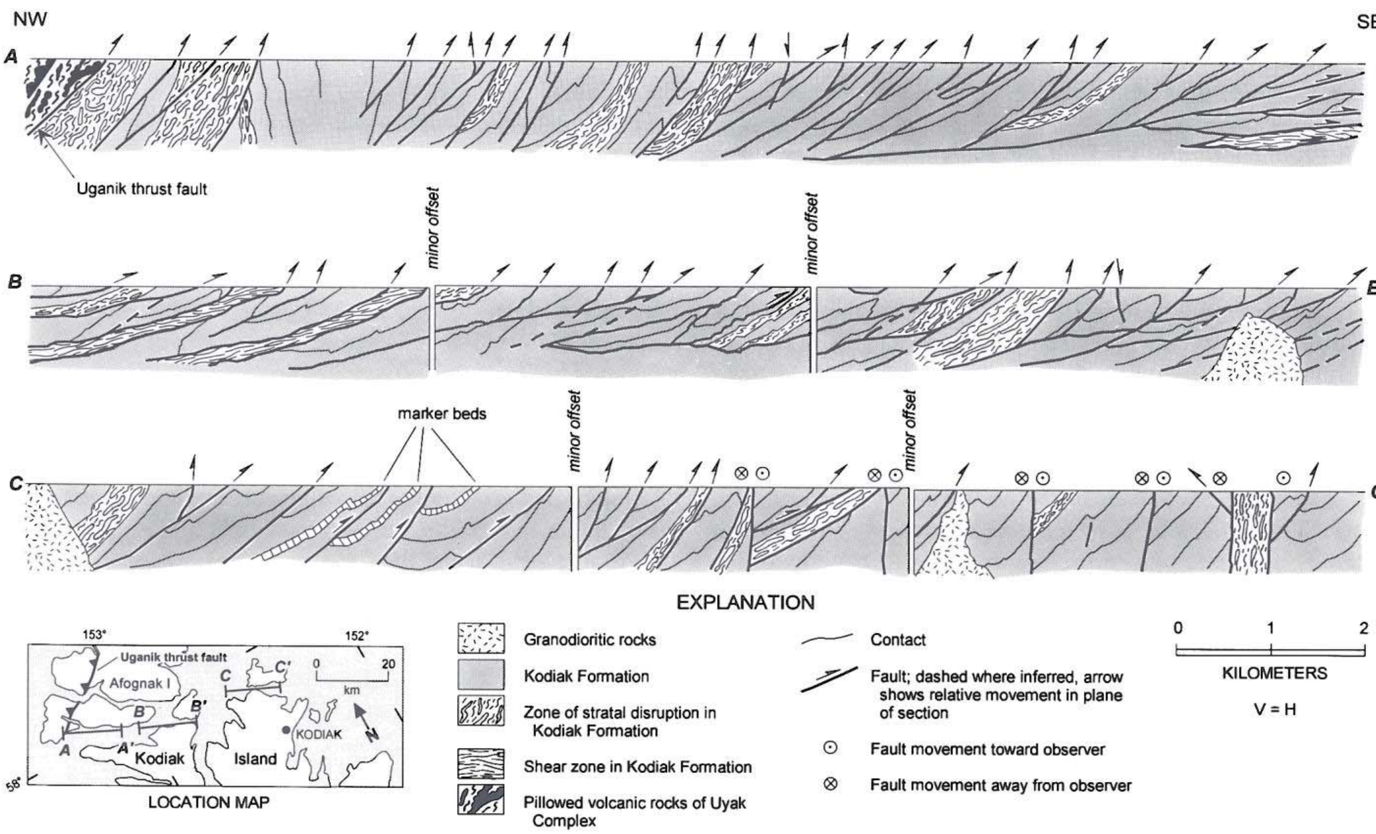


Figure 9. Detailed structure section across part of the Kodiak Formation on Kodiak Island (modified from Sample and Moore, 1987).

lowly dipping structures, and a low-strain southeastern belt with steeply dipping structures; and (2) fault geometries locally resemble duplex fault zones in which high-angle listric reverse faults stop at subhorizontal detachment faults below and above in strata that were previously tilted.

In the Chugach Mountains along the Trans-Alaska Crustal Transect, the flysch and basalt assemblage is thrust relatively northward beneath both the Wrangellia composite terrane along the Border Ranges fault and the melange assemblage along the Tazlina fault (Fig. 8). In this area, the Border Ranges fault (BRF1 in Fig. 8) is a folded low-angle thrust along which the Wrangellia terrane has been displaced as much as 40 km southward. The contact is marked by a zone of mylonitic rocks and by local blocks of variably serpentinized ultramafic rocks (Plafker and others, 1989). The lower plate sequence is complexly deformed by tight, chevron to isoclinal, major and minor folds and thrust faults that commonly verge south. Coaxial north-verging folds are superposed on south-verging structures over a large segment of the northern Chugach Mountains, including the area shown in Figure 8 (Nokleberg and others, 1989). The regional parallelism of axial planes of folds, faults, and foliation or cleavage is striking.

In the Kenai and western Chugach mountains, the fault contact between the flysch and basalt assemblage and the melange assemblage in many places is a well-defined thrust that dips northwestward at low to moderate angles and truncates tight folds in the underlying flysch (Cowan and Boss, 1978; Winkler and others, 1984; Plafker and others, 1989; D. C. Bradley, 1991, oral commun.; Winkler 1992). Elsewhere, the fault is a complex imbricated zone in which slivers of the two units may be juxtaposed. Deformation in the flysch and basalt assemblage is especially prounouced near the fault contact with numerous surfaces of intensive shearing in the Valdez Group that are defined by boudins of sandstone oriented subparallel to the main fault surface. Pervasively sheared rocks consistently grade structurally downward into well-bedded sandstone and phyllite from 100 m to 2 km south and east of the fault. Rocks of the overriding melange assemblage do not show a similar increase in intensity of deformation as they approach the fault. Similar fabric contrasts occur across the correlative Uganik thrust in the Kodiak Islands (Fig. 9), where a slip vector of $334° \pm 7°$ was determined for the fault by Moore and Wheeler (1978).

The Eagle River fault in the northern Kenai and western Chugach mountains is cut by numerous high-angle faults, which generally are upthrown to the northwest. Map patterns of the fault near Anchorage (Clark, 1972; Winkler, 1992) indicate that the Eagle River fault may be folded into a broad open syncline as well. The age of major offset on the Eagle River fault is well constrained regionally by paleontologic and radiometric information. The fault truncates rocks of the Valdez Group that contain Late Cretaceous megafossils, and it is intruded by numerous felsic to intermediate hypabyssal dikes that are similar to intrusions dated as early to middle Eocene in nearby areas (Winkler and others, 1984). In the Seldovia area in the southern Kenai Mountains, Bradley and Kusky (1992) mapped folds that have wavelengths of about 1 km that deform the Chugach Bay fault (Fig. 6).

Age. The Late Cretaceous (early Maastrichtian and late Campanian) age of the flysch and basalt assemblage is based on age-diagnostic Inoceramids and foraminifers. Early Maastrichtian *Inoceramus,* including *I. kusiroensis, I. balticus,* and *I. concentrica* occur at 11 localities in the Shumagin Formation, 9 localities in the Kodiak Formation, and 15 localities in the Valdez Group in the northern Kenai and western Chugach mountains (Jones and Clark, 1973; Budnick, 1974; J. W. Miller, 1984, 1985, written communs. to J. C. Sample; J. W. Miller, 1986, written commun. to D. Fisher; J. W. Miller, *in* Winkler, 1992). One occurrence of poorly preserved Campanian or Maastrichtian Inoceramids was found in the Valdez Group in the southern Kenai Mountains (D. L. Jones, *in* Tysdal and Plafker, 1978), and a single specimen of the Campanian *I. schmidti* came from the flysch facies of the Yakutat Group (Jones and Clark, 1973). In addition, Late Cretaceous (Campanian to Maastrichtian) foraminifers have been recovered from well cores in the Yakutat Group flysch (W. V. Sliter, *in* Rau and others, 1983). No fossils have been recovered from the Sitka Graywacke, which has been tentatively correlated with the flysch and basalt assemblage on lithology and its structural position within the Chugach terrane (Plafker and others, 1977).

Deformation and accretion of the flysch and basalt assemblage was completed prior to emplacement of post-tectonic plutons of middle to late Paleocene age in the Shumagin, Sanak, and Kodiak islands and of early to early middle Eocene age on the mainland to the east (Fig. 7). Accretion, however, may have been essentially synchronous with deposition in an active subduction environment and could have begun as early as Campanian time.

Interpretation. Metabasalt in the Valdez Group is inferred to be the remnant of a primitive intraoceanic island arc that formed within the Kula plate during Campanian to early Maastrichtian time and migrated toward an Andean-type continental margin (Lull and Plafker, 1990). Deep-sea fan deposits of basaltic sediments and tuff from the intraoceanic arc were mixed with volcaniclastic sediments and tuff from a continent-margin arc as the island arc approached the continent. Arc-continent collision in latest Cretaceous to early Paleocene time resulted in successive offscraping and accretion to the continental margin of the flysch, mixed flysch and basaltic tuff, and basalt that make up the flysch and basalt assemblage of the Chugach terrane.

Petrography of the flysch and sparse interbedded metaandesite tuff indicate derivation from an evolving magmatic arc as sediments were derived from increasingly deeper levels from west to east in the accretionary prism. Turbidite facies associations and paleocurrent determinations indicate dominantly westward transport of sediment. Deposition was largely confined to a trench, probably as narrow fans that became elongated in the direction of the trench axis but possibly also as minor infilling from the north by slumps or through channels (Nilsen and Zuffa, 1982). Sedimentological and isotopic data indicate that a major part of this sediment came from the southeastern Alaska and British Columbia region and was transported northwestward along the continental margin (Nilsen and Moore, 1979; Nilsen and Zuffa, 1982; Decker and Plafker, 1983).

Structures and metamorphism in the Kodiak Formation have been interpreted to indicate underthrusting and underplating by accretion of duplex structures at a minimum depth of 10 km with attendant stratal disruption and formation of slaty cleavage, thrust faults, and folds (Sample and Fisher, 1986; Sample and Moore, 1987). Crenulation cleavage, secondary folds, and thrust faults were subsequently formed by postaccretion intrawedge shortening. Duplex structures have not yet been recognized in outcrop other than in the Kodiak Islands, and the extent to which this mechanism applies to accretion elsewhere in the Chugach terrane is not known.

Flysch and basalt assemblage and the Late Cretaceous Kluane arc. The turbidites of the flysch and basalt assemblage are inferred to have been deposited in a trench associated with a southward- to seaward-facing continental margin (Andean type) arc that extended from British Columbia to the Alaska Peninsula (Fig. 5). The continuity of the flysch and basalt assemblage suggests that it was accreted along a relatively linear margin before counterclockwise bending of western Alaska to form the Gulf of Alaska. We infer that this magmatic arc, informally named the Kluane arc by Plafker and others (1989), was the source of most of the detritus. Plutonic rocks of Late Cretaceous and younger age, having appropriate compositions to be the roots of the inferred Kluane arc, occur discontinuously in two belts that appear to be dextrally offset some 400 km along the Denali fault (Nokleberg and others, 1985; this volume, Chapter 10). The northern part of this belt extends northward from the central Alaska Range through the Talkeetna Mountains to the Denali fault (Alaska Range–Talkeetna Mountains belt of Hudson, 1983); the southern segment is inferred to extend from the Kluane Lake area in Canada southward through the Coast Mountains of southeastern Alaska and British Columbia (Monger and others, 1982; Brew and Ford, 1984). The belt consists of 85 to 45 Ma calc-alkalic plutonic rocks in British Columbia (Armstrong, 1988), 72 to 55 Ma rocks in southeastern Alaska (Barker and others, 1986; Loney and Brew, 1987; Brew, this volume), 74 to 50 Ma rocks in the Aleutian Range, and 77 to 65 Ma rocks in the Talkeetna Mountains (Hudson, 1983; Moll-Stalcup, this volume). Although rocks of Late Cretaceous age appear to compose a relatively small part of the southern segment (Brew, this volume), their scarcity may be due to masking by the voluminous Paleogene magmatism in the region.

Hollister (1979) and Crawford and Hollister (1982) have shown that the southern segment of the belt in the Coast Mountains of British Columbia was uplifted rapidly in two major pulses: a younger one between 62 and 48 Ma (early Tertiary), and an earlier one, probably Late Cretaceous in age. This crystalline belt includes plutonic rocks of appropriate composition for a magmatic arc and is interpreted as a deeply eroded segment of an extensive Late Cretaceous and early Tertiary magmatic arc that traverses much of southern Alaska (the Kluane arc of Plafker and others, 1989; Fig. 5). The Coast Mountains segment of the arc is inferred to be the primary sediment source for the flysch sequence; additional sediments were contributed from segments of the arc in central and western Alaska. Alternative sediment sources other than the Kluane arc are possible, but they all require highly improbable scenarios of longer sediment-transport distances from source regions and/or large postemplacement strike slip of the Chugach terrane away from its source region.

Metamorphic complex of the Saint Elias area. Metamorphosed flysch and basalt constitute an east-west–trending, structurally bound block 80 km long and as wide as 15 km that underlies the highest part of the rugged Saint Elias Mountains in Alaska, including Mt. Saint Elias (Saint Elias terrane of Jones and others, 1987, and Silberling and others, this volume). On the south the complex is emplaced against unmetamorphosed Cretaceous and Tertiary rocks of the Yakutat terrane along the Chugach–Saint Elias fault system; on the north it is emplaced against lower grade metamorphic rocks of the Chugach terrane along an inferred extension of the Fairweather fault system beneath glaciers of the Saint Elias Mountains (Fig. 6).

Interleaved and penetratively deformed epidote-amphibolite-grade metabasalt and metaflysch make up most of the metamorphosed complex of the Saint Elias area. The schistose rocks are intruded by small 50 Ma granitic plutons and by at least one undated layered gabbro that is known from float on glacial moraines derived from the south face of Mount Saint Elias (Plafker, unpublished data).

Rocks that make up the metamorphic complex of the Saint Elias area are similar to the metamorphosed flysch and basalt assemblage of the Chugach terrane in the southern Saint Elias Mountains in metamorphic grade, structure, and lithology, and in the age of the intruding Tertiary plutons. Hence, these rocks are here considered to be a displaced block of the Chugach terrane rather than a separate terrane.

Structural and lithologic data suggest that the metamorphosed complex of the Saint Elias area was probably sliced off the Chugach terrane and displaced to its present position by dextral movement along the Fairweather fault. The original position of the comlex is uncertain. However, a good match can be made with lithology and structure of the Chugach terrane south of the Alsek River, about 50 km southeast of Yakutat; this position requires some 200 km offset along the Fairweather fault.

Paleomagnetic data. The only paleomagnetic data for igneous rocks of the Chugach terrane, from the Crillon–La Perouse layered gabbro of Loney and Himmelberg (1983), have been interpreted as indicating that the Chugach terrane moved 25° to 26° northward and rotated 90° counterclockwise relative to the North America craton (Grommé and Hillhouse, 1981). Since the paleomagnetic work was completed, the gabbro has been dated as middle Tertiary in age, probably 28 ± 8 Ma (Loney and

Himmelberg, 1983). The young age of the gabbro indicates that the paleolatitude determination is incorrect because it requires that the pluton be translated northward at twice the displacement rate of the Pacific plate (Plafker, 1984). The assumption of initial horizontality for the gabbro layers may be incorrect and/or the pluton may have been affected by a postemplacement northeastward tilt to give the apparent inclination anomaly of $19° \pm 8°$. A prominent decrease in metamorphic grade of country rocks from southwest to northeast across the gabbro body is compatible with tilting, but the apparent large rotation remains unexplained.

Paleomagnetic studies of Cretaceous sedimentary rocks of the Chugach terrane were carried out at two sites in the Shumagin Formation (Stone and Packer, 1979) and one in the Kodiak Formation (Stone and others, 1982). Although these studies yield mean paleolatitudes from 43° to 69° south of the predicted North American reference, the magnetizations are possibly contaminated by a postdeformational component, so the Cretaceous paleolatitude determinations may be invalid (Hillhouse and Coe, this volume).

Latest Cretaceous and Paleogene accretionary assemblages

Most of the latest Cretaceous and Paleogene accretionary assemblages of the Southern Margin composite terrane are juxtaposed against the western Chugach terrane along the Contact fault system and related structures (Figs. 2 and 6). From oldest to youngest these accreted units are (1) the Late Cretaceous and early Paleocene Ghost Rocks Formation in the Kodiak Islands area, (2) the late Paleocene through early middle Eocene Orca Group in the Prince William Sound region, (3) the unnamed sequence of probable early Eocene age on the Resurrection Peninsula, and (4) the Eocene Sitkalidak Formation of the Kodiak Islands (Fig. 7). The Ghost Rocks Formation has also been referred to by some workers as the Ghost Rocks terrane (Plafker, 1987; Jones and others, 1987; Silberling and others, this volume), and the Prince William terrane consists principally of the Orca Group. Limited available age control suggests that both the Resurrection Peninsula sequence and the Sitkalidak Formation may be in part or entirely coeval with the Orca Group. However, because of uncertainties in the age of these units, they are described separately from it in the sections that follow.

The Contact fault system (Plafker and others, 1977) extends from just east of Mount Saint Elias (long 140°W) to the Kodiak Islands. In northern and eastern Prince William Sound, it consists of steep to gently north dipping reverse faults that separate foliated flysch and greenstone of the Valdez Group on the north from strongly deformed flysch and tholeiite of the Orca Group on the south (Winkler and Plafker, 1981b; Winkler and others, 1981). In this area, a profound change in deep crustal structure indicates that the fault is a fundamental structural boundary (Fuis and others, 1991; Fuis and Plafker, 1991; Wolf and others, 1991). Successive accretionary wedges within the Orca Group may be bounded by faults that splay southwestward from the Contact fault system (Winkler and Plafker, 1981b). Minor structures along faults in eastern Prince William Sound indicate that predominantly dextral strike-slip displacements have been superimposed on structures formed in a thrust or oblique thrust stress regime (Winkler and Plafker, 1981b; Plafker and others, 1986). Although some post–early Eocene shear has affected plutons south of the Contact fault, strike-slip displacement must be minor because plutons that intrude across the fault in the region east of Prince William Sound have no measurable offset (Fig. 6).

In much of western Prince William Sound, the Contact fault is not well defined due to a combination of pore exposure and similarity in the structural trends, metamorphic grade, and lithology of the juxtaposed units (Tysdal and Case, 1979; Bol and others, 1992; Dumoulin, 1987). Age relations suggest that the Contact fault should lie west of the Resurrection Peninsula sequence (Fig. 6).

In the Kodiak Islands, the Contact fault marks the boundary between flysch of the Chugach terrane and the Ghost Rocks Formation to the southeast. The Ghost Rocks Formation includes kinematic indicators that indicate underthrusting beneath the adjacent Kodiak Formation. The Kodiak Formation shows a late phase of right-lateral strike-slip faulting within 20 km of the Contact fault (Sample and Moore, 1987) that is not similarly developed in the Ghost Rocks Formation. This strike-slip faulting must have developed prior to emplacement of the Ghost Rocks Formation. The current exposure of the Contact fault is steep and may not represent the structure along which the Ghost Rocks Formation was underthrust. Seismic-reflection lines northeast of the Kodiak Islands show no obvious structural boundary along the projection of the Contact fault (Moore and others, 1991).

Ghost Rocks Formation. The Ghost Rocks Formation is exposed in a belt about 10 km wide along the southeast side of the Kodiak Islands and underlies a total onshore and offshore area of about 6000 km^2 (Fig. 6). In the Kodiak area the formation is juxtaposed against the Late Cretaceous Kodiak Formation on the northwest along the Contact fault. On the southeast, the Ghost Rocks Formation is faulted against younger Tertiary rocks along the Resurrection fault. Correlative rocks are not known elsewhere in the accretionary complex. The Resurrection Peninsula sequence, which has been tentatively correlated with the Ghost Rocks Formation (Jones and others, 1987), is now known to be younger than that sequence and is considered separately in a following section.

Lithology. The Ghost Rocks Formation comprises a complexly deformed assemblage of sandstone and mudstone with interbedded volcanic rocks and minor pelagic limestone that locally is devoid of any stratal continuity (Moore, 1969; Moore and others, 1983; Byrne, 1984). The clastic rocks include turbiditic sandstone-rich and argillite-rich units with local channelized cobble-boulder conglomerates containing clasts of chert, sandstone, limestone, and greenstone. Primary structures and depositional contacts are locally well preserved. The argillite-rich units include interbedded pillow basalt, tuff, chert-rich pebble conglomerate, and minor limestone containing pelagic foraminifers. Sandstone compositions are dominated by lithic fragments of volcanic origin; quartz and feldspar in about equal proportions are less abundant (G. R. Winkler, *in* Nilsen and Moore, 1979; Bryne, 1984). These compositions are compatible with derivation from a volcanic arc or slightly dissected volcanic-arc source region.

The volcanic rocks in the Ghost Rocks Formation include both LREE-depleted tholeiitic basalt and LREE-enriched calc-alkaline basaltic andesite to andesite (Hill and others, 1981; Barker, this volume). Andesite flows as thick as 10 m are interbedded with the coarse clastic rocks, mainly in the sandstone-rich units. The major and minor element composition of the basalt is most consistent with an oceanic source, most probably a spreading ridge. In contrast, the andesitic rocks are interpreted as having been derived from a hybrid magma that most probably formed by assimilation of flysch sediments of the accretionary prism in a MORB-like basalt. Hypabyssal plutons of gabbro to quartz diorite that cut the Ghost Rocks Formation and units to the northwest are inferred to be part of this same magmatic system (Hill and others, 1981; Barker, this volume).

The Ghost Rocks Formation has been metamorphosed to prehnite-pumpellyite facies. The combined metamorphic mineral assemblages, vitrinite reflectance data, and fluid-inclusion results suggest a maximum temperature of 250 to 260 °C and burial depths of 10 to 12 km (Moore and others, 1963; Vrolijk and others, 1988).

Structure. Foliation and axial traces of folds in the Ghost Rocks Formation generally trend northeast, parallel to the outcrop pattern. Coherent units show a broadly coaxial deformation succeeded by small-scale conjugate folds and the development of spaced cleavage. Melange units show a layer-parallel, noncoaxial deformation with pervasive small-scale cataclastic shear zones and a deformed, gently plunging lineation (Moore and others, 1983; Bryne, 1982, 1984; Fisher and Bryne, 1987). In some places igneous rocks are deformed by these structures and in others they postdate the structures; igneous activity was apparently contemporaneous with northwest-directed shortening (Bryne, 1982, 1984).

Age. The age of the Ghost Rocks Formation is uncertain but is considered in this chapter to be Late Cretaceous and Paleocene. The unit postdates accretion of the Campanian and early Maastrichtian Kodiak Formation to the northwest and predates emplacement of late Paleocene intrusive rocks. Limestone at four localities contain rare, poorly preserved planktonic foraminifers of both Late Cretaceous (middle to late Maastrichtian) age and Paleocene age (Table 2; Moore and others, 1983). Volcanic rocks in the unit are undated, although at one locality limestone of possible Paleocene age is in contact with pillow basalt (Nilsen and Moore, 1979) and at another locality Maastrichtian limestone occurs as lenses in basalt (Table 2). Andesitic rocks in the unit are inferred to be comagmatic with hypabyssal plutonic rocks in the Kodiak Islands that have K-Ar radiometric ages of about 62 Ma (Hill and others, 1981; Moore and others, 1983; Moll-Stalcup, this volume; Wilson and others, this volume). The hypabyssal intrusions, which cut across the deformed Ghost Rocks Formation, indicate an early Paleocene minimum age for deposition and accretion of the unit.

Paleomagnetic data. Paleomagnetic inclination anomalies from volcanic rocks in the Ghost Rocks Formation fall into two general populations that assume a Paleocene age. (1) Andesitic rocks from the inboard part of the unit at Alitak Bay are 16° ± 9° north of their Paleocene paleolatitude. (2) Basalt from the outboard part of the unit at Kiliuda Bay is 31° ± 9° north of its Paleocene paleolatitude (Plumley and others, 1983; Hillhouse and Coe, this volume). At Kiliuda Bay rotation was counterclockwise at about 45°, and at Alitak Bay it was clockwise at about 90°.

Interpretation. We interpret the Ghost Rocks Formation as a trench or trench-slope deposit with a significant component of ocean-floor basalt and andesite related to ridge-trench interaction (Hill and others, 1981; Moore and others, 1983; Barker, this volume). The argillite unit and associated basalt were most probably deposited in a hemipelagic environment. They may be the distal equivalent of the sandstone-rich unit with its associated andesitic rocks that probably were deposited adjacent to a subduction zone characterized by near-trench volcanism (Moore and others, 1983). Conglomerate-clast lithology in the sandstone-rich unit is compatible with derivation from nearby parts of the Chugach and Peninsular terranes. The deformation, metamorphism, and igneous activity associated with these units are appropriate for emplacement in a subduction zone along the seaward margin of the Chugach terrane. Deposition, major deformation, metamorphism, and intrusion occurred in the brief interval from the middle Maastrichtian to the early Paleocene.

The paleomagnetic data indicate latitudinal displacement of about 16° relative to the craton since the early Paleocene. The large inclination anomaly for the Kiliuda Bay basalt samples (31°) suggests that these rocks are exotic oceanic crustal fragments, possibly as old as Late Cretaceous, and that they do not necessarily indicate the paleolatitude of the enclosing accretionary prism (Plafker, 1990). This interpretation differs from that of Coe and others (1985), who inferred that the paleomagnetic data represent a single population with an averaged Paleocene paleolatitude 25° ± 7° farther south. Comagmatic granitic intrusive rocks that occur in close proximity across the boundaries of the Chugach, Peninsular, and Ghost Rocks terranes suggest that these terranes were in about their present relative positions by early Paleocene time (Davies and Moore, 1984). Paleomagnetic data suggest that the northeast margin of the Wrangellia composite terrane (which includes the Peninsular terrane) was in place relative to North America by about 55 Ma (Hillhouse and others, 1985; Hillhouse and Coe, this volume). If so, the Ghost Rocks Formation has not moved appreciably northward since that time, unless there are very large undetected dextral strike-slip displacements on suitably oriented faults inboard of these units. The 16° of relative motion must have occurred in the interval from early Paleocene to 55 Ma.

Orca Group. The Orca Group is a deep-sea-fan flysch complex interbedded with subordinate oceanic volcanic rocks

TABLE 2. FORAMINIFERA FROM THE GHOST ROCKS FORMATION, ALASKA*

Sample No. Collector	Latitude Longitude	Age	Lithology	Fauna	Paleontologist or Comments
AMe-76-21† MF-3421§ G. W. Moore	57°13.1'N 153°02.9'W	Probable Paleocene	Limestone	? *Subbotina* spp., *S.* sp. cf. *S. triangularis*, *S. triloculinoides* group	R. Z. Poore, U.S.G.S., written commun. to G. W. Moore, Oct. 7, 1976.
AMc-76-56† MF-3422§ G. W. Moore	57°23'N 152°36.1'W	Probable Paleocene	Limestone overlying pillow lava	*Globigerina pseudobulloides* Plummer (or a closely related taxon), *Planorotalites* sp.?	Age designation based on correct identification of *Planorotalites* sp.?
				?*Subbotina* spp., *S.* sp. cf. *S. triangularis*, *S. triloculinoides* group	R. Z. Poore, U.S.G.S., written commun. to G. W. Moore, Oct. 7, 1976; Oct. 22, 1976.
HZe† W. Connelly	57°13'N 153°00'W	Paleocene	Limestone block	*Globigerina* spp., *G.* sp. cf, *G. yeguaensis*, Wienzierl and Applin, abundant	W. V. Sliter, U.S.G.S., written commun. to G. Plafker, March 1992.
78-KN-C8-A† T. Byrne	56°56.5'N 153°38.8'W	Late Cretceous, middle to upper Maastrichtian	Limestone lenses in pillow basalt	*Contusotruncana patelliformis* (Gandolfi), *Globotruncana arca* (Cushman), *G.* sp. cf. *G. hilli* (Pessagno), *G. linneiana* (d'Orbigny), *Globotruncanella havanensis* (Voorwijk), *G.* sp. cf. *G. petaloidea* (Gandolfi), *Globotruncanita stuarti* (de Lapparent), *G.* sp. cf. *G. stuartiformis* (Dalbiez), *Hedbergella* spp., *Heterohelix* spp., *Planoglobulina acervulinoides* (Egger), *Pseudoguembelina* sp. cf. *P. costulata* (Cushman), *Pseudotextularia elegans* (Rzehak), *Rugoglobigerina rugosa* (Plummer), *R.* sp. cf. *R. hexacamerata* (Brönnimann)	W. V. Sliter, U.S.G.S., written commun. to G. Plafker, Feb. 8, 1993.

Note: U.S.G.S is United States Geological Survey.
*Identified in thin section
†Field number.
§U.S. Geological Survey collection number.

and minor hemipelagic mudstone (Winkler, 1976; Winkler and Plafker, 1981b; Helwig and Emmet, 1981; Nelson and others, 1985) that forms an outcrop belt more than 100 km wide that extends from the western Chugach Mountains beneath Prince William Sound and southwestward beneath the continental shelf and slope (Fig. 6). The Orca Group makes up most or all of the Prince William terrane as defined by Jones and others (1987). Possibly correlative units are the Sitkalidak Formation (Fig. 7) and the Resurrection Peninsula sequence, described below. The onshore area is roughly 21,000 km^2 and the total area, including the inferred offshore area underlain by the Orca Group, is at least 140,000 km^2.

