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Chapter 33

Overview of the geology and tectonic evolution of Alaska

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INTRODUCTION

In this chapter we present a brief overview of major aspects of the geology and tectonic evolution of Alaska. Our objective has been to incorporate the lithologic, structural, paleontologic, geophysical, and paleomagnetic data presented in this volume and elsewhere into a series of generalized interpretive maps that depict our version of the Phanerozoic tectonic evolution of Alaska. Where necessary, adjacent areas of Canada and the conterminous United States are discussed and shown on the maps. Many stratigraphic and tectonic relations germane to Alaska are present in those regions and some terranes now in Alaska were derived from regions to the south.

Our interpretation emphasizes evaluation of the data according to plate tectonics models and the concept that much of Alaska is a collage of tectonostratigraphic terranes that have been displaced to varying degrees relative to each other and to the North American craton. Many problems remain, however, and alternative interpretations have been proposed by others for virtually every major aspect of the model presented here. We hope that this synthesis will highlight crucial areas for future research in order to resolve ambiguities among the array of data sets and analog models.

Principal data sources

The first part of this chapter presents the major constraints used to develop the models of the Phanerozoic tectonic evolution of Alaska that follow. This synthesis is based on the geologic and geophysical literature of Alaska and adjacent regions of the North American continent and ocean basins, much of which is summarized in this volume. Space limitations preclude acknowledging all sources of data and ideas. The cited papers, many of which are syntheses of broad areas and topics, contain extensive bibliographic references to original data sources.

Base maps used in all figures are Albers equal-area projections. Geologic time terms used are those of Palmer (1983). Unless otherwise stated, orientations of all geologic and geographic features refer to present geographic coordinates.

LITHOTECTONIC TERRANES OF ALASKA

Figure 1 shows all but the smallest structurally bound lithotectonic terranes and subterranes that have been delineated in Alaska and adjacent parts of Canada as well as major areas of Cretaceous and Cenozoic basinal deposits. As defined by Jones and others (1983), Howell and others (1985), and Howell (1989), lithotectonic terranes (also called "suspect" or "tectonostratigraphic" terranes) are fault-bounded geologic packages of regional extent characterized by a geologic history different from that of neighboring terranes. They may or may not have had large displacements relative to nearby terranes. Terrane recognition, displacement histories, timing of accretion, and boundary conditions have been the subjects of an extensive literature (e.g., Coney and others, 1980; Coney and Jones, 1985; Jones and others, 1977, 1983, 1987; Monger and others, 1982, 1991; Monger and Berg, 1987; Saleeby, 1983; Plafker, 1990), and many of the terrane names and definitions in Alaska have continued to evolve since the terrane concept was introduced. Detailed studies have shown that some of these terranes may have undergone little or no displacement relative to adjacent terranes and that the original terrane definitions either have been modified or are no longer applicable. Except as otherwise noted, in this paper we adhere to the terrane nomenclature of Silberling and others (this volume, Plate 3) to describe these lithologically distinctive belts of rock.

Terranes shown in Figure 1 include displaced and/or rotated noncrystalline and crystalline fragments of the continental margin; probable continental margin magmatic arcs; dominantly oceanic crust and associated sedimentary rocks; intraoceanic magmatic arcs, oceanic plateaus, and rift-fill assemblages; and arc-related accretionary prisms. The main tectonic affinity of the larger terranes is indicated by map patterns. Several unique terranes too small to depict or name in Figure 1 are present primarily along major suture boundaries; these include fault slivers of adjacent terranes, fragments of exotic terranes that were probably carried to their present positions along the margins of larger terranes, and small crystalline terranes, the origins of which are obscured by plutonism and/or metamorphism.

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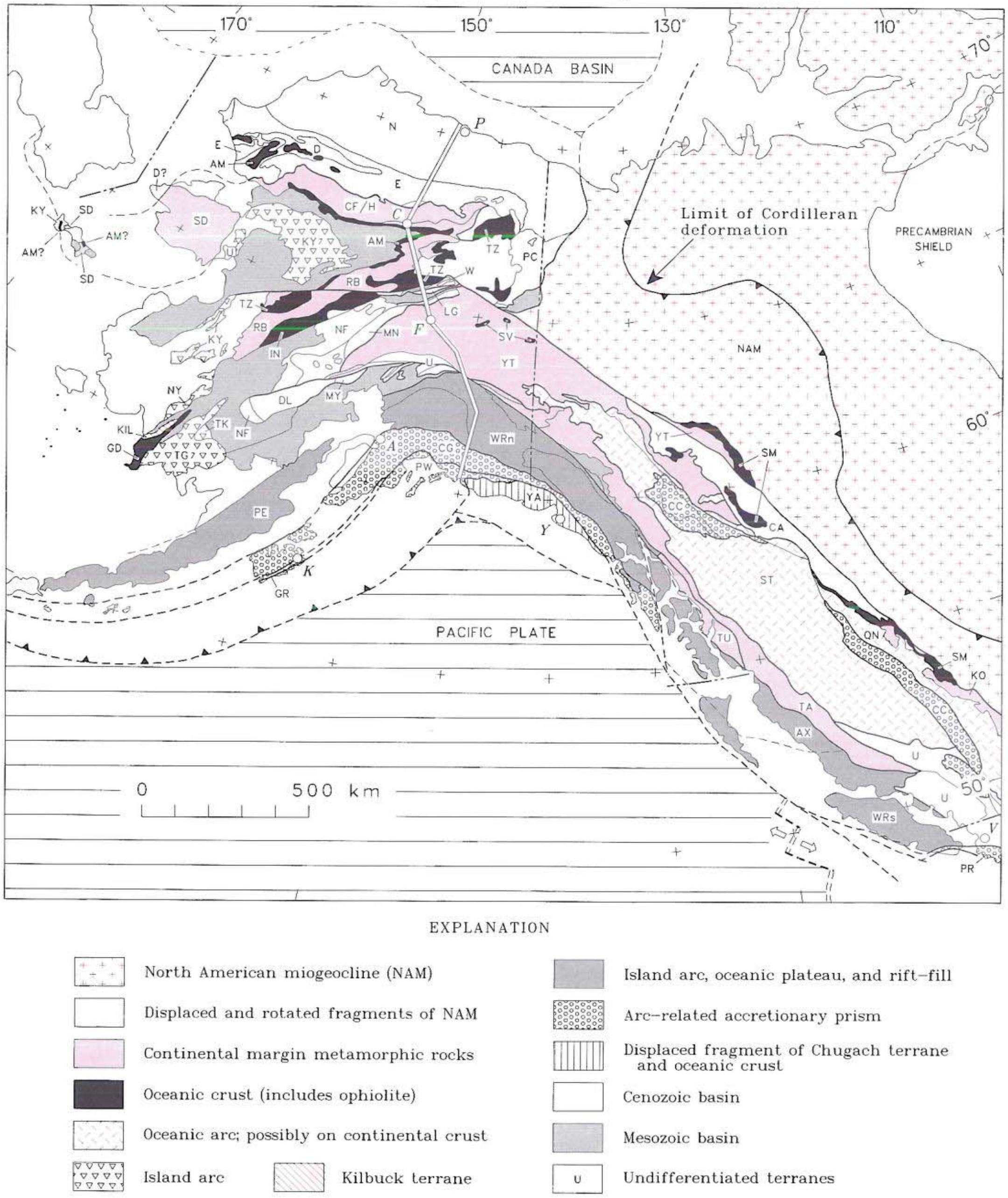

Figure 1. Generalized distribution and inferred tectonic affinity of selected terranes in Alaska and western Canada. North American craton: NAM: Displaced and/or rotated fragments of the North American craton margin: N, North Slope; E, Endicott; D, Delong Mountains; PC, Porcupine; MN, Minchumina; NF, Nixon Fork; DL, Dillinger; CA, Cassiar; MY, Mystic; W, undifferentiated Baldry, Minook, White Mountains, and Wickersham terranes. Dominantly metamorphic terranes of continental affinity: SD, Seward; CF/H, Coldfoot and Hammond; RB, Ruby; YT, Yukon-Tanana; KO, Kootenay; TA, Tracy Arm; TU, southern Taku. Precambrian metamorphic terrane of probable continental margin arc affinity: KIL, Kilbuck and related Idono Complex. Magmatic arc terrane of probable continental margin affinity: QN, Quesnellia; ST, Stikine. Dominantly oceanic terranes: AM, Angayucham; GD, Goodnews; IN, Innoko; LG, Livengood; SM, Slide Mountain; SV, Seventymile; TZ, Tozitna. Intraoceanic magmatic arc terranes: KY, Koyukuk; NY, Nyack; TG, Togiak; TK, Tikchik(?). Magmatic arc, oceanic plateau, and rift-fill assemblages: AX, Alexander; PE, Peninsular; WRn, Wrangellia (Alaska); WRs, Wrangellia (British Columbia). Arc-related accretionary prisms: CG, Chugach; GR, Ghost Rocks; PW, Prince William; CC, Cache Creek; PR, Pacific Rim. Displaced fragment of Chugach terrane and oceanic crust: YA, Yakutat terrane. Terranes generalized from Silberling and others (this volume, Plate 3). The double north-south line is the approximate route of the Trans-Alaska oil pipeline and of a major geological and geophysical study of the deep crust of Alaska (Trans-Alaska Crustal Transect). Locality abbreviations: A, Anchorage; C, Coldfoot; F, Fairbanks; K, Kodiak; P, Prudhoe Bay; V, Vancouver; Y, Yakutat.

TERRANES AND COMPOSITE TERRANES

In the tectonic reconstructions that follow, most larger terranes in the Cordillera of Alaska and Canada outboard of the North American craton are grouped into composite terranes (CTs) based on affinities in their inferred lithotectonic setting and tectonic evolution. These are the Arctic CT, Central CT, Yukon CT, Togiak-Koyukuk CT, Oceanic CT, Wrangellia CT, and Southern Margin CT (Fig. 2). As used in this chapter, a composite terrane is an aggregate of subordinate terranes which are grouped based on an interpretation of similar lithotectonic kindred or affinity. This is similar to Coney's (1989) definition for a superterrane. It differs from the Howell and others (1985) definition for a composite terrane in that there is no implication regarding whether the terranes came together before or after accretion to the continent. We adopt this definition because timing

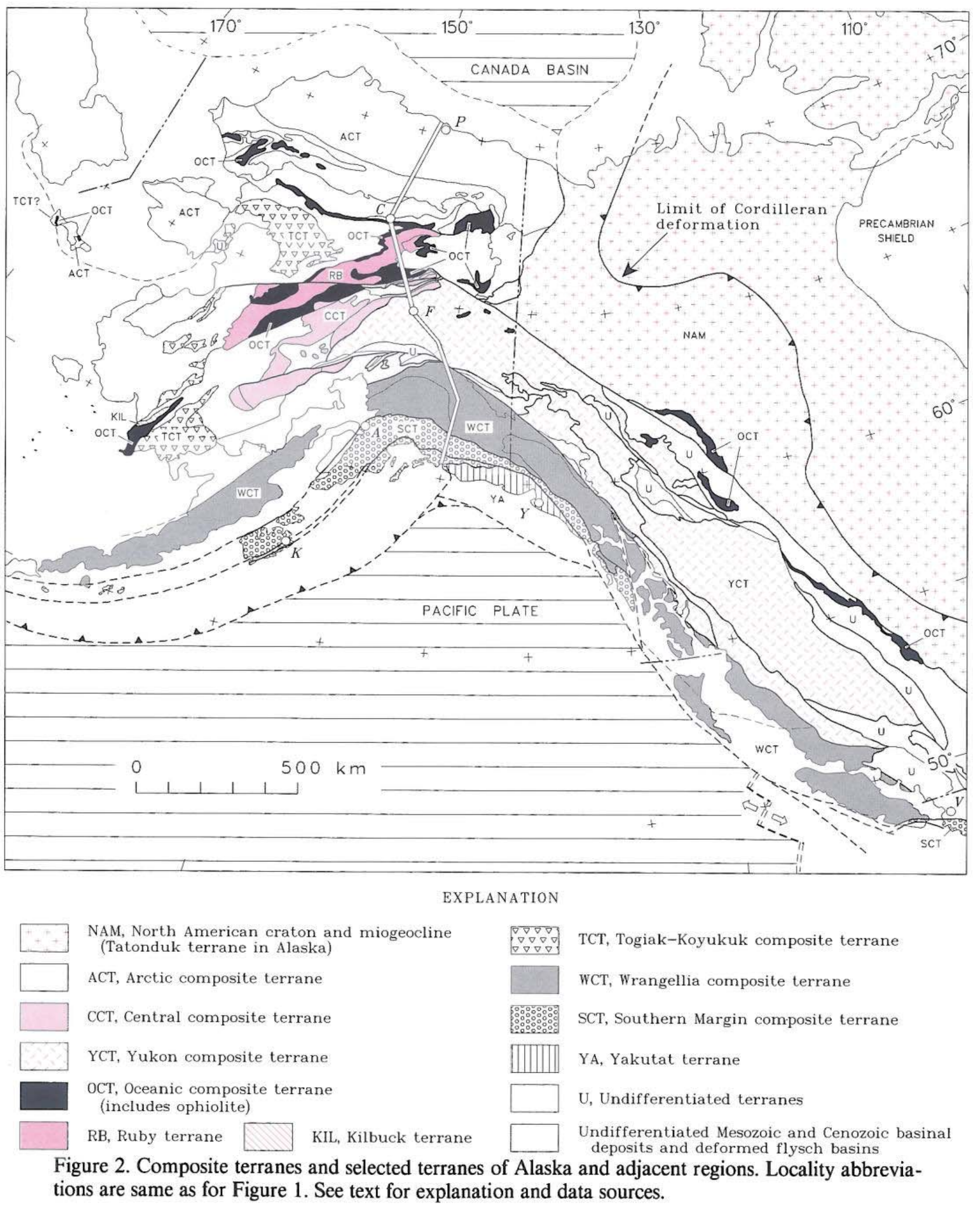

Figure 2. Composite terranes and selected terranes of Alaska and adjacent regions. Locality abbreviations are same as for Figure 1. See text for explanation and data sources.

of accretion is inapplicable in the case of composite terranes such as the Arctic CT, which rotated away from the craton but probably never was separated from it at the hinge (eastern) end.