The Orca Group is bounded on the north by the Contact fault system, on the south in the Chugach Mountains by the Chugach–Saint Elias fault system, and on the southeast by the offshore Kayak Island structural zone and its onshore extension east of the Copper River. The south and west boundaries offshore are not well known, although seismic reflection data and a characteristic magnetic signature of the volcanic rocks in the unit suggest that the Orca Group probably extends beneath much or all of the continental shelf. An exploratory well 3600 m deep near Middleton Island bottomed in deformed strata that are possibly correlative with the Orca Group, although the paleontological data do not preclude the alternative interpretation that they are as young as late Eocene (Plafker and others, 1982; Rau and others, 1983; Plafker, 1987).

Clastic rocks. Monotonous sequences of thin- to thick-bedded turbidites consisting of sandstone, siltstone, and mudstone are the dominant clastic components. Abundant primary sedimentary features indicate deposition from sediment gravity flows, chiefly turbidity currents.

The sandstone is feldspathic to lithofeldspathic. Lenticular, matrix-supported pebbly mudstone and sandstone also are widespread, and at one locality, along Valdez Arm north of Galena Bay, calcareous concretions in debris-flow deposits contain abundant fossil crabs and rare pelecypods and gastropods. The pebbly mudstone, sandstone, and debris flows apparently mark distributary channels that fed mid-fan depositional lobes.

Sandstone compositions are variable but on the average comprise roughly equal amounts of quartz, feldspar, and rock fragments (Winkler, 1976; Dumoulin, 1987; Gergen and Plafker, 1988). About 30% to 50% of the rock fragments are volcanic and as much as 20% are metamorphic; plagioclase makes up 80% to more than 90% of the total feldspar. These compositions are compatible with derivation from a mixed dissected magmatic arc and high-grade metamorphic provenance.

A minor but ubiquitous component of the unit is massive, clast-supported, well-rounded pebble, cobble, and boulder conglomerate. Typical clast assemblages include greenstone, sandstone, argillite, and limestone; less common are felsic porphyry and tuff, granitoid rocks, sandstone, limestone, and orthoquartzite. At one locality just east of the mouth of the Copper River, the conglomerate consists of rhyolitic welded tuff and porphyry cobbles and boulders and less than 10% sandstone clasts. The massive conglomerates probably represent inner fan channel-fill deposits that mark entry points of major feeder channels onto the Orca submarine-fan complex. The presence of cobble- to boulder-size siliceous welded tuff and orthoquartzite clasts suggests proximity to a continental source for part of the sediment.

Volcanic rocks. Mafic volcanic rocks, which constitute 15% to 20% of the Orca Group, crop out in three major discontinuous belts: (1) along the northern margin of Prince William Sound, (2) from Hinchinbrook Island eastward to the east side of the Copper River, and (3) offshore on the continental shelf. The largest of these volcanic sequences are shown in Figure 6.

The landward belt of mafic volcanic rocks is 150 km long, as much as 12 km wide, and extends in a broad arc along the western, northern, and northeastern Prince William Sound. The belt is marked by pronounced positive residual gravity anomalies (Case and others, 1966) and aeromagnetic anomalies (Case and Tysdal, 1979). Large changes in total amplitude of the anomalies along strike, however, indicate that in places the volcanic sequences thin markedly, either stratigraphically or structurally. The rocks are dominantly tabular bodies of altered basalt, consisting chiefly of pillowed, massive, or crudely columnar flows, pillow breccia, and aquagene tuff with variable amounts of associated gabbro and diabase as sills or sheeted dikes. At Knight Island in western Prince William Sound, an ophiolite complex consists of a core of peridotite, sheared ultramafic rocks, and thousands of meters (structural thickness) of sheeted dikes that are surmounted by more than 1500 m of pillow-basalt breccia and massive flows (Richter, 1965; Tysdal and Case, 1979; Nelson and others, 1985). Small bodies of gabbro intrude both the sheeted dike complex and the sedimentary section that is interbedded with and encloses the volcanic sequence. Southwest of Knight Island the proportion of argillaceous rocks interbedded with, or intruded by, the mafic igneous sequence increases and the stratigraphy of the volcanic rocks is disrupted. This area of strongly deformed rocks was referred to as the Bainbridge melange by Helwig and Emmet (1981). Along regional strike to the east there is no equivalent belt of melange.

A second belt of mafic volcanic rocks extends discontinuously from Hinchinbrook Island in southeastern Prince William Sound to the Cordova area and east of the Copper River mouth along the south and east margin of the Prince William terrane; thinner volcanic sequences occur sporadically in eastern Prince William Sound north of Cordova (Fig. 6; Winkler and Plafker, 1981b). Volcanic rocks in the southern belt typically have pronounced aeromagnetic anomalies but no associated gravity anomalies, suggesting that the bodies are thin or rootless. The volcanic sequences are dominantly massive flows, pillow basalt, pillow breccia, and aquagene tuff as thick as 2500 m. Sheeted dikes are not present in any of these sequences, and, in general, they contain a greater proportion of interbedded sedimentary rocks than those of the northern belt. Red or green argillite or varicolored chert is locally associated with the amygdaloidal volcanic rocks, pillow breccia, or aquagene tuff, and in a few places upper surfaces of volcanic rocks are mantled with thin beds of bioclastic limestone. Fragmental bioclastic limestone with abundant shallow-water fossils and pelagic limestone containing foraminifers indicate deposition above the carbonate compensation depth in shallower water than normal flysch (Winkler, 1976). In some parts of the belt, and as far southwest as Montague Island, red or green argillite, limestone, and tuffaceous fine-grained sedimentary rocks are interbedded with typical flysch but other volcanic rocks are lacking (Helwig and Emmet, 1981; Dumoulin and Miller, 1984).

The third belt of volcanic rocks occurs within the Orca Group on the continental shelf in the Gulf of Alaska where it is defined by large positive anomalies in the aeromagnetic data (Winkler and Plafker, 1981b; J. E. Case, G. Plafker, and G. R. Winkler, unpublished data). By analogy with the onshore geology and geophysics, they are interpreted as discontinuous volcanic sequences at or near the sea floor that are probably similar to the volcanic rocks of the southern Prince William Sound belt. Geochemical data show that the volcanic and related intrusive rocks of the Orca Group have diverse compositions that indicate several possible interpreted origins (Barker, this volume, Table 3). Of 19 samples analyzed, 12 are basalt, 5 are diabase, and 2 are basaltic andesite. On an AFL diagram, samples plot in both the tholeiitic and calc-alkalic fields. High CaO (13% to 14%) in three samples is probably due to abundance of calcite as veinlets and amygdule filings. On the basis of minor element geochemistry, these rocks fall into four distinct suites, as follows: (1) moderately LREE-enriched samples from east of the Copper River (at Ragged Mountain) in a setting that is compatible with enriched MORB; (2) samples from the northern Prince William Sound belt that have flat REE trends, slight negative Eu anomalies, mainly N-MORB compositions, and a slight calc-alkaline affinity; (3) samples from the southern belt near Cordova and east of the Copper River at Ragged Mountain, and one from the northern belt in northeastern Prince William Sound that have low REE abundances and strong depletion of LREE compared to HREE that could indicate low-K tholeiite; and (4) one basaltic metaandesite from the northern belt in western Prince William

Sound that has a composition suggestive of contaminated basaltic andesite (similar to basaltic andesite of the Ghost Rocks Formation).

Thickness. The stratigraphic thickness of the Orca Group in outcrop is estimated as many thousands of meters (possibly 6 to 10 km), but accurate determinations of thickness are precluded by the pervasive tight folding and imbricate faulting together with poor biostratigraphic control (Winkler and Plafker, 1981b; Tysdal and Case, 1979; Helwig and Emmet, 1981). Refraction and reflection seismic data indicate a vertical thickness of about 14 to 18 km beneath the continental shelf and 18 to 20 km in Prince William Sound (Brocher and others, 1991).

Metamorphism. The entire Orca Group was converted to transitional continental crust during a major thermal event that was accompanied by widespread plutonism at about 50 Ma (Barker and others, 1992; Moll-Stalcup, this volume). During this event the rocks underwent dominantly laumontite and prehnite-pumpellyite facies metamorphism and local greenschist facies metamorphism (to biotite grade) near the larger plutons east of Prince William Sound (Fig. 6). Widespread thermal metamorphism of the Orca Group accompanied emplacement of early Oligocene sills, stocks, and small plutons in northern and western Prince William Sound that range in composition from gabbro to granite (Tysdal and Case, 1979; Nelson and others, 1985; G. Plafker and G. B. Dalrymple, unpublished data).

Structure. The Orca Group was deformed in two major and distinct episodes. The first episode preceded intrusion of the granitoid rocks and probably was contemporaneous with accretion. It is characterized by complex folding and faulting that produced a penetrative slaty cleavage. Fold axial planes and faults are vertical to seaward vergent; a notable exception is a zone of landward-vergent structures up to 15 km wide that extends from Montague Island to Hinchinbrook Island (Plafker, 1967; Winkler, 1976; Helwig and Emmett, 1981; Plafker and others, 1986). Regional strike is generally northeast in most of the area, but in a zone extending eastward from northeastern Prince William Sound, it is highly variable and even north to northwest (Fig. 6; Plafker and others, 1986). In eastern Prince William Sound the axial planes, cleavage or schistosity, and compositional layering have vertical to steep north dips, and fold axes and lineations plunge gently northeast or southwest. Parallelism of subhorizontal major and minor fold axes and lineations, where they are not affected by later folding, indicates dominantly orthogonal convergence and local areas of oblique convergence during accretion. Within a few hundred meters of the Contact fault system, intense folding and faulting in both upper and lower plate rocks commonly resulted in general parallelism of structures on both sides of the fault. An exception is the area just east of Prince William Sound, where major northeast-trending units and structures in the Orca Group extend obliquely into a dominantly east trending segment of the Contact fault system (Fig. 6).

Upper contacts of the volcanic rocks are generally concordant with the enclosing flysch, and lower contacts may be either concordant or faulted, where exposed. These relations suggest that the volcanic sequences did not function as semirigid blocks that were decoupled from stresses imposed on the flyschoid sequences. Instead, volcanic sequences generally share the same pattern of folds and faults that typifies the complexly deformed flysch. Although exposed volcanic sequences southwest of Knight Island were described as blocks in melange by Helwig and Emmet (1981), many of the "blocks" exhibit intrusive and depositional contacts with the enclosing rocks, indicating that they are not structurally disrupted (Tysdal and Case, 1979). Superimposed on the accretionary fabric of the Orca Group are younger open folds and related structures that are associated with broad regional warping in northeastern Prince William Sound and in the area to the east (Nokleberg and others, 1989). This warping is best displayed in the arcuate trace of the Contact fault system and by planar structures within the Orca Group near the fault. The transition from east-west to northeast trends defines part of the axis of the Alaskan orocline of Carey (1958). North-northeast strikes and near-vertical dips of the axial planes of the open folds indicate mainly east-southeast to west-northwest compression. Local zones of right-lateral shear within the Orca Group west of this axis may reflect late-stage counterclockwise bending of the west limb of the orocline. Additional northwest-directed late Cenozoic compressional deformation, as manifested by slip on minor conjugate strike-slip faults, may be related to emplacement of the Yakutat terrane against and beneath the Orca Group.

Age. Paleontologic data indicate that Orca Group strata range in age from late Paleocene through middle Eocene. Age-diagnostic fossil assemblages include foraminifers (29), diatoms and silicoflagellates (1), radiolarians (8), coccoliths (1), dinoflagellates (1), and one megafauna of mollusks and crabs (Plafker and others, 1985b).

The lower age range of the unit is uncertain but is presumably late Paleocene on the basis of age-diagnostic planktonic foraminifers at nine localities. Radiometric data constrain the younger age limit for much, if not all, of the Orca Group to the early middle Eocene (51 to 53 $\pm$ 1.6 Ma). This age limit is taken as the emplacement age of the early middle Eocene plutons that intruded and metamorphosed the sequence.

Paleomagnetic data. Paleomagnetic studies of pillow basalt in the Orca Group have yielded low-quality and contradictory results. Data from the Knight Island area in western Prince William Sound suggest little or no northward displacement (Hillhouse and Grommé, 1977), whereas preliminary analysis of data from the northeastern part of Prince William Sound suggests an origin possibly 40° to the south (Plumley and Plafker, 1985). However, these data are suspect because of the possibility that widespread thermal events of probable early to middle Eocene and early Oligocene age have reset the magnetization. Attempts to obtain paleomagnetic data from sedimentary rocks in the Orca Group have been unsuccessful because the magnetization has been overprinted by younger events (Hillhouse and Grommé, 1985). Geologic data indicate that the Orca Group was accreted to the Chugach terrane by 51 ± 3 Ma and that postaccretion horizontal displacement along the Contact fault suture between these terranes is no more than a few tens of kilometers (Winkler and Plafker, 1981b).

Interpretation. The bulk of the siliciclastic rocks that constitute the Orca Group was deposited as a deep-sea fan complex with paleocurrents and distinctive associations of turbidite facies indicating sediment transport and deposition on westward-sloping fans (Winkler, 1976). The combined sandstone compositions and sediment transport directions are compatible with a provenance mainly in the Kluane arc (Fig. 5). Sedimentation coincides with the main phase of uplift of the Coast Mountains of British Columbia and Alaska between 62 and 48 Ma (Hollister, 1979, 1982; Crawford and Hollister, 1982) and with the counterclockwise oroclinal bending of western Alaska (Plafker, 1987; Hillhouse and Coe, this volume). Minor sediment contributions to the deep-sea fans came from the adjacent Chugach terrane (Winkler, 1976).

Coeval submarine volcanism resulted in intercalation of local basalt masses within prisms of terrigenous sediment. Rapid northeast to north movement of the Kula plate resulted in progressive offscraping of these deposits, together with far-traveled material carried into the area by the Kula plate, against previously accreted rocks along the continental margin of what is now the northern and western Gulf of Alaska (Helwig and Emmett, 1981). Deformation of the Orca Group began prior to complete dewatering of the sedimentary rocks (Winkler, 1976) and soon was followed by intrusions of granodiorite, granite, and tonalite plutons, ranging in age from 53.5 to 50.5 Ma (± 1.6 Ma) in eastern Prince William Sound and the area to the east (Plafker and others, 1989).

The mafic volcanic rocks and ophiolite that make up the northern belt are probably a relatively coherent slice of oceanic crust, on the basis of the composition, distribution, and associated positive magnetic and gravity anomalies. An origin at the Kula-Farallon ridge is compatible with the occurrence of ophiolite and MORB-type lavas. Volcanic rocks in the southern belt and offshore are more likely rootless fragments of submarine ridges or seamount chains, on the basis of their variable composition, lenticularity along strike, the high proportion of glassy, vesiculated, or fragmental textures, their local association with nonflyschoid shallow-water sediments, and the absence of ophiolite sequences or strong positive gravity anomalies. Possible sites for eruption of the basalts are leaky transform faults along the continental margin (Tysdal and Case, 1979) or primitive intraoceanic arcs—environments that give rise to more diverse magma types and the formation of both LREE-enriched and LREE-depleted lavas (Lull and Plafker, 1990).

Resurrection Peninsula sequence. The Resurrection Peninsula sequence occupies an outcrop belt 21 km long and as much as 6 km wide on the mainland south of Seward (Fig. 6). The sequence is juxtaposed against rocks of the Chugach terrane to the northwest along a structure that may be a continuation of the Contact fault system, although its position in this area has not been well determined. The nature of the southern contact beyond the Resurrection Peninsula is unknown.

This sequence is along structural strike with the Ghost Rocks Formation, and it was tentatively included within the Ghost Rocks terrane on the basis of structural continuity and paleomagnetism (Plafker, 1987). Subsequently, the Resurrection Peninsula sequence has been shown to be in part or entirely younger than the Ghost Rocks Formation (Nelson and others, 1989), and the available age data suggest that it may be correlative with the Orca Group in Prince William Sound. However, because it is not known to be continuous in outcrop with the Orca Group, and because of the possibility that the ages of dated igneous rocks are minimum ages, the sequence is described separately here from the Orca Group.

Lithology. The Resurrection Peninsula and adjacent islands are underlain by an ophiolitic sequence that grades from mainly gabbro (in part cumulate) at the base, through a sheeted mafic dike complex, to pillow basalt at the top (Tysdal and Case, 1979; M. L. Miller, *in* Winkler and others, 1984). Serpentinized peridotite and pyroxenite occur as pods in the gabbro and as fault-bounded slices in adjacent flysch; dikes and plugs of plagiogranite intrude the upper parts of the gabbro. Siltstone is locally interbedded with the pillow basalt and interbedded tuff, and siltstone locally appears to stratigraphically overlie the ophiolitic rocks.

All rocks in the sequence are affected by low-greenschist facies metamorphism with a later prehnite facies overprint (Dusel-Bacon, this volume). The metamorphism, together with serpentinization of the ultramafic rocks and a lack of penetrative fabric, indicates mainly thermal and hydrothermal metamorphism related to hot circulating water on the sea floor, rather than the regional greenschist metamorphism (to biotite grade) that has affected adjacent Valdez Group rocks. The prehnite, however, could also be the result of a younger prehnite-pumpellyite-grade metamorphic event related to emplacement of these rocks in an accretionary sequence.

Structure. The ophiolitic rocks occur in two fault-bounded, apparently coherent slices; the main body on Resurrection Peninsula forms a homoclinal slab that dips steeply to moderately west (M. L. Miller, *in* Winkler and others, 1984). Structural data indicate polyphase deformation that included folding about a vertical structural axis during one phase (Bol and others, 1992). All contacts of the Resurrection Peninsula sequence with the adjacent rocks of the Valdez Group are faults, and the contact is a thrust fault at least locally (Nelson and others, 1985; M. L. Miller, *in* Winkler and others, 1984; Bol and others, 1992).

Age. The best crystallization age for part of the Resurrection Peninsula sequence is a U-Pb zircon age of 57 ± 1 Ma from a trondhjemite intrusion (Nelson and others, 1989). Four samples of altered basaltic greenstone from the Resurrection Peninsula and one from the nearby Renard Island yield K-Ar whole-rock ages ranging from 54.4 ± 2.7 to 45.7 ± 2.3 Ma (Winkler and others, 1984, Table 5) that are probably minimum ages and are compatible with the U-Pb age. These data suggest a probable age close to that of the Paleocene-Eocene boundary and a correlation with the younger part of the Orca Group rather than with the Ghost Rocks Formation, as previously inferred by Plafker (1987).

Paleomagnetic data. An excellent data set for basalts and sheeted dikes of the Resurrection Peninsula sequence indicates a paleomagnetic discrepancy of 13° ± 9°, assuming an early Eocene age; they also indicate counterclockwise rotations of about 90° (Bol and others, 1992).

Interpretation. The Resurrection Peninsula sequence is a relatively coherent fragment of oceanic crust and upper mantle that was offscraped and accreted with flysch deposits, presumably at the inner wall of a trench. Emplacement age of the Resurrection Peninsula rocks is not known; it is inferred to postdate accretion of the Late Cretaceous Valdez Group and to be coeval with, or to slightly predate, accretion of the parts of the Orca Group that are outboard of the sequence.

Rocks of the Resurrection Peninsula sequence were tentatively correlated with the Ghost Rocks Formation by Plafker (1987) on the basis of similarities in paleomagnetic signature and structural position. However, this correlation is now considered unlikely because at least part of the sequence is 5 m.y. younger than the Ghost Rocks Formation. The early Eocene isotopic age reported by Nelson and others (1989) favors correlation with oceanic rocks in the Orca Group; a suggestion made by some of the earliest workers in the area (Grant and Higgins, 1910). The ophiolitic sequence is very similar to the thick undated pillow-basalt and sheeted-dike sequences of the Orca Group that make up most of Knight Island in western Prince William Sound (Tysdal and Case, 1979).

The paleomagnetic data indicate northward displacement of between 4° and 22° since crystallization of the igneous rocks. If the age of the sampled rocks is about 57 Ma, as suggested by isotopic data, only the minimal displacements are compatible with evidence indicating that the amalgamated Wrangellia and Southern Margin composite terranes were at about their present paleolatitude at 55 Ma (Hillhouse and Coe, this volume). Alternatively, if the 57 Ma age is a minimum emplacement age for these rocks, earlier relative poleward displacement of the sequence is required and could have occurred by a combination of northward movement relative to the Chugach terrane and by dextral slip along faults between these terranes and the craton, as proposed by Bol and others (1992). A major difficulty with this alternative, however, is that cumulative dextral slip on all known early Tertiary faults between the Resurrection Peninsula sequence and the craton can account for no more than about 8° of northward displacement (Plafker, 1987).

Sitkalidak Formation. The Sitkalidak Formation (Moore, 1969) crops out along the southeastern coast of Kodiak Island and on adjacent offshore islands, where it forms a belt 165 km long and up to 25 km wide (Fig. 6). It is separated from the older Ghost Rocks Formation to the northwest by the Resurrection fault and is conformably to unconformably overlain by younger Tertiary units (Moore, 1969; Moore and Allwardt, 1980). Although the age range is uncertain, available data suggest that the sequence is in part or entirely correlative with the Orca Group of the Prince William terrane (Fig. 7).

The Sitkalidak Formation and correlative deformed accreted rocks form the acoustic basement offshore from the Kodiak Islands. Seismic reflection data and stratigraphy in holes drilled for petroleum exploration suggest that comparable rocks underlie much or all of the continental shelf and possibly the upper slope off the Kodiak Islands (Fisher and others, 1987; Hoose, 1987; Olson and others, 1987).

Lithology. The Sitkalidak Formation consists of massive sandstone, interbedded sandstone and siltstone, mudstone, and conglomerate deposited by turbidity currents. Although the sandstone-siltstone ratio is highly variable, the overall ratio is about 50:50. The sandstone beds are medium to coarse grained, poorly graded, and average about 1.0 to 1.5 m in thickness. Intervening beds are well-graded fissile siltstone and fine-grained sandstone beds that vary in thickness from a few centimeters to 50 cm. Sandstone modes of the Sitkalidak Formation are characterized by quartz and feldspar, in about equal proportions, that together constitute aobut 50% to 60% of the total detrital grains (Stewart, 1976; Lyle and others, 1977; G. R. Winkler, *in* Nilsen and Moore, 1979; Moore and others, 1983). Lithic fragments of dominantly volcanic and sedimentary origin constitute most of the remainder, and minor constituents are epidote, pyroxene, biotite, and muscovite. Sandstone composition suggests a mixed provenance with a dominant magmatic-arc component. Stratigraphic thickness of the unit is about 3000 m (Moore, 1969).

The Sitkalidak Formation is metamorphosed to the zeolite facies; peak metamorphic temperatures were 100 to 125 °C and maximum burial depths were 2.4 to 3.9 km (Moore and Allwardt, 1980).

Structure. Two general structural styles that suggest different modes of accretion have been recognized within the Sitkalidak Formation (Moore and Allwardt, 1980). One characterizes an inboard unit of seaward-verging strata that are tightly folded but not disrupted; the other characterizes a more deformed outboard unit of landward-verging strata and commonly exhibits stratal disruption along cataclastic shear zones with web structures (Fig. 9; Sample and Moore, 1987).

Age. The Sitkalidak Formation is younger than the Late Cretaceous and early Paleocene Ghost Rocks Formation and older than the overlying Oligocene strata of the Sitkinak Formation. Although Moore (1969) and subsequent workers (e.g., Armentrout, 1975; Olson and others, 1987) assigned an Oligocene age to the formation, that assignment is based on a very sparse and poorly preserved fossil fauna. The megafauna consists of a single long-ranging fossil clam of unknown age significance (a new genus of Vesicomyidae) and small fragments of a fossil crab (*Calianassa* aff. *C. porterensis*) of a type that occurs in late Eocene rocks of western Washington but has an uncertain age range. Ten samples from the formation have yielded a poorly preserved predominantly agglutinated bathyal foraminiferal assemblage consisting of long-ranging forms (Lyle and others, 1977; Clendenen and others, 1992). This assemblage includes *Ammosphaeroidinia*? sp., *Bathysiphon alexanderi, B. sanctaecrucis, B. eocenica, Haplophragmoides* sp., *H. obliquicameratus* Marks, *H.* cf. *deformes, Nodosarella atlantisae hispidula* (Cushman), *Nodosaria arundinea* Schwager, *Praeglobobulimina ovata cowlitzensis* (Beck), *Reophax* sp., *Rhabdammina eocenica* Cushman and Hanna, and *Trochammina globegeriniformis* (Parker and Jones). The presence of *P. ovata cowlitzensis* constrains the depositional age to the Eocene (Clendenen and others, 1992). Possibly correlative strata penetrated in three stratigraphic test wells on the continental shelf, beneath a regional unconformity, contain Eocene microfossils; one well (KSSD No. 1; Fig. 10) includes strata of early and middle Eocene age, on the basis of dinocyst fossils and to a lesser extent on foraminifers (Olson and others, 1987).

Interpretation. The facies sequences, paleocurrents, and variable pebble-clast compositions suggest deposition as a series of coalescing submarine fans, probably on a trench floor or in a trench-slope basin (Nilsen and Moore, 1979). The unit consists mainly of outer fan turbidites that locally include some basin-plain and inner fan deposits; paleocurrents indicate general transport of sediments both downslope and parallel to the slope with a major feeder system in the vicinity of Sitkalidak Island (Nilsen and Moore, 1979; Moore and Allwardt, 1980).

The combined sedimentological and structural data suggest that the more deformed part of the Sitkalidak Formation was emplaced as an obductively offscraped trench-fill sequence and that the less-deformed inboard part probably accumulated within a slope basin (Moore and Allwardt, 1980). At least the older part of the unit may be equivalent to the Orca Group on the basis of its age, lithology, structure, and position within the accretionary complex. Sandstone compositions are compatible with a common dissected continental-margin magmatic-arc source for these units.

The difference in metamorphism between the Sitkalidak and

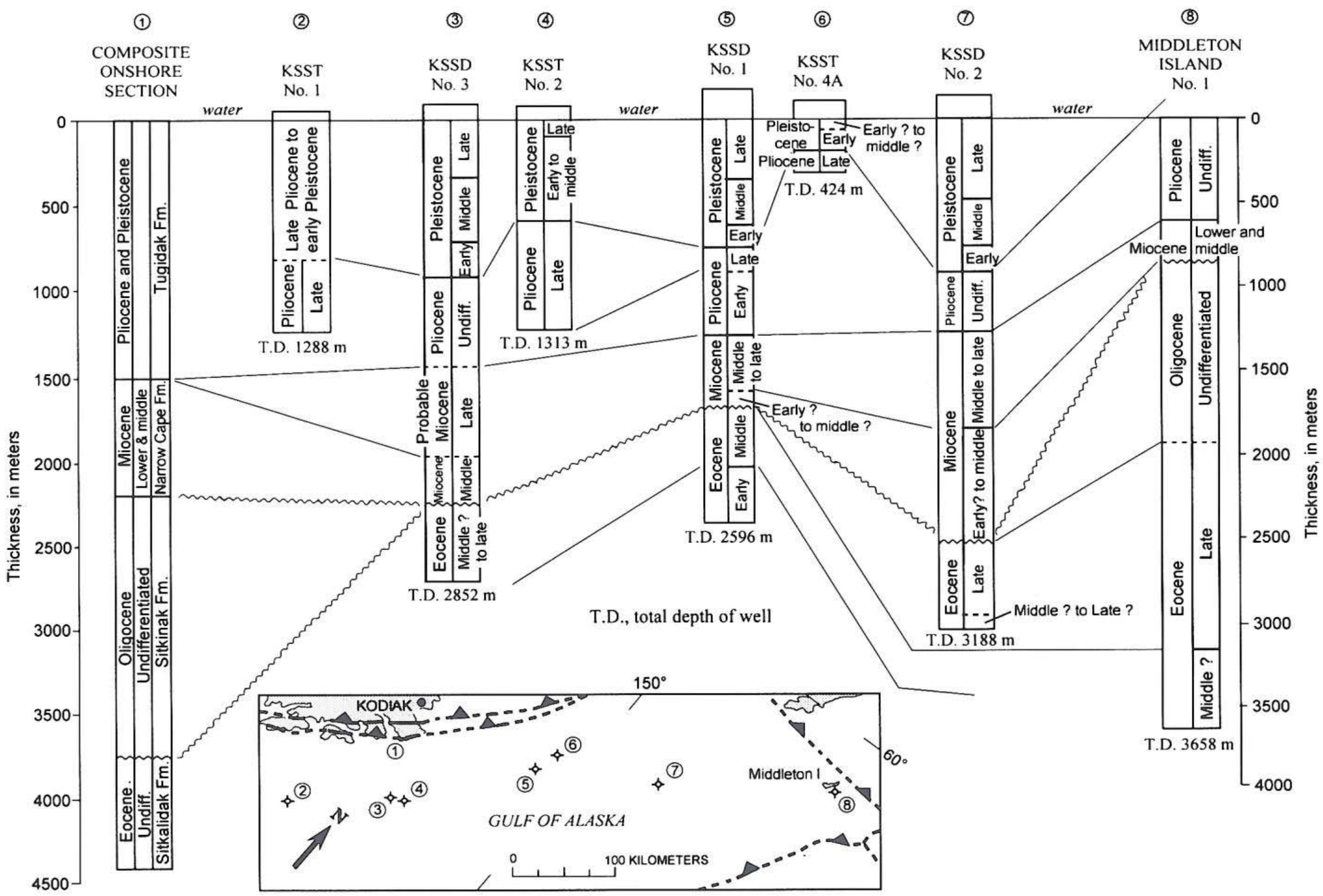


Figure 10. Correlation chart for Tertiary overlap assemblages from outcrops on the Kodiak Islands and from wells on the Kodiak and Middleton shelves. Adapted from North American Commission on Stratigraphic Nomenclature (1983); Rau and others (1983); Olson and others (1987); Schaff and Gilbert (1987).