In Alaska, the relatively large Ruby terrane in interior Alaska and the Yakutat terrane in southern Alaska (units RB and YT, Figs. 1 and 2) are not included with the CTs. Although it is likely that the Ruby terrane was originally part of the Arctic CT, we discuss it separately from the Arctic CT to emphasize differences in their Cretaceous and Tertiary rotation histories. The Yakutat terrane is discussed separately because its relation to nearby terranes is uncertain. In addition, there are small, isolated terranes whose relations to nearby terranes also are uncertain. Of these small terranes, the Kilbuck terrane in western Alaska is differentiated (KIL, Figs. 1 and 2) because it includes the only Early Proterozoic rocks in Alaska. Small terranes not discussed in this paper are mainly those along and near the Denali fault in south-central Alaska (unpatterned areas, Figs. 1 and 2).

All terranes west of the craton have moved to some extent, although many questions remain concerning the nature, timing, and magnitude of these displacements. The composite terranes and Ruby terrane were assembled into their present relative positions mainly from Middle Jurassic to Eocene time. The Yakutat terrane has been accreting to the southern margin of Alaska from Miocene time to the present. Variably metamorphosed Cretaceous flysch separates many of the internally deformed but coherent displaced terranes. Postaccretionary basin deposits, for which information on underlying terranes is sparse or absent, are present throughout Alaska and occupy extensive tracts of western Alaska (Kirschner, this volume).

North American craton margin

The small segment of the Cordilleran miogeocline in east-central Alaska (unit NAM, Figs. 1 and 2), which constitutes less than 1% of the total area of Alaskan terranes, is generally considered to be part of the autochthonous North American plate (Churkin and others, 1982; Jones and others, 1987). These strata display a well-preserved succession of Precambrian and Paleozoic miogeoclinal rocks that correlates closely with rocks to the east and southeast on the margin of the North American craton (Churkin and others, 1982; Dover, this volume). Howell and Wiley (1987) argued that strata in this area are an allochthonous part of the craton margin. The base of the sequence in Alaska consists of Late Proterozoic shelf to offshelf clastic rocks, including glacial diamictites, carbonate rocks, chert, and pillow basalt. Precambrian rocks are overlain by Cambrian to Devonian carbonate rocks, shale, and chert deposited during a major marine transgression that followed probable Late Proterozoic to early Paleozoic continental margin extension and subsidence (Howell and Wiley, 1987). The upper part of the sequence consists of Devonian clastic fan deposits derived from a western source terrain overlain by Upper Devonian and Mississippian siliceous shale and limestone. Permian and Triassic shallow-marine limestone and minor clastic rocks overlie the older sequence with angular unconformity.

Arctic composite terrane

The Arctic CT (unit ACT, Fig. 2) makes up about 25% of the area of Alaskan terranes. As used here the Arctic CT includes the Arctic Alaska terrane (Silberling and others, this volume, Plate 3; Moore and others, this volume) and its subterranes (North Slope, Endicott, Delong Mountains, Coldfoot, Hammond), the Porcupine and Seward Peninsula terranes, and probably parts of Saint Lawrence Island. The Arctic Alaska terrane and its constituent subterranes of Silberling and others (this volume) are equivalent to the Arctic Alaska superterrane and its constituent terranes as redefined by Moore (1992). In this volume, summaries of the regional geology of the Arctic CT are by Dover (southeastern Brooks Range), Grantz and others (Arctic basin and margins), Moore and others (Brooks Range and North Slope), and Till and Dumoulin (Seward Peninsula and St. Lawrence Island). Relevant topical studies include those by Barker (volcanic rocks), Dusel-Bacon (metamorphism), Hudson (anatectic granites), Kirschner (basins), Miller (plutonic rocks), and Patton (ophiolites). In this synthesis, we interpret the Arctic CT as a segment of the North American miogeocline that was displaced to its present position by rotation away from Arctic Canada.

The stratigraphy is characterized by deformed Late Proterozoic to Devonian rocks that record a history of continental margin and carbonate platform sedimentation, emplacement of Late Proterozoic and Cambrian tholeiitic basalt, and eruption of andesitic volcanic rocks of probable Ordovician age (Moore and others, this volume). A single occurrence of Cambrian trilobites of Siberian affinity suggests that at least part of the composite terrane is exotic to Alaska (Grantz and others, 1991) or that there was a marine connection with Eurasia at that time. In the metamorphic belt along the southern margin of the Arctic CT, metaclastic rocks are intruded by Proterozoic metagranitic rocks as old as 750 Ma and the rocks locally retain evidence of an amphibolite facies metamorphic event (Karl and others, 1989). The pre–Upper Devonian rocks (Franklinian sequence) were deformed, intruded by late Early to Middle Devonian granitic plutons, and locally (in the northeast Brooks Range and Arctic Slope subsurface) metamorphosed during the Late Devonian Ellesmerian orogeny. The Franklinian sequence is overlain by the thrust-imbricated Ellesmerian sequence of Upper Devonian to Lower Cretaceous clastic rocks, platform carbonate rocks, chert, and shale, in which the clastic rocks were derived from a source to the north. The Lower Cretaceous to Cenozoic Brookian sequence is made up of thrust-imbricated clastic foreland basin deposits derived from a southern source.

Major tectonic events recorded in the rocks are (1) Late Proterozoic deformation and metamorphism; (2) convergence and arc magmatism probably during the Ordovician; (3) probable continental-margin arc magmatism during the Early and

Middle Devonian followed by deposition of thick sequences of Upper Devonian coarse clastic rocks and regional deformation (Ellesmerian orogeny) (formation of rift basins may have accompanied or immediately followed the continental margin magmatic activity; (4) Late Jurassic to Early Cretaceous collision of the Togiak-Koyukuk CT along the southern margin of the Arctic CT that resulted in structural shortening of 200–500 km, obduction of oceanic crust, and high-pressure–high-temperature metamorphism of lower plate rocks; (5) synorogenic to postorogenic uplift and extension(?) in the southern Arctic CT accompanied by Early Cretaceous to mid-Cretaceous sedimentation northward into the Colville foreland basin and southward into the Yukon-Koyukuk basin; (6) incipient rifting in the Late Jurassic, followed by Barremian to Campanian rifting along the northern margin, large-scale counterclockwise rotation of the Arctic CT, and opening of the Arctic Ocean basin; and (7) Late Cretaceous to early Tertiary longitudinal compression, east-west shortening, and counterclockwise rotation of the Arctic CT.

Central composite terrane

The Central CT (unit CCT, Fig. 2) constitutes about 7% of the area of Alaskan terranes between the Brooks and Alaska ranges. The region is characterized by large areas of discontinuous and poor exposures, so that relations between and among terranes are generally not well known. Summaries in this volume of major aspects of the geology and tectonic evolution of the Central CT are by Decker and others (southwest), Dover and Foster and others (east-central), and Patton and others (west-central). Topical studies include those by Barker (volcanic rocks), Arth (crustal composition), Dusel-Bacon (metamorphism), Kirschner (basins), Miller (pre-Cenozoic plutonic rocks), Moll-Stalcup (Cretaceous and Cenozoic magmatic rocks), and Patton and others (ophiolites). The combined Central CT and Ruby terrane are equivalent to the Central CT of Plafker (1990). Although they are currently juxtaposed, they are discussed separately in this chapter to emphasize uncertainties in their original relative positions and possible differences in their kinematic histories.

The central CT consists of dominantly northeast-southwest–trending terranes interpreted as rifted, rotated, translated, and imbricated fragments of the northwest-trending miogeocline along the North American craton, and as having close stratigraphic ties to miogeoclinal rocks in adjacent parts of the Yukon Territory of Canada (Tempelman-Kluit, 1984). A possible exception is the belt of ultramafic and associated deep-marine bedded rocks (Livengood terrane) that is interleaved with the continental margin terranes north of Fairbanks (Fig. 1).

The Central CT consists of (1) Late Proterozoic and Cambrian(?) clastic deposits including abundant bimodal quartzite (Wickersham terrane) and (2) Late Proterozoic metamorphic basement overlain by shelf and offshelf Middle Cambrian to Upper Devonian carbonate rocks and mainly terrigenous clastic or cherty Permian, Triassic, and Lower Cretaceous marine sedimentary rocks (Nixon Fork terrane). A collection of Middle Cambrian trilobites from the Nixon Fork terrane suggests a connection with Siberia in the early Paleozoic (Palmer and others, 1985). Cordilleran Early Devonian and younger faunas indicate that by that time, the Nixon Fork and related shelf to basinal terranes of the southern Central CT were adjacent to the North American plate (Mamet and Plafker, 1982; Blodgett and Gilbert, 1992; Decker and others, this volume). The Central CT also consists of (3) Ordovician bimodal volcanic rocks, volcaniclastic rocks, and conglomerate overlain by Silurian and Devonian carbonate rocks and capped by undated clastic sedimentary rocks (White Mountains terrane); (4) a Paleozoic sequence mainly of complexly deformed Ordovician graptolitic shale, Ordovician and uppermost Devonian to Pennsylvanian radiolarian chert, quartzitic turbidites, pillow basalt, basinal marine carbonate rocks, Silurian and Upper Devonian reefal limestone, and Permian turbidites, chert, argillite, and conglomerate (Minchumina, Mystic, and Dillinger terranes); and (5) relatively small areas of Early Cambrian or older harzburgitic ultramafic rocks and associated gabbro that structurally underlie a sequence of deep-marine Ordovician radiolarian chert, interbedded undated mafic volcanic and carbonate rocks, and Devonian limestone (Livengood terrane).

The small Livengood terrane (unit LG, Fig. 1) consists of mantle peridotite intruded by Cambrian diorite and gabbroic rocks having K-Ar ages of 552–556 ± 17 Ma (Loney and Himmelberg, 1988; D. J. Turner, 1987, written commun.) and depositionally(?) overlying Upper Ordovician radiolarian chert and graptolitic shale. It is unique in that it is the only pre-Mesozoic ophiolite known in Alaska. The origin of the terrane is conjectural: it most likely represents an ultramafic ridge and overlying deep-sea sediments that formed during continental rifting in a manner analogous to the peridotite ridges formed along the west Iberia margin during opening of the North Atlantic basin (Boillot and Winterer, 1988). Extension along the continental margin at about 555–600 Ma is compatible with tectonic subsidence data for continental margin sequences of early Paleozoic age in Alaska (Howell and Wiley, 1987) and in the southern Canadian Rocky Mountains (Bond and Kominz, 1984). The ultramafic and mafic crystalline rocks of the Livengood terrane were later tectonically imbricated with continental margin sedimentary rocks, probably in Late Cretaceous to early Tertiary time.

Rocks in the Central CT record: (1) emplacement of ultramafic and deep-marine rocks (Livengood terrane) and continental margin clastic sedimentation and magmatism (White Mountain terrane) that is probably related to late Precambrian to Ordovician continental margin extension (Stewart, 1976; Aleinikoff and Plafker, 1989); (2) an originally south- to west-facing continental margin consisting of a dominantly shelf sequence (Nixon Fork and White Mountains terranes) that is inferred to have interfingered offshore with slope and basin facies, including mafic volcanic and local ultramafic rocks (Minchumina, Dillinger, Mystic, Wickersham, and Livengood terranes) (Decker and others, this volume; Patton and others, this volume, Chapter 7); and (3) Devonian(?) folding and northeast-verging thrusting toward the craton in the White Mountains terrane (Weber and others, 1988; Moore and Nokleberg, 1988).

Ruby terrane

The Ruby terrane (unit RB, Fig. 2) in interior Alaska constitutes about 3% of the area of Alaskan terranes. As with the Central CT, the Ruby terrane is an area of generally poor exposures, so relations between the Ruby terrane and adjacent terranes of the Central and Oceanic CTs are not well known. The geology and tectonic evolution of the Ruby terrane are summarized in this volume in the regional papers by Dover and by Patton and others (this volume, Chapter 7). Topical studies include those by Arth (crustal composition), Dusel-Bacon (metamorphism), and Miller (pre-Cenozoic plutonic rocks).