Ghost Rocks formations indicates ~8 km of vertical displacement along the Resurrection fault that separates them. However, marine seismic-reflection data show no obvious structural boundary along the projection of the Resurrection fault to the northeast (Moore and others, 1991).

Late Cenozoic accretionary sequences associated with the Aleutian Arc and megathrust

Accreted post-Eocene strata are inferred to underlie large areas of the continental margin west of Middleton Island, and they occur at the base of the slope in an area about 100 km long by 40 km wide that is bounded by the easternmost Aleutian megathrust, the Transition fault system, and the Kayak Island fault zone (Fig. 6).

Sediments on the present oceanic crust consist of 3 to 5 km of deep-sea fan and trench-fill turbidites mainly of Pliocene and Quaternary age that overlie a thin layer of Tertiary abyssal sediments of Eocene to Miocene age (von Huene and others, 1987; Drummond, 1986). The age of the basal abyssal sediments and underlying basalt crust ranges from chron 15 (about 37 Ma) at the eastern end of the Aleutian Trench to chron 24 (about 56 Ma) off the Sanak Islands (Atwater and Severinghaus, 1989). The sedimentary rocks and oceanic crust are being accreted to, and underthrust beneath, the continental slope with resultant seaward progradation of the accretionary prism.

In the segment south of Middleton Island, accreted post-Eocene strata are inferred to underlie much of the continental margin in a belt that is close to 100 km wide perpendicular to the trench (von Huene and others, 1987; Moore and others, 1991). A decollement at the base of the slope typically separates the section into a deformed and accreted upper part and a relatively undeformed subducted lower part (von Huene and others, 1987). The deformed upper part, which underlies much of the continental slope, includes both seaward- and landward-verging thrust faults and associated folds (von Huene and others, 1987; Moore and others, 1991). The inner margin of these accreted rocks is marked, at least locally, by an out-of-sequence thrust fault that juxtaposes deformed and indurated Paleogene strata against Pleistocene slope sediments (see section on deep crustal structure, below). Where identified on deep seismic reflection profiles near Stevenson Basin (Fig. 11), this boundary is located close to the continental shelf edge. The sequence below the basal decollement is progressively underplated at depth beneath the accretionary prism along the entire 300 km width that it can be seen seismically (Moore and others, 1991).

At the eastern end of the Aleutian megathrust, offscraped oceanic sedimentary rocks underlie the lower 1 to 1.5 km of the

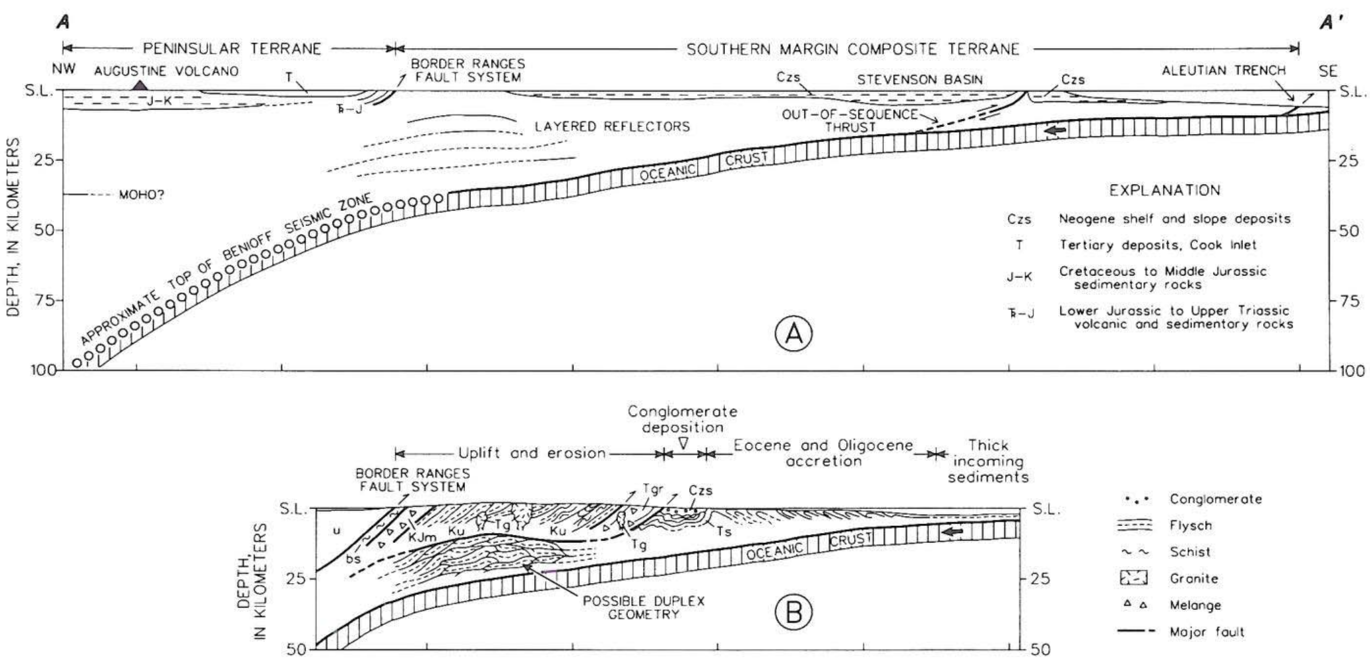


Figure 11. Interpreted deep crustal structure along the EDGE marine geophysical transect through Kennedy Entrance from the Pacific plate to the Aleutian arc; location of section shown in Figure 6. A: Section based on seismic-reflection data; base of oceanic crust projects into zone of intense seismicity of downgoing slab. Velocities for depth conversions obtained from wells, from velocity models used to locate earthquakes, and from preliminary results of unreversed piggyback ocean-bottom seismometer studies. B: Inferred structure of the Mesozoic and Paleogene accretionary prisms showing emplacement of layered reflectors by underplating in response to seaward growth of margin during late Eocene or Oligocene time; see Figure 6 for explanation of unit symbols (after Moore and others, 1991).

continental slope south of the Transition fault system (unit Czu, Fig. 6). These accreted strata form a large faulted anticlinal ridge and a subparallel basin on the landward side that contains young tilted sediments (Bruns and Schwab, 1983, section 922). The inner margin of accreted late Cenozoic strata cannot be resolved with available seismic reflection data. The margin shown in Figure 6 coincides with the south limits of the Yakutat terrane as deduced by Griscom and Sauer (1990) from magnetic data. Samples dredged from the south flank of the anticlinal ridge and the continental slope to the north are slightly indurated to well-indurated siliciclastic sediments and calcareous sediments that contain a microfauna of Pliocene through Pleistocene age and locally abundant reworked Paleogene microfossils (Plafker, 1987). The dredge samples appear to be accreted trench deposits that were subjected to unusually rapid lithification, possibly due to tectonic deformation related to plate convergence. Pelagic sediments have not been recovered, and the microfossils indicate a terrigenous sediment source. This suggests that the accretionary prism in this area consists dominantly of fan and trench-fill turbidites without a significant component of abyssal sediments.

Structures within and below the accretionary prism appear to be highly variable along strike. A significant gap in the late Cenozoic accretionary prism apparently occurs along this margin at the inner trench wall off Middleton Island. In that area the oceanic crust and its blanket of about 3.5 km of sediment is apparently thrust at least 14 km beneath the continental slope (Fig. 3, A–A‴) and there is no evidence for a Cenozoic accretionary prism comparable to those that occur both to the southwest and northeast.

Overlap assemblages and basinal sequences

Arc-related rocks of the Southern Margin composite terrane are in fault contact with, or are unconformably overlain by, relatively undeformed overlap assemblages that are exposed locally along the southeast margin of the Kodiak Islands, and underlie Chirikof, Tugidak, Sitkinak, and Middleton islands as well as much of the contiguous continental shelf and slope (Fig. 6). Thickness and lithology of the sequences has been studied in offshore areas mainly by regional seismic-reflection profiles, six deep stratigraphic test wells on the Kodiak shelf, and one well drilled for petroleum on the Middleton shelf near Middleton Island. Stratigraphic correlations between onshore sections in the Kodiak Islands and offshore wells of the Kodiak and Middleton shelves are shown in Figure 10. The following summary of these deposits is based mainly on data in Wiley (1986), Bruns and Carlson (1987), Bruns and others (1987), Plafker (1987), Schaff and Gilbert (1987), Turner (1987), von Huene and others (1987), and Vallier and others (this volume).

Basinal sequences east of the Middleton shelf are discussed in a following section on the Yakutat terrane.

Sanak and Shumagin basins. The Sanak and Shumagin basins (Fig. 6) are large offshore sedimentary basins that overlie the Mesozoic accretionary prism in the vicinity of the Sanak Islands and the Shumagin Islands (von Huene and others, 1987). The Sanak basin is a complex of fault-bounded troughs containing sediments more than 8 km thick, whereas the Shumagin basin is a relatively simple depression with as much as 2.5 km of fill (Fig. 6). The basin fills are inferred to be Miocene and younger clastic and volcaniclastic(?) strata. Acoustic basement probably consists of the same sequence of highly deformed Late Cretaceous turbidites and older melange that crops out on the nearby islands (Fig. 7). Additional detail on the stratigraphy and structure of these basins was given by Bruns and others (1987) and Vallier and others (this volume).

Kodiak Islands and Kodiak shelf. Basinal and overlap sequences of late Oligocene and younger age are intermittently exposed in outcrop from Kodiak to Chirikof Island and are inferred from seismic reflection and well data to underlie much of the contiguous continental shelf (Fig. 6).

The lower part of the overlap sequence in outcrop includes about 1500 m of fossiliferous sandstone, siltstone, conglomerate, and minor coal of the Sitkinak Formation and 700 m of sandy marine siltstone of the Narrow Cape Formation. Both units were deposited in a nearshore environment; the Sitkinak Formation is Oligocene in age (Moore, 1969), and the Narrow Cape is middle Miocene (Clendenen and others, 1992). Sandstone compositions suggest a local source with progressive exposure and recycling of older sediments and unroofing of granitic plutons (Fisher and von Huene, 1980). The upper part of the section consists of about 1500 m of Pliocene, fossiliferous, interbedded sandstone, siltstone, and conglomeratic sandy mudstone of the Tugidak Formation, much of which was deposited in a shallow glaciomarine environment. Strata penetrated in the offshore wells are generally similar in lithology to the Tugidak and Narrow Cape formations (Turner, 1987); Oligocene strata equivalent in age to the onshore Sitkinak Formation are known to be present offshore only in the Middleton Island No. 1 well on the Middleton shelf (Fig. 10).

Major continental margin basins in this region are the Tugidak and Albatross basins (each filled with about 5 km of strata) and the Stevenson basin (7 km of strata). The basin sequences are of middle Miocene or younger age (Fig. 10) and all contain folds and faults that are at least partly contemporaneous with basin filling (von Huene and others, 1987; Hoose, 1987; Olson and others, 1987). On the Kodiak shelf, local basin subsidence is inferred to result from downward flexure of the underlying lithosphere as a consequence of vertical thickening of the adjacent accretionary prism near the shelf edge (Moore and others, 1991; Clendenen and others, 1992).

Middleton shelf. Seismic data indicate that the late Cenozoic section beneath the Middleton shelf landward from Middleton Island is variable, with a maximum thickness of 5 km (Bruns, 1979). Anticlines are characteristically tight and extensively faulted and have irregular but predominantly east-west to northeast-southwest trends. Multiple minor unconformities and growth features within the late Cenozoic section indicate that local deformation was contemporaneous with deposition.

The section beneath the Middleton shelf is known primarily from the Middleton Island No. 1 well (Fig. 10) that penetrated 3700 m of an uninterrupted sequence of Eocene and younger clastic sedimentary strata (Rau and others, 1983; Keller and others, 1984). Samples of Quaternary glaciomarine rocks were dredged from the adjacent continental slope, and about 1100 m of late Pliocene and early Pleistocene glaciomarine strata are exposed on Middleton Island (Plafker, 1987). The lower 1700 m in the Middleton Island well consists of Eocene siltstone and sandstone that were deposited in progressively shallower marine environments, from bathyal at the base to middle or upper bathyal at the top of the section, as indicated by benthonic foraminifera assemblages (Rau and others, 1983). The age of the base of this interval is uncertain; it is most likely late early to early middle Eocene, on the basis of benthonic foraminifers (Rau and others, 1983), late middle Eocene, on the basis of coccoliths (J. D. Bukry, *in* Keller and others, 1984), or earliest late Eocene, on the basis of sparse planktonic foraminifers (Keller and others, 1984). The Eocene section is overlain by about 1000 m of Oligocene and 300 m of early and middle Miocene siltstone, claystone, and minor sandstone deposited at middle to upper bathyal depths, as indicated by the benthonic foraminifera fauna (Rau and others, 1983). The upper 625 m of the well penetrates a Pliocene sequence of siltstone, mudstone, and conglomeratic sandy mudstone with a fauna that indicates deposition in a cold, shallow-marine environment, probably partly of glaciomarine origin, comparable to the depositional environment of the section exposed on Middleton Island.

Middleton Island is on a shelf-edge structural high. This is the only part of the basin where a thick, gently dipping section (Fig. 3, A–A‴) can be observed on marine seismic reflection profiles, and the reflectors can be traced from the vicinity of the well southward to the continental slope. Middleton Island has undergone Holocene northwestward tilting of as much as 28°, faulting, and earthquake-related tectonic uplift at a rate that averages close to 1 cm/yr and continues to the present time (Plafker and Rubin, 1978). However, paleontologic and dipmeter data suggest that the section in the nearby well is not complicated by steep dips or faulting, except possibly close to the bottom (Fig. 3, A–A‴). These relations suggest that there may be a fault between Middleton Island and the well.

The geology of the shelf near Middleton Island differs from that of the Kodiak shelf in that its thick, relatively undeformed Oligocene and Eocene marine section underlies the regional sub-Miocene unconformity (Fig. 10) and that the turbidite sequence of the Eocene Sitkalidak Formation is not encountered in the well. Stratigraphic relations require that the accretionary prism beneath the outer Middleton shelf is middle Eocene or older in age, and it is most probably the Orca Group (Plafker, 1987). The absence of deep reflectors in seismic profiles elsewhere on the Middleton shelf indicates that the Eocene and Oligocene parts of the basinal sequence occur mainly on the outer shelf and slope and that these strata may thin landward onto the Orca Group close to the shelf edge, as depicted schematically in Figure 3, section A-A‴. Paleontologic data from Eocene and younger Tertiary strata in the Middleton Island well favor the interpretation that they were deposited at about their present paleolatitude relative to the North America continental margin (Keller and others, 1984).

Edgecumbe volcanics and the Sitka shelf. In the Sitka area of southeastern Alaska, the Edgecumbe Volcanics unconformably overlap rocks of the Chugach terrane over an area of 260 km^2 (Fig. 6). The volcanic rocks comprise a bimodal sequence of tholeiitic basalt and calc-alkalic flow and pyroclastic rocks at least in part of Holocene age (Brew, this volume). Structural control for the location of this volcanic field is enigmatic; Brew (this volume) suggests that the field is localized along an unidentified zone of extension that is related to the offshore Fairweather strike-slip fault.

Rocks of the Chugach terrane beneath the continental shelf of southeastern Alaska west of Chatham Strait are unconformably overlain by a cover of acoustically transparent strata of probable Neogene age that locally fill small elongate basins as much as 3 km thick (Bruns and Carlson, 1987). The bedded strata are gently to moderately folded, and they are locally displaced along active strands of the Queen Charlotte fault.

Plutonic rocks

The Southern Margin composite terrane is extensively intruded by plutonic rocks of gabbroic to granitic composition and mid-Cretaceous to middle Cenozoic age. Widespread metamorphism of the accreted rocks is related to emplacement of these plutons, especially the numerous calc-alkaline plutons of Paleocene and Eocene age (Fig. 6). The geology of the plutonic rocks is briefly summarized here. Additional data on their occurrence, mineralogy, geochemistry, and age are given in other chapters of this volume, especially those by Brew, Hudson, Miller, and Moll-Stalcup, and in other references cited.

Cretaceous granitic rocks. Sparse, weakly foliated to nonfoliated Cretaceous granitic plutons less than a few square kilometers in area (too small to show in Fig. 6) are locally emplaced into melange along the north margin of the Chugach terrane in the western Chugach Mountains (Pavlis, 1982) and in the Tarr Inlet area of the southeastern Saint Elias Mountains (Yakutat-Chichagof belt of Hudson, 1983). Similar granitic plutonic rocks are emplaced into the Yakutat Group melange in the eastern part of the Yakutat terrane. One such pluton in the Mount Fairweather quadrangle north of Lituya Bay is 20 to 30 km long and averages 2 km in width (Fig. 6). A Cretaceous pluton in the western Chugach Mountains that is too small to show in Figure 6 reportedly is emplaced across the Border Ranges fault (Pavlis, 1982).

Most of the plutonic rocks are highly altered and locally foliated trondhjemite, tonalite, and diorite. Alteration consists of extensive saussuritization, sericitization, and replacement of biotite by prehnite and chlorite. Plutons in this suite have limited distribution and are dated mainly by K-Ar analyses. In the Chugach terrane, isotopic ages of these plutons range from 124 to 100 Ma in the western Chugach Mountains (Pavlis, 1982; Pavlis and others, 1988; Winkler, 1992) and about 119 to 97 Ma in the Tarr Inlet area (Decker and Plafker, 1982); the only dated rock of this suite in the Yakutat terrane is 96 ± 4.5 Ma (Fig. 7).

Pavlis (1982) interpreted granitic rocks of the Cretaceous suite in the western Chugach Mountains to be products of near-trench magmatism related to docking of the Wrangellia composite terrane against North America. Emplacement ages correspond to a widespread thermal event in Alaska that resulted in resetting of K-Ar ages in granitic rocks (Plafker and others, 1989) and greenstone (Silberman and others, 1981) in the southern part of the Wrangellia terrane. At about the same time or shortly thereafter, subduction was taking place along the south margin of the Chugach terrane as indicated by local blueschist facies metamorphism dated at 106 to 91 Ma on Chichagof Island (Decker and others, 1980). Thus, the distance between the mid-Cretaceous trench and the plutons was approximately the width of the Chugach terrane, or between 50 and 100 km. As with the better-studied Paleogene plutons described below, the Cretaceous plutons may represent anatectic melts above leaky or unusually hot segments of the subducting Kula plate.

Paleocene and Eocene granitic rocks. Granitic plutons of Paleocene and Eocene age (Sanak-Baranof belt of Hudson, 1983; and this volume) are by far the most abundant intrusive rocks in the southern margin accretionary complex. They are discontinuously exposed for 2100 km along the Gulf of Alaska margin from the Sanak Islands to Chatham Strait. They commonly underlie 5% to 10% of the outcrop area of the accretionary assemblage except in some of the more deeply eroded parts of the Chugach and Saint Elias mountains, where the plutons and associated migmatite make up as much as 20% to 25% of the outcrop over large areas (Fig. 6). These plutons appear to have been intruded in two major episodes, although this impression may be a function of the limited number of dated samples, most of which are by K-Ar or Rb-Sr methods.

During the first episode in the Paleocene (64 to 60 Ma), a western group of plutons was emplaced into the Shumagin, Kodiak, and Ghost Rocks formations from the Sanak Islands to the Kodiak Islands. The second episode was during the Eocene (about 57 to 42 Ma), when the eastern group of plutons was emplaced into flysch and melange of the McHugh Complex and into the Valdez, Kelp Bay, and Yakutat groups and their metamorphosed equivalents from the Kenai Peninsula to Chatham Strait (Fig. 7). The eastern group of plutons shows a general tendency to be younger from west to east, although the change is not uniform across the region; for example, plutonic rocks with biotite K-Ar ages as old as 49 Ma occur in the southern part of this belt (Brew, this volume). Coeval felsic to intermediate hypabyssal dikes, sills, and small stocks commonly are associated with the plutons, but coeval hypabyssal intrusions that are not obviously connected to plutons are also widely distributed throughout the Prince William and Chugach terranes. Similar shallow intrusive bodies also occur in the Wrangellia and Peninsular terranes north of the Border Ranges fault system.

Most plutons are 50 to 100 km^2 in area, but they range from less than 1 km^2 to about 600 km^2. They tend to be elongate parallel to the structural trend of the wall rocks, except in the eastern Chugach Mountains, where the plutons trend east-northeast obliquely across the prevailing east-west structures (Fig. 6). Compositionally, the plutonic rocks are calc-alkaline and dominantly granodiorite, tonalite, and quartz diorite; granite, diorite, and gabbro are less common. Contacts are generally gradational and migmatitic at deep structural levels in much of the eastern Chugach and Saint Elias mountains, but sharply crosscutting at the higher structural levels exposed elsewhere. In the Ghost Rocks Formation on the Kodiak Islands and in the Orca Group in eastern Prince William Sound, field relations, ages, and geochemistry indicate that small bodies of gabbro and diorite probably are comagmatic with nearby Paleogene siliceous plutonic rocks (Hill and others, 1981; Barker and others, 1992). Zoned hornfels aureoles are present around many of these bodies. On southern Baranof Island, for example, flysch in a 1200 km^2 area is metamorphosed to albite-epidote hornfels in an outer aureole and to hornblende hornfels, amphibolite, and possibly pyroxene hornfels in an inner aureole (Loney and Brew, 1987; Dusel-Bacon, this volume).

The Paleocene and Eocene belt of granitoid rocks is anomalous in that the rocks intrude the accretionary prism and are located more than 100 km oceanward from rocks of the coeval magmatic arc. The field relations and a variety of geochemical data suggest an origin largely by anatectic melting of cold flyschoid graywacke, argillite, and basalt of the accretionary prism (Hudson and others, 1979; Hudson, this volume; Hill and others, 1981; Farmer and others, 1987; Barker and others, 1992). Sustained magmatic activity is required to produce the plutons in a 2100-km-long belt over a time span of 10 to 15 m.y. Barker and others (1992) reviewed a variety of mechanisms that have been proposed for melting the flysch, but because of thermal considerations they favor underplating by basaltic liquid. Although the source of the basaltic magma is uncertain, the observed magmatic complexity could involve subduction of one or more ridge-transform systems of the Kula and Farallon plates (Marshak and Karig, 1977; Barker and others, 1992), possibly with opening of mantle windows beneath parts of the accretionary prism as a consequence of subduction of the landward limb of the Kula-Farallon ridge (Plafker and others, 1989).

Hypabyssal phases of these intrusive rocks in adjacent areas of the Peninsular, Chugach, and Ghost Rocks terranes in the Kodiak Islands suggest that there has been no large relative movement between these terranes since the early Paleocene (Davies and Moore, 1984). Similarly, hypabyssal intrusive rocks that cross the boundaries between the Peninsular, Wrangellia, Chugach, and Prince William terranes in the western Chugach Mountains indicate that these terranes were in about their present relative positions by the middle Eocene (Plafker and others, 1989). Paleomagnetic data place the Wrangellia composite terrane and the attached terranes of the Southern Margin composite terrane at about their present latitude by at least 55 Ma (Hillhouse and others, 1985; Hillhouse and Coe, this volume).

Oligocene and younger granitic rocks. Post-Eocene intrusive rocks in the Southern Margin composite terrane consist of a suite of small intermediate to felsic plutons that are similar in composition, mineralogy, and occurrence to the Paleogene plutons except that most of them are not foliated.

Oligocene plutons with roughly circular outcrop areas as large as 270 km^2 intrude both the Valdez and Orca groups in western Prince William Sound (Fig. 6; Tysdal and Case, 1979; Nelson and others, 1985). The plutons are dominantly granite; more mafic marginal and early intrusive phases range in composition from granodiorite to two-pyroxene gabbro. K-Ar ages for plutonic rocks of this suite range from 38 to 34 Ma.

Intermediate-composition rocks younger than Oligocene are mainly small elongate hypabyssal bodies in the Yakutat and Saint Elias quadrangles of the Saint Elias Mountains (Hudson and others, 1977) and on Baranof Island (Loney and Brew, 1987); these plutons are too small to show in Figure 6. The rocks are dominantly muscovite-biotite granodiorite, commonly with more mafic quartz diorite and tonalite in the border zones. Three plutons dated by K-Ar within the Chugach terrane in the Yakutat quadrangle yield ages of about 30 to 20 Ma (Hudson and others, 1977), and one yielded a U-Pb age on zircon of 35 Ma (G. Plafker, 1981, unpublished data).

In general, the available data indicate that the Oligocene and younger granitoid rocks are grossly similar in composition and mineralogy to those of the Eocene suite. Without detailed studies, we suspect that they also may have formed by anatectic melting of the Mesozoic accretionary prism that makes up the wall rocks.

Late Eocene(?) and younger gabbroic rocks. A belt of layered gabbro bodies extends from the Fairweather Range to northern Chichagof Island in southeastern Alaska, the largest of which are shown in Figure 6 (see also Brew, this volume; Patton and others, this volume, Chapter 21). These plutons are of special interest because they contain potentially valuable occurrences of nickel, copper, and platinum-group minerals (Nokleberg and others, this volume, Chapter 10). In the mountainous Fairweather Range, four plutons of layered gabbro are known, two of which contain ultramafic cumulates. The largest is the La Perouse pluton, which is 27 km long, is as wide as 12 km, and underlies an area of 260 km^2. It consists of as much as 6000 m of layered gabbro, gabbronorite, and norite with a basal zone of ultramafic rocks at least 680 m thick; the rocks were emplaced at about 1055 °C and 5.4 kbar (Loney and Himmelberg, 1983; Brew, this volume). The age of the layered gabbro is between 41 and 19 Ma, most probably 28 ± 8 Ma (Hudson and Plafker, 1981; Loney and Himmelberg, 1983).

Small Tertiary gabbro or norite bodies and associated tonalite plutons just south of Cross Sound on Yakobi Island and northern Chichagof Island may be related to the layered gabbro plutons in the Fairweather Range, although available age data from the tonalite suggest that their earlier emplacement at about 43 to 34 Ma (Himmelberg and others, 1987; Brew, this volume).

The tectonic setting for emplacement of the mafic-ultramafic rocks is poorly understood. The rocks are considerably younger than the youngest rocks of the accretionary complex they intrude, and they appear to be too close to the continental margin to be arc related. Furthermore, the age data suggest emplacement during a time of dominantly dextral strike-slip motion along the southeastern Alaska margin (Engebretsen and others, 1985). The most likely possibility is that the mafic-ultramafic rocks represent deep magma chambers and feeders to volcanoes that formed above local areas of extension along the middle Tertiary continental margin. In this respect they may be analogous to the present Edgecumbe volcanic field, which is just inboard of the transform margin in southeastern Alaska (Fig. 6).

Deep crustal structure

Seismic refraction-reflection studies, together with earthquake seismology and potential-field geophysical data, provide insights into the deep crustal structure across the Southern Margin composite terrane and more landward parts of the Aleutian arc (Figs. 11 and 12). Much of the data are from two major transects: (1) a marine transect (EDGE transect) that extends from seaward of the Aleutian Trench through Kennedy Entrance into the volcanic arc near the Alaska Peninsula (Fisher and others, 1987; Moore and others, 1991); and (2) the Trans-Alaska Crustal Transect (TACT), which runs from the Pacific plate near the eastern end of the Aleutian Trench into Prince William Sound and from there onshore across all of Alaska, generally following the Richardson Highway and the trans-Alaska oil pipeline (Page and others, 1989; Griscom and Sauer, 1990; Brocher and others, 1991; Fuis and Plafker, 1991; Fuis and others, 1991).

EDGE transect. Along the EDGE transect, Moore and others (1991) showed gently dipping oceanic crust and the underlying Moho extending from the Aleutian Trench northwestward for more than 200 km beneath the accreted rocks of the Southern Margin composite terrane to a depth of 30 km or more (Fig. 11). North of the accretionary complex, earthquake seismologic data show a marked steepening of the subduction zone to about 45° at a depth of about 100 km beneath the Aleutian magmatic arc on the Alaska Peninsula (Fig. 11). Thus, the EDGE transect provides a virtually complete image of the accretionary prism.