The Ruby terrane consists primarily of structurally complex quartz-mica schist, quartzite, calcareous schist, metabasalt, quartzo-feldspathic schist and gneiss, and marble. The rocks probably originated as a continental margin assemblage, on the basis of both the quartz-rich compositions of the metamorphic rocks and the high silica and potassium compositions and high strontium initial ratios of crustal melt plutons that intrude the terrane (Patton and others, this volume, Chapter 7; Arth, this volume). The rocks contain sparse Ordovician, Silurian, and Devonian fossils, but could be as old as Proterozoic in age. Metamorphic grade is dominantly greenschist facies; high-pressure glaucophane-bearing greenschist facies rocks and intermediate- to high-pressure amphibolite facies rocks are present locally. The metamorphic assemblage is locally intruded by an Early Devonian metagranite (390 Ma) and by mid-Cretaceous granitic plutons that are especially voluminous in the part of the terrane north of the Kaltag fault.

Rocks in the Ruby terrane record: (1) early Paleozoic continental margin sedimentation followed by emplacement of granitic plutons, a history similar to that of the southern Arctic CT and Yukon CT, which suggests possible structural continuity of these terranes in Early Devonian time; (2) high-pressure–high-temperature metamorphism and penetrative deformation that is inferred to be related to Late Jurassic to Early Cretaceous ophiolite obduction and arc accretion (Patton and others, this volume, Chapter 7); and (3) widespread mid-Cretaceous plutonism and retrograde metamorphism related to arc magmatism and/or crustal melting (Arth, this volume; Miller, this volume, Chapter 16) that extended eastward into the Yukon CT and westward into the Arctic CT and stitched these terranes together by mid-Cretaceous time (Fig. 3).

Kilbuck terrane and Idono Complex

The Kilbuck terrane (Figs. 1 and 2) in southwestern Alaska and the tiny Idono Complex (located about 300 km northeast of the Kilbuck terrane) are the only Early Proterozoic rocks known in Alaska. They consist of fault-bounded slices of penetratively deformed gneiss and schist of upper amphibolite to granulite facies (Box and others, 1990; Miller and others, 1991). The metaplutonic rocks yield 2.06–2.07 Ga zircon U/Pb crystallization ages and show involvement of Archean crust with a model age of about 2.5 Ga. Isotopic systems were disturbed by younger metamorphic or plutonic processes at about 1.7–1.8 Ga, 190–180 Ma, and 140–120 Ma. The geochemical and isotopic data are most compatible with an origin of the early Precambrian rocks in a continental margin arc.

Structural relations of the Early Proterozoic rocks to nearby terranes are uncertain. Their location along strike with the metamorphic Late Proterozoic basement of the Ruby terrane suggests that, like the Ruby terrane, they may be displaced fragments of a continental margin arc built on the North American craton, as postulated by Miller and others (1991) and Decker and others (this volume). A North American craton origin, however, is problematic because (1) although rocks of this age are in the Wopmay orogen to the southeast in Canada (Hoffman, 1989), the Alaska rocks differ from analyzed Wopmay rocks in their Nd model ages (Box and others, 1990); and (2) known post-Jurassic dextral strike-slip displacements (<1000 km) on intracontinental faults in Alaska and Canada are insufficient to permit translation of fragments to southwestern Alaska from even the closest part of the present craton margin; an earlier episode of large-scale dextral displacement would be required. Permissible alternative interpretations are that the Kilbuck terrane and Idono Complex are part of an exotic terrane or that they are exotic continental margin fragments that were emplaced in an accretionary prism associated with the Togiak-Koyukuk arc and later dispersed to their present locations by strike-slip faulting.

Yukon composite terrane

The Yukon CT (unit YCT, Fig. 2) makes up about 10% of the area of Alaskan terranes. The composite terrane consists mainly of crystalline rocks (Yukon-Tanana terrane) and overlying arc-related rocks (Stikine terrane) in east-central and southeastern Alaska. Similar rocks underlie vast tracts in adjacent parts of Canada (Nisling-Kootenay terranes and the Pelly Gneiss) and probably also extend beneath parts of the Coast Mountains of southeastern Alaska, including all or parts of the Tracy Arm terrane and Taku terrane.

The Yukon CT as defined here differs from Composite terrane I of Monger and others (1982), the Stikinian superterrane of Saleeby (1983), and the Intermontane superterrane of Wheeler and McFeely (1991) mainly in that it does not include the complex of pericratonic, arc, and oceanic terranes (Cassiar, Quesnellia, Cache Creek, and Slide Mountain terranes) that lie east of the Yukon CT in Canada. Primary data sources in this volume for the following summary are Brew (late Mesozoic and Cenozoic magmatism), Dusel-Bacon (metamorphic rocks), Foster and others (Yukon-Tanana region), Gehrels and Berg (southeastern Alaska), Miller (pre-Cenozoic plutonic rocks), and Silberling and others (terranes). Data for the Canadian part of the composite terrane are mainly from Gabrielse and Yorath (1991); Hansen (1990), Monger and Berg (1987), Monger (1989), Monger and others, (1991), Mortensen (1992), Tempelman-Kluit (1979), and Wheeler and McFeely (1991).

Crystalline rocks of the Yukon CT all have strong affinities with rocks of the North America craton margin (Hansen, 1990; Samson and others, 1991; Mortensen, 1992; Foster and others, this volume). They consist mainly of (1) sparse orthogneiss of Late Proterozoic age; (2) polymetamorphosed and polydeformed quartz-rich schist and grit, pelitic schist, and sparse marble of Precambrian(?), Devonian, and Mississippian age; and (3) orthogneiss, augen gneiss, and intermediate to felsic volcanic rocks of Late Devonian to Early Mississippian age containing zircons with Proterozoic inheritance and Sm-Nd model ages consistent with values for North American cratonal basement. In metaclastic rocks of the Yukon-Tanana terrane, the presence of Early Proterozoic (about 2.1 to 2.3 Ga) zircons (Dusel-Bacon, this volume, Chapter 15; Foster and others, this volume), suggest a possible provenance in the Nahanni Province along the craton margin in northwest Canada (Hoffman, 1989).

Variably metamorphosed upper Paleozoic and Upper Triassic to Middle Jurassic carbonate and volcanic arc rocks (Stikine terrane) underlie small areas of east-central and southeastern Alaska, and they cover large tracts of the Yukon CT in contiguous areas of Canada. In east-central Alaska the Stikine terrane (Taylor Mountain terrane of Hansen, 1990) consists of intensely deformed epidote-amphibolite to amphibolite grade volcanic rocks, carbonate rocks, carbonate, chert, and quartz-rich schist and associated Upper Triassic to Lower Jurassic intrusive rocks. In Canada, Stikine terrane rocks as old as Upper Triassic (Mihalynuk and Mountjoy, 1989) locally depositionally overlie Yukon-Tanana terrane crystalline basement and are characterized by variably metamorphosed, stratigraphically stacked Mississippian through Jurassic marine and nonmarine volcanic and sedimentary strata and coeval intrusions (Monger and Berg, 1987). In southeastern Alaska the Stikine assemblage consists of upper Paleozoic carbonate and clastic strata and Upper Jurassic to Middle Jurassic arc-related rocks; contacts with adjacent terranes are obscured by faulting or younger plutonism (Gehrels and Berg, this volume). In this chapter we follow the interpretation, based on stratigraphic evidence cited by Mihalynuk and Mountjoy (1989) and others, that the Stikine terrane was originally depositional on the crystalline complex of the Yukon-Tanana terrane and that the original relations have been obscured in Alaska and in much of Canada by younger structural deformation and plutonism. Alternative interpretations, based mainly on Nd isotopic data from igneous rocks, are that the Stikine terrane has been structurally juxtaposed against the Yukon CT along major unidentified strike-slip faults or by overthrust faults involving hundreds of kilometers of displacement (Coney, 1989; Samson and others, 1991).

The rocks record (1) Late Devonian and mid-Cretaceous(?) continental margin magmatism inferred to be arc related; (2) arc magmatism in the late Paleozoic and in the Late(?) Triassic and Middle Jurassic (Stikine terrane); (3) closure of the Cache Creek Sea and accretion of the Yukon CT against the continental margin with intense deformation along a broad eastern suture zone in early Middle Jurassic time (Tempelman-Kluit, 1979; Hanson, 1990; Ricketts and others, 1992); (4) major episodes of regional plutonism and metamorphism to amphibolite facies mainly in Early Jurassic time in mainland Alaska (Dusel-Bacon, this volume, Chapter ??) and in pre–Late Triassic time in southeastern Alaska (Rubin and Saleeby, 1991); and (5) mid-Cretaceous plutonism and crustal extension accompanied by formation of subhorizontal metamorphic fabrics and detachments in east-central Alaska and adjacent areas (Pavlis and others, 1993; Hansen, 1990).

Paleomagnetic inclination data for Jurassic strata of the Stikine terrane have been cited as indicating post-Jurassic northward displacement of the Stikine terrane of about 13° relative to the craton (Monger and Irving, 1980); however, subsequent revisions in Jurassic North American reference poles appear to eliminate the need for latitudinal shift of the terrane (Irving and Wynne, 1990; Vandall and Palmer, 1990).

Togiak-Koyukuk composite terrane

The Togiak-Koyukuk CT (unit TCT, Fig. 2) in western Alaska constitutes about 5% of the area of terranes of Alaska. The geology of much of this region is imperfectly known because bedrock exposures commonly are poor and because large areas are covered with overlap deposits or water. Summaries of the geology in this volume are those of Decker and others (regional geology of southwest Alaska), Patton and others (regional geology of west-central Alaska), Barker (Mesozoic volcanic rocks), Dusel-Bacon (metamorphism), Miller (plutonic rocks), Moll-Stalcup (Late Cretaceous and Cenozoic magmatism), and Patton and others (ophiolite).

The Togiak-Koyukuk CT is a dismembered and rotated Late Triassic and older(?) through Early Cretaceous intraoceanic complex of arc-related volcanic and volcaniclastic rocks and their intrusive equivalents, that mainly comprises the Togiak, Koyukuk, and Nyac terranes but also includes Early Cretaceous rocks in parts of the Innoko terrane. Basement beneath the Togiak terrane consists of a younger assemblage of Late Triassic ophiolite and an older assemblage of Paleozoic and Triassic volcanic rocks, limestone, and chert. Arc rocks of the Koyukuk terrane are depositionally overlain by mid-Cretaceous (Albian-Cenomanian) marine and nonmarine sedimentary rocks in the Yukon-Koyukuk basin and by Upper Cretaceous and Paleogene volcanic rocks; in the Togiak terrane arc rocks are overlain by Upper Cretaceous volcanic rocks and marine sedimentary rocks.

The rocks record (1) imbrication, subduction, and local Middle Jurassic high-temperature–low-pressure metamorphism of Kobuk Sea oceanic crust of Devonian to Early Jurassic age in an accretionary prism; (2) Middle Jurassic through Early Cretaceous arc volcanism; (3) emplacement of the arc complex against an attenuated continental margin consisting of the Arctic and Central CTs and the Ruby and Kilbuck(?) terranes beginning in latest Jurassic or earliest Cretaceous time (about 144 Ma); (4) arc accretion that was preceded by at least 150 km subduction of the attenuated continental margin beneath Kobuk Sea oceanic crust (Oceanic CT) with attendant regional metamorphism and deformation of lower plate rocks; and (5) widespread mid-Cretaceous plutonism and Late Cretaceous and early Tertiary arc volcanism and related plutonism.

Oceanic composite terrane

The Oceanic CT makes up about 5% of the area of Alaskan terranes (unit OCT, Fig. 2). It comprises mainly the Angayucham, Tozitna, Innoko, Goodnews, and probably the Seventymile terranes, and defines a discontinuous belt that extends from western Alaska to the border with Canada. The geology and evolution of these oceanic terranes is summarized in this volume by Decker and others, Dover, Patton and others, Moore and others, and Foster and others; data on the composition of some of the volcanic rocks are presented by Barker and Barker and others (this volume). The terranes are similar in lithology to the Slide Mountain and related oceanic terranes located along structural strike to the southeast in adjacent parts of Canada (Fig. 1). They differ mainly in that available data suggest that the oceanic terranes in Canada and possibly the Seventymile terrane in eastern Alaska were accreted by early Middle Jurassic time (Mortensen, 1992), rather than in Late Jurassic and Early Cretaceous time (see below).

The Oceanic CT consists dominantly of oceanic basalt, volcanogenic and oceanic sedimentary rocks, and minor ultramafic rocks of Devonian to Early Jurassic age. In this chapter we follow the interpretation of Patton and others (1989; this volume, Chapter 21) that the oceanic terranes are dismembered fragments of the paleo-Pacific crust that were obducted as extensive thrust sheets onto the continental margin before and during accretion of magmatic arc rocks of the Togiak-Koyukuk CT in Late Jurassic and Early Cretaceous time. The closed ocean basin in Alaska has been referred to informally as the Kobuk Sea (Plafker, 1990). Lithologically equivalent rocks in contiguous parts of Canada, and possibly the Seventymile terrane in eastern Alaska, were emplaced against and over adjacent terranes during Middle Jurassic or earlier closure of the Cache Creek Sea. Obduction of the Oceanic CT was accompanied by widespread greenschist and blueschist metamorphism, by craton-verging compressional deformation, and by inverted structural stacking within much of the oceanic rocks. According to the model presented in this chapter, southeast vergence is predicted in the Ruby terrane. Results of a detailed study of the shear sense of mylonites along parts of the detachment zone in the northern Ruby terrane and the nearby Oceanic CT are ambiguous in that they indicate pre-mid-Cretaceous tectonic transport dominantly toward the northwest but locally toward the southwest (Miyaoka and Dover, 1990).