Along the projected axis of the Kodiak Islands and Kenai Mountains, the seismic reflection data show a series of layered reflectors that extend from about 10 to 35 km below the surface and through the bulk of the crust (Fisher and others, 1987; Moore and others, 1991). Surface exposures and wells along the seaward margin of the Kodiak Islands and across the Kodiak shelf indicate that a large volume of rock was accreted during Eocene and Oligocene(?) time. In order to maintain critical taper, the accretionary prism had to become thicker as well as wider. Thus the layered reflectors are interpreted as underplated deposits (Byrne, 1986), perhaps nappes and crustal-scale duplex structures, that caused the prism to thicken (Moore and others, 1991). These reflectors have also been interpreted as detached pieces of oceanic crust (Fisher and others, 1987). If the layered reflectors really represent underplated Eocene rocks, then the Prince William

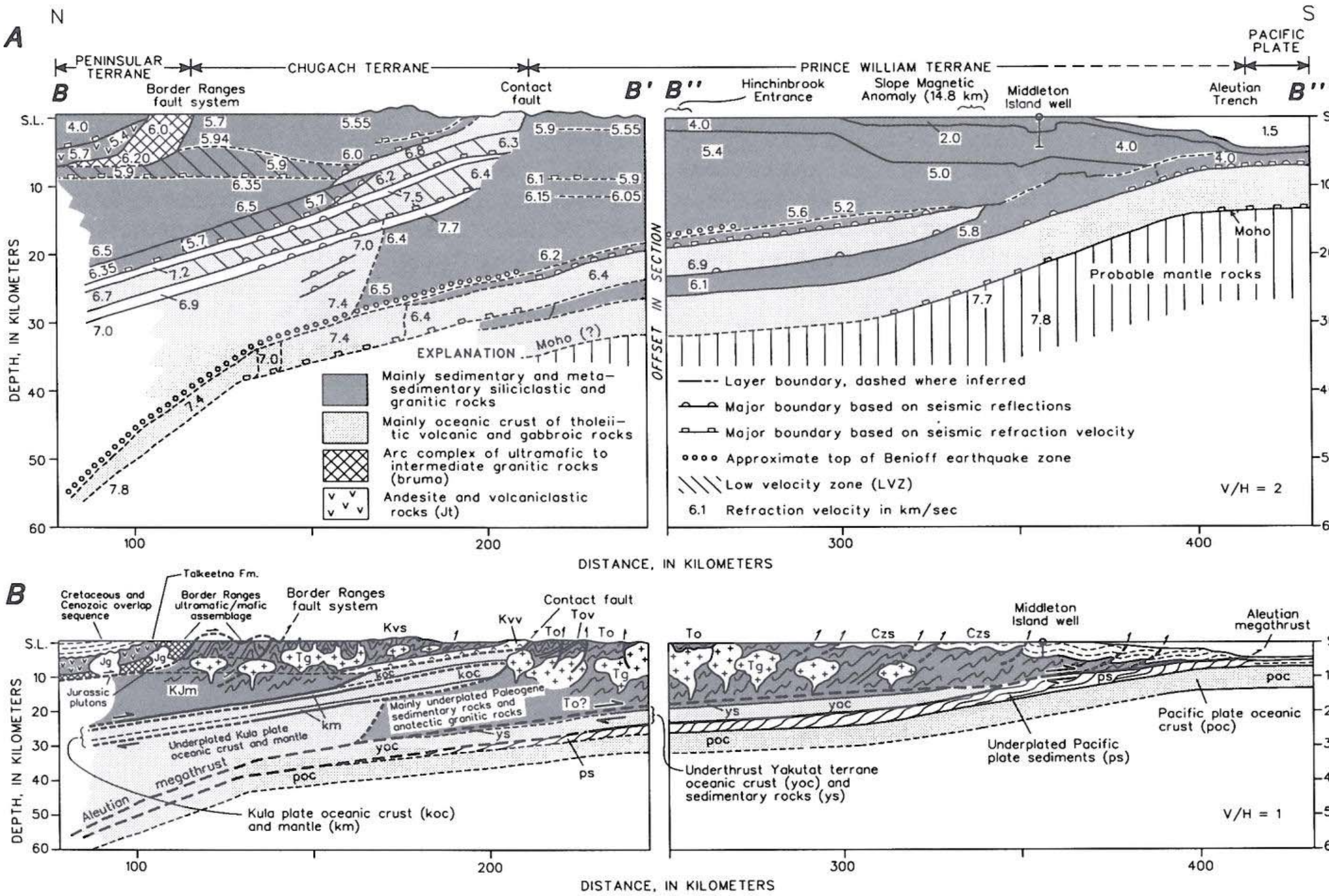


Figure 12. Interpreted deep crustal structure along the offshore and onshore Trans-Alaska Crustal Transect (TACT); location of section shown in Figure 6. A: Geophysical model based on refraction data (Fuis and others, 1991, and unpublished data; Brocher and others, 1991), seismic-reflection data offshore and along part of the transect onshore (Fisher and others, 1989 and unpublished data), earthquake seismic data (Page and others, 1989), offshore magnetic data (Griscom and Sauer, 1990) and surface and well geology (Plafker, 1987; Plafker and others, 1989). B: Interpreted geologic section showing underthrust Pacific plate and Pacific plate with overlying Yakutat terrane crust in seaward part of the section, the compressed, underthrust, and intruded, Mesozoic and Cenozoic accretionary complexes, and extensive underplating beneath the Mesozoic accretionary complex north of the Contact fault by oceanic crust and sedimentary rocks of the Kula plate. Modified from Plafker and others (1989), scenario B of Fuis and Plafker (1991), and Brocher and others (1991 and unpublished data). See Figure 6 for explanation of unit symbols.

terrane would directly underlie the Chugach terrane, indicating that the tectonostratigraphic terranes here are at least in part crustal flakes.

The EDGE seismic-reflection data (Fig. 11) and information from wells (Fig. 10) indicate that the shelf edge is marked by a prominent out-of-sequence thrust fault that separates the Paleogene and Neogene accretionary sequences. Such thrusts are one means whereby an accretionary prism may thicken and maintain critical taper. This out-of-sequence thrust separates accretionary packages of contrasting ages and may be an analog of the faults bounding the principal accretionary units in the Kodiak Islands.

Trans-Alaska crustal transect. Along the TACT route, seismic reflection data and earthquake seismicity indicate that the Benioff zone dips northward at an average angle of about 9° from the Aleutian Trench to 20 to 25 km depth beneath the Contact fault about 175 km arcward from the trench, that the zone is about 35 to 40 km deep beneath the Border Ranges fault, and that its maximum depth is 90 to 100 km beneath Mount Drum in the Wrangell Mountains (Page and others, 1989). The underthrusting slab consists of the Pacific plate and its sedimentary cover within about 85 km of the trench; to the north the Pacific plate is overlain by a platelet of subducted oceanic crust that may have originally been part of the Pacific plate but is now basement to the Yakutat terrane. The top of the subducted oceanic crust has been traced by seismic reflection data to depths of about 20 km beneath the Prince William terrane in northern Prince William

Sound (Fig. 12; Brocher and others, 1991). Geologic relations and earthquake data suggest that the main decollement (Aleutian megathrust) is near the top of the subducted Pacific plate seaward of the southern edge of the Yakutat terrane as defined by the slope magnetic anomaly (Griscom and Sauer, 1990) and that it is near the top of the Yakutat terrane oceanic crust and overlying sedimentary rocks to the north. The earthquake data suggest little or no relative motion at the present time between the Yakutat terrane and Pacific plate (Lahr and Plafker, 1980; Plafker, 1987; Page and others, 1989).

From south to north, salient features of the crustal structure shown in Figure 12 above the underthrusting Pacific plate and Yakutat terrane are as follows. (1) Reflection and refraction data reveal that Pacific plate oceanic crust with a cover of about 3.5 km of pelagic and hemipelagic sediment is underthrust along a subhorizontal decollement beneath the Prince William terrane (Orca Group and granitic rocks) and the overlying basinal sediments for about 40 km landward from the Aleutian Trench (Plafker and others, 1982) and that the subducted oceanic crust and mantle can be delineated downdip for almost 100 km (Brocher and others, unpublished). North-south–trending magnetic anomalies on the subducted Pacific plate can be mapped for as much as 150 km beneath the slope and shelf west of the transect (Griscom and Sauer, 1990). (2) The southern edge of the subducted Yakutat terrane basement, which is marked by a strong positive magnetic anomaly (slope magnetic anomaly), is about 15 km deep where it extends beneath the transect 75 km north of the Aleutian Trench (Fig. 6; Griscom and Sauer, 1990). (3) From the slope magnetic anomaly, the top of the underthrust Yakutat terrane oceanic crust (compressional wave velocities are 6.4 to 6.9 km/s) can be traced beneath the Orca Group of the Prince William terrane as a gently warped, highly reflective layer that deepens northwestward from 14 km or less beneath the outer continental shelf to about 20 km in northern Prince William Sound close to the Contact fault (Brocher and others, 1991). (4) The upper plate (Prince William terrane) consists dominantly of flysch and subordinate mafic volcanic rocks of the Orca Group and flysch-melt granitic intrusive rocks (4.0 km/s to 6.2 km/s). These rocks thicken northward from 4 to 6 km beneath the continental slope to as much as 22 km at the Contact fault and they also extend beneath the Chugach terrane as a thick wedge (average velocity to 6.5 km/s) that is as much as 27 km deep about 50 km north of the Contact fault. The overlying basinal sequence of late Eocene and younger clastic sedimentary rocks has velocities of 4.0 km/s or less and is probably no more than 6 km thick. (5) The Chugach terrane north of the Contact fault consists of an accreted primitive intraoceanic arc (average velocity of 6.8 km/s; Lull and Plafker, 1990) overlain by a Mesozoic accretionary prism of flysch and melange with associated flysch-melt granitic rocks (average velocity 5.5 to 6.5 km/s). This assemblage is interpreted in Figure 12 as a northward-thickening wedge that extends from its outcrop at the Contact fault to a depth of about 17 km beneath the Border Ranges fault (alternative B of Fuis and Plafker, 1991); an alternative interpretation is that the prism is truncated beneath the north half of the terrane by a subhorizontal decollement at a depth of about 9 km (marked by low-velocity layer, 5.9 km/s) that extends northward beneath the Border Ranges fault and much of the adjacent Peninsular terrane (alternative A of Fuis and Plafker, 1991). (6) The central and northern Chugach terrane is underplated by a northward-dipping and thickening sequence interpreted as tectonically underplated Kula plate and mantle (6.2 to 7.8 km/s). The upper layer of this sequence is a coherent slab that dips gently northward from a few kilometers below the surface at the Contact fault to 20 km or more beneath the Border Ranges fault and the Peninsular terrane (Fisher and others, 1989; Fuis and Plafker, 1991; Fuis and others, 1991). (7) Although the Border Ranges fault at the surface is marked by a major lithologic and structural contrast between accreted flysch and melange of the Chugach terrane against Jurassic layered gabbro and ultramafic rocks of the Peninsular terrane as well as by gravity and magnetic anomalies, upper crustal compressional wave velocities (between 5.7 and to 6.0 km/s) apparently do not reflect the lithologic change across the terrane boundary. This lack of velocity contrast suggests that the seismic velocities at depth in the Peninsular terrane have been significantly reduced by emplacement of Middle Jurassic and younger granitic rocks along the refraction line (Plafker and others, 1989; Fuis and Plafker, 1991; Nokleberg and others, this volume, Chapter 10).

YAKUTAT TERRANE

The Yakutat terrane lies outboard of the Southern Margin composite terrane in the northern Gulf of Alaska. It is 600 km long, a maximum of 200 km wide, and has an area of about 58,000 km^2. The terrane is bounded on the east and north by the Fairweather and Chugach–Saint Elias faults, on the west by the Kayak Island structural zone, and on the south by the Transition fault system (Figs. 2 and 6). Two other structural zones, the Pamplona and Dangerous River zones, divide the Yakutat terrane into three parts that have distinct lithologic and structural features (Fig. 6). Cenozoic rocks on opposite sides of the Pamplona zone have undergone marked differences in deformation. Basement of the terrane differs on opposite sides of the Dangerous River zone and the two parts of the basement are linked by overlapping terrigenous clastic rocks of Paleogene age (Figs. 7 and 13). Except as otherwise noted, the following summary of the geology of the Yakutat terrane is after Plafker (1987).

Basement rocks and the Dangerous River zone

The north- to northwest-trending Dangerous River zone marks an abrupt change in the basement geology and the thickness of the overlying stratigraphic section. Changes in the geology across this zone are documented by dredge samples across it on the continental slope and by seismic-reflection profiles that show abrupt westward thickening across it. On land, possibly correlative structural features are inferred from marked differences in the depth to basement in wells near Yakutat and from juxtaposed

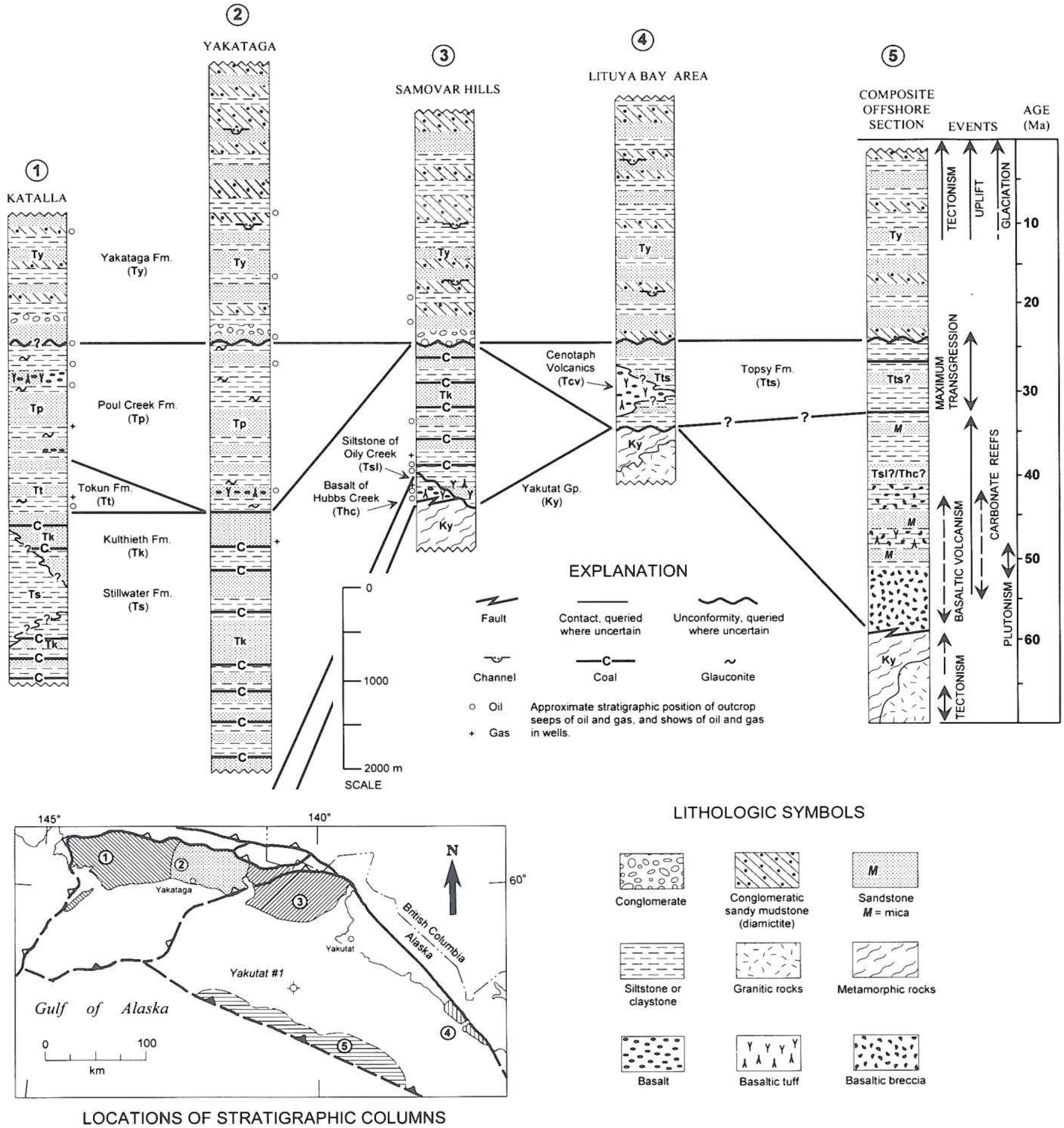


Figure 13. Generalized composite onshore and offshore stratigraphic sections of basinal strata in the Yakutat terrane. Modified from Plafker (1987). Circled numbers show locations of stratigraphic sections.

Cretaceous and Tertiary units along down-to-the-west faults in a nunatak north of the Malaspina Glacier (Fig. 13; Plafker, 1987, Fig. 1A). The Yakutat Group is believed to terminate at the Dangerous River zone, because it does not crop out to the west despite exposure of deep structural levels in areas of extreme topographic relief.

East of the Dangerous River zone. East of the Dangerous River zone, basement rocks are upper Mesozoic flysch and melange of the Yakutat Group, minor serpentinite, and a variety of Tertiary intrusive rocks, most of which are similar in composition and age to intrusive rocks emplaced in the southern part of the Chugach terrane. Metamorphic grade is dominantly prehnite-pumpellyite facies except near some of the plutons, where it is as high as lower greenschist facies. The geology of the Yakutat Group, interpreted as a displaced segment of the Chugach terrane, has already been described as part of the melange and flysch assemblage of the Chugach terrane. In outcrops in the Samovar Hills (a large nunatak north of Malaspina Glacier), the Yakutat Group is locally unconformably overlain by Eocene marine siltstone and sandstone with minor coal, and it is in fault contact with early Eocene bedded rocks (Fig. 13).

Structural trends, metamorphic isograds, and lithologic units in the Yakutat Group trend northwest roughly parallel to the trend of the Fairweather fault and are truncated obliquely on the west by the Dangerous River zone. The offshore Fairweather Ground is inferred to be underlain by the Yakutat Group, as indicated by samples dredged from the continental slope and shelf (Plafker, 1987) and by aeromagnetic anomalies interpreted to result from plutons within the sequence (Taylor and O'Neill, 1974).

West of the Dangerous River zone. West of the Dangerous River zone, the basement is Paleocene(?), early Eocene, and possibly Paleocene oceanic basalt beneath the continental shelf (determined from dredge samples and seismic refraction data). The basement onshore is unknown but is inferred to be comparable to that offshore, except that the sedimentary section near the north margin of the terrane may be deposited unconformably on older strata, such as equivalents of the Orca Group. This part of the terrane consists of a relatively undeformed segment between the Dangerous River and Pamplona zones and a highly deformed segment from the Pamplona zone to the Kayak Island zone (Fig. 6). Stratigraphically overlying the basement is an early Eocene through Oligocene bedded sequence of clastic rocks with minor coal and volcanic rocks having a composite thickness of almost 6 km. A clastic overlap sequence of middle Miocene and younger age that is as thick as 4 km unconformably overlies the Paleogene section.

The configuration and lithology of the basement rocks on which the Cenozoic bedded sequence was deposited (Fig. 3, B–B′, C–C′, D–D′) are known from (1) explosion-refraction data on the continental shelf (Bayer and others, 1978); (2) wide-angle seismic recordings obtained from a large airgun source during marine multichannel-reflection profiling in the northern Gulf of Alaska (Brocher and others, 1991); (3) dredge samples along the continental slope; (4) the Yakutat #1 well, which penetrated basalt at a depth of 5350 m and bottomed at 5430 m; (5) calculated depths of magnetic basement beneath the continental slope and shelf along two lines perpendicular to the Transition fault (Griscom and Sauer, 1990); and (6) outcrops of basalt in the Malaspina Glacier area described in the preceding section. The basement across much of the onshore area is concealed. It is likely that at least part of the Tertiary sequence along the north margin of the terrane was deposited on a basement of rocks such as the Orca Group, which is exposed just north of the Chugach–Saint Elias fault (Fig. 3, B–B′).

The basaltic basement rocks dredged from the continental slope consist of tholeiites some of which are enriched in large ion lithophile elements (LILE) and some of which are depleted in LILEs. These rocks were interpreted as normal mid-ocean ridge and oceanic island basalt, respectively, by Davis and Plafker (1986).

Cenozoic stratigraphy

Cenozoic sedimentary rocks are marine siliciclastic sediments, with minor amounts of volcanic rocks and coal, having a composite maximum thickness of 9500 m (Fig. 13). Each epoch from Paleocene (latest part only) through the Holocene is represented. Three major subdivisions of Cenozoic rocks are recognized onshore and offshore on the basis of fossils and gross lithologic characteristics: (1) late Paleocene and Eocene continental to marine clastic coal-bearing strata and early to middle Eocene basalt, (2) Oligocene and early Miocene marine clastic, glauconitic, and basaltic strata, and (3) an overlap assemblage of middle Miocene to Holocene, predominantly marine and glaciomarine clastic strata. Changes in depositional environment are characteristically gradational and appear to transgress time in different parts of the basin. Important exceptions are the regional unconformities that occur above the Yakutat Group and between the Paleogene strata, and overlap sequences of Miocene and younger age.

Late Paleocene, Eocene, and early Oligocene(?). The onshore sequence is at least 3000 m thick, and reflects marine regression, warm seas, and a subtropical to paratropical climate during the late Paleocene, Eocene, and possibly earliest Oligocene. Major stratigraphic units deposited during this interval are a basal sequence of deep marine volcanic and volcaniclastic strata (basalt of Hubbs Creek and siltstone of Oily Lake) and a thick sequence of slope and shelf clastic deposits (Tokun and Stillwater formations) that grade upward and landward into shallow-marine and nonmarine strata (Kulthieth Formation). These units crop out in a belt extending from the west side of Yakutat Bay to the western margin of the Yakutat terrane (Figs. 6 and 13).

The oldest paleontologically dated rocks in the Yakutat terrane are Paleocene coal-bearing nearshore marine strata that unconformably overlie Yakutat Group flysch at one small isolated nunatak in the Malaspina Glacier area, east of the Dangerous River zone (Samovar Hills section, Fig. 13). Elsewhere, the oldest dated strata above pre-Tertiary basement rocks are early to middle Eocene marine mafic volcanic rocks and fine-grained clastic rocks that were deposited in a shallow to moderately deep marine environment. Strata of this age are known to be exposed onshore only in a section in the Samovar Hills section north of Malaspina Glacier (Fig. 13).

The basalt of Hubbs Creek occurs as a large fault-bounded block and in small isolated outcrops. Its distribution suggests that it may conformably overlie the Yakutat Group and is in turn overlain by the siltstone of Oily Lake. The basalt unit consists of several hundred meters of ~15% basaltic flows. 75% agglomerate, and 10% tuff, and has been cut by numerous diabasic dikes and sills. Shell fragments and algal and bryozoan remains within the volcaniclastic units are nondiagnostic as to age; they indicate a shallow subtropical marine environment of formation, but were probably deposited in slope to bathyal water depths. Whole-rock K-Ar ages on basalt fragments yield apparent minimum ages of 40.0 ±4.8 and 50.0 ± 3.9 Ma (analyses by Krueger Enterprises, Inc., 1980). The older age probably is closest to the crystallization age of the rock, because it is similar to the paleontologically dated overlying marine unit. The basaltic unit is correlated with basaltic breccia on the continental slope (Fig. 13) and at the bottom of a petroleum exploration well (Yakutat #1 in Fig. 6) on the adjacent continental shelf because of similarities in lithology, age, and stratigraphic occurrence. The basalt of Hubbs Creek is of special interest because large seepages of oil and gas are associated with its outcrop distribution (Plafker, 1987, Fig. 1, inset A).

The siltstone of Oily Lake consists of 100 to 200 m of thick-bedded tuffaceous siltstone with a small percentage of basaltic lapilli tuff, vitric tuff, and very fine grained, calcareous, locally graded sandstone in beds 10 to 30 cm thick. A sparse fauna of foraminifers indicates a middle Eocene (Ulatisian) age and suggests outer shelf to upper slope conditions of deposition. The siltstone unit onshore correlates closely in age and lithology with the oldest siltstones dredged on the continental slope (Fig. 13). The siltstone units onshore and offshore are particularly rich in mature organic material and numerous seepages of oil and gas occur within the outcrop area of the siltstone of Oily Lake (Plafker, 1987, Fig. 1, inset A).

The Kulthieth Formation on the mainland consists of a thick sequence of coal-bearing, alluvial-plain, delta-plain, barrier-beach, and shallow-marine deposits. These units intertongue offshore and on Kayak and Wingham islands into deeper marine deltaic and prodeltaic strata of the Tokun Formation; farther west the Kulthieth Formation intertongues with the prodeltaic strata of the Stillwater Formation. The Kulthieth Formation and correlative units contain an abundant marine mollusk fauna, a sparse marine microfauna, and a leaf flora of early to middle Eocene, late Eocene, and possible early Oligocene age. These strata correlate in lithology and age with the lower middle part of the composite sections on the continental slope (Fig. 13).

Late Eocene(?), Oligocene, and early Miocene. Rocks of possible late Eocene, Oligocene, and possible early Miocene age are exposed intermittently along the coastal belt from Icy Bay to Ragged Mountain and on Kayak Island, where they are as much as 1800 m thick (Fig. 13). They also were penetrated in wells drilled for petroleum along the coast and in at least three wells drilled on the adjacent outer continental shelf. Predominantly argillaceous sediment—in part glauconitic, organic rich, and intercalated with intrabasinal water-laid alkalic basaltic tuff, breccia, and pillow lava—accumulated to form the Poul Creek Formation and perhaps the lower sandy part of the Redwood Formation. The strata were deposited during a general marine transgression, and much of the sequence reflects neritic to bathyal environments within the oxygen-minimum zone. Poorly dated volcaniclastic strata of the Cenotaph Volcanics and the intercalated siltstone and sandstone of the Topsy Formation, which overlie pre-Tertiary basement in a relatively small basin between Lituya Bay and Cross Sound in the eastern part of the terrane (Fig. 13), may be partly equivalent in age to the Poul Creek Formation. The Poul Creek Formation is equivalent in age to the upper middle part of the composite continental slope section.

Paleogene sandstone compositions. The Paleogene sandstones are predominantly lithofeldspathic but include rare feldspatholithic and feldspathic compositions (average Q_{37-40} F_{34-41} L_{5-27}). Lithic fragments are dominantly volcanic (67% to 92%), but include moderately abundant metamorphic (5% to 27) and sparse sedimentary (3% to 6%) components (Winkler and others, 1976). Polycrystalline quartzose grains average close to 1% of total quartz grains. Heavy minerals and micas make up an average of 0.8% to 2.2%, and generally increase upward in the sequence. Composition of the sandstone suggests that the source is a complex volcanic-arc terrane where progressively deeper granitic and metamorphic sources were exposed from the early Eocene through the Oligocene.

Neogene overlap assemblages. Since the middle Miocene, and possibly as early as latest Oligocene, an enormous volume of clastic sediment that makes up the Yakataga Formation and most or all of the Redwood Formation was shed from the Chugach and Saint Elias mountains onto the adjacent continental margin (Fig. 13). The formation unconformably overlaps older units and the boundaries of the Yakutat terrane with the Prince William terrane to the west and the Chugach terrane to the southeast. Uplift of the Chugach and Saint Elias mountains during this interval resulted from collision of the Yakutat terrane with, and from partial underthrusting of it beneath, adjacent terranes to the north.

The Yakataga Formation is characterized by rapidly deposited siliciclastic sediments that include an abundance of glacially derived material from the mountains to the north, whereas the Redwood Formation consists of nonglacial siliciclastic sediments with abundant conglomerate. The sediment was deposited predominantly in a shelf to upper bathyal environment, but locally in nearshore or even continental environments onshore in the Malaspina Glacier area, and in deeper bathyal environments offshore. The Yakataga Formation is widely distributed onshore and underlies much of the continental shelf and slope. It is as much as 4600 m thick onshore (Fig. 13) and more than 5000 m thick offshore (see isopach contours, Fig. 6). The Redwood Formation is about 1370 m thick and crops out only onshore in the western part of the Yakutat terrane (Katalla area of the eastern Cordova quadrangle). Sandstone compositions are similar to those of the Paleogene strata, which were the source for much of the Neogene sediment (Winkler and others, 1976).

The abundant microfauna and megafauna indicate that the age of the Yakataga Formation increases from east to west across the region and that the most likely age for the base is early to middle Miocene at Kayak Island and early middle Miocene in the Yakataga section (see a review of paleontological data in Marincovich, 1990). Yakataga Formation sedimentation continues to the present in structurally low areas both onshore and offshore.

Structure

Structural style within the Yakutat terrane differs significantly in its three major segments: east of the Dangerous River zone, between the Dangerous River and Pamplona zones, and between the Pamplona and Kayak Island zones (Fig. 6). These differences mainly reflect the type of basement, thickness of the Cenozoic sequence, and degree of coupling with the Pacific plate (Bruns, 1979, 1983; Bruns and Schwab, 1983; Plafker, 1987).

East of the Dangerous River zone. East of the Dangerous River zone, the structural style of the Yakutat Group is generally similar to that of the melange and flysch units within the Chugach terrane north of the Fairweather fault. A significant difference is that the rocks are also deformed and interleaved in a broad distributive zone of late Cenozoic dextral shear related to the Fairweather transform fault system, which forms the northeast boundary of the terrane.

The only fold known within the Cenozoic strata in this segment is a tight anticline that lies between the Fairweather fault and an inferred offshore fault along the northeast margin of the Yakutat basin (Fig. 6). The structure consists of a gently dipping north flank and a vertical to slightly overturned south limb. Approximate parallelism of the fold and the Fairweather fault reflects a significant component of compression in a broad zone across the northeast margin of the Yakutat terrane. Uplifted Holocene marine terraces on the south limb of this structure indicate continuing active growth (Hudson and others, 1976).