Our interpretation for the origin of the oceanic rocks differs from a more stabilistic model in which the rocks are considered to be disrupted remnants of local parautochthonous intracontinental rifts (Gemuts and others, 1983; Dover, this volume). In our judgment, the rift model does not account for the close association in time and space of the intraoceanic arc rocks of the Togiak-Koyukuk CT and thrust sheets of the Oceanic CT or for the long-lived dominantly pelagic sedimentary sequences that characterize much of the Oceanic CT.

Wrangellia composite terrane

The allochthonous Wrangellia composite terrane (unit WCT, Fig. 2) occurs mainly between the Denali and Border Ranges fault systems, where it constitutes about 20% of the area of Alaskan terranes; it also underlies large tracts of adjacent parts of Canada. The geology of the Wrangellia CT is summarized in this volume by Nokleberg and others (regional geology of south-central Alaska), Gehrels and Berg (regional geology of southeastern Alaska), Barker (pre-Cenozoic volcanism), Brew (late Mesozoic and Cenozoic magmatism in southeastern Alaska), Moll-Stalcup (Late Cretaceous and Tertiary magmatism in mainland Alaska), Miller and Richter (eastern Aleutian arc volcanism), Dusel-Bacon (metamorphism), and Patton and others (ophiolites).

The composite terrane is characterized by Late Proterozoic(?) and younger magmatic arc, oceanic plateau(?), and rift-fill assemblages (mainly the Wrangellia, Peninsular, Alexander, and northern Taku terranes), and the Late Jurassic to mid-Cretaceous magmatic arc and flysch deposits of the Gravina-Nutzotin belt. The northern part of the Taku terrane of Silberling and others (this volume, Plate 3) is included here as a fault-displaced fragment of Wrangellia (Plafker and others, 1989). As used here, the Wrangellia CT corresponds in part with Composite Terrane II of Monger and others (1982), the Wrangellia super-terrane of Saleeby (1983), and the Insular Composite Terrane of Wheeler and McFeely (1991). The Alexander terrane was together with Wrangellia and was the basement beneath at least part of Wrangellia by Early Pennsylvanian time (Gardner and others, 1988). The combined Wrangellia and Alexander terranes were together with the Peninsular terrane at least by Late Triassic time and possibly by the Early Permian (Plafker and others, 1989; Nokleberg and others, this volume, Chapter 10).

The central and southern segments of the Taku terrane of Silberling and others (this volume, Plate 3) have been reinterpreted as the exposed western margin of the Yukon-Tanana or comparable terranes of continental affinity (Rubin and Saleeby, 1992; McClelland and others, 1992a, 1992b). In addition, at least part of the dominantly crystalline Tracy Arm terrane in the Coast Mountains of Alaska and British Columbia was juxtaposed against the Wrangellia CT since mid-Cretaceous time (Crawford and others, 1987), and perhaps as early as the Middle Jurassic (McClelland and others, 1992a; Rubin and Saleeby, 1992).

The Alexander terrane consists of three subterranes that are characterized by a pre–Middle Ordovician volcanic-sedimentary-plutonic metamorphic complex overlain by Ordovician to Late Triassic variably metamorphosed mafic to felsic volcanic rocks, clastic and carbonate rocks, and by compositionally variable Ordovician and younger plutonic rocks.

The northern part of Wrangellia in Alaska (unit WRn, Fig. 1) is characterized by Early Pennsylvanian to Early Permian variably metamorphosed mafic to intermediate arc-related volcanic and intrusive rocks, overlying Middle to Late Triassic subaerial basalt and related intrusive rocks up to 6,000 m thick, and overlying Upper Triassic to Lower Jurassic shallow-marine clastic, siliceous, and calcareous rocks. In British Columbia, the southern part of Wrangellia (unit WRs, Fig. 1) shares the same Upper Triassic stratigraphy consisting of a sequence of dominantly marine basalt and marine sedimentary rocks; it differs from the Alaska part in that the oldest exposed units consist of arc volcanic rocks and associated intrusive rocks of Silurian and Devonian age, the Carboniferous and Early Permian are represented by chert and limestone, and the Paleozoic section is overlain by Upper Triassic and Jurassic andesitic volcaniclastic rocks (Monger and Berg, 1987; Brandon and others, 1986). Although the Wallowa terrane of Oregon has been considered to be part of Wrangellia (Jones and others, 1977), the calc-alkaline composition of the Triassic volcanic rocks (Sarewitz, 1983) makes such an association unlikely.

The Peninsular terrane is characterized by a well-stratified sequence of variably metamorphosed Paleozoic(?) volcanic rocks, Permian limestone, Upper Triassic (Norian) basalt, limestone, argillite, and tuff, Upper Triassic and Lower Jurassic andesitic flows, breccias, and volcaniclastic siltstone and sandstone, Middle Jurassic to Cretaceous fossiliferous clastic rocks and minor bioclastic limestone, and Jurassic batholithic granitic rocks (Detterman and Reed, 1980; Jones and others, 1987; Nokleberg and others, this volume, Chapter 10).

The rocks record (1) possible arc magmatism in the Alexander terrane during the Late Proterozoic and Cambrian(?) and arc magmatism during the Early Ordovician to Late Devonian and Late Jurassic to Early Cretaceous; (2) arc magmatism in the British Columbia part of the Wrangellia terrane during the Silurian, Devonian, and latest Triassic to earliest Middle Jurassic; (3) arc magmatism in the Alaska part of the Wrangellia terrane during the Early(?) Pennsylvanian to Early Permian, Late Jurassic to Early Cretaceous, and Cenozoic time; (4) arc magmatism on the Peninsular terrane during the latest Triassic and Early Jurassic and post-Eocene time intervals and local near-trench plutonism in mid-Cretaceous time (Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10). In addition, plutonism that may be arc related was widespread in the Wrangellia CT during the Middle and Late Jurassic and latest Cretaceous to early Tertiary (Hudson, 1983; Barker and Miller, this volume; Nokleberg and others, this volume, chapter 10); (5) Late Silurian to Early Devonian deformation in part of the Alexander terrane with development of a thick clastic wedge of redbeds (Klakas orogeny of Gehrels and Saleeby, 1987); (6) Middle to Late Triassic emplacement of voluminous sequences of tholeiitic basalt and gabbro in the Wrangellia, northern Taku, and Peninsular terranes and of bimodal basalt and felsic rocks in the Alexander terrane due either to rifting (Barker and others, 1989) or to initiation of a mantle plume (Richards and others, 1991); (7) paleomagnetic anomalies indicating large Late Triassic to mid-Cretaceous northward displacement (up to 25°) relative to the North American craton (Haeussler and others, 1992; Hillhouse and Coe, this volume; Plumley, 1990, oral commun.; Van der Voo and others, 1980); and (8) emplacement against the continental margin in Alaska and British Columbia by mid-Cretaceous time (Crawford and others, 1987; Rubin and Saleeby, 1992) and possibly as early as Middle Jurassic time (McClelland and others, 1992a), accompanied by intense contractional deformation and collapse of intervening flysch basins.

Southern Margin composite terrane

The Southern Margin CT (unit SCT, Fig. 2), which makes up about 20% of the area of the terranes of Alaska, includes the Chugach, Ghost Rocks, and Prince William terranes. The geology of this CT is described in this volume by Plafker and others (southern margin) and Gehrels and Berg (southeastern), Barker (volcanic rocks), Brew (Late Cretaceous and Tertiary magmatism in southeastern Alaska), Moll-Stalcup (Late Cretaceous and Tertiary magmatism in mainland Alaska), Dusel-Bacon (metamorphism), and Patton and others (ophiolite).

In Alaska the Southern Margin CT is a compound, complexly deformed, accretionary prism of Upper Triassic to Paleogene oceanic rocks, melange, and flysch. To the southeast, probably correlative rocks make up the Pacific Rim terrane of coastal Vancouver Island in British Columbia (Monger and Berg, 1987), and the various Mesozoic arc-related accretionary complexes in the conterminous United States and Mexico (Silberling and others, 1992).

The rocks of the Southern Margin CT record (1) intermittent offscraping of oceanic rocks and dominantly arc-related volcaniclastic and volcanic rocks against the Pacific margin of the Wrangellia CT during crustal convergence from Early Jurassic to middle Eocene time; (2) local blueschist facies metamorphism of accreted rocks in Early Jurassic and mid-Cretaceous time; (3) widespread high-temperature–low-pressure metamorphism and intrusion of anatectic tonalitic plutons in Eocene time; and (4) paleomagnetic anomalies indicating 16°–30° northward displacement relative to the craton of Late Cretaceous to middle Eocene volcanic rocks within the accretionary prism (Plumley and others, 1983; Hillhouse and Coe, this volume).

Yakutat terrane

The Yakutat terrane (unit YT, Fig. 2) along the northern Gulf of Alaska constitutes about 5% of the terranes of Alaska. The geology of this terrane is discussed in this volume by Plafker and others (regional), Moll-Stalcup (Late Cretaceous and Cenozoic magmatism) and Barker (accreted volcanic rocks). The Yakutat terrane is an allochthonous fragment of the continental margin that is inferred to have been displaced to its present position by dextral strike-slip faulting (Plafker and others, this volume, Chapter 12). The terrane has a composite basement of Paleocene(?) and Eocene oceanic crust in the western part and a fragment of the Southern Margin CT in the eastern part.

The rocks record (1) about 180 km offset of the Southern Margin CT along the Chatham Strait segment of the Denali fault in late Paleocene or early Eocene time; (2) deposition of a thick sequence of Eocene and younger siliciclastic rocks and minor mafic volcanic rocks and coal derived from the Coast Mountains, Wrangellia CT, and Southern Margin CT; (3) northwestward displacement of the terrane to its present position by about 600 km of post-Oligocene dextral slip on the Queen Charlotte–Fairweather transform fault system along its northeastern boundary and by a comparable amount of underthrusting of the northern and northwestern boundaries beneath the adjacent Southern Margin CT; and (4) collision-related deformation, mountain building, seismicity, and deposition of thick sequences of marine clastic and glaciomarine sedimentary rocks from middle Miocene time to the present.

MAGMATIC BELTS

The distribution, composition, and age of pre-Cenozoic plutonic and volcanic belts in Alaska help constrain timing of joining ("stitching") of one or more terranes and the petrotectonic setting of the terranes. The best-defined belts of plutonic rocks and arc-related volcanic rocks are depicted schematically in Figure 3; their salient features are outlined below.

Devonian to Early Mississippian magmatic belt

A magmatic belt of dominantly granitic intrusive rocks and local andesitic to felsic volcanic rocks of late Early to Middle Devonian age (mainly 380–390 Ma) extends along the southern

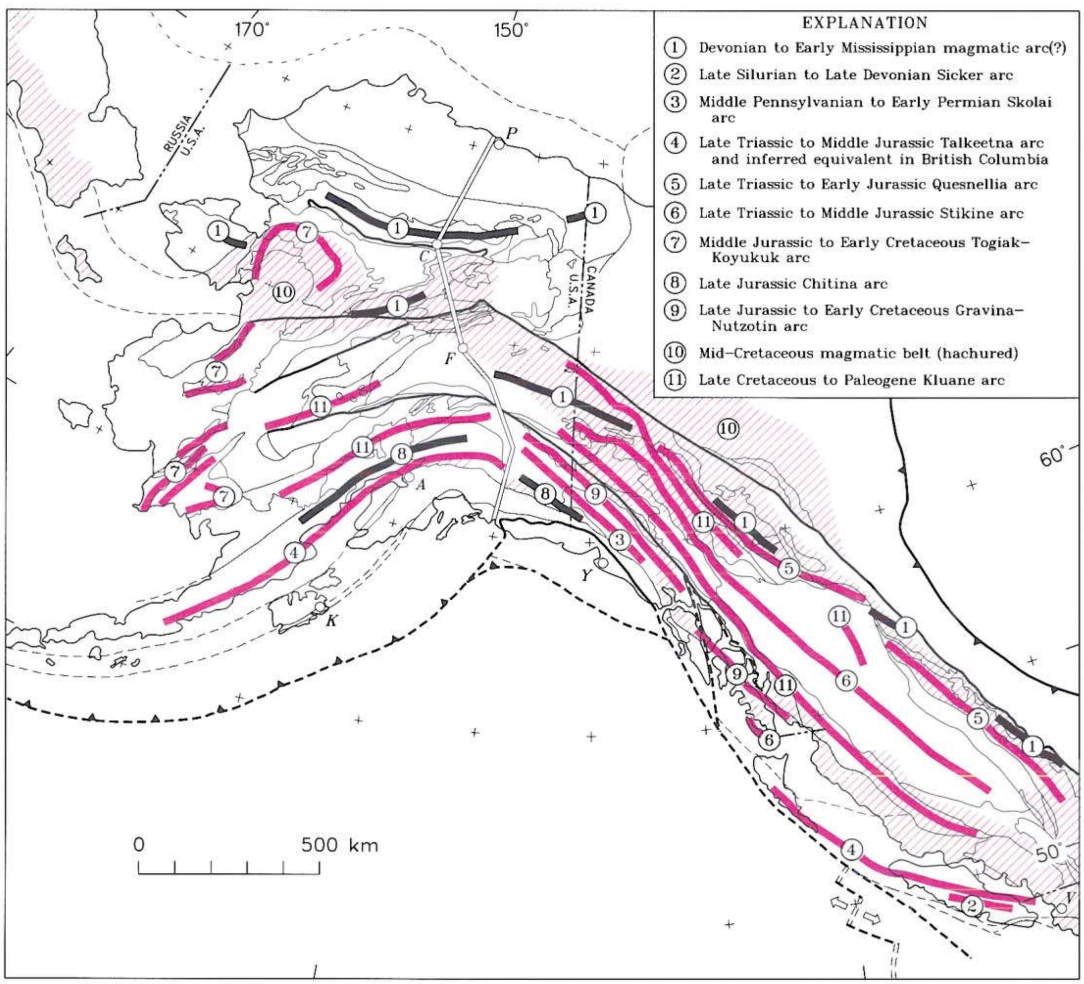

Figure 3. Major pre-Cenozoic magmatic belts of Alaska. Wide red lines indicate approximate axes of volcanic arc rocks; wide black lines indicate approximate axes of dominantly plutonic rocks interpreted as arc related; red hachures show approximate distribution of mid-Cretaceous plutonic and volcanic rocks. Locality abbreviations are same as for Figure 1. See text for explanation and data sources.

Arctic CT (Hammond and Coldfoot terranes) and occurs locally in the Ruby terrane (Fig. 3, no. 1). Rocks of similar composition, but Late Devonian to earliest Mississippian in age (350–370 Ma), underlie much of the Yukon CT in east-central Alaska. These crystalline rocks have been widely interpreted as part of a discontinuous magmatic belt that was emplaced in and on early Paleozoic or older rocks of the continental margin (Dillon and others, 1980; Nokleberg and others, 1989; Plafker, 1990; Mortensen, 1992). The magmatic belt is generally coeval with granitoid plutonism that extends southward through Yukon Territory in Canada and with plutonism and volcanism in the Klamath and Sierra Nevada mountains of Oregon and California, as summarized by Rubin and others (1991). An alternative explanation proposed for the belt is that the magmatism represents anatectic melting of continental crust along zones of extension (Hudson, this volume). However, this interpretation is less compatible with the local occurrences of comagmatic andesitic volcanic rocks and approximately coeval compressional deformation in parts of the belt.

Sicker arc

Metamorphosed volcanic and plutonic rocks of the Sicker arc (Fig. 3, no. 2) on Vancouver Island are of Late Silurian to Late Devonian age (370–420 Ma), although the oldest age for the base of the sequence is not known (Brandon and others, 1986). Possibly correlative rocks in the southern Alexander terrane make up a metamorphosed arc complex mainly of Early Ordovician to Early Devonian age that includes plutonic rocks of Early Silurian to Early Devonian age (430–405 Ma) (Gehrels and Saleeby, 1987). These data suggest a possible link between the southern Wrangellia and Alexander terranes as early as the Silurian.

Skolai arc

The Skolai arc (Fig. 3, no. 3) in the northern Wrangellia CT consists of andesitic volcanic rocks, shallow-marine sedimentary rocks, and shoshonitic plutonic rocks that range in age from at least Middle Pennsylvanian to Early Permian (Nokleberg and others, this volume, Chapter 10). Plutonic rocks having U-Pb zircon ages of 210 Ma are emplaced across the contact of the Wrangellia and Alexander terranes, indicating that they were together by Pennsylvanian time (Gardner and others, 1988).

Talkeetna arc

The Talkeetna arc (Fig. 4, no. 4) consists of intraoceanic volcanic and volcaniclastic rocks of latest Triassic and Early Jurassic age in the Peninsular terrane of the northern Wrangellia CT and probably the coeval arc rocks of the latest Triassic to earliest Middle Jurassic Bonanza Group in the British Columbia part of the Wrangellia CT. The Talkeetna arc and the coeval arc rocks in the southern Wrangellia CT are inferred to have been part of the same arc that was disrupted by about 600 km of sinistral displacement (Plafker and others, 1989; Nokleberg and others, this volume, Chapter 10). The associated accretionary prism, the Chugach terrane, consists of volcaniclastic flysch, melange that contains exotic rocks, including sparse limestone blocks containing a Permian Tethyan fusulinid fauna, and minor blueschist facies rocks (Plafker and others, this volume, Chapter 12).

Quesnellia arc

The ocean-facing Quesnellia arc (Fig. 3, no. 5) and its associated accretionary prism complex, the Cache Creek terrane, are entirely in Yukon Territory and British Columbia, but their histories are a critical part of the evolution of outboard accreted terranes, including the Yukon-Tanana and Stikine terranes (Fig. 1). The Quesnellia arc (Quesnellia terrane) consists of Late Triassic and Early Jurassic calc-alkaline to alkaline volcanic rocks and comagmatic plutonic granitic rocks, along with volcaniclastic rocks, argillite, and minor limestone, that includes some upper Paleozoic carbonate rocks. The arc and associated rocks overlie late Precambrian to early Paleozoic metamorphic rocks that have continental crust affinity (Monger and Berg, 1987). The Cache Creek terrane along the ocean-facing side of the Quesnellia arc includes extensive tracts of carbonate rocks containing a distinctive Tethyan fusulinid and coral fauna of Permian age and blueschist facies metamorphic rocks of Late Triassic age (Monger and Berg, 1987). The Quesnellia arc can be interpreted as part of a long-lived fringing arc complex that evolved above an eastward-dipping subduction zone along the northeast Pacific margin (Saleeby, 1983; Miller, 1987). According to this interpretation, rocks of Tethyan affinity in the accretionary prism represent far-traveled guyots and their carbonate caps that were scraped off oceanic crust and incorporated as exotic blocks in the Cache Creek accretionary complex. In Alaska, the Quesnellia arc is broadly coeval with the Stikine and Talkeetna arcs and the Cache Creek accretionary prism may be partly coeval with the oldest rocks of the Southern Margin CT accretionary prism (Figs. 2 and 3).

Stikine arc

The Stikine arc (Fig. 3, no. 6) underlies much of the Cordillera in Yukon Territory and British Columbia, but locally underlies small areas of southeastern and east-central Alaska. In southeastern Alaska and contiguous parts of Canada it consists of a stacked sequence of Late Triassic to Middle Jurassic marine clastic and volcaniclastic rocks, volcanic rocks and comagmatic intrusive bodies, and minor carbonate rocks (Gehrels and Berg, this volume). In east-central Alaska it may be represented by an assemblage of variably metamorphosed volcanic rocks, carbonate rocks, chert, and quartz-rich pelitic rocks. Its age is uncertain, but it must be older than the Late Triassic to Early Jurassic granitic plutons that intrude it (Foster and others, this volume). The magmatic arc is built mainly on a thick upper Paleozoic arc sequence of the Stikine terrane (Monger and Berg, 1987) and probably in part on crystalline basement of the Yukon-Tanana terrane (Gehrels and Berg, this volume). Paleomagnetic data indicate latitudinal stability relative to the craton for Jurassic rocks in the Canadian part of the arc (Irving and Wynne, 1990; Vandall and Palmer, 1990).

Togiak-Koyukuk arc

The Togiak-Koyukak arc in western Alaska (Fig. 3, no. 7) consists of Middle Jurassic through Early Cretaceous calc-alkalic volcanic rocks, intrusive rocks, and volcaniclastic rocks that locally overlie oceanic rocks of Late Triassic and older(?) age (Barker, this volume; Decker and others, this volume; Patton and others, this volume, Chapter 7). The arc includes faulted and warped segments of the Togiak, Koyukuk, and Nyac terranes and parts of the Innoko terrane (Fig. 1). Together, these terranes compose the Togiak-Koyukuk CT described in a previous section.

Chitina arc

The Chitina arc (Fig. 3, no. 8) is a belt of calc-alkalic plutonic rocks of mainly Late Jurassic age (Tonsina-Chichagof belt of Hudson, 1983) that stitches across part of the northern Wrangellia and Alexander terranes (Plafker and others, 1989; Nokleberg and others, this volume, Chapter 10). It is interpreted as the roots of a magmatic arc, based on the dominantly tonalitic composition of the rocks and the linearity and continuity of the belt (Hudson, 1983). In Alaska the belt is locally truncated along its southern margin by the Border Ranges fault (MacKevett, 1978).

Gravina-Chisana arc

The Gravina-Chisana arc (Gravina-Nutzotin belt of Berg and others, 1972) (Fig. 3, no. 9) consists of a moderately to intensely deformed sequence of clastic and volcaniclastic sedimentary rocks with subordinate andesitic and basaltic volcanic rocks of Late Jurassic and Early Cretaceous age (Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10). The arc sequence, which is built on the inner margins of the Wrangellia and Alexander terranes, extends discontinuously from southeastern Alaska to the Alaska Range in south-central Alaska, where it links the Alexander and Wrangellia terrane. In southeastern and central Alaska it is thrust beneath the Yukon CT to the northeast (Csejtey and others, 1982; Gehrels and others, 1990; Nokleberg and others, this volume).

Mid-Cretaceous magmatic belt

Mid-Cretaceous (mainly late Early to early Late Cretaceous, or about 110–80 Ma) plutonism and associated thermal metamorphism occurred in a wide belt between the southern Brooks Range and the Alaska Range (Fig. 3, no. 10) and locally extends to the southern margin of the Wrangellia CT (Dusel-Bacon, this volume; Gehrels and Berg, this volume; Miller, this volume, Chapter 16). In west-central Alaska there were two episodes of magmatism—one from 113 to 99 Ma and a volumetrically lesser one from 89 to 79 Ma (Miller, this volume, Chapter 16; Patton and others, this volume, Chapter 7). The plutonic rocks have a wide compositional range, including ultrapotassic nepheline syenite, tonalite through granodiorite, and biotite granite and two-mica granite (Miller, this volume, Chapter 16). Granitic to tonalitic plutonism was accompanied in the Yukon CT in Alaska by volcanism (Bacon and others, 1990) and by extension along with local formation of subhorizontal fabrics and detachments (Pavlis and others, 1993). The magmatic belt in Alaska appears to be at least in part coextensive with major belts of plutonism and arc volcanism that extend southeastward into adjacent areas of Canada (Armstrong, 1988) and westward into the Russian far east (Albian to Turonian Ohkotsk-Chukotsk magmatic belt of Parfenov and Natal'in, 1986). Mid-Cretaceous magmatism is considered to be subduction related both in Canada and Siberia, and it is likely that at least some of the coeval magmatic activity in Alaska is also of subduction origin (Bacon and others, 1990; Miller, this volume, Chapter 16). An alternative interpretation is that the plutonic rocks of interior Alaska are crustal melts related to large-scale mid-Cretaceous extension (Miller and Hudson, 1991; Hudson, this volume), even though isotopic data indicate that some of the region in which the plutons occur is underlain by oceanic crust (Arth, this volume). In Alaska, this broad belt of mid-Cretaceous magmatism is broadly coeval with (1) extensive resetting of K-Ar and other isotopic ages (Dusel-Bacon, this volume); (2) greenschist facies metamorphism including widespread retrograde metamorphism of higher grade rocks; and (3) thermal overprinting of the preexisting remnant magnetization (Hillhouse and Coe, this volume) that appears to extend far beyond the magmatic belt.

Kluane arc

The Kluane arc (Fig. 3, no. 11) is represented by an arcuate belt of latest Cretaceous and Paleogene magmatism (75–56 Ma) that extends from southwestern to southeastern Alaska. Volcanic and plutonic rocks in a wide zone stitch across most major terranes in western, central, and east-central Alaska (Moll-Stalcup, this volume). Variably metamorphosed intermediate composition plutonic rocks that occur along the Wrangellia-Yukon CT boundary and underlie much of the Coast Mountains of southeastern Alaska and British Columbia (Armstrong, 1988; Plafker and others, 1989; Brew, this volume). A broad belt of coeval plutonic and volcanic rocks mainly within the Yukon CT in Yukon Territory (Armstrong, 1988) may be part of the arc complex, but is not shown in Figure 3. A distinct magmatic lull in Canada from 70 to 60 Ma (Armstrong, 1988) is not recognized in Alaska.

TRANSLATIONS AND ROTATIONS

The present complex pattern of lithotectonic terranes in Alaska reflects interactions of the oceanic plates with the North American plate and resulting large-scale translations and rotations. Figure 4 illustrates the most important assumptions regarding displacements and rotations in Alaska that were used in the reconstruction of the tectonic evolution model that follows. Much of the geologic data are summarized in the various regional papers in this volume. Paleomagnetic data are from well-dated volcanic and carbonate rocks for which the paleohorizontal can be determined (Hillhouse and Coe, this volume; Haeussler, 1992). The more conservative Northern Hemisphere option has been chosen in all cases where initial polarity can not be specified.