Between the Dangerous River and Pamplona zones. The Dangerous River and Pamplona zones bound the roughly triangular central part of the Yakutat terrane on the northeast and northwest, respectively. This segment of the terrane consists of Paleogene oceanic crust overlain by Cenozoic strata that thicken northward from about 6 km beneath the middle of the continental slope to almost 10 km beneath the inner continental shelf (Bayer and others, 1978). This segment of the Yakutat terrane has been carried passively on the underthrust Pacific plate, and the Cenozoic strata are virtually undeformed, except where they are bowed downward and fill deep Neogene basins or where they are draped over structural highs in the basement (Figs. 3, B–B′, C–C′, D–D′, and 6).

West of the Pamplona zone. In the western and northwestern parts of the Yakutat terrane, late Cenozoic underthrusting of the Prince William terrane that continues to the present has resulted in formation of a fold and thrust belt that is as wide as 120 km; the Pamplona zone is the present deformational front (Figs. 3, B–B′, C–C′, and 6). This deformed belt is a northeastward continuation of the convergence associated with the Aleutian megathrust, and it occupies the entire western part of the terrane west of the Pamplona zone and its onshore equivalents to the northeast. Its southern margin is obscure because the Pamplona zone extends into the Transition fault system along the base of the continental slope. The terrane boundary is arbitrarily assumed to follow the inferred westward projection of the Transition fault as indicated by the slope magnetic anomaly. Magnetic and seismic data indicate that the oceanic crust of the western Yukatat terrane is about 10 to 12 km deep within and near the Kayak Island zone (Bayer and others, 1978; Brocher and others, 1991; Griscom and Sauer, 1990).

The onshore and offshore structure of most of the western segment is dominated by broad synclines and tight anticlines and faulted anticlines that trend east to northeast; the largest of these faults are delineated in Figure 6. Many of the anticlinal structures were targets for unsuccessful exploratory drilling onshore in the coastal belt from 1954 to 1963 and offshore from 1969 to 1983. Individual structures range in width from about 4 to 10 km, and their closure on the lower Yakataga horizon extends 15 to 40 km along strike. Anticlines are generally asymmetric and doubly plunging and are commonly bounded on the seaward side by high-angle thrust faults. Dips on the flanks of the anticlines commonly range from 5° to 45° on the landward side to vertical or overturned on the seaward side. Sharp but unfaulted flexures on the south limb of many folds suggest deformation above structural ramps at depth.

Along the north and west margins of the western segment of the Yakutat terrane, the intensity of folding and magnitude of fault displacements increases significantly (Figs. 3, B–B′, D–D′, and 6). This complexity is attributed to deformation of the bedded sequence of the Yakutat terrane against the relatively resistant Prince William terrane. On Kayak Island, the entire sequence is nearly vertical or overturned and is repeated along several major thrust faults due to deformation after the middle Miocene and prior to emplacement of a dacite plug (Plafker, 1987) dated at 6.2 Ma by Nelson and others (1985). Rogers (1977) noted that seismic profiles show sequential folds that formed as a front of deformation migrated southeastward from the Kayak Island area to the Pamplona zone during the development of this late Cenozoic structural belt. Additional details on the pattern and development of the offshore structures were given by Bruns and Schwab (1983).

Structural shortening in the vicinity of Kayak Island is conservatively calculated to exceed 20 km across a horizontal distance of 10 km (Plafker, 1974). In the outcrop belt to the northeast, shortening normal to the regional strike is estimated to be about 45% in the Paleogene sequence and less than 25% in the

Neogene units at surface levels (Plafker, 1974). Abnormally high fluid pressures encountered at depth in all offshore holes in this belt, together with bore-hole deformation, reflect northwest-southeast-directed lateral stresses (Hottman and others, 1979). High fluid pressures probably facilitate large-scale beding-plane detachment thrusts above the underthrusting basaltic basement of the Yakutat terrane, as depicted schematically in Figure 3, section D–D′. Wide-angle seismic data confirm this model of underthrusting of the Yakutat terrane (Brocher and others, 1991).

Ongoing deformation of structures within this segment of the terrane in indicated by (1) earthquake-related uplift of late Holocene marine terraces along the south flank of a coastal anticline (Sullivan anticline) west of Icy Bay at an average rate of 10.5 mm/yr (Plafker and others, Plate 12, this volume), (2) geodetically detectable horizontal deformation in the same region (Savage and Lisowski, 1988), (3) deformation of well bore holes (Hottman and others, 1979), and (4) seismic activity (Plafker and others, Plate 12, this volume).

Intrusive rocks

East of the Dangerous River zone, intrusive rocks within the Yakutat Group are generally comparable in age and composition to intrusive rocks within the accretionary complex of the Southern Margin composite terrane. These rocks include trondhjemite and diorite plutons of known or probable Early Cretacoeus age (largest about 50 km^2) and tonalite and granodiorite of early Eocene age (largest about 40 km^2) and middle to late Eocene age (Fig. 6). Less common are small tonalite-granodiorite plutons and diabase sills and plugs of Oligocene age and one middle Miocene hypabyssal dacite porphyry body at least 12 km long and as wide as 3 km that has a whole-rock K-Ar age of 13 ± 06 Ma.

West of the Dangerous River zone, intrusive rocks are scarce and too small to show in Figure 6. The largest is a unique elongated dacite plug 4 km long and 1.5 km wide that forms a prominent landmark 500 m high at the south end of Kayak Island (Winkler and Plafker, 1981b; Plafker, 1987). The plug has a microgranitic and porphyritic texture and is emplaced into nearly vertical late Oligocene and early Miocene marine clastic sedimentary strata that are thermally metamorphosed within 100 m of the contact. It has a whole-rock K-Ar age of 6.2 ± 0.3 Ma (Nelson and others, 1985). This intrusion is of special interest because it is situated within a structurally complex belt just east of the suture between the Yakutat and Prince William terranes (Fig. 3, D–D′). Emplacement of the plug postdates the main phase of subduction-related deformation at Kayak Island and suggests that near-trench magmatism continued beneath the underthrusting Yakutat terrane as recently as latest Miocene time.

Small altered alkalic to diabasic hypabyssal intrusive rocks of unknown age are locally exposed on the mainland in the Katalla area. Diabase to gabbroic dikes and sills are sparsely distributed in outcrop areas of Paleogene strata and are probably feeders to early and late Oligocene volcanic rocks in the Poul Creek Formation and Cenotaph Volcanics.

Boundary faults

Displacement of the Yakutat terrane relative to the continental margin and the Pacific plate has been driven largely by late Cenozoic motion of the Pacific plate. The present motion of this plate relative to the North America plate in the northern Gulf of Alaska at long 145°W is deduced as N17°W at about 55 mm/yr (DeMets and others, 1990). It averaged about N16°W at 63 mm/yr for the past 5 m.y. and from 5 to 28 Ma it was N24°–34°W at an average of 45 mm/yr (Engebretsen and others, 1985). The degree of coupling between the Pacific plate and Yakutat terrane has undoubtedly varied through time, depending upon how displacement was shared between the Fairweather and Transition fault systems. At present, the Yakutat terrane is moving mainly with the Pacific plate at about 50 mm/yr relative to North America and the relative velocity between the Pacific plate and Yakutat terrane is estimated at only about 4 mm/yr (Plafker and others, Plate 12, this volume).

Fairweather fault. The dextral strike-slip Fairweather fault, which forms the north boundary of the Yakutat terrane, is part of a ridge-trench transform system that includes the Queen Charlotte fault off the coast of British Columbia. The surface trace of the Fairweather fault is readily visible on land for about 280 km from Cross Sound on the southeast to its juncture with the Chugach–Saint Elias fault in the vicinity of Yakutat Bay, and it has been delineated offshore across the continental shelf to Chatham Strait (Fig. 6) by seismic-reflection and earthquake data. It is inferred to connect with the Queen Charlotte fault in the vicinity of Chatham Strait.

Onshore, the trace of the Fairweather fault is marked by broad shear zones in bedrock and by a topographic trench as much as 1 km wide. Holocene scarps and dextrally offset drainages occur along the trace at numerous localities, and coseismic dextral displacements of at least 3.5 m and vertical displacements of 1 m occurred during the M_s 7.9 Lituya Bay earthquake of July 10, 1958 (Plafker and others, 1978). For most of its length, the fault juxtaposes rocks interpreted as different facies of the Chugach terrane. These are mainly zeolite facies Mesozoic flysch and melange of the Yakutat Group, with associated Paleogene granitoid rocks on the southwest against schistose mafic and pelitic rocks of epidote-amphibolite and amphibolite grade and associated Paleogene plutons on the northeast. The pre-Holocene displacement history along the fault is conjectural. As discussed below, correlation of the Dangerous River zone with the Chatham Strait fault requires about 600 km of Neogene dextral slip.

Transition fault system. The boundary of the Pacific plate with the eastern and central segments of the Yakutat terrane is the Transition fault system (Figs. 2 and 6), which extends along the base of the continental slope. At its northwest end it extends into the maze of faults at the juncture of the Aleutian megathrust and Pamplona zone; however, its associated slope magnetic anomaly can be traced about 200 km to the northwest beneath the Prince William terrane (Griscom and Sauer, 1990). The east end of the fault is poorly constrained but most likely intersects the Fairweather–Queen Charlotte fault system south of Cross Sound (Fig. 6).

East of the Dangerous River zone, the Transition fault system truncates the pre-Tertiary basement; west of this zone, it truncates the Paleogene oceanic crust and overlying clastic sequence. This truncation, together with numerous slickensided rocks in dredge samples from the lower continental slope, suggests large-scale displacement along the Transition fault system—displacement that has affected dredged samples of Cretaceous(?), Eocene, Oligocene, and late Pliocene or younger age.

Truncation of the Paleogene basaltic basement west of the Dangerous River zone is the likely source of the prominent linear positive anomaly informally referred to as the "slope magnetic anomaly" along much of the continental slope inboard of the Transition fault (Griscom and Sauer, 1990; Godson, this volume). Apparent northwestward extension of the slope magnetic anomaly beneath the Prince William terrane suggests a minimum of 200 km of subduction parallel to the Transition fault system. This amount of subduction represents about 7.3 m.y. of displacement parallel to the Transition fault system at present convergence rates and directions as given by DeMets and others (1990), or about 5.7 m.y. using the displacement rates for this time interval given by Engebretsen and others (1985). The magnetic anomaly beneath the Prince William terrane south of Montague Island has been modeled as a basalt slab, the top of which is about 15 km deep; it is ~3 km thick at its south margin (Fig. 3, A–A′; Griscom and Sauer, 1990).

Dextral oblique slip on the Transition fault system during the past 5 m.y. is suggested by the present orientation of the Transition fault system relative to Pacific plate motion, by the orientation of the folds and faults adjacent to the fault system southwest of the Fairweather Ground structural high (Fig. 6), and by the focal mechanisms for the Cross Sound earthquakes (Page, 1975) along the fault trace east of the Fairweather Ground.

A complex fold and thrust belt associated with convergence along the Aleutian megathrust intersects the Transition fault at its western end. From this intersection, the fold and thrust belt extends northeastward across the continental slope between the Kayak Island and Pamplona zones (Fig. 6). It then extends onshore as a poorly exposed zone of deformation that ultimately connects with the Fairweather transform fault in the vicinity of Yakutat Bay (Fig. 6). The entire Yakutat terrane west of the Pamplona zone and much of the adjacent Prince William terrane have been deformed during the late Cenozoic as a result of this convergence.

Chugach–Saint Elias fault system. The Chugach–Saint Elias fault system along the north boundary of the Yakutat terrane (Fig. 6) marks the inner margin of a broad zone along which unmetamorphosed Late Cretaceous and Paleogene strata of the Yakutat terrane are thrust relatively beneath variably metamorphosed rocks of the Valdez and Orca groups. Dips are in the range of 30° to 45° N at the few localities where the fault plane is exposed. At its west end it terminates at an inferred intersection with the onshore extension of the Kayak Island zone (Ragged Mountain fault), and on the east it terminates against the Fairweather fault.

The Kayak Island zone. The west margin of the Yakutat terrane onshore is an irregular series of structures that include (1) west-dipping thrust faults on the mainland and on Kayak Island (Ragged Mountain and Kayak Island faults, respectively) and (2) the offshore Kayak Island zone, which is characterized by complex structures that appear as seismic basement on marine seismic reflection profiles. At its southwest end, the Kayak Island zone is inferred to merge with the east end of the Aleutian megathrust, although it cannot be traced across the contitental slope with available geophysical data.

Displacement history of the Yakutat terrane

The Yakutat terrane is clearly allochthonous with respect to adjacent terranes to the north on the basis of differences in lithology and metamorphism of the late Mesozoic rocks, the provenance of Paleogene siliciclastic rocks, the age and lithology of Paleogene basaltic rocks, paleomagnetic data, and much of the paleontologic data. Together, these data suggest that the Yakutat terrane was transported to its present position during late Cenozoic time by dextral strike slip along the Fairweather–Queen Charlotte transform fault system from a site along the continental margin north of Puget Sound off southeastern Alaska and British Columbia (Plafker, 1987). An alternative model by Keller and others (1984) that is based on limited foraminiferal data requires much greater northward terrane transport from a region off northern California. That model, however, appears to be incompatible with most other critical data for the terrane source, as discussed below.

Correlation of the Dangerous River zone with the Chatham Strait fault. The Chugach terrane is abruptly truncated on the east at the Chatham Strait fault (Fig. 2), where the belt is about 100 km wide across structural trend and consists of melange with minor serpentinite (Kelp Bay Group) and flysch (Sitka Graywacke), into which are emplaced abundant Paleogene granitic plutons. To the southeast, a conspicuous gap in the Mesozoic accretionary belt extends at least as far south as Vancouver Island, Canada. Similarly, in the Yakutat terrane, melange (with minor serpentinite) and flysch of the Yakutat Group and associated Paleogene plutons constitute a belt about 100 km wide that is abruptly terminated on the west at the Dangerous River zone (Fig. 6). The Kelp Bay Group and Sitka Graywacke in southeastern Alaska correlate with the Yakutat Group on the basis of similarities in age, lithology, structure, flysch source directions, and the plutons emplaced in these units (Plafker, 1987; Fig. 7). According to this interpretation, the Yakutat Group was originally southeast of Chatham Strait (Fig. 14), and the Dangerous River zone is the offset equivalent of the Chatham Strait fault. This correlation requires ~600 km of dextral strike slip of the Yakutat Group and Dangerous River zone relative to the Chugach terrane and Chatham Strait fault along the Fairweather fault (see section on tectonic evolution).

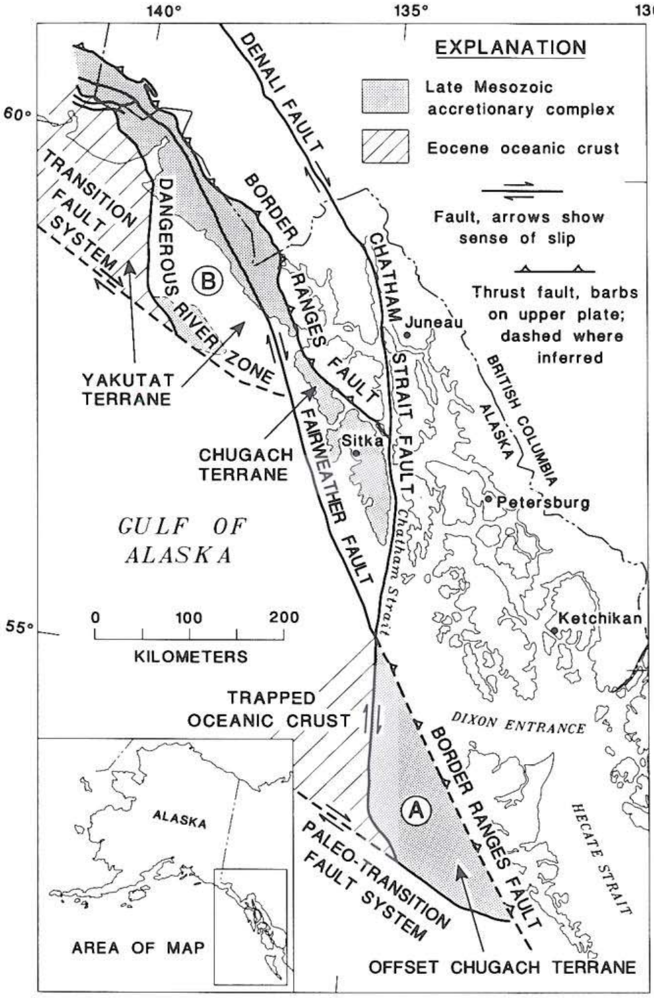


Figure 14. Diagram showing preferred origin of Yakutat Group rocks in the eastern Yakutat terrane as a displaced fragment of the late Mesozoic accretionary complex that comprises the Chugach terrane. A: Early(?) Eocene reconstructed position of the late Mesozoic Chugach terrane after about 180 km dextral offset along the Chatham Strait fault segment of the Denali fault system (Hudson and others, 1982). B: Present position of displaced late Mesozoic Chugach terrane and position after about 600 km late Cenozoic northward displacement along the Fairweather fault. Note that according to this reconstruction, the Dangerous River zone is an offset segment of the Chatham Strait fault and the Transition fault system is an offset segment of a Paleogene transform fault. See Figure 7 for Mesozoic columnar sections in southeastern Alaska and in the Yakutat terrane.

Wrangellia terrane source of exotic blocks in melange. Exotic olistostromal blocks within the Yakutat Group melange, some of which are kilometer-scale in size, require a nearby Wrangellia terrane source during the Late Jurassic and Early Cretaceous. The most suitable source is the segment of Wrangellia terrane that is now exposed in the Queen Charlotte Islands and Vancouver Island; similar rocks may also be present on the continental margin off British Columbia and as far north as Chatham Strait (Fig. 14; Table 3). No other source terrane for this combination of exotic blocks is known south of Vancouver Island. Thus, the exotic blocks constrain the allowable maximum relative motion between the Wrangellia terrane and the Yakutat terrane to about 800 km, the probable exposure length of the Wrangellia terrane along the continental margin south of Chatham Strait (Monger and Berg, 1987).

Provenance of clastic sedimentary rocks. Systematic regional compositional changes in the sandstone of the Late Cretaceous flysch of the Chugach and Yakutat terranes (Zuffa and others, 1980; Winkler and others, 1976) indicate a provenance from a dissected magmatic arc. The inferred arc is most likely the southern part of the Kluane arc (Fig. 5), the roots of which are now represented by the plutonic belt that makes up much of the Coast Mountains of British Columbia and southeastern Alaska (Plafker and others, 1989). Further evidence of a provenance along the continental margin to the southeast comes from (1) regional stratigraphic studies of Paleogene sandstones that tie sandstones in the Yakutat terrane with coeval sandstones in continental basins of southeastern Alaska (Chisholm, 1985); (2) isotopic studies that tie the flysch in the Chugach Mountains to a source in the Coast Mountains (Farmer and others, 1987); and (3) evidence for two major pulses of uplift and deep erosion in the Coast Mountains during the Paleogene and probable Late Cretaceous that could have supplied the enormous quantity of sediment in the latest Cretaceous and Paleogene sequences (Hollister, 1979, 1982). In addition, isotopic and trace element analysis of a single suite of detrital muscovite from Eocene sandstone of the Yakutat terrane suggests a source in high-grade crystalline rocks of the types that occur in the Omineca crystalline belt of southern British Columbia (Heller and others, 1992).

Paleomagnetic data. Reliable paleomagnetic data on the displacement history of the Yakutat terrane have not been obtained onshore (Hillhouse and Grommé, 1985). Van Alstine and others (1985) reported $13° \pm 3°$ of post–early Eocene displacement relative to cratonal North America, with no more than 20° of rotation, on the basis of preliminary data from the offshore Yakutat #1 well (Fig. 6). If correct, these data suggest that the sampled strata were deposited somewhere between what is now Puget Sound, Washington, and Chatham Strait during the early Eocene; a more exact position depends on the amount of post–early Eocene dextral slip on faults between the craton and the Yakutat terrane (Plafker, 1987).

TECTONIC EVOLUTION—A MODEL

Our data indicate a complex Mesozoic to Holocene tectonic evolution for the southern Alaska continental margin. This interpretation is focused on evolution of the accreted terranes that constitute the Southern Margin composite terrane and the Yakutat terrane, and is based mainly on the geologic and geophysical data discussed in this chapter. Relevant regional geologic data for adjacent regions are incorporated where necessary to provide a broad perspective. We emphasize, however, that no single model has yet been devised that satisfactorily explains all the geologic,

TABLE 3. EXOTIC BLOCKS OF THE YAKUTAT GROUP MELANGE AND THEIR POSSIBLE SOURCE UNITS IN THE WRANGELLIA TERRANE

Melange Block				Possible Source	
Lithology	Maximum dimension	Age	Reference	Unit	Reference
Tonalite and diorite	2 km	Middle and Late Jurassic (178 ± 10 Ma and 160 ± 3.5 Ma)	Hudson and others, 1977	Island intrusions; Queen Charlotte Island and Vancouver Island	Sutherland-Brown, 1968; Muller, 1977; Armstrong, 1988
Volcanogenic sandstone	Float (about 20 cm)	Early Jurassic (Sinemurian based on the ammonite *Crucilobiceras* sp.)	G. Plafker, unpublished data; fossil identification by R. W. Imlay, written commun., Nov. 5, 1968	Kunga Formation, Queen Charlotte Island; Bonanza Volcanics, Vancouver Island	Sutherland-Brown, 1968; Muller, 1977
Limestone	800 m	Possible Late Triassic (silicified gastropods and thin-walled pelecypods)	G. Plafker, unpublished data; fossils identified by N. J. Silberling, written commun., 1968	Kunga Formation, Queen Charlotte Island; Quatsino Limestone, Vancouver Island	Sutherland-Brown, 1968; Muller, 1977
Pillow basalt (greenstone)	5 km	Possible Late Triassic (close association with fossiliferous limestone)	G. Plafker, unpublished data	Karmutsen Formation, Queen Charlotte Island and Vancouver Island	Sutherland-Brown, 1968; Muller, 1977
Shallow-water limestone	5 m	Early Permian (conodonts: *Hindeodus* sp., *Neogondolella* sp., *Sweetoganthus whitei* (Rhodes)	S. M. Karl, written commun., Oct. 1980; fossils identified by B. R. Wardlaw, written commun., Oct. 9, 1980	Buttle Lake Limestone, Vancouver Island	Brandon and others, 1986

paleontologic, geophysical, and paleomagnetic data, because some of these data are mutually contradictory and/or internally inconsistent.

Our model for the tectonic evolution of terranes in and adjacent to the study area is shown diagrammatically in plan view (Fig. 15) for eight time periods and in cross sections (Fig. 16) for five time periods from the Late Triassic to the present.

Relative plate motions are after Engebretsen and others (1985), except that the cessation of Kula-Pacific plate spreading is assumed to predate by a few million years the onset of arc volcanism in the Alaska Peninsula at about 50 ± 2 Ma (Plafker, 1987) and to coincide approximately with the early to middle Eocene widespread thermal event along the east margin of the Gulf of Alaska. The change in relative plate motions probably resulted from welding of the Kula and Pacific plates together, rather than from subduction of the entire Kula plate, as suggested by Lonsdale (1988). The model assumes that counterclockwise oroclinal bending of western Alaska, including the Southern Margin composite terrane, occurred mainly in the Paleogene for reasons summarized by Plafker (1987). The present coordinate grid and coastal outline of western North America shown in Figure 15 (C–H) are for reference only; they do not imply knowledge of the actual position of the terranes of southern Alaska relative to the North American craton before early Tertiary time.

Paleozoic and Triassic; pre ~215 Ma

The tectonic model begins with an amalgamated Wrangellia composite terrane having an intraoceanic volcanic, plutonic, and sedimentary basement as old as Precambrian at the south end (Alexander terrane) and late Paleozoic at the north end (Wrangellia and Peninsular terranes) (Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10). Pennsylvanian and Early Permian volcanism of the Skolai arc was followed by widespread shallow-marine conditions and carbonate deposition in many parts of the composite terrane. In the Middle and Late Triassic (Ladinian to Norian), widespread marine to subaerial basaltic volcanism and local bimodal volcanism throughout much of the composite terrane reflect a major regional event variously attributed to rifting, back-arc spreading, or mantle-plume activity (see discussions in Barker and others, 1989; Barker, this volume; Nokleberg and others, this volume, Chapter 10). Volcanism was followed by shallow-marine sedimentation. Biostratigraphic data have been interpreted as indicating that parts of the Wrangellia composite terrane were probably isolated by a seaway from terranes to the east until accretion to North America in the middle to Late Cretaceous (Jones and Silberling, 1982). Paleomagnetic data from Alaska (Hillhouse and Coe, this volume) suggest a Late Triassic paleolatitude about 3100 ± 600 km to the south, at about the present latitude of southern California (Fig. 15A, inset), assuming a Northern Hemisphere origin.

Late Triassic to Late Jurassic; ~215 to 160 Ma

By Late Triassic time, the Wrangellia composite terrane was assembled into approximately its present configuration except that the northern and British Columbia parts of the Wrangellia terrane probably had not been separated by sinistral strike-slip offset (Plafker and others, 1989). The Late Triassic (late Norian) and Early Jurassic to early Middle Jurassic ocean-facing Talkeetna magmatic arc developed across the Peninsular terrane and across the Queen Charlotte Islands and Vancouver Island parts of the Wrangellia terrane during left-oblique subduction of the Farallon plate. Accretion and metamorphism of the glaucophanic greenschist assemblage of the Chugach terrane along the seaward margin of the Talkeetna arc during latest Triassic to early Middle Jurassic time indicate a northward-dipping subduction zone (Fig. 16A). Although the time of accretion of the relatively low grade metamorphic rocks of the melange assemblage is unknown, some of this unit may have been emplaced during the Jurassic.

The location of the Wrangellia composite terrane and associated Southern Margin composite terrane during the existence of the Talkeetna arc is speculative; the position shown in Figure 15A (inset) is based on (1) inferred continuity of the Talkeetna arc with coeval arcs that are now distributed along the continental margin from central California to northern British Columbia and (2) the requirement from paleomagnetic data that the composite terrane was about 3100 km south of its present position in the Late Triassic.

During the Middle and Late(?) Jurassic orogenic deformation resulted in tectonic attenuation of the seaward margin of the Talkeetna arc with collapse of any forearc that may have been present, so that parts of the glaucophanic greenschist assemblage were juxtaposed against deep-level plutonic rocks of the adjacent Peninsular terrane (Fig. 16A).

Late Jurassic to Early Cretaceous; 160 to 120 Ma

In Late Jurassic time the Chitina magmatic arc, now represented by a linear belt of tonalitic plutons (about 153 ± 4 Ma), developed along the seaward margin of the Alexander and Wrangellia terranes. The southeastward continuation of this magmatic belt may be the younger plutons of the Island intrusives on Queen Charlotte and Vancouver islands (Armstrong, 1988). During Valanginian to Barremian (about 135 to 120 Ma) time magmatism shifted inland to the Chisana andesitic arc in the Alexander and northern Wrangellia terranes, possibly due to a decrease in dip of the subduction zone (Fig. 16B).

Flysch and volcaniclastic rocks from these arcs were deposited on both sides of the Wrangellia composite terrane during this interval. Within the Chugach terrane, abundant arc-derived volcaniclastic rocks were deposited on the ocean floor and intertongued with oceanic pelagic sediments and basalt. These deposits were subsequently emplaced into the accretionary complex as the melange assemblage. Olistostromal blocks in the melange were derived from the adjacent Peninsular and Wrangellia terranes and indicate limited postemplacement strike-slip movement between the composite terrane and the Chugach terrane. Although the time of accretion of the melange assemblage is not well constrained, at least part of it probably continued to be accreted during this interval above a north-dipping subduction zone (Fig. 16B).

Truncation and intense shearing of the southern part of the Wrangellia composite terrane are inferred to have occurred during 600 to 1000 km of sinistral displacement of the British Columbia segment of the Wrangellia terrane relative to the Alaska segment (Plafker and others, 1989; Nokleberg and others, this volume, Chapter 10). The inferred displacement postdates Late Jurassic plutonism and predates Late Cretaceous accretion of the flysch and basalt assemblage of the Chugach terrane.

Early Cretaceous to late Paleocene; 120 to 62 Ma

During the interval from the Aptian to Campanian (about 120 to 84 Ma) the Kula plate formed and moved northeast with increased velocity relative to the North American craton and terranes along the continental margin (Fig. 15C). During this interval of dextral-oblique transpression along the continental margin, we infer that the combined Southern Margin and Wrangellia composite terranes were displaced rapidly northward to approximately their present position relative to inboard terranes. Docking of the Wrangellia composite terrane against inboard terranes in mainland Alaska during this interval is indicated along and near the suture zone by termination of marine sedimentation after Cenomanian time, by deformation of flysch basins, and by widespread magmatism and metamorphism (Nokleberg and others, this volume, Chapter 10). Data from southeastern Alaska, however, suggest that the Wrangellia composite terrane may have been emplaced in about its present position relative to inboard terranes as early as Middle Jurassic to middle Cretaceous time (Gehrels and Berg, this volume).

The Campanian and early Maastrichtian interval was characterized by a major outpouring of volcanogenic sediment from the Kluane arc, most of which was deposited on the Kula plate. Simultaneously, a primitive island arc developed within the Kula plate but within reach of deep-sea fans from the Kluane arc. The flysch and basaltic island-arc rocks were successively accreted to older rocks of the accretionary complex above a northeast-dipping subduction zone to form the bulk of the Mesozoic Chugach accretionary prism (Fig. 16C).