Counterclockwise rotation of the Arctic composite terrane

In northern Alaska, paleomagnetic data from clastic rocks in oriented well cores from near Prudhoe Bay indicate that the Arctic CT rotated some 66° counterclockwise away from the Arctic Canada margin between about 130–100 Ma (Halgedahl and Jarrard, 1987). In the Amerasian basin of Canada (not shown in Fig. 4), stratigraphic and structural data indicate that

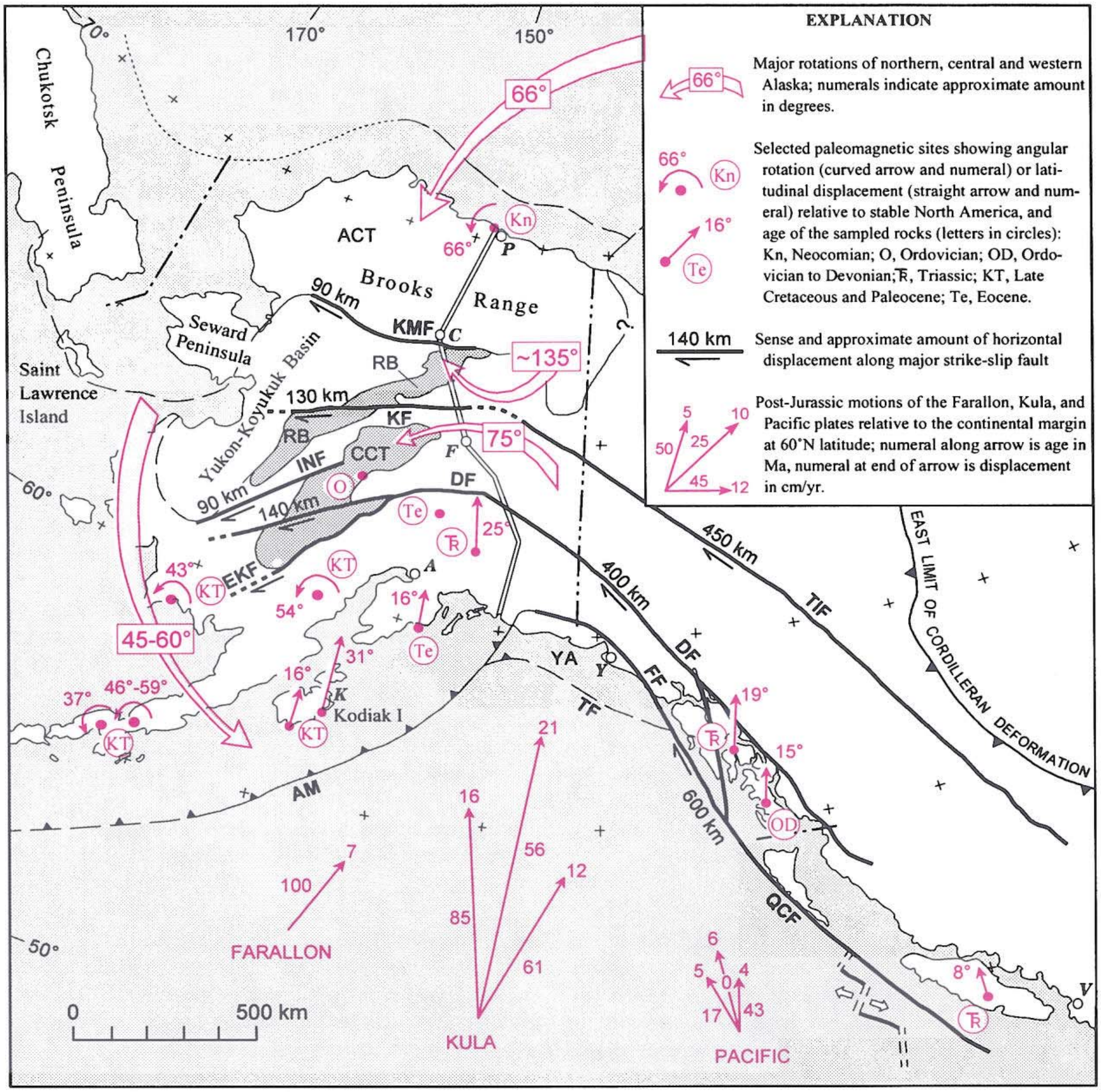

Figure 4. Significant rotations, translations, and plate motions in Alaska and adjacent parts of Canada. Open arrows indicate major rotations of northern and western Alaska. Fault abbreviations: AM, Aleutian megathrust; DF, Denali fault; EKF, East Kulukak fault; FF, Fairweather fault; KF, Kaltag fault; KMF, Kobuk-Malemute fault; INF, Iditarod-Nixon Fork fault; QCF, Queen Charlotte fault; TF, Transition fault; TIF, Tintina fault; ACT, Arctic composite terrane; CCT, Central composite terrane; RB, Ruby terrane. Locality abbreviations are same as for Figure 1. See text for explanation and data sources.

rifting was mainly during the late Albian to Cenomanian interval and that rotation of Arctic Alaska continued until about the end of the Cretaceous (Embry and Dixon, 1990).

Some of the more widely held alternative models for the evolution of the Arctic CT are reviewed by Nilsen (1981) and Moore and others (this volume). They include (1) a stabilist interpretation having the Arctic CT in its present position relative to North America since Paleozoic time (e.g., Bogdanov and Tilman, 1964; Churkin and Trexler, 1981); (2) northward translation from the northern Canadian part of the Cordilleran orogen in Yukon Territory by large-scale dextral slip along the Tintina fault followed by dextral offset along the postulated Porcupine lineament (Jones, 1982); and (3) westward translation from a position somewhere between the eastern Arctic Islands of Canada and northern Greenland by large-scale sinistral slip on a postulated transform fault along the present southern margin of the Canada basin (Oldow and others, 1987).

Counterclockwise oroclinal bend of western Alaska and western Arctic composite terrane

In western Alaska, geologic and paleomagnetic data indicate that at about 65–50 Ma, the region between the Kaltag fault and Kodiak Island was rotated 45°–60° counterclockwise about a vertical axial plane that coincides approximately with long 146°W. Before rotation of western Alaska, the continental margin is assumed to have been more linear with general northwest to north structural trends, except for the Ruby terrane, which may already have been rotated to a northeast trend during mid-Cretaceous time (see below). There are no reliable data for the paleolatitudes of rock units in western Alaska because all paleomagnetic sites are overprinted by younger chemical or thermal events.

Interpretation of oroclinal bending of western Alaska is based mainly on (1) abrupt bends in major intraplate transcurrent faults, most notably the Tintina and Denali faults (Grantz, 1966; Hickman and others, 1990); (2) the concave-oceanward distribution of Late Cretaceous arc-related rocks (Plafker and others, this volume, Chapter 12) and differences in the orientation of slip vectors in coeval rocks on opposite limbs of the bend (Moore and Connolly, 1979); (3) deformation of Late Cretaceous and Paleogene accreted rocks in the axis of the oroclinal bend in southern Alaska (Plafker and others, this volume, Chapter 12); and (4) paleomagnetic data from Late Cretaceous and early Tertiary rocks in western Alaska (Hillhouse and Coe, this volume; Plumley and others, 1983). A possible mechanism for oroclinal bending is Late Cretaceous and Paleogene convergence of about 2.5 to 6 cm/yr between the North American and Eurasian plates (Engebretsen and others, 1985).

Geologic data bracket the timing of the great southward-looping syntaxial bend, which extends from the western Brooks Range through the Seward Peninsula and Saint Lawrence Island to the Chukotsk Peninsula, as middle Late Cretaceous to the middle Tertiary (Patton and Tailleur, 1977).

Clockwise rotation of the Ruby terrane

The Ruby terrane and structurally overlying slabs of the Oceanic CT are inferred in our model to have rotated about 135° clockwise relative to the southern margin of the Arctic CT to form the southern boundary of the Yukon-Koyukuk basin (Fig. 4). This interpretation follows that of Tailleur (1980) and is based on correlation of the Ruby terrane with crystalline rocks of the southern Arctic CT and on the geometric relations among these terranes, which suggest rotation of the Ruby terrane about a hinge close to its present northeastern end. It differs from earlier models in that we suggest that rotation most likely occurred in two stages. The first stage, which was concurrent with opening of the Arctic basin in Early to mid-Cretaceous time, was accompanied by voluminous sedimentation in a proto-Koyukuk basin. The second stage, caused primarily by Late Cretaceous to early Tertiary northwestward displacement of the Yukon CT, resulted in final closure of the Yukon-Koyukuk basin and as much as 50% shortening by deformation of the enclosed sedimentary rocks.

A number of tectonic models have been proposed for emplacement of the Ruby and adjacent terranes, but no single model accounts adequately for the apparent continuity of crystalline and oceanic terranes around the eastern apex of the Yukon-Koyukuk basin, the distribution of overlying oceanic terranes, pre–Late Cretaceous filling and deformation of the Yukon-Koyukuk basin, and the timing and amount of strike-slip displacement available on the major intraplate faults of Alaska. Models for the northern group of terranes and Yukon-Koyukuk basin are (1) clockwise oroclinal bending of the Ruby terrane away from the southern Brooks Range in Late Cretaceous to early Tertiary time (Tailleur, 1980); (2) late Paleozoic rifting from the southern Brooks Range followed by pre–Early Cretaceous counterclockwise rotation to open the Yukon-Koyukuk basin (Patton, 1970); and (3) dextral offset of the Ruby and related terranes from the eastern end of the southern Brooks Range along a postulated major northeast-trending strike-slip fault named the Porcupine lineament by Churkin and Carter (1979).

Counterclockwise rotation and northwestward displacement of the Central composite terrane

Terranes that constitute the Central CT and structurally overlying slabs of the Oceanic CT are inferred in our model to have undergone as much as 75° counterclockwise rotation away from the margin of continental North America (Tailleur, 1980; Patton and others, this volume, chapter 7). The sense of rotation is compatible with early Paleozoic facies trends in the terranes, which indicate a shale-out toward the south and southeast in present coordinates (Churkin and others, 1982; Decker and others, this volume). Although poorly constrained, timing of this rotation corresponds to the Late Cretaceous to early Tertiary counterclockwise bending of western Alaska and northwestward displacement of the Yukon CT.

Paleomagnetic inclination data from Ordovician and younger Paleozoic carbonate rocks in the Nixon Fork area of the Central CT (Figs. 1 and 4), indicate no significant difference (± 10°) between present and Ordovician paleolatitudes (Plumley, 1984). These data, together with stratigraphic similarities to lower Paleozoic strata of the North American miogeocline (Decker and others, this volume), are a key element in the tectonic reconstructions that follow because they constrain the Paleozoic location of the Nixon Fork and related terranes to nearby parts of the continental margin. The paleomagnetic data further suggest that the Nixon Fork terrane may have rotated about 75°–110° clockwise (Plumley, 1984); timing of the rotation is poorly constrained and we follow the interpretation of Patton and others (this volume, Chapter 7), who suggest that it could reflect post-Paleozoic rotation of the fault slices sampled, rather than rotation of the entire Central CT.

Tectonic models proposed for emplacement of all or parts of the Central CT and adjacent terranes include (1) emplacement of the Nixon Fork and related terranes by dextral strike-slip faulting (Tailleur, 1980; Patton and others, this volume, chapter 7); (2) large clockwise rotation of the Nixon Fork and related terranes away from the North American miogeocline, probably in the late Paleozoic or early Mesozoic (Churkin and others, 1982; Plumley, 1984; Plafker, 1990); and (3) a stabilistic model in which the Central CT and Ruby terrane were part of a southwesterly directed peninsular extension of the Paleozoic North American margin (Decker and others, this volume).

Northwestward movement of the Yukon composite terrane

The Yukon CT has been displaced northwest relative to the craton at least 450–900 km by dextral slip on the Tintina and related intraplate faults that make up its landward boundary (Gabrielse, 1985). Offsets on the Tintina fault and its splays are discussed below.

Mid-Cretaceous plutonic rocks of the Coast Plutonic Complex in British Columbia and the North Cascade Range in Washington have systematic inclination anomalies that have been interpreted to indicate (1) 1100–2400 km of northward translation (Irving and others, 1985; Beck and others, 1981; Umhoefer and others, 1989), (2) postemplacement tilt of the sampled rocks (Butler and others, 1989; Brown and Burmester, 1991), or (3) a combination of translation and tilt. Because of uncertainty regarding effects of regional tilt on the Cretaceous plutonic rocks, we have not incorporated these displacements in our tectonic model.

Northward movement of the Wrangellia composite terrane

Paleomagnetic data from Ordovician to Devonian limestone and Triassic basalt in the Alaska part of the Wrangellia CT (Figs. 1 and 4) indicate that it was 0°–15° south of its present position relative to the craton in the early Paleozoic (Van der Voo and others, 1980) and about 25° south in the Late Triassic (Hillhouse, 1987; Haeussler, 1992; Plumley, 1990, oral commun.). Paleomagnetic data from volcanic flow rocks indicate that the Wrangellia CT was at about its present latitude by late Paleocene or early Eocene time (Hillhouse, 1987). Paleomagnetic data from Vancouver Island in the southern part of the Wrangellia terrane indicate that it was at about the same paleolatitude as northern Wrangellia in Late Triassic and Jurassic time (Yole and Irving, 1980). At least 5° of the present difference in latitude of northern and southern Wrangellia may be due to postemplacement sinistral faulting (Plafker and others, 1989). The combined geologic data and plate tectonic reconstructions suggest that final suturing to southern Alaska was in the Late Cretaceous, most likely during the Cenomanian to Maastrichtian (Coney and Jones, 1985; Plafker and others, 1989; Plafker and others, this volume, Chapter 12). However, a strong case has been made for earlier accretion to North America in the mid-Cretaceous in Alaska (Csejtey and others, 1982; Nokleberg and others, 1985, 1989), by latest Albian time in southern British Columbia (Monger and others, 1982; Thorkelson and Smith, 1989), or as early as the Middle Jurassic in southeastern Alaska (McClelland and others, 1992a). In our model we follow McClelland and others (1992a) in assuming that the Wrangellia terrane moved northward to about its present position relative to inboard terranes by Late Jurassic time. Juxtaposition of the Wrangellia and Yukon CTs in their approximate present positions was primarily during the mid-Cretaceous. In central Alaska, at least local flysch deposition occurred in basins along the suture zone in Late Cretaceous time (Coney and Jones, 1985).

Northward displacement of oceanic crustal rocks in the Southern Margin composite terrane

Within the accretionary assemblage of the Southern Margin CT, paleomagnetic inclinations for Late Cretaceous to Paleocene volcanic rocks (Fig. 4) suggest 16°–31° northward translation relative to the craton (Plumley and others, 1983; Coe and others, 1985; Hillhouse, 1987; Hillhouse and Coe, this volume). We interpret these samples to be offscraped exotic oceanic fragments, and therefore they do not indicate the paleolatitude of the enclosing accretionary prism. In this respect they are similar to exotic rocks with large paleomagnetic anomalies that occur in accretionary prisms along the continental margin of the conterminous United States (Silberling and others, 1992). As noted in the following section, as much as 8° of the indicated northward displacement could occur by dextral slip on major inboard faults.

Displacement on major transcurrent faults

Geologic data indicate that the larger intraplate strike-slip faults in Alaska and adjacent parts of Canada have dextral offsets of tens to hundreds of kilometers (Fig. 4). Cumulative Late Cretaceous and early Tertiary dextral displacement is about 450 km on the northern Tintina fault and total post-Devonian displacement on the fault and its splays is about 900 km (Gabrielse, 1985; Price and Carmichael, 1986). Late Cretaceous to early Tertiary dextral slip on the Denali fault is about 400 km (Grantz, 1966; Nokleberg and others, 1985; Hickman and others, 1990). There has been about 600 km of late Cenozoic dextral displacement on the Fairweather fault (Plafker and others, this volume, Chapter 12). Cumulative displacement on these intraplate faults results in northward latitudinal shifts relative to the craton that can account for as much as 8° of the paleomagnetic inclination anomalies in terranes outboard of the Tintina fault.

About 450 km of post–Middle Jurassic to pre-Eocene offset has been documented along the northern Tintina fault in northwestern Yukon Territory (Gabrielse, 1985). The fault can be traced into Alaska discontinuously about 125 km to long 146°W, where it splays into a complex of west- to southwest-trending strike-slip and thrust faults (Dover, this volume). In east-central Alaska, the main strike-slip movement on the Tintina fault was post–Early Cretaceous in age and predates the deposition of poorly dated Tertiary(?) rocks (Dover, this volume). It is not known how slip is partitioned west of the mapped Tintina fault trace in Alaska. Approximately 310 km of dextral slip can be accounted for by offsets across known or inferred major splays of the Tintina fault in central and western Alaska (Fig. 4). Offset on the Kobuk-Malemute fault is poorly constrained at 90 km or more (Dillon and others, 1987; Dover, this volume). Offset is 160 on the Kaltag fault (Patton and Hoare, 1968), and about 90 km on the Iditarod–Nixon Fork fault (Miller and Bundtzen, 1988). The remainder of the Tintina fault slip may be accommodated by distributive shear on unidentified strike-slip faults between these structures (Dover, this volume), by compressional shortening during and after oroclinal bending (Chapman and others, 1985), or by a combination of these mechanisms.

Relative plate motions

Mid-Cretaceous and younger motions of the Farallon, Kula, and Pacific plates relative to a northwest-trending continental margin at lat 60°N are shown as vectors in Figure 4 (Engebretsen and others, 1985). Relative plate motions were about 7 cm/yr orthogonal convergence during subduction of the Farallon plate (100–85 Ma) and 12–21 cm/yr dextral-oblique convergence during subduction of the Kula plate (85–61 Ma). We assume that the demise of the Kula plate predated the onset of arc volcanism in the Alaska Peninsula (K-Ar ages 50 $\pm$ 2 Ma) and coincided approximately with the widespread early to middle Eocene thermal event along the eastern margin of the Gulf of Alaska (Plafker and others, this volume, Chapter 12). Since about 50 Ma, Pacific–North American plate relative motions were northwesterly at 4–6 cm/yr with dextral to dextral-oblique convergence on the northwest-trending transform margin and orthogonal convergence on the northeast-trending Aleutian Arc margin.

Poorly constrained ocean-floor magnetic anomalies for the Farralon plate from 180 to 100 Ma indicating sinistral oblique convergence of 4–12 cm/yr (Engebretsen and others, 1985) are not incorporated in our model or shown in Figure 4. If correct, an important consequence of these plate kinematic reconstructions is that significant post–Late Triassic northward transport of allochthonous terranes, such as the Wrangellia CT, was possible only after onset of Kula plate relative motions in the Late Cretaceous. This assumption was incorporated in previous models for the evolution of the southern Alaska margin (Plafker, 1990; Plafker and others, this volume, Chapter 12). We have not used the pre-100 Ma reconstructions in our model because the geologic data indicate that the Wrangellia CT in Alaska was probably close to its present position relative to inboard terranes by Late Jurassic time (McClelland and others, 1992a) and that it was juxtaposed against the Yukon CT by mid-Cretaceous time in Alaska (Gehrels and Berg, this volume; Nokleberg and others, this volume, Chapter 10) and British Columbia (Crawford and others, 1987; Monger and others, 1982; Thorkelson and Smith, 1989). Instead, we follow McClelland and others (1992a) in inferring a period of significant margin-parallel northward movement that may correspond with a lull in arc magmatism in the Wrangellia CT in the Jurassic from about Bajocian to Oxfordian time (183–156 Ma). Thus, the major part of the northward displacement or the Wrangellia CT could have taken place during this ~27 m.y. interval with the remainder accommodated by dextral transpression during Kula plate time.

TECTONIC EVOLUTION—A MODEL

In this section we present a model for the Phanerozoic tectonic evolution of the major elements of Alaska and contiguous areas based primarily on the geologic and geophysical constraints outlined above. The model illustrates the tectonic evolution of composite terranes and terranes in schematic plan view reconstructions for eight time intervals (Fig. 5). The figures do not incorporate internal deformation of the terranes and composite terranes: they do restore known displacements along major intraplate strike-slip faults.

Although large rotations and translations are indicated, the model is conservative in that it assumes Northern Hemisphere options for the paleomagnetic data, and probable North American affinities during the Phanerozoic for the Arctic, Central, Yukon, Wrangellia, and Southern Margin CTs as well as for the Ruby and Yakutat terranes. Much more mobilistic models for one or more of these terranes can be, and have been, postulated (e.g., Engebretsen and others, 1985; Gehrels and Saleeby, 1987; Stone and others, 1982).

We emphasize that no single model has yet been devised to accommodate all the geologic, paleontologic, geophysical, and paleomagnetic data, because many of these data are mutually contradictory and/or internally inconsistent. The main benefit of attempting to model the tectonic evolution of all of Alaska is that it provides a guide for future research by highlighting problems with the available data and interpretations.

Precambrian

The tectonic model in Figure 5 begins with the Cambrian because the Precambrian history is too fragmentary to permit a meaningful map reconstruction. Early Proterozoic metamorphic

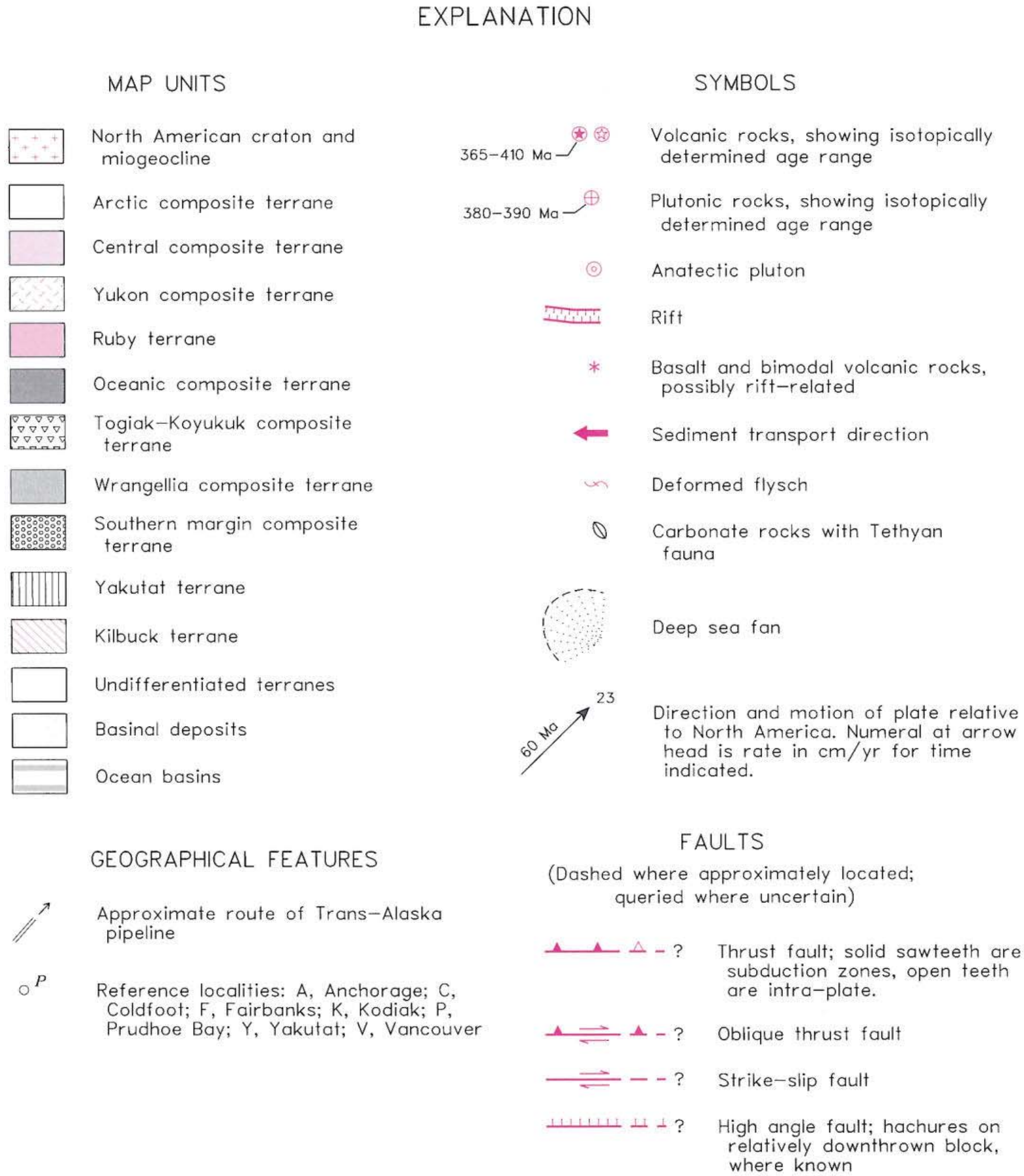

Figure 5 (on following four page spreads). Schematic diagrams depicting the Phanerozoic evolution of major tectonic elements of Alaska and adjacent areas of Canada. Terrane outlines are dashed where the presence or location are the most speculative. Orientations of geologic and geographic features are relative to present geographic coordinates. Terrane abbreviations are the same as in Figure 1. See text for explanation and data sources.

rocks (2.1 Ga) are known in Alaska only in the Kilbuck terrane and Idono Complex in western Alaska (Fig. 1). They have isotopic signatures that suggest an origin in a craton margin magmatic arc (Miller and others, 1991). Decker and others (this volume) suggest that they may be offset fragments of the Ruby terrane and that all of the Precambrian rocks in southwestern Alaska probably originated along the craton margin of North America. Although plausible, this interpretation can not be substantiated because the cratonic rocks have no close age and isotopic equivalents in the Ruby terrane or elsewhere in western North America.

The only other Early Proterozoic ages in Alaska are from detrital and inherited zircons in Late Proterozoic and Paleozoic rocks (Miller and others, 1991). They occur in (1) the western Brooks Range (2.06 and 2.26 Ga), (2) the eastern Alaska Range (2.1 Ga), and (3) the Yukon CT in east-central and southeastern Alaska (2.1–2.3 Ga). The provenance for the detrital zircons is unknown.

The western continental margin of North America, including what is now northern and eastern Alaska, was shaped by Late Proterozoic rifting beginning at about 850 Ma and possibly continuing into early Paleozoic time. Rifting was followed by gradual subsidence and initial deposition of thick sequences of clastic and carbonate rocks of the Cordilleran miogeocline (Stewart, 1976). Known and inferred Late Proterozoic rocks of the Arctic, Central, and Yukon CTs and the Ruby terrane are widely interpreted as having formed mainly, if not entirely, in the Cordilleran miogeocline (Dover, this volume; Foster and others, this volume; Moore and others, this volume; Patton and others, this volume, Chapter 7; Silberling and others, this volume).