The early and middle(?) Paleocene was an interval of relatively slow sedimentation during which the predominantly oceanic Late Cretaceous and early Paleocene Ghost Rocks Formation was accreted to the southern margin of the Chugach terrane in what is now the Kodiak Islands. Accretion was followed by a major mid-Paleocene (64 to 62 Ma) thermal event that resulted in plutonism throughout much of the Southern Margin composite terrane from the Kodiak Islands area westward; local near-trench andesitic volcanism contributed to the Ghost Rocks Formation. Although coeval rocks have not been found east of the Kodiak Islands, they may be present at depth within the accretionary complex.

Late Paleocene to middle Eocene; 62 to 48 Ma

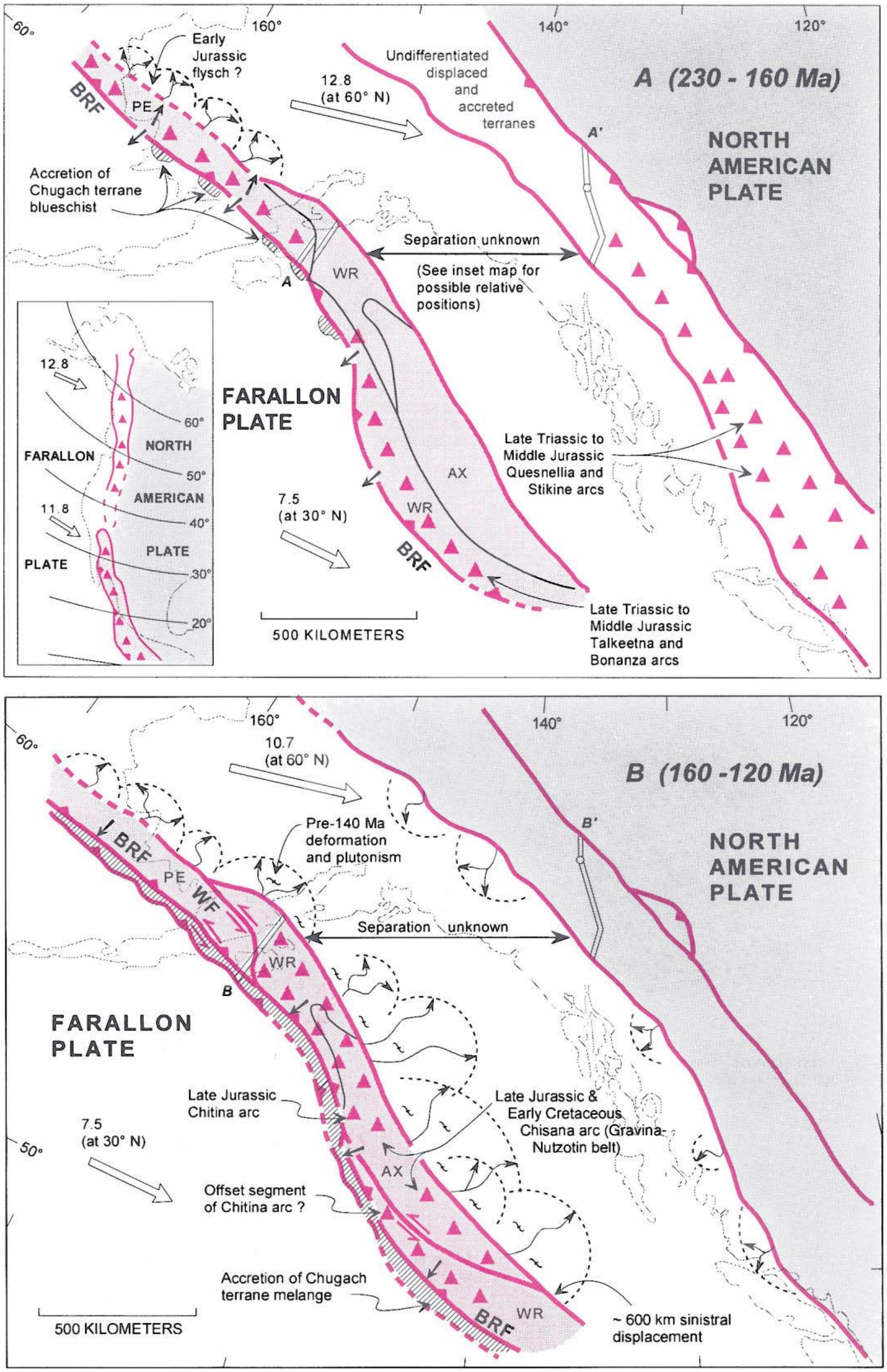
Paleomagnetic data indicate that the Wrangellia composite terrane and the attached Southern Margin composite terrane were at their present latitude by at least 55 Ma. The Paleocene and Eocene interval was characterized by rapid northward underthrusting of the Kula plate beneath the continental margin and by counterclockwise oroclinal bending of what is now western Alaska, probably beginning in the Late Cretaceous or early Paleocene.

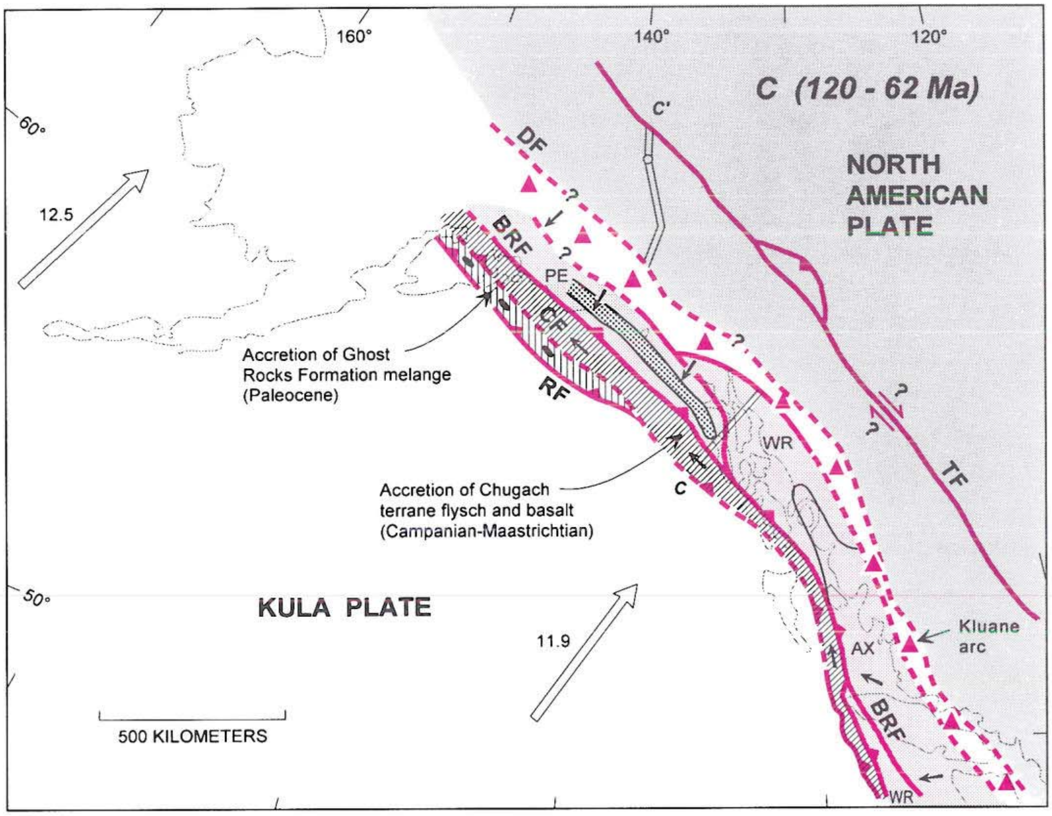
Oblique to orthogonal underthrusting resulted in plutonism and uplift that formed the ancestral Coast Mountains of British Columbia and Alaska and were related to late-stage activity of the Kluane magmatic arc and at least two subparallel coeval magmatic belts that developed in western Alaska (Fig. 15D). During this interval, multiple slices of Kula plate crust and sediments were emplaced beneath the older units of the accretionary complex (Fig. 16D).

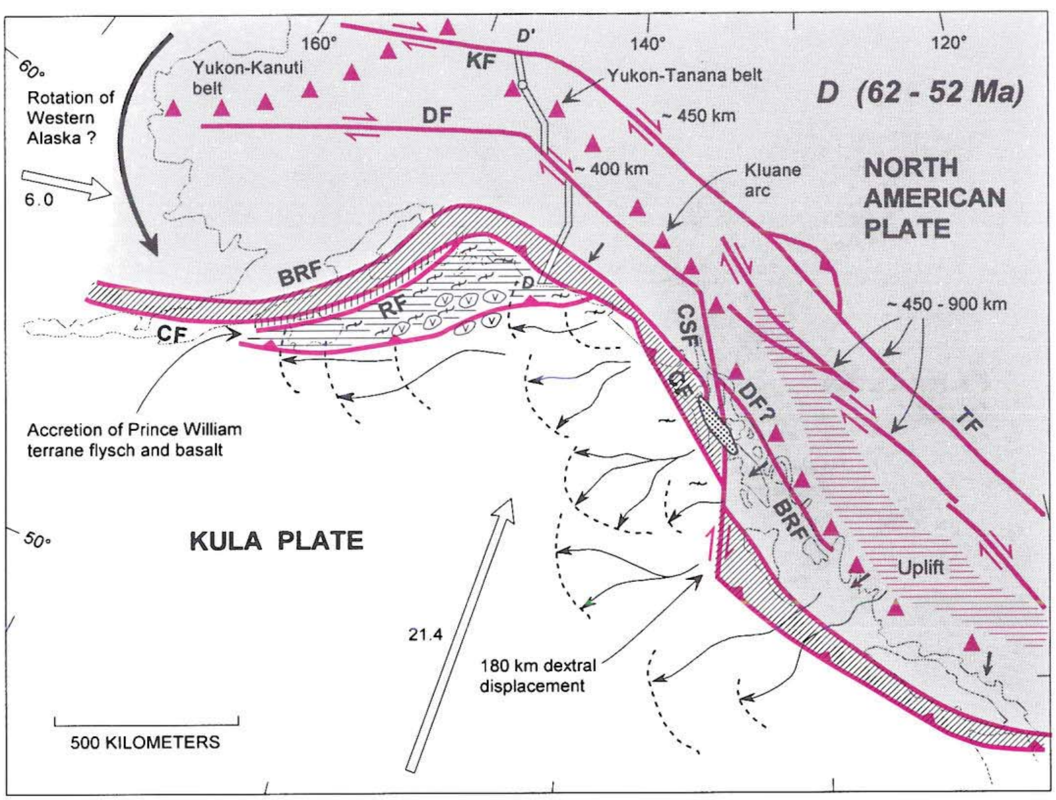
From about late Paleocene through middle Eocene time (62 to 48 Ma), an enormous flood of sediment derived dominantly from renewed uplift of the what is now the Coast Mountains was deposited mainly onto the Kula plate as deep-sea fans. These fans were subsequently carried rapidly northward on the Kula plate and, together with compositionally variable basaltic oceanic rocks, were progressively emplaced in a trench along the northern and western parts of the Southern Margin composite terrane to form the Sitkalidak Formation, Resurrection Peninsula sequence, and Orca Group of the Prince William terrane (Fig. 15, D and E).

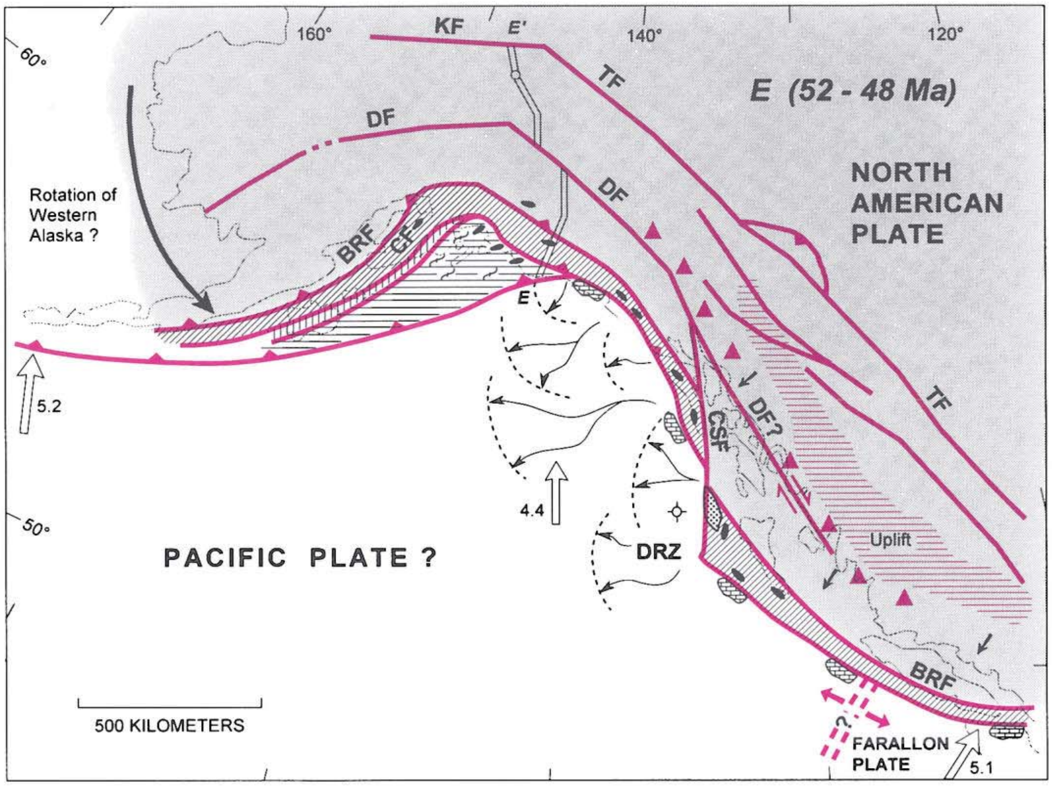
Cumulative dextral displacement of about 400 km on the Denali fault (Nokleberg and others, 1985) and 600 to 1000 km on the subparallel Tintina fault system (Gabrielse, 1985) may have occurred in part or entirely during this interval. However, the timing for major displacements on these interior faults cannot be bracketed more closely than latest Cretaceous to late Eocene; displacement at low rates has continued throughout the Cenozoic

Figure 15. Diagrams illustrating the inferred Mesozoic and Cenozoic evolution of the geology of the southern Alaska margin (modified from Plafker, 1987; Plafker and others, 1989). Tectonostratigraphic terranes are after Silberling and others (this volume), composite terranes are after Plafker and Berg (this volume, Chapter 33), and vectors for relative motions of oceanic plates are after Engebretsen and others (1985), except for present relative motions, which are after DeMets and others (1990). Abbreviations as in Figures 2, 3, and 6. **A:** Late Triassic and Early to Middle Jurassic configuration of composite terranes showing major magmatic arcs and glaucophanic greenschist assemblage rocks of the Chugach terrane accreted to southwest margin of Peninsular and Wrangellia terranes. Inset diagram shows a possible reconstruction of the position of the terranes relative to North America on the basis of paleomagnetic data suggesting about 28° of post-Triassic northward displacement of the Wrangellia composite terrane (WCT) relative to the craton and inferred continuity of Stikine and Talkeetna arcs. **B:** Late Jurassic and Early Cretaceous locations of the Chitina and Chisana magmatic arcs on the Wrangellia composite terrane and partly coeval melange facies rocks of the Chugach terrane accreted to southwestern margin of the Wrangellia composite terrane. During this interval sinistral strike slip may have moved the British Columbia part of the Wrangellia terrane as much as 600 km into its present position relative to the northern part of the Wrangellia terrane. Middle to Late Jurassic deformation and plutonism along the east margin of the Wrangellia composite terrane may possibly be due to collisions with continental terranes to the east. **C:** Initiation of Kula plate relative motion with docking of the Wrangellia composite terrane against inboard terranes in the interval from late Early to early Late Cretaceous. The Late Cretaceous Kluane magmatic arc developed in part over crushed flysch basins along the suture and was the main source of the Campanian and Maastrichtian flysch facies rocks of the Chugach terrane that were accreted to the southwestern margin of the Wrangellia composite terrane. Onset of counterclockwise oroclinal bending of western Alaska. Accretion of the Ghost Rocks terrane and exotic far-traveled fragments of oceanic rocks to the southern margin of the Chugach terrane by 62 Ma and late Paleocene anatectic plutonism from the Sanak Islands to the Kodiak Islands. **D:** About 8° northward translation of the Chugach and Ghost Rocks terranes relative to craton by dextral displacement on the Tintina and Denali fault systems. Counterclockwise oroclinal bending of western Alaska with formation of magmatic arcs in the western interior. Main episode of dextral offset on northwest-trending intracontinental faults (Tintina and Denali). Plutonism and uplift of the Coast Mountains, deep-sea fan sedimentation on the Kula plate, and accretion to the northern and western limbs of the Alaska orocline. **E:** Accretion of the Prince William and related terranes completed by the early middle Eocene. Eocene anatectic plutonism and associated metamorphism inferred to be related to subduction of the Kula plate. Wrangellia composite terrane at or close to its present position relative to North America by about 55 Ma. Offset of continental margin and Chugach terrane by 180–150 km displacement along the Chatham Strait fault (CSF) to form the proto-Dangerous River zone (DRZ); local accumulation of sediments, including carbonate reef detritus along continental margin. Probable continued dextral offset on intracontinental faults. **F:** Initiation of northwestward relative motion of the Pacific plate; beginning of arc volcanism on the Alaska Peninsula. Formation of the Transition fault system (TFS) as a transform fault outboard of the proto-Yakutat terrane; continued rapid sedimentation along continental margin and on ocean floor; possible accumulation of Zodiac fan deposits on oceanic crust off what is now southern British Columbia. **G:** Landward stepping of transform boundary to the Queen Charlotte–Fairweather fault system (QCF/FF) to form the Yakutat terrane. Onset of Wrangell Mountains volcanism after northwestward subduction of the Yakutat terrane to about 100 km depth. Continued slow deep-marine sedimentation on Yakutat terrane. **H:** Continued northward displacement totaling 600 km for the Yakutat terrane, possibly with about 20° counterclockwise rotation. Extreme uplift due to transpression along north and northeast margins of the Yakutat terrane accompanied by major pulse of clastic sedimentation on continental margins and dep-sea floor, culminating in Pliocene and Quaternary time.

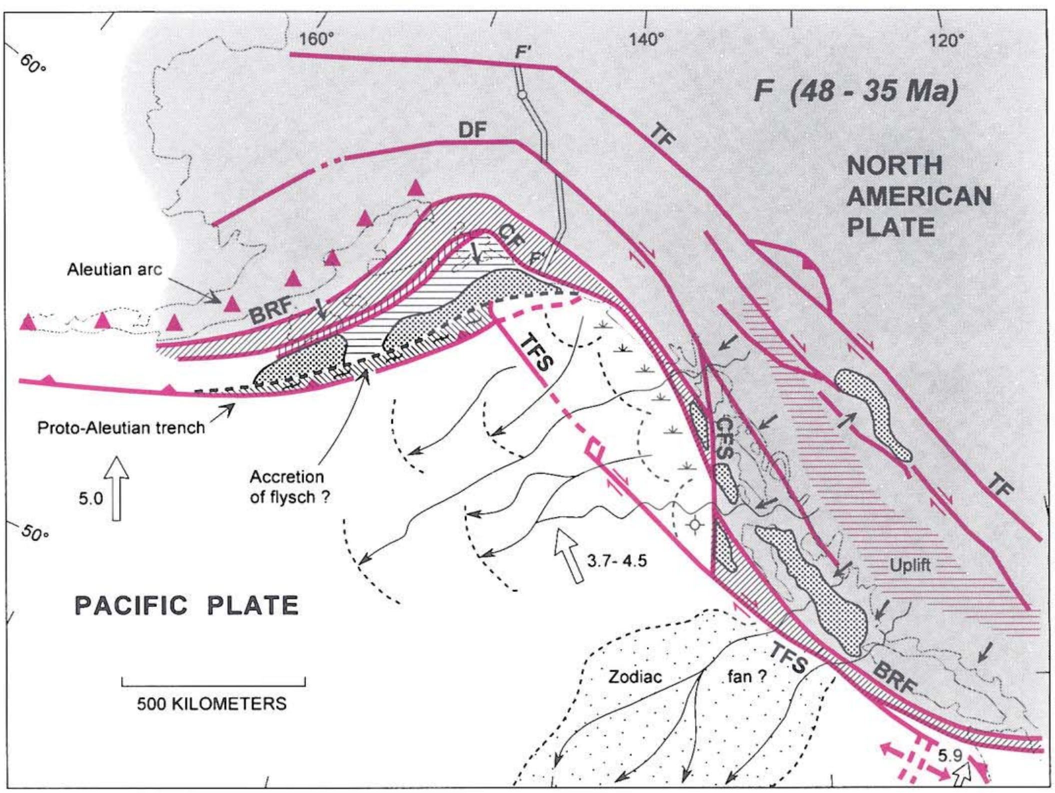

A (230 - 160 Ma)
NORTH AMERICAN PLATE
FARALLON PLATE
160°
140°
120°
60°
Early Jurassic flysch ?
12.8 (at 60° N)
Undifferentiated displaced and accreted terranes
A'
BRF
PE
Accretion of Chugach terrane blueschist
Separation unknown
(See inset map for possible relative positions)
WR
A
AX
Late Triassic to Middle Jurassic Quesnellia and Stikine arcs
7.5 (at 30° N)
Late Triassic to Middle Jurassic Talkeetna and Bonanza arcs
500 KILOMETERS
12.8
11.8
FARALLON
PLATE
NORTH
AMERICAN
PLATE
60°
50°
40°
30°
20°
B (160 -120 Ma)
NORTH AMERICAN PLATE
FARALLON PLATE
10.7 (at 60° N)
B'
Pre-140 Ma deformation and plutonism
BRF
PE
WF
Separation unknown
WR
B
Late Jurassic Chitina arc
Late Jurassic & Early Cretaceous Chisana arc (Gravina-Nutzotin belt)
50°
7.5 (at 30° N)
AX
Offset segment of Chitina arc ?
Accretion of Chugach terrane melange
~ 600 km sinistral displacement
500 KILOMETERS


160°
140°
120°
C (120 - 62 Ma)
C'
60°
DF
NORTH
AMERICAN
PLATE
12.5
BRF
PE
CF
Accretion of Ghost
Rocks Formation melange
(Paleocene)
RF
WR
TF
Accretion of Chugach
terrane flysch and basalt
(Campanian-Maastrichtian)
C
50°
KULA PLATE
11.9
Kluane
arc
AX
BRF
500 KILOMETERS
WR

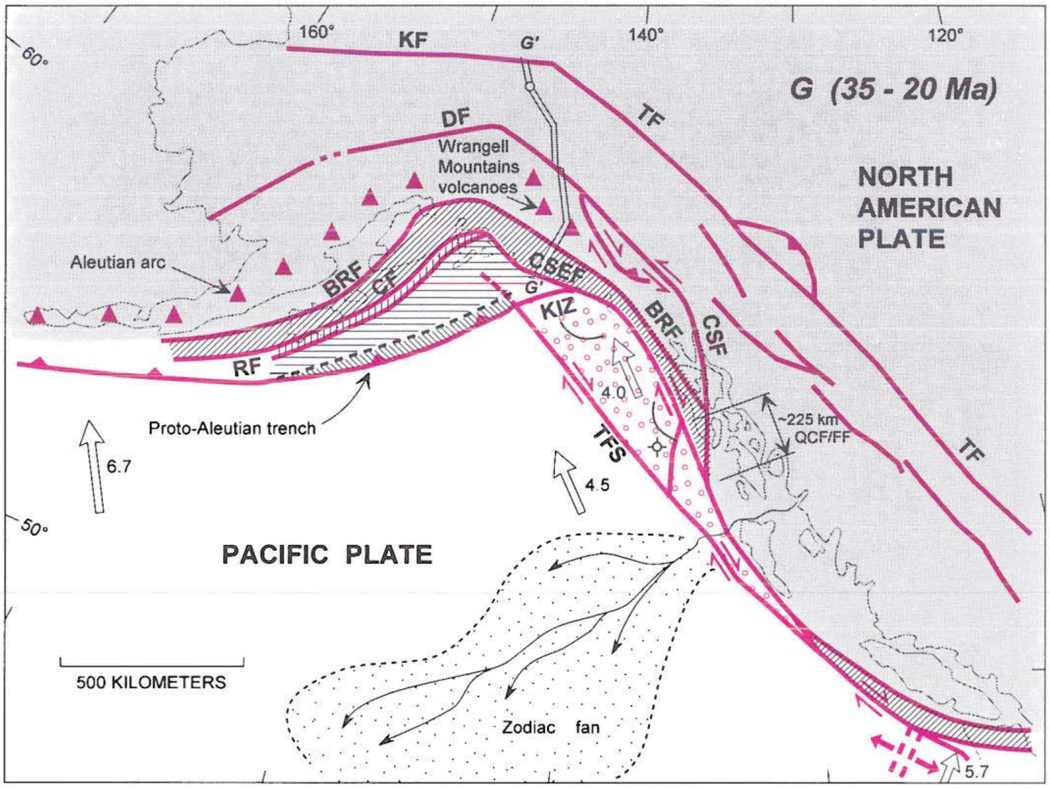

60°
160°
D'
140°
120°
Yukon-Kanuti
belt
KF
Yukon-Tanana belt
D (62 - 52 Ma)
Rotation of
Western
Alaska ?
DF
~ 450 km
6.0
~ 400 km
Kluane
arc
NORTH
AMERICAN
PLATE
BRF
D
RF
CSF
~ 450 - 900 km
CF
CF
DF?
TF
Accretion of Prince William
terrane flysch and basalt
BRF
50°
KULA PLATE
Uplift
21.4
180 km dextral
displacement
500 KILOMETERS



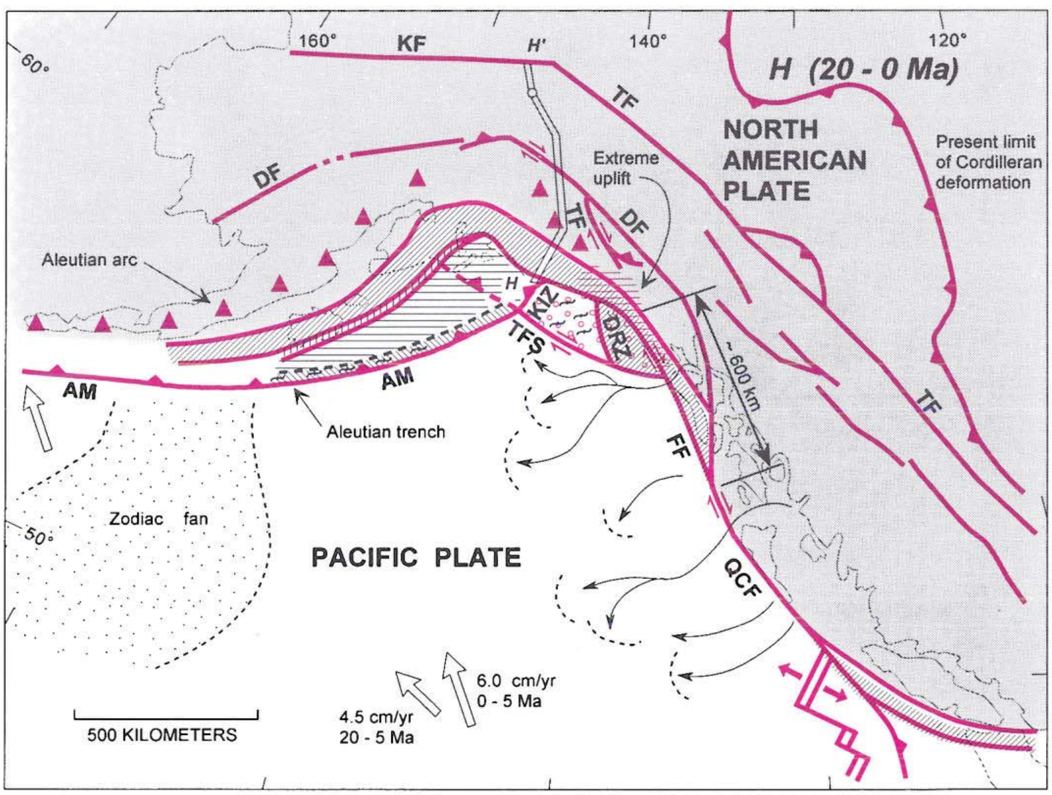
E (52 - 48 Ma)
160°
140°
120°
60°
50°
KF
E'
E
TF
DF
DF
DF?
CF
BRF
BRF
CSF
DRZ
Rotation of
Western
Alaska ?
NORTH
AMERICAN
PLATE
Uplift
PACIFIC PLATE ?
FARALLON
PLATE
5.2
4.4
5.1
500 KILOMETERS



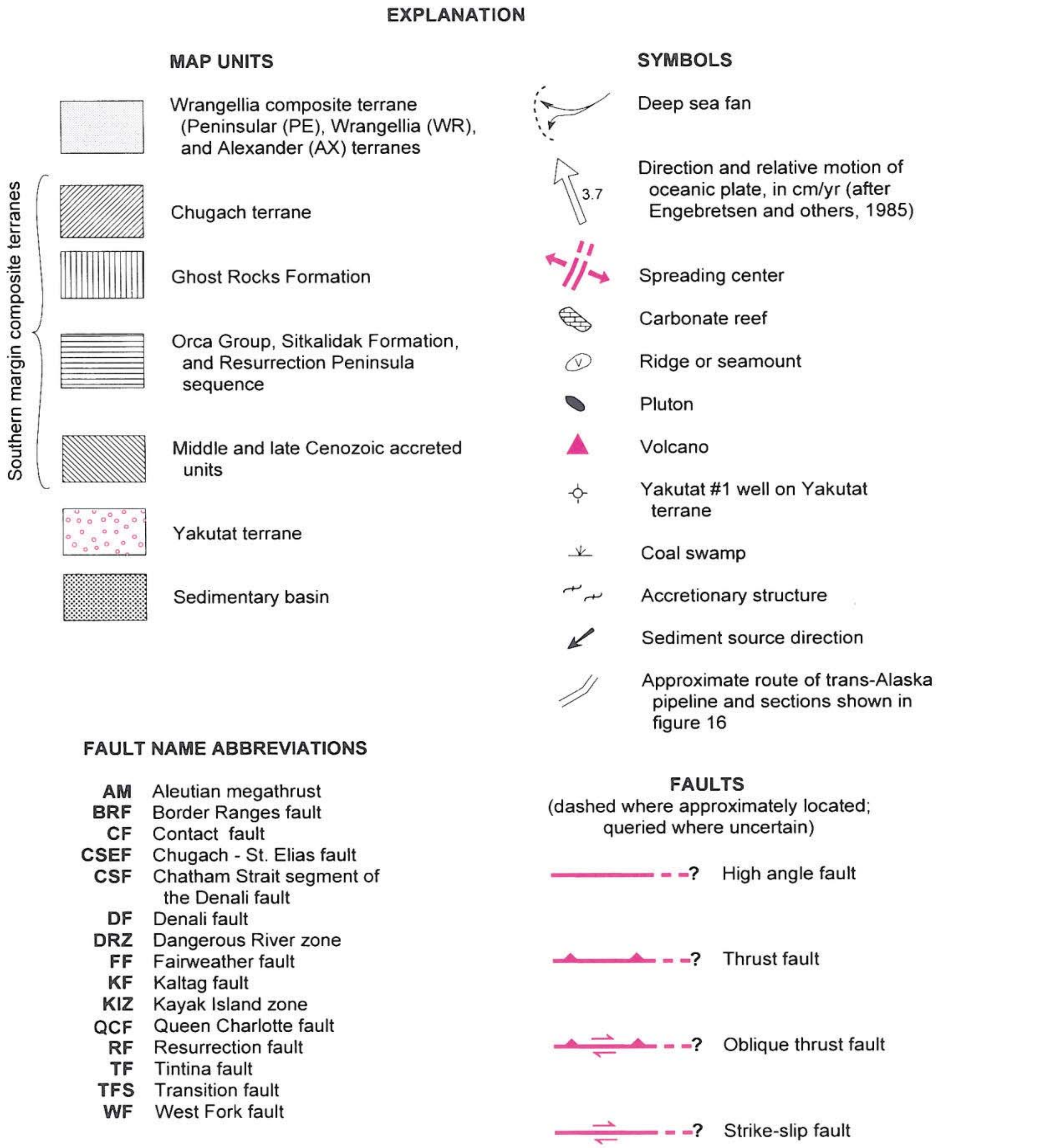
F (48 - 35 Ma)
160°
140°
120°
60°
50°
F'
F
TF
TF
DF
CF
BRF
BRF
CFS
TFS
TFS
Aleutian arc
Proto-Aleutian trench
Accretion
of flysch ?
NORTH
AMERICAN
PLATE
Uplift
PACIFIC PLATE
Zodiac
fan ?
5.0
3.7- 4.5
5.9
500 KILOMETERS



160°
KF
G'
140°
120°
60°
G (35 - 20 Ma)
TF
DF
Wrangell
Mountains
volcanoes
NORTH
AMERICAN
PLATE
Aleutian arc
BRF
CF
CSEF
G'
KIZ
BRF
CSF
RF
Proto-Aleutian trench
4.0
~225 km
QCF/FF
TFS
6.7
4.5
TF
50°
PACIFIC PLATE
500 KILOMETERS
Zodiac fan
5.7



160°
KF
H'
140°
120°
60°
H (20 - 0 Ma)
TF
NORTH
AMERICAN
PLATE
Present limit
of Cordilleran
deformation
DF
Extreme
uplift
TF
DF
Aleutian arc
H
KIZ
DRZ
TFS
~ 600 km
AM
AM
Aleutian trench
FF
TF
Zodiac fan
50°
PACIFIC PLATE
QCF
6.0 cm/yr
0 - 5 Ma
4.5 cm/yr
20 - 5 Ma
500 KILOMETERS



on some of these structures, most notably on the Denali fault system.

In the northern and eastern Gulf of Alaska, the middle Eocene interval (52 to 48 Ma) was marked by north to northwest subduction and the demise of the Kula-Farallon ridge, an event that probably mimics the one that began as much as 10 m.y. earlier to the west. A major coeval thermal event resulted in plutonism and low-pressure high-temperature metamorphism from about 54 to 48 Ma in the Chugach, Prince William, and eastern Yakutat terranes east of the Kodiak Islands area. These plutons are emplaced across the suture between the Southern Margin and Wrangellia composite terranes, indicating that the terranes were in about their present relative positions at that time. The thermal event may have resulted from juxtaposition of mantle rocks directly beneath the accretionary complex as the landward limb of the Kula plate was subducted (as depicted in Figure 16D); other mechanisms such as leakage of basaltic magma through a fragmented Kula plate, or subduction of very young and hot oceanic crust may have caused, or contributed to, the heating.

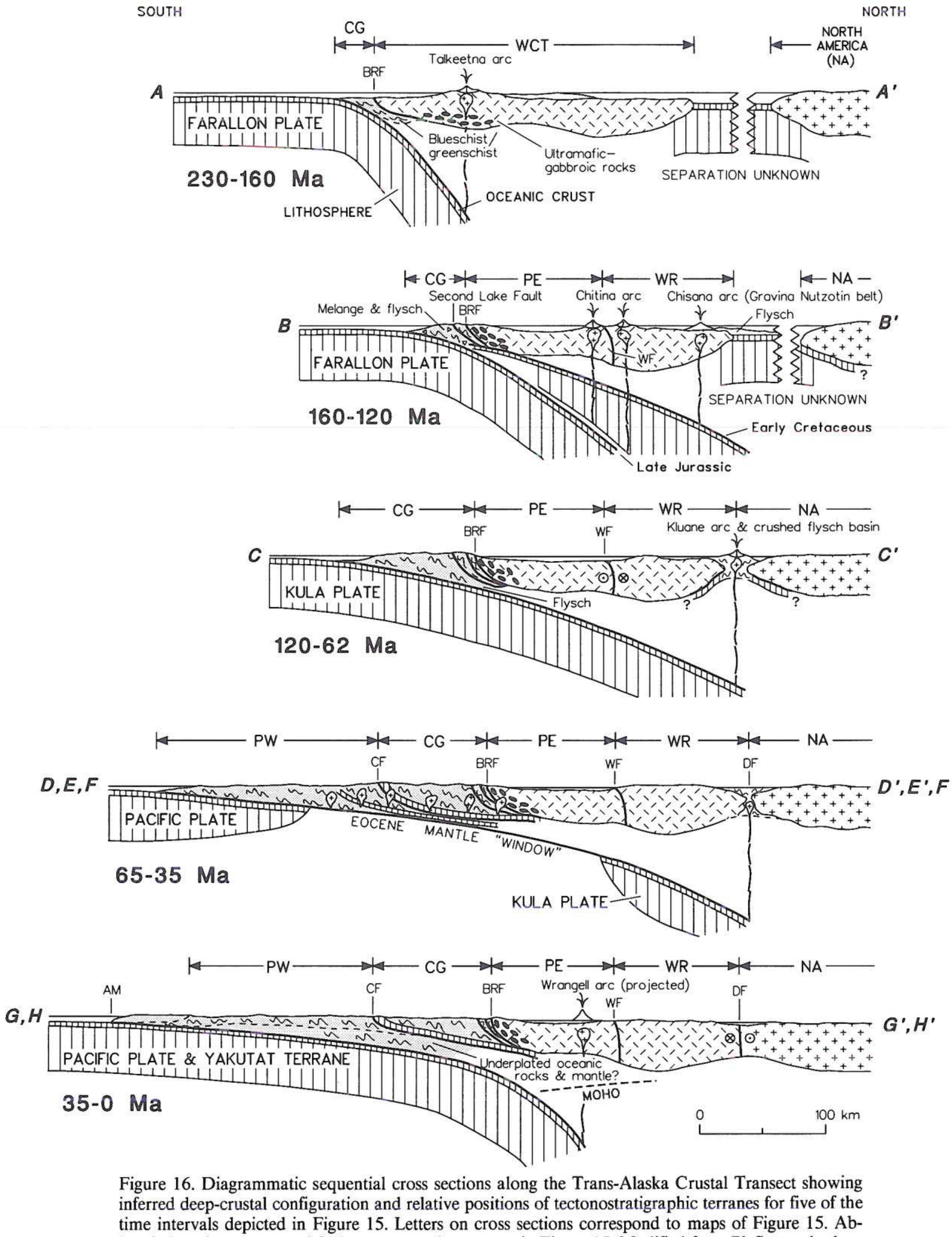


Figure 16. Diagrammatic sequential cross sections along the Trans-Alaska Crustal Transect showing inferred deep-crustal configuration and relative positions of tectonostratigraphic terranes for five of the time intervals depicted in Figure 15. Letters on cross sections correspond to maps of Figure 15. Abbreviations for terrane and fault names are the same as in Figure 15. Modified from Plafker and others (1989). Abbreviations as in Figures 2, 3, and 6.

Minor oroclinal bending continued that refolded structures in the Prince William terrane and possibly in the Chugach terrane. Dextral slip of ~180 km on the Chatham Strait fault is inferred to have truncated the Chugach terrane toward the beginning of this time interval or possibly a few million years earlier (Figs. 14 and 15E). During and immediately after faulting, early to middle Eocene marine clastic deposits from a crystalline-complex source, carbonate-reef detritus, and minor coal were deposited along the margins of the offset fragment of Chugach terrane and on oceanic crust to the west.

Middle Eocene to early Oligocene; 48 to 35 Ma

Andesitic volcanism associated with the Aleutian arc began on the Alaska Peninsula at about 50 Ma, a few million years after the onset of northwestward motion of the Pacific plate. Subduction beneath the Kodiak shelf was probably accompanied by accretion and underplating of deep-sea sediments and oceanic crust outboard of the Orca Group and equivalent rocks.

The Transition fault system developed across the northeastern Gulf of Alaska, and the main deposition of the Paleogene alluvial-fan-delta sequence took place on trapped oceanic crust northeast of the Transition fault system. Early Oligocene felsic plutonism in western Prince William Sound and small felsic and mafic to ultramafic intrusive bodies to the east may be related to leakage of basalt through the crust along this paleotransform-fault system. A locally derived Paleogene basinal sequence overlying the Yakutat Group was deposited in the eastern part of the Yakutat terrane. Sediments of interior and shelf-margin basins, and possibly the Zodiac deep-sea fan, were derived mainly from erosion of the uplifted crystalline rocks of what are now the Coast Mountains.

Late Oligocene to early Miocene; 35 to 20 Ma

Continued northwestward subduction of the Pacific plate was accompanied by andesitic volcanism on the Alaska Peninsula and Aleutian Islands, by sedimentation in shelf basins, and possibly by accretion and underplating of trench deposits and oceanic crust to the seaward part of the accretionary complex.

At about 30 Ma, the transform-fault boundary stepped inboard from the Transition fault system to the Queen Charlotte–Fairweather fault system to form the Yakutat terrane; motion of the Pacific and North American plates was shared between the Queen Charlotte–Fairweather system and the Transition fault system. Andesitic arc volcanism began in what are now the Wrangell Mountains at about 25 Ma following about 225 km subduction of the Yakutat terrane (the amount required to reach about 100 km depth beneath the Wrangell Mountains). Scattered small felsic intrusions emplaced near the Fairweather fault may be related to local areas of high heat flow along zones of extension. Fold and thrust belts were initiated along the Kayak Island zone and Chugach–Saint Elias fault system as a consequence of convergence and underthrusting of the Yakutat terrane beneath adjacent terranes to the north and west.

Early Miocene to present; 20 to 0 Ma

Continued northwestward subduction of the Pacific plate and Yakutat terrane was accompanied by andesitic volcanism in the Alaska Peninsula and Wrangell Mountains segments of the ancestral Aleutian arc, by continued sedimentation in shelf basins, and by subduction and probable underplating beneath the accretionary complex. About 1000 km of northwestward motion of the Pacific plate relative to the continental margin was shared approximately equally between the Queen Charlotte–Fairweather transform and the Transition fault systems. Transpression along the north margin of the Yakutat terrane resulted in extreme uplift of the Chugach Mountains and Fairweather Range and concurrent deposition of thick, locally derived late Cenozoic clastic sequences, including abundant marine glacial deposits (Yakataga and Redwood formations) in continental margin basins on the continental shelves and on the deep-sea floor. Folding and thrusting along the north and west margins of the Yakutat terrane progressed southward and eastward with time, so the deformational front is now at the Pamplona zone. Underthrusting and large-scale subduction of ocean crust and the overlying sediments took place along both the Aleutian megathrust and the Kayak Island zone; compressional deformation within the eastern Prince William terrane was relatively minor. Paleomagnetic data from Eocene sedimentary rocks suggest that the Yakutat terrane may have rotated counterclockwise ~20° as it moved into the bend of the northern Gulf of Alaska.

As a consequence of ~600 km of northwestward displacement and subduction, less than half of the Yakutat terrane remains. Subduction of this remaining part of the terrane, which is caught in the junction between the Aleutian megathrust and the Queen Charlotte–Fairweather transform-fault system, becomes increasingly difficult because it involves the relatively thick eastern segment of the Yakutat terrane with its Mesozoic transitional continental crust. The complex and extremely active deformation that characterizes the late Cenozoic history of the northern Gulf of Alaska will continue until the remaining part of the Yakutat terrane is either completely subducted or is accreted to the continental margin.

Discussion

The tectonic model presented here is compatible with most geologic, seismic, potential field, and paleomagnetic data, and with major aspects of plate reconstructions for the northeast Pacific region.

Nevertheless, many important questions can only be addressed by additional high-quality geologic mapping of critical areas and by detailed topical studies. Unresolved problems due to conflicting or inadequate data have been noted throughout this chapter. Some of the more pressing subjects for future research are listed here. (1) The mechanism for juxtaposition of the deep-level glaucophanic greenschist and plutonic rocks of the Talkeetna magmatic arc along the Border Ranges fault and the disposition of the sediment derived from subsequent uplift and erosion that exposed these rocks. (2) The timing of accretion of the Mesozoic melange assemblage of the Chugach terrane and the provenance of the included blocks. (3) Discrepancies between some paleomagnetic data for the Ghost Rocks Formation, Orca Group, and Resurrection Peninsula sequence that indicate deposition of volcanic rocks in the unit 16° to 31° south of their present latitudes, and geologic evidence and other paleomagnetic data that suggest accretion at about their present latitudes by 55 Ma with limited (about 8°) northward displacement of these terranes relative to the craton by dextral slip on major transcurrent faults. (4) The sources of channel-fill conglomerate in the Orca Group that includes sparse orthoquartzite and abundant metarhyolite tuff derived from a probable craton. (5) Apparent major differences between the Eocene and younger basinal strata penetrated in the Middleton Island well and the deformed Eocene and Oligocene turbidites penetrated in the Kodiak shelf stratigraphic test wells. (6) The discrepancy between estimated subduction of about 600 km of Yakutat terrane crust along the Kayak Island zone and the absence of either a greatly thickened sequence within the fold-thrust belt between the Kayak Island and Pamplona zones, as would be expected for large-scale offscraping and imbrication, or geophysical evidence west of the Pamplona zone that might indicate a volume of underplated low-density sediment commensurate with the amount of underthrusting. (7) Controls for post-Eocene magmatism along the dominantly transform margin of the eastern Gulf of Alaska. (8) The apparent contrast in structural style along the eastern Aleutian Trench between accretion off the Kodiak area and underplating off the Middleton Island area.

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REFERENCES CITED

Armentrout, J. M., 1975, Molluscan biostratigraphy of the Lincoln Creek Formation, southwest Washington, *in* Weaver, D. W., Hornaday, G. R., and Tipton, A., eds., Paleogene symposium and selected technical papers on future energy horizons of the Pacific Coast: Long Beach, California, American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, Society of Economic Geologists, Pacific sections, p. 14–48.

Armstrong, R. L., 1988, Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera, *in* Clark, S. P., Jr., Burchfiel, B. C., and Suppe, J., eds., Processes in continental lithospheric deformation: Geological Society of America Special Paper 218, p. 55–91.

Atwater, T., and Severinghaus, J., 1989, Tectonic maps of the northeast Pacific, *in* Winterer, E. L., Hussong, D. M., and Decker, R. W., eds., The eastern Pacific Ocean and Hawaii: Boulder, Colorado, The Geology of North America, v. N, p. 15–20.

Bacon, C. R., Foster, H. L., and Smith, J. G., 1990, Rhyolitic calderas of the Yukon-Tanana terrane, east central Alaska: Volcanic remnants of a mid-Cretaceous magmatic arc: Journal of Geophysical Research, v. 95, p. 21,451–21,461.

Barker, F., Arth, J. G., and Stern, T. W., 1986, Evolution of the Coast batholith along the Skagway traverse, Alaska and British Columbia: American Mineralogist, v. 71, p. 632–643.

Barker, F., Sutherland Brown, A., Budahn, J. R., and Plafker, G., 1989, Back-arc with frontal-arc component origin of Triassic Karmutsen basalt, British Columbia, Canada: Chemical Geology, v. 75, p. 81–102.

Barker, F., Farmer, G. L., Ayuso, R. A., Plafker, G., and Lull, J. S., 1992, The 50-Ma granodiorite of the eastern Gulf of Alaska: Melting in an accretionary prism in the forearc: Journal of Geophysical Research, v. 97, p. 6757–6778.

Bayer, K. C., Mattick, R. E., Plafker, G., and Bruns, T. R., 1978, Refraction studies between Icy Bay and Kayak Island, eastern Gulf of Alaska: U.S. Geological Survey Journal of Research, v. 6, p. 625–636.

Berg, H. C., Jones, D. L., and Richter, D. H., 1972, Gravina-Nutzotin belt—Tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska, *in* Geological Survey research 1972: U.S. Geological Survey Profession Paper 800-D, p. D1–D24.

Bol, A. J., Coe, R. S., Grommé, C. S., and Hillhouse, J. W., 1992, Paleomagnetism of the Resurrection Peninsula, Alaska: Implications for the tectonics of southern Alaska and the Kula-Farallon ridge: Journal of Geophysical Research, v. 97, p. 17,213–17,232.

Bradley, D. C., and Kusky, T. M., 1992, Deformation history of the McHugh Complex, Seldovia quadrangle, south-central Alaska, *in* Bradley, D. C., and Ford, A. B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 17–32.

Brandon, M. T., Orchard, M. J., Parrish, R. R., Sutherland Brown, A., and Yorath, C. J., 1986, Fossil ages and isotopic dates from Paleozoic Sicker Group and associated intrusive rocks, Vancouver Island, British Columbia, *in* Current research, Part A: Geological Survey of Canada Paper 86-1A, p. 683–696.

Brew, D. A., and Ford, A. B., 1984, Tectonostratigraphic terranes in the Coast plutonic-metamorphic complex, southeastern Alaska, *in* Reed, K. M., and Bartsch-Winkler, S., eds., The United States Geological Survey in Alaska: Accomplishments during 1982: U.S. Geological Survey Circular 939, p. 90–93.

Brew, D. A., Karl, S. M., and Miller, J. W., 1988, Megafossils (*Buchia*) indicate Late Jurassic age for part of the Kelp Bay Group on Baranof Island, southeastern Alaska, *in* Galloway, J. P., and Hamilton, T. D., eds., Geological studies in Alaska by the United States Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 147–149.

Brocher, T. M., Fisher, M. A., Geist, E. L., and Christensen, N. I., 1989, A high-resolution seismic reflection/refraction study of the Chugach-Peninsular terrane boundary, southern Alaska: Journal of Geophysical Research, v. 94, p. 4441–4455.

Brocher, T. M., Moses, M. A., Fisher, M. A., Stephens, C. D., and Geist, E. L., 1991, Images of the plate boundary beneath southern Alaska, *in* Meissner, R., and others, eds., Continental lithosphere; deep seismic reflections: American Geophysical Union Geodynamic Series, v. 22, p. 241–246.

Bruns, T. R., 1979, Late Cenozoic structure of the continental margin, northern Gulf of Alaska, *in* Sisson, A., ed., The relationship of plate tectonics to Alaskan geology and resources (Proceedings, Alaska Geological Society Symposium, 6th, 1977, Anchorage): Anchorage, Alaska Geological Society, p. I1–I30.

——, 1983, 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-1480, 22 p., 3 sheets, scale 1:500,000.

Bruns, T. R., and Carlson, P. R., 1987, Geology and petroleum potential of the southeast Alaska continental margin, 1987, *in* Scholl, D. W., Grantz, A., and Vedder, J. G., eds., Geology and petroleum potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 269–282.

Bruns, T. R., and Schwab, W. C., 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, 20 p., 4 sheets, scale 1:250,000.

Bruns, T. R., von Huene, R., Culotta, R. C., Lewis, S. D., and Ladd, J. W., 1987, Geology and petroleum potential of the Shumagin margin, Alaska, *in* Scholl, D. W., Grantz, A., and Vedder, J. G., eds., Geology and petroleum potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 157–189.

Budnick, R. T., 1974, The geologic history of the Valdez Group, Kenai Peninsula, Alaska—Deposition and deformation at a Late Cretaceous consumptive plate margin [Ph.D. thesis]: Los Angeles, University of California, 139 p.

Burns, L. E., 1985, The Border Ranges ultramafic and mafic complex, south-central Alaska: Cumulate fractionates of island-arc volcanics: Canadian Journal of Earth Sciences, v. 22, p. 1020–1038.

Byrne, T., 1982, Structural evolution of coherent terranes in the Ghost Rocks Formation, Kodiak Island, Alaska, *in* Leggett, J. K., ed., Trench and forearc sedimentation and tectonics in modern and ancient subduction zones: Geological Society of London Special Publication 10, p. 229–242.

——, 1984, Early deformation in melange terranes of the Ghost Rocks Formation, Kodiak Islands, Alaska, *in* Raymond, L. A., ed., Melanges: Their nature, origin, and significance: Geological Society of America Special Paper 198, p. 21–51.

——, 1986, Eocene underplating along the Kodiak shelf, Alaska: Implications and regional correlations: Tectonics, v. 5, p. 403–421.

Carden, J. R., Connelly, W., Forbes, R. B., and Turner, D. L., 1977, Blueschists of the Kodiak Islands, Alaska: An extension of the Seldovia schist terrane: Geology, v. 5, p. 529–533.

Carey, S. W., 1958, The tectonic approach to continental drift, *in* Carey, S. W., convenor, Continental drift—A symposium (1956): Hobart, Australia, Tasmania University Geology Department, p. 177–355.

Case, J. E., and Tysdal, R. G., 1979, Geologic interpretation of aeromagnetic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-880D, 2 sheets, scale 1:250,000.

Case, J. E., Barnes, D. F., Plafker, G., and Robbins, S. L., 1966, Regional gravity survey of Prince William Sound: U.S. Geological Survey Professional Paper 543-C, 12 p.

Chisholm, W. A., 1985, Comment *on* "Model for the origin of the Yakutat block, an accreting terrane in the northern Gulf of Alaska": Geology, v. 13, p. 87.

Clark, S.H.B, 1972, Reconnaissance bedrock geologic map of the Chugach Mountains near Anchorage, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-350, scale 1:250,000.

——, 1973, The McHugh Complex of south-central Alaska: U.S. Geological Survey Bulletin 1372-D, p. D1–D11.

Clendenen, W. S., Sliter, W. V., and Byrne, T., 1992, Tectonic implications of the Albatross sedimentary sequence, Sitkinak Island, Alaska, *in* Bradley, D. C., and Ford, A. B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 52–70.

Coe, R. S., Globerman, B. R., Plumley, P. W., and Thrupp, G. A., 1985, Paleomagnetic results from Alaska and their tectonic implications, *in* Howell, D. G., ed., Tectonostratigraphic terranes of the circum-Pacific region: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Sciences Series, v. 1, p. 85–108.

Connelly, W., 1978, Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, p. 755–769.

Connelly, W., and Moore, J. C., 1979, Geologic map of the northwest side of the Kodiak and adjacent islands, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1057, 2 sheets, scale 1:250,000.

Cowan, D. S., and Boss, R. F., 1978, Tectonic framework of the southwestern Kenai Peninsula, Alaska: Geological Society of America Bulletin, v. 89, p. 155–158.

Crawford, M. L., and Hollister, L. S., 1982, Contrast of metamorphic and structural histories across the Work Channel lineament, Coast Plutonic Complex, British Columbia: Journal of Geophysical Research, v. 87, p. 3849–3860.

Csejtey, B., Jr., Cox, D. P., Evarts, R. C., Stricker, G. D., and Foster, H. L., 1982, The Cenozoic Denali fault system and the Cretaceous accretionary development of southern Alaska: Journal of Geophysical Research, v. 87, p. 3741–3754.

Davies, D. L., and Moore, J. C., 1984, 60 m.y. intrusive rocks from the Kodiak Islands link the Peninsular, Chugach and Prince William terranes: Geological Society of America Abstracts with Programs, v. 16, p. 277.

Davis, A., and Plafker, G., 1986, Eocene basalts from the Yakutat terrane: Evidence for the origin of an accreting terrane in southern Alaska: Geology, v. 14, p. 963–966.

Decker, J. E., 1980a, Geology of a Cretaceous subduction complex, western Chichagof Island, southeastern Alaska [Ph.D. thesis]: Stanford, California, Stanford University, 135 p.

——, 1980b, Geology of a Cretaceous subduction complex, western Chichagof Island, southeastern Alaska: Ann Arbor, Michigan, Dissertation Abstracts International, v. 41, p. 4040B–4041B.

Decker, J. E., and Plafker, G., 1982, Correlation of rocks in the Tarr Inlet suture zone with the Kelp Bay Group, *in* Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 119–123.

——, 1983, The Chugach terrane—A Cretaceous subduction complex in southern Alaska: Geological Society of America Abstracts with Programs, v. 15, p. 386.

Decker, J. E., Wilson, F. H., and Turner, D. L., 1980, Mid-Cretaceous subduction event in southeastern Alaska: Geological Society of America Abstracts with Programs, v. 12, p. 103.

DeMets, C., Gordon, R. G., Argus, D. F., and Stein, S., 1990, Current plate motions: Geophysical Journal International, v. 101, p. 425–478.

Dickinson, W. R., and Suczek, C. A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164–2182.

Dodds, C. J., and Campbell, R. B., 1988, Potassium-argon ages of mainly intrusive rocks in the Saint Elias Mountains, Yukon and British Columbia: Geological Survey of Canada Paper 87-16, 43 p.

Drummond, K. J., 1986, Plate-tectonic map of the circum-Pacific region, northeast quadrant: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, scale: 1:10,000,000.

Dumoulin, J. A., 1987, Sandstone composition of the Valdez and Orca groups, Prince William Sound, Alaska: U.S. Geological Survey Bulletin 1774, 37 p.

Dumoulin, J. A., and Miller, M. L., 1984, The Jeanie Point complex revisited, *in* Coonrad, W. L., and Elliott, R. L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 75–77.

Engebretsen, D. C., Cox, A., and Gordon, R. G., 1985, Relative motions between oceanic and continental plates in the Pacific basin: Geological Society of America Special Paper 206, 59 p.

Farmer, G. L., Barker, F., and Plafker, G., 1987, A Nd and Sr isotopic study of Mesozoic and early Tertiary granitic rocks in south-central Alaska: Geological Society of America Abstracts with Programs, v. 19, no. 6, p. 376.

Fisher, D., and Byrne, T., 1987, Structural evolution of underthrusted sediments, Kodiak Islands, Alaska: Tectonics, v. 6, p. 775–793.

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

Fisher, M. A., von Huene, R., and Smith, G. L., 1987, Reflections from midcrustal rocks within the Mesozoic subduction complex near the eastern Aleutian Trench: Journal of Geophysical Research, v. 92, p. 7907–7915.

Fisher, M. A., Brocher, T. M., Nokleberg, W. J., Plafker, G., and Smith, G. L., 1989, Seismic-reflection images of the crust of the northern part of the

Chugach terrane, Alaska: Results of a survey for the Trans-Alaska Crustal Transect (TACT): Journal of Geophysical Research, v. 94, p. 4424–4440.

Forbes, R. B., and Lanphere, M. A., 1973, Tectonic significance of mineral ages of blueschists near Seldovia, Alaska: Journal Geophysical Research, v. 78, p. 1383–1386.

Fuis, G. S., and Plafker, G., 1991, Evolution of deep structure along the Trans-Alaska Crustal Transect, Chugach Mountains and Copper River basin, southern Alaska: Journal of Geophysical Research, v. 96, p. 4229–4253.

Fuis, G. S., Ambos, E. L., Mooney, W. D., Christensen, N. I., and Geist, E., 1991, Crustal structure of accreted terranes in southern Alaska, Chugach Mountains and Copper River basin, from seismic refraction results: Journal of Geophysical Research, v. 96, p. 4187–4227.

Gabrielse, H., 1985, Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia: Geological Society of America Bulletin, v. 96, p. 1–14.

Gergen, L. D., and Plafker, G., 1988, Petrography of sandstones of the Orca Group from the southern Trans-Alaskan Crustal Transect (TACT) route and Montague Island, *in* Galloway, J. P., and Hamilton, T. D., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 156–159.

Grant, U. S., and Higgins, D. F., 1910, Preliminary report on the mineral resources of the southern part of Kenai Peninsula, *in* Brooks, A. H., and others, compilers, Mineral resources of Alaska, report on progress of investigations, 1909: U.S. Geological Survey Bulletin 442, p. 166–178.

Griscom, A., and Sauer, P. E., 1990, Interpretation of magnetic maps of the northern Gulf of Alaska, with emphasis on the source of the slope anomaly: U.S. Geological Survey Open-File Report 90-348, 18 p.

Gromme, C. S., and Hillhouse, J. W., 1981, Paleomagnetic evidence for northward movement of the Chugach terrane, southern and southeastern Alaska, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B70–B72.

Haeussler, P. J., Coe, R. S., Onstott, T. C., and Renne, P., 1989, A second look at the paleomagnetism of the Late Triassic Hound Island Volcanics of the Alexander terrane: Eos (Transactions, American Geophysical Union), v. 70, p. 1068.

Heller, P. L., Tabor, R. W., O'Neil, J. R., Pevear, D. R., Shafiqullah, M., and Winslow, N. S., 1992, Isotopic provenance of Paleogene sandstones from the accretionary core of the Olympic Mountains, Washington: Geological Society of America Bulletin, v. 104, p. 140–153.

Helwig, J., and Emmet, P., 1981, Structure of the early Tertiary Orca Group in Prince William Sound and some implications for the plate tectonic history of southern Alaska: Alaska Geological Society Journal, v. 1, p. 12–35.

Hill, M. D., Morris, J., and Whelan, J., 1981, Hybrid granodiorites intruding the accretionary prism, Kodiak, Shumagin, and Sanak islands, southwest Alaska: Journal of Geophysical Research, v. 86, p. 10,569–10,590.

Hillhouse, J. W., and Grommé, C. S., 1977, Paleomagnetic poles from sheeted dikes and pillow basalt of the Valdez(?) and Orca groups, southern Alaska: Eos (Transactions, American Geophysical Union), v. 58, p. 1127.

——, 1985, Paleomagnetism of sedimentary rocks, Prince William Sound and Yakutat terranes, *in* Bartsch-Winkler, S., ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 60–62.

Hillhouse, J. W., Grommé, C. S., and Csejtey, B., Jr., 1985, Tectonic implications of paleomagnetic poles from lower Tertiary volcanic rocks, south-central Alaska: Journal of Geophysical Research, v. 90, p. 12,523–12,535.

Himmelberg, G. R., Loney, R. A., and Nabelek, P. I., 1987, Petrogenesis of gabbronorite at Yakobi and northwest Chichagof Islands, Alaska: Geological Society of America Bulletin, v. 98, p. 265–279.

Hollister, L. S., 1979, Metamorphism and crustal displacements: New insights: Episodes, v. 1979, no. 3, p. 3–8.

——, 1982, Metamorphic evidence for rapid (2 mm/yr) uplift of a portion of the Central Gneiss Complex, Coast Mountains, B.C.: Canadian Mineralogist, v. 20, p. 319–332.

Hoose, P. J., 1987, Seismic stratigraphy and tectonic evolution of the Kodiak shelf, *in* Turner, R. F., ed., Geological and operational summary, Kodiak shelf stratigraphic test wells, western Gulf of Alaska: Anchorage, Alaska, Minerals Management Service Outer Continental Shelf Report MMS 87-0109, p. 71–101.

Hottman, C. E., Smith, J. H., and Purcell, W. R., 1979, Relationship among earth stresses, pore pressure, and drilling problems offshore Gulf of Alaska: Journal of Petroleum Technology, v. 31, p. 1477–1484.

Howell, D. G., Jones, D. L., and Schermer, E. R., 1985, Tectonostratigraphic terranes of the circum-Pacific region, *in* Howell, D. G., ed., Tectonostratigraphic terranes of the circum-Pacific region: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 1, p. 3–30.

Hudson, T., 1983, Calc-alkaline plutonism along the Pacific rim of southern Alaska, *in* Roddick, J. A., ed., Circum-Pacific plutonic terranes: Geological Society of America Memoir 159, p. 159–169.

Hudson, T., and Plafker, G., 1981, Emplacement age of the Crillon–La Perouse pluton, Fairweather Range, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B90–B94.

——, 1982, Paleogene metamorphism of an accretionary flysch terrane, eastern Gulf of Alaska: Geological Society of America Bulletin, v. 93, p. 1280–1290.

Hudson, T., Plafker, G., and Rubin, M., 1976, Uplift rates of marine terrace sequences in the Gulf of Alaska, *in* Cobb, E. H., ed., The United States Geological Survey in Alaska: Accomplishments during 1975: U.S. Geological Survey Circular 733, p. 11–13.

Hudson, T., Plafker, G., and Lanphere, M. A., 1977, Intrusive rocks of the Yakutat–Saint Elias area, south-central Alaska: U.S. Geological Survey Journal of Research, v. 5, p. 155–172.

Hudson, T., Plafker, G., and Peterman, Z. E., 1979, Paleogene anatexis along the Gulf of Alaska marine: Geology, v. 7, p. 573–577.

Hudson, T., Plafker, G., and Dixon, K., 1982, Horizontal offset history of the Chatham Strait fault, *in* Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 128–132.

Jones, D. L., and Clark, S.H.B., 1973, Upper Cretaceous (Maestrichtian) fossils from the Kenai-Chugach mountains, Kodiak and Shumagin islands, southern Alaska: U.S. Geological Survey Journal of Research, v. 1, p. 125–136.

Jones, D. L., and Silberling, N. J., 1982, Mesozoic stratigraphy: The key to tectonic analysis of southern and central Alaska, *in* Leviton, A. E., and others, eds., Fronters of geological exploration of western North America (American Association for the Advancement of Science, Pacific Section, Annual Meeting, 60th Moscow, Idaho, 1979): American San Francisco, California, American Association for the Advancement of Science, p. 139–153.

Jones, D. L., Silberling, N. J., Berg, H. C., and Plafker, G., 1981, Map showing tectonostratigraphic terranes columnar sections, and summary description of terranes: U.S. Geological Survey Open-File Report 81-792, scale 1:2,500,000.

Jones, D. L., Silberling, N. J., Coney, P. J., and Plafker, G., 1987, Lithotectonic terrane map of Alaska (west of the 41st meridian): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-A, scale 1:2,500,000.

Karl, S. M., Decker, J. E., and Johnson, B. R., 1982, Discrimination of Wrangellia and the Chugach terrane in the Kelp Bay Group on Chichagof and Baranof islands, southeastern Alaska, *in* Coonrad, W. L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 124–128.

Karl, S. M., Brew, D. A., and Wardlaw, B. R., 1990, Significance of Triassic marble from Nakwasina Sound, southeastern Alaska, *in* Dover, J. H., and Galloway, J. P., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological Survey Bulletin 1946, p. 21–28.

Keller, G., von Huene, R., McDougall, K. R., and Bruns, T. R., 1984, Paleoclimatic evidence for Cenozoic migration of Alaskan terranes: Tectonics, v. 3, p. 473–495.

Kelley, J. S., 1985, Geologic setting of the Kenai Peninsula and Cook Inlet Tertiary basin, south-central Alaska, *in* Sisson, A., ed., Guide to the geology of the Kenai Peninsula, Alaska: Anchorage, Alaska Geological Society, p. 3–19.

Kienle, J., and Turner, D. L., 1976, The Shumagin-Kodiak batholith—A Paleocene magmatic arc?, *in* Short notes on Alaskan geology—1976: Alaska Division of Geological and Geophysical Surveys Geologic Report 51, p. 9–11.

Lahr, J. C., and Plafker, G., 1980, Holocene Pacific–North American plate interaction in southern Alaska: Implications for the Yakataga seismic gap: Geology, v. 8, p. 483–486.

Little, T. A., 1990, Kinematics of wrench and divergent-wrench deformation along a central part of the Border Ranges fault system, northern Chugach Mountains, Alaska: Tectonics, v. 9, p. 585–611.

Loney, R. A., and Brew, D. A., 1987, Regional thermal metamorphism and deformation of the Sitka Graywacke, southern Baranof Island, southeastern Alaska: U.S. Geological Survey Bulletin 1779, 17 p.

Loney, R. A., and Himmelberg, G. R., 1983, Structure and petrology of the La Perouse gabbro intrusion, Fairweather Range, southeastern Alaska: Journal of Petrology, v. 24, p. 377–423.

Loney, R. A., Brew, D. A., Muffler, L.J.P., and Pomeroy, J. S., 1975, Reconnaissance geology of Chichagof, Baranof, and Kruzof islands, southeastern Alaska: U.S. Geological Survey Professional Paper 792, 105 p.

Lonsdale, P., 1988, Paleogene history of the Kula plate: Offshore evidence and onshore implications: Geological Society of America Bulletin, v. 100, p. 733–754.

Lull, J. S., and Plafker, G., 1985, Petrography of sandstone from the Yakutat Group, Malaspina district, southern Alaska, *in* Bartsch-Winkler, S., and Reed, K. M., eds., The U.S. Geological Survey in Alaska: Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 73–77.

—— , 1990, Geochemistry and paleotectonic implications of metabasaltic rocks in the Valdez Group, southern Alaska, *in* Dover, J. H., and Galloway, J. P., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological Survey Bulletin 1946, p. 29–38.

Lyle, W., Morehouse, J., Palmer, I. F., Jr., Bolm, J. G., Moore, G. W., and Nilsen, T. H., 1977, Tertiary formations in the Kodiak Island area, Alaska, and their petroleum reservoir and source-rock potential: Fairbanks, Alaska Division of Geological and Geophysical Surveys Open-File Report 114, 48 p.

MacKevett, E. M., Jr., and Plafker, G., 1974, The Border Ranges fault in south-central Alaska: U.S. Geological Survey Journal of Research, v. 2, p. 323–329.

Marincovich, L., Jr., 1990, Molluscan evidence for early middle Miocene marine glaciation in southern Alaska: Geological Society of America Bulletin, v. 102, p. 1591–1599.

Marshak, R. S., and Karig, D. E., 1977, Triple junctions as a cause for anomalously near-trench igneous activity between the trench and volcanic arc: Geology, v. 5, p. 233–236.

McClelland, W. C., Gehrels, G. E., and Saleeby, J. B., 1992, Upper Jurassic–Lower Cretaceous basinal strata along the Cordilleran margin: Implications for the accretionary history of the Alexander-Wrangellia-Peninsular terrane: Tectonics, v. 11, p. 823–835.

Mitchell, P. A., 1979, Geology of the Hope-Sunrise (gold) mining district, north-central Kenai Peninsula, Alaska [M.S. thesis]: Stanford, California, Stanford University, 123 p.

Monger, J.W.H., and Berg, H. C., 1987, Lithotectonic terrane map of western Canada and southeastern Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-B, 12 p., scale 1:2,500,000.

Monger, J.W.H., Price, R. A., and Tempelman-Kluit, D. J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70–75.

Moore, G. W., 1969, New Formations on Kodiak and adjacent islands, Alaska, *in* Cohee, G. V., Bates, R. G., and Wright, W. B., compilers, Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1967: U.S. Geological Survey Bulletin 1274-A, p. A27–A35.

Moore, J. C., 1973, Cretaceous continental margin sedimentation, southwestern Alaska: Geological Society of America Bulletin, v. 84, p. 595–613.

—— , 1974, Geologic and structural map of part of the outer Shumagin Islands, southwestern Alaska: U.S. Geological Survey Miscellaneous Investigation Series Map I-815, scale 1:63,360.

Moore, J. C., and Allwardt, A., 1980, Progressive deformation of a Tertiary trench slope, Kodiak Islands, Alaska: Journal of Geophysical Research, v. 85, p. 4741–4756.

Moore, J. C., and Connelly, W., 1979, Tectonic history of the continental margin of southwestern Alaska: Late Triassic to earliest Tertiary, *in* Sisson, A., ed., The relationship of plate tectonics to Alaskan geology and resources: (Proceedings, Alaska Geological Society Symposium, 6th, 1977, Anchorage): Anchorage, Alaska Geological Society, p. H1–H29.

Moore, J. C., and Wheeler, R. L., 1978, Structural fabric of a melange, Kodiak Islands, Alaska: American Journal of Science, v. 278, p. 739–765.

Moore, J. C., Byrne, T., Plumley, P. W., Reid, M., Gibbons, H., and Coe, R. S., 1983, Paleogene evolution of the Kodiak Islands, Alaska: Consequences of ridge-trench interaction in a more southerly latitude: Tectonics, v. 2, p. 265–293.

Moore, J. C., and 11 others, 1991, EDGE deep seismic reflection transect of the eastern Aleutian arc-trench layered lower crust reveals underplating and continental growth: Geology, v. 19, p. 420–424.

Muller, J. E., 1977, Geology of Vancouver Island: Geological Survey of Canada Open-File Map 463, scale 1:250,000.

Nelson, S. W., and Blome, C. D., 1991, Preliminary geochemistry of volcanic rocks from the McHugh Complex and Kachemak terrane, southern Alaska: U.S. Geological Survey Open-File Report 91-134, 14 p.

Nelson, S. W., Dumoulin, J. A., and Miller, M. L., 1985, Geologic map of the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1645-B, 16 p., scale 1:250,000.

Nelson, S. W., Blome, C. D., Harris, A. G., Reed, K. M., and Wilson, F. H., 1986, Late Paleozoic and Early Jurassic fossil ages from the McHugh Complex, *in* Bartsch-Winkler, S., and Reed, K. M., eds., Geological studies studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 60–64.

Nilsen, T. H., and Bouma, A. H., 1977, Turbidite sedimentology and depositional framework of the Upper Cretaceous Kodiak Formation and related stratigraphic units, southern Alaska: Geological Society of America Abstracts with Programs, v. 9, p. 1115.

Nilsen, T. H., and Moore, G. W., 1979, Reconnaissance study of Upper Cretaceous to Miocene stratigraphic units and sedimentary facies, Kodiak and adjacent islands, Alaska: U.S. Geological Survey Professional Paper 1093, 34 p.

Nilsen, T. H., and Zuffa, G. G., 1982, The Chugach terrane, a Cretaceous trench-fill deposit, southern Alaska, *in* Leggett, J. K., ed., Trench-forearc geology; sedimentation and tectonics on modern and ancient active plate margins, conference: Geological Society of London Special Publication 10, p. 213–227.

Nilsen, T. H., Plafker, G., Atwood, D. E., and Hill, E. R., 1984, Sedimentology of flysch of the upper Mesozoic Yakutat Group, Malaspina district, Alaska, *in* Reed, K. M., and Bartsch-Winkler, S., eds., The United States Geological Survey in Alaska: Accomplishments during 1982: U.S. Geological Survey Circular 939, p. 57–60.

Nokleberg, W. J., Jones, D. L., and Silberling, N. J., 1985, Origin and tectonic evolution of the Maclaren and Wrangellia terranes, eastern Alaska Range, Alaska: Geological Society of America Bulletin, v. 96, p. 1251–1270.

Nokleberg, W. J., Plafker, G., Lull, J. S., Wallace, W. K., and Winkler, G. R., 1989, Structural analysis of the southern Peninsular, southern Wrangellia, and northern Chugach terranes along the Trans-Alaska Crustal Transect, northern Chugach Mountains, Alaska: Journal of Geophysical Research, v. 94, p. 4297–4320.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841–875.

Olson, D. L., Larson, J. A., and Turner, R. F., 1987, Biostratigraphy, *in* Turner, R. F., ed., Geological and operational summary, Kodiak shelf stratigraphic test wells, western Gulf of Alaska: Anchorage, Alaska, Minerals Management Service, Outer Continental Shelf Report MMS 87-0109, p. 139–191.

Page, R. A., 1975, Evaluation of seismicity and earthquake shaking at offshore sites: Houston, Texas, Annual Offshore Technology Conference, 7th, Proceedings, v. 3, p. 179–190.

Page, R. A., Stephens, C. D., and Lahr, J. C., 1989, Seismicity of the Wrangell and Aleutian Wadati-Benioff zones and the North American plate along the Trans-Alaska Crustal Transect, Chugach Mountains and Copper River basin, southern Alaska: Journal of Geophysical Research, p. 16,059–16,082.

Palmer, A. R., 1983, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, p. 503–504.

Pavlis, T. L., 1982, Origin and age of the Border Ranges fault of southern Alaska and its bearing on the late Mesozoic evolution of Alaska: Tectonics, v. 1, p. 343–368.

Pavlis, T. L., and Crouse, G. W., 1989, Late Mesozoic strike-slip movement on the Border Ranges fault system in the eastern Chugach Mountains, southern Alaska: Journal of Geophysical Research, v. 94, p. 4321–4332.

Pavlis, T. L., Monteverde, D. H., Bowman, J. R., Rubenstone, J. L., and Reason, M. D., 1988, Early Cretaceous near-trench plutonism in southern Alaska: A tonalite-trondhjemite intrusive complex injected during ductile thrusting along the Border Ranges fault system: Tectonics, v. 7, p. 1179–1199.

Plafker, G., 1967, Surface faults on Montague Island associated with the 1964 Alaska earthquake: U.S. Geological Survey Professional Paper 543-G, 42 p.

—— , 1974, Gulf of Alaska coastal zone, *in* Spencer, A. M., ed., Mesozoic-Cenozoic orogenic belts; data for orogenic studies: Geological Society of London Special Publication 4, p. 573–576.

—— , 1984, Comment *on* "Model for the origin of the Yakutat block, an accreting terrane in the northern Gulf of Alaska": Geology, v. 12, p. 563.

—— , 1987, Regional geology and petroleum potential of the northern Gulf of Alaska continental margin, *in* Scholl, D. W., Grantz, A., and Vedder, J. G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 229–268.

—— , 1990, Regional geology and tectonic evolution of Alaska and adjacent parts of the northeast Pacific Ocean margin: Proceedings of the Pacific Rim Congress 90: Queensland, Australia, Australasian Institute of Mining and Metallurgy, p. 841–853.

Plafker, G., and Campbell, R. B., 1979, The Border Ranges fault in the Saint Elias Mountains, *in* Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B102–B104.

Plafker, G., and Rubin, M., 1978, Uplift history and earthquake recurrence as deduced from marine terraces on Middleton Island, Alaska, *in* Proceedings of Conference VI, Methology for identifying seismic gaps and soon-to-break gaps: U.S. Geological Survey Open-File Report 78-943, p. 687–721.

Plafker, G., Jones, D. L., and Pessagno, E. A., Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin, *in* Blean, K. M., ed., The United States Geological Survey in Alaska: Accomplishments during 1976: U.S. Geological Survey Circular 751-B, p. B41–B43.

Plafker, G., Hudson, T., Bruns, T. R., and Rubin, M., 1978, Late Quaternary offsets along the Fairweather fault and crustal plate interactions in southern Alaska: Canadian Journal of Earth Sciences, v. 15, p. 805–816.

Plafker, G., Bruns, T. R., Winkler, G. R., and Tysdal, R. G., 1982, Cross section of the eastern Aleutian arc, from Mount Spurr to the Aleutian Trench near Middleton Island, Alaska: Geological Society of America Map and Chart Series MC-28P, scale 1:250,000.

Plafker, G., Harris, A. G., and Reed, K. M., 1985a, Early Pennsylvanian conodonts from the Strelna Formation, Chitina Valley, *in* Bartsch-Winkler, S., ed., The U.S. Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 71–74.

Plafker, G., Keller, G., Barron, J. A., and Blueford, J. R., 1985b, Paleontologic data on the age of the Orca Group, Alaska: U.S. Geological Survey Open-File Report 85-429, 24 p.

Plafker, G., Nokleberg, W. J., Lull, J. S., Roeske, S. M., and Winkler, G. R., 1986, Nature and timing of deformation along the Contact fault system in the Cordova, Bering Glacier, and Valdez quadrangles, *in* Bartsch-Winkler, S., and Reed, K. M., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 74–77.

Plafker, G., Nokleberg, W. J., and Lull, J. S., 1989, Bedrock geology and tectonic evolution of the Wrangellia, Peninsular, and Chugach terranes along the Trans-Alaska Crustal Transect in the Chugach Mountains and southern Copper River basin, Alaska: Journal of Geophysical Research, v. 94, p. 4255–4295.

Plumley, P. W., and Plafker, G., 1985, Additional estimate of paleolatitude for the Paleocene/Eocene(?) Prince William terrane–Orca volcanics: Geological Society of America Abstracts with Programs, v. 17, p. 401.

Plumley, P. W., Coe, R. S., and Byrne, T., 1983, Paleomagnetism of the Paleocene Ghost Rocks Formation, Prince William terrane, Alaska: Tectonics, v. 2, p. 295–314.

Rau, W. W., Plafker, G., and Winkler, G. R., 1983, Foraminiferal biostratigraphy and correlations in the Gulf of Alaska Tertiary province: U.S. Geological Survey Oil and Gas Investigations Chart OC-120, 11 p., 3 sheets.

Richter, D. H., 1965, Geology and mineral deposits of central Knight Island, Prince William Sound, Alaska: Alaska Division of Mines and Minerals Geologic Report 16, 37 p.

Roeske, S. M., 1986, Field relations and metamorphism of the Raspberry Schist, Kodiak Islands, Alaska, *in* Evans, B. W., and Brown, E. H., eds., Blueschists and eclogites: Geological Society of America Memoir 164, p. 169–184.

Roeske, S. M., Mattinson, J. M., and Armstrong, R. L., 1989, Isotopic ages of glaucophane schists on the Kodiak Islands, southern Alaska, and their implications for the Mesozoic tectonic history of the Border Ranges fault system: Geological Society of America Bulletin, v. 101, p. 1021–1037.

Roeske, S. M., Snee, L. W., and Pavlis, T. L., 1991, Strike-slip and accretion events along the southern Alaska plate margin in the Cretaceous and early Tertiary: Geological Society of America Abstracts with Programs, v. 23, p. 428–429.

Rogers, J. F., 1977, Implications of plate tectonics for offshore Gulf of Alaska petroleum exploration: Houston, Texas, Annual Offshore Technology Conference, 9th, Proceedings, v. 1, p. 11–16.

Saleeby, J. B., 1983, Accretionary tectonics of the North American Cordillera: Annual Review of Earth and Planetary Sciences, v. 11, p. 45–73.

Sample, J. C., and Fisher, D. M., 1986, Duplex accretion and underplating in an ancient accretionary complex, Kodiak Islands, Alaska: Geology, v. 14, p. 160–163.

Sample, J. C., and Moore, J. C., 1987, Structural style and kinematics of an underplated slate belt, Kodiak and adjacent islands, Alaska: Geological Society of America Bulletin, v. 99, p. 7–20.

Savage, J. C., and Lisowski, M., 1988, Deformation in the Yakataga seismic gap, southern Alaska, 1980–1986: Journal of Geophysical Research, v. 93, p. 4731–4744.

Schaff, R. G., and Gilbert, W. G., 1987, Southern Alaska region correlation chart, *in* Correlation of stratigraphic units of North America (COSUNA) project: Tulsa, Olkahoma, American Association of Petroleum Geologists.

Silberman, M. L., MacKevett, E. M., Jr., Connor, C. L., Klock, P. R., and Kalechitz, G., 1981, K-Ar ages of the Nilolai Greenstone from the McCarthy quadrangle, Alaska—The "docking" of Wrangellia, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B61–B63.

Sisson, V. B., and Onstott, T. C., 1986, Dating blueschist metamorphism: A combined $^{49}Ar/^{39}Ar$ and electron microprobe approach: Geochimica et Cosmochimica Acta, v. 50, p. 2111–2117.

Sisson, V. B., Hollister, L. S., and Onstott, T. C., 1989, Petrologic and age constraints on the origin of a low-pressure/high-temperature metamorphic complex, southern Alaska: Journal of Geophysical Research, v. 94,

p. 4392–4410.

Stewart, R. J., 1976, Turbidites of the Aleutian abyssal plain: Mineralogy, provenance, and constraints for Cenozoic motion of the Pacific plate: Geological Society of America Bulletin, v. 87, p. 793–808.

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

Stone, D. B., Panuska, B. C., and Packer, D. R., 1982, Paleolatitudes versus time for southern Alaska: Journal of Geophysical Research, v. 87, p. 3697–3707.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Sutherland-Brown, A., 1968, Geology of the Queen Charlotte Islands, British Columbia: British Columbia Department of Mines and Petroleum Resources Bulletin 54, 225 p.

Taylor, P. T., and O'Neill, N. J., 1974, Results of an aeromagnetic survey of the Gulf of Alaska: Journal of Geophysical Research, v. 79, p. 719–723.

Turner, F. J., 1981, Metamorphic petrlogy (second edition): New York, McGraw Hill, 524 p.

Turner, R. F., ed., 1987, Geological and operational summary, Kodiak shelf stratigraphic test wells, western Gulf of Alaska: Anchorage, Alaska, Minerals Management Service, Outer Continental Shelf Report MMS 87-0109, 341 p.

Tysdal, R. G., and Case, J. E., 1979, Geologic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-1150, 12 p., scale 1:250,000.

Tysdal, R. G., and Plafker, G., 1978, Age and continuity of the Valdez Group, southern Alaska, *in* Sohl, N. F., and Wright, W. B., compilers, Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1977: U.S. Geological Survey Bulletin 1457-A, p. 120–131.

Van Alstine, D. R., Bazard, D. R., and Whitney, J. W., 1985, Paleomagnetism of cores from the Yakutat well, Gulf of Alaska: Eos (Transactions, American Geophysical Union), v. 66, p. 865.

Van der Voo, R., Jones, M., Grommé, C. S., Eberlein, G. D., and Churkin, M., Jr., 1980, Paleozoic paleomagnetism and northward drift of the Alexander terrane, southeastern Alaska: Journal of Geophysical Research, v. 85, p. 5281–5296.

von Huene, R., Fisher, M. A., and Bruns, T. R., 1987, Geology and evolution of the Kodiak margin, Gulf of Alaska, *in* Scholl, D. W., Grantz, A., and Vedder, J. G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 191–212.

Vrolijk, P., Myers, G., and Moore, J. C., 1988, Warm fluid migration along tectonic melanges in the Kodiak accretionary complex, Alaska: Journal of Geophysical Research, v. 93, p. 10,313–10,324.

Wiley, T. J., 1986, Sedimentary basins of offshore Alaska and adjacent regions: U.S. Geological Survey Open-File Report OF 86-35, 118 p.

Winkler, G. R., 1976, Deep-sea fan deposition of the lower Tertiary Orca Group, eastern Prince William Sound, Alaska, *in* Miller, T. P., ed., Recent and ancient sedimentary environments in Alaska (Symposium Proceedings): Anchorage, Alaska Geological Society, p. R1–R20.

——, 1992, Geologic map, cross sections, and summary geochronology of the Anchorage quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-2283, scale 1:250,000.

Winkler, G. R., and Plafker, G., 1981a, Tectonic implications of framework grain mineralogy of sandstone from the Yakutat Group, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B68–B70.

——, 1981b, Geologic map and cross sections of the Cordova and Middleton Island quadrangles, southern Alaska: U.S. Geological Survey Open-File Report 81-1164, scale 1:250,000.

Winkler, G. R., McLean, H., and Plafker, G., 1976, Textural and mineralogical study of sandstones from the onshore Gulf of Alaska Tertiary province, southern Alaska: U.S. Geological Survey Open-File Report 76-198, 48 p.

Winkler, G. R., Silberman, M. L., Grantz, A., Miller, R. J., and MacKevett, E. M., Jr., 1981, Geologic map and summary geochronology of the Valdez quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 80-892-A, scale 1:250,000, 2 sheets.

Winkler, G. R., Miller, M. L., Hoekzema, R. B., and Dumoulin, J. A., 1984, Guide to the bedrock geology of a traverse of the Chugach Mountains from Anchorage to Cape Resurrection: Anchorage, Alaska Geological Society, 40 p.

Wolf, L. W., Stone, D. B., and Davies, J. N., 1991, Crustal structure of the active margin, south-central Alaska: An interpretation of seismic refraction data from the Trans-Alaska Crustal Transect: Journal of Geophysical Research, v. 96, p. 16,455–16,469.

Yao, A., Matsuoka, A., and Nakatani, T., 1982, Triassic and Jurassic radiolarian assemblages in southwest Japan: News of Osaka Micropaleontologists, Special Volume 5, p. 27–43.

Zuffa, G. G., Nilsen, T. H., and Winkler, G. R., 1980, Rock-fragment petrography of the Upper Cretaceous Chugach terrane, southern Alaska: U.S. Geological Survey Open-File Report 80-713, 28 p.

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