In the Alexander terrane segment of the Wrangellia CT, magmatism began during the Late Proterozoic in a probable

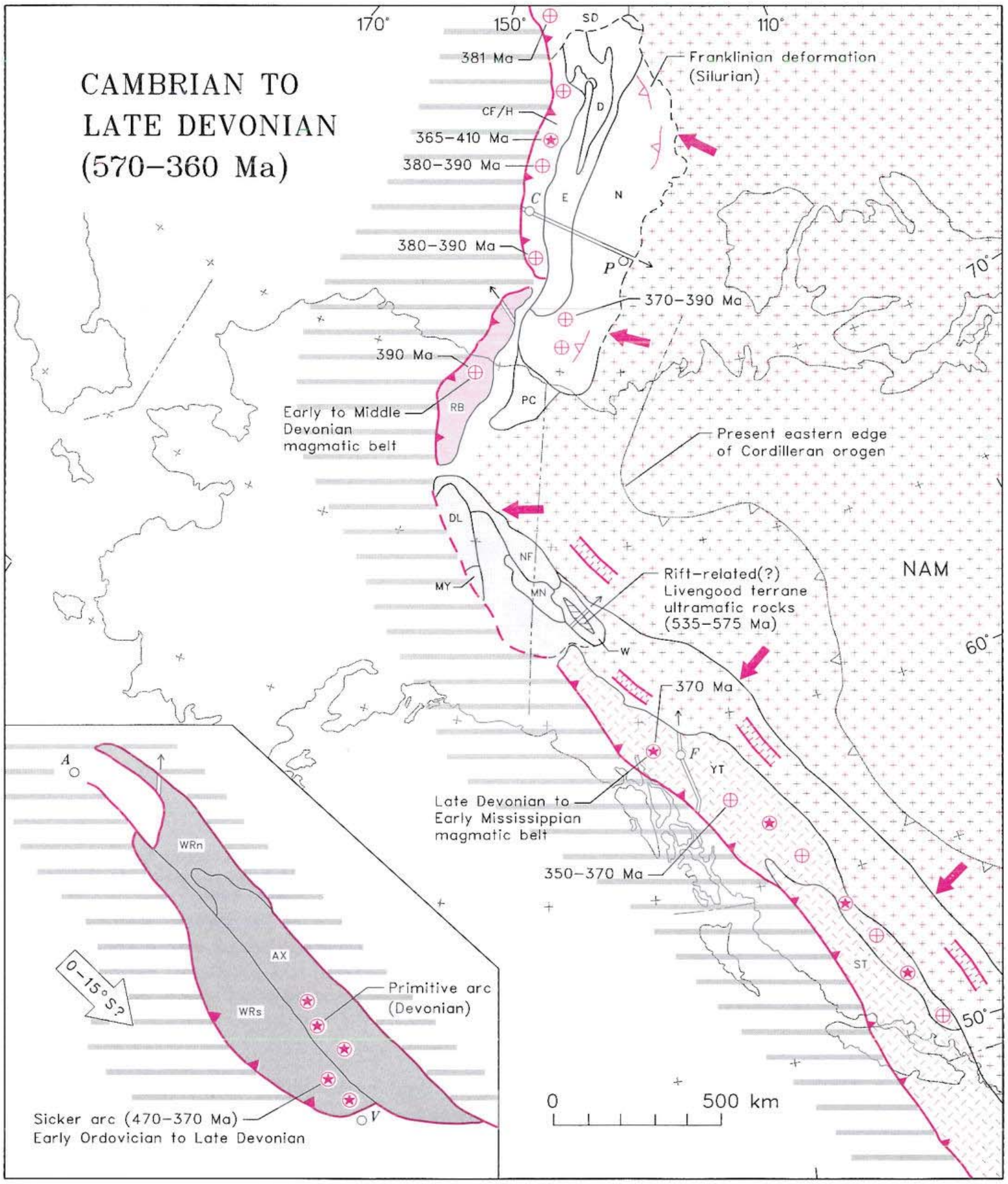

Figure 5a. Cambrian to Late Devonian: Inferred configuration of continental margin composite terranes and terranes showing sediment source direction, rift basins, Devonian to Early Mississippian arc-related(?) magmatic belt, and location of Cambrian or older rift-related(?) ultramafic rocks of the Livengood terrane. Box shows Wrangellia intraoceanic composite terrane and locations of Ordovician to Late Devonian arc magmatism; paleomagnetic data indicate a paleolatitude within 15° of its present latitude, assuming a Northern Hemisphere option.

intraoceanic environment; there are no data on the location of the composite terrane at that time.

Cambrian to Late Devonian (570–360 Ma)

The early Paleozoic western craton margin in what is now Alaska and contiguous parts of Canada can be established in a general way from the distribution of craton-related rocks, autochthonous sequences of the Cordilleran miogeocline, and by isotopic data. The approximate locations of the Arctic and Central CTs relative to the craton margin (Fig. 5A) are based on the paleomagnetic data indicating that the Nixon Fork terrane segment of the Central CT was at about its present latitude in Ordovician time, and by removing the rotation of the Arctic CT to restore it to a position contiguous with the Cordilleran miogeocline of Arctic Canada. The position of the Ruby terrane is based

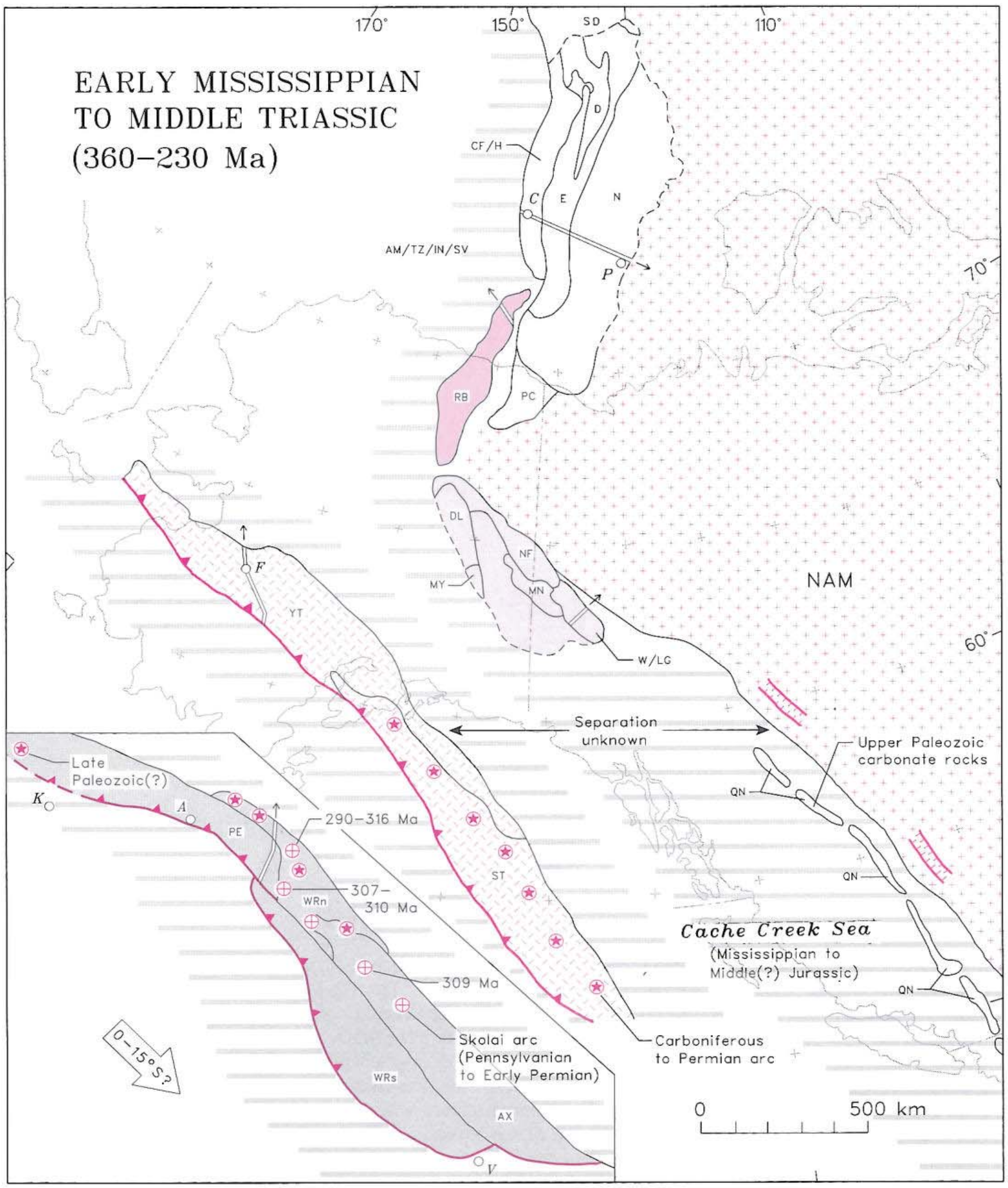

Figure 5B. Early Mississippian to Middle Triassic: Passive margin sedimentation occurred on the Arctic and Central CTs. The Cache Creek Sea opened in Mississippian time and the Yukon CT was a rifted continental fragment. Carboniferous to Early Permian magmatic arcs developed on the southern Yukon CT (Stikine terrane) and Wrangellia CT above east(?)-dipping subduction zones.

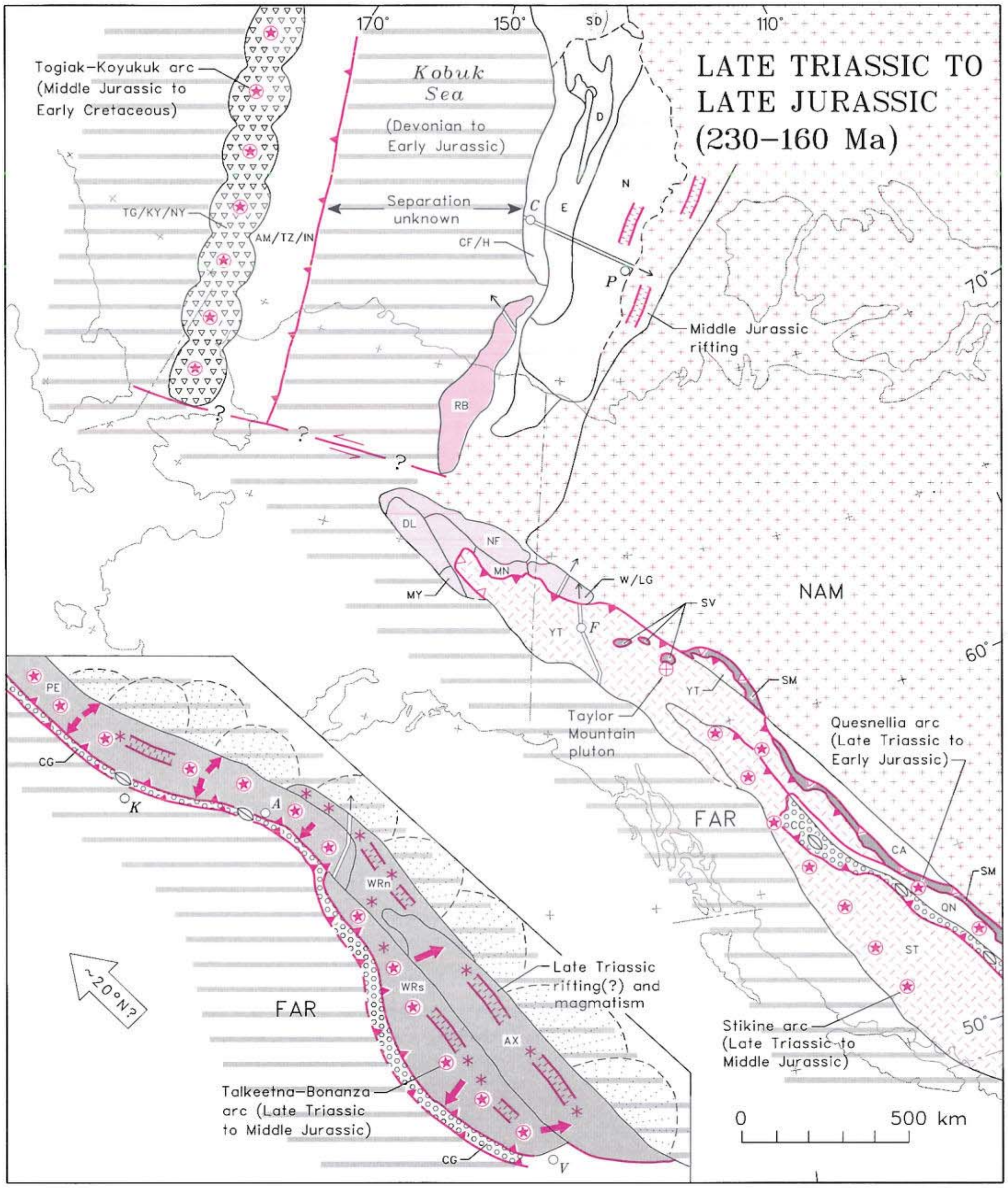

Figure 5C. Late Triassic to Late Jurassic: Passive margin sedimentation occurred on the Arctic CT. Arc volcanism and subduction took place on the intraoceanic Togiak-Koyukuk CT in the Middle Jurassic. The Late Triassic to Early Jurassic Quesnellia arc and its accretionary prism (Cache Creek terrane) were active along the continental margin in the Late Triassic and Early Jurassic above an east-dipping subduction zone. The Yukon CT closed the Cache Creek Sea from the Late Triassic to Early Jurassic, during which time Stikine arc was active above a probable west-dipping subduction zone. By Early Jurassic time, the Yukon CT collapsed against inboard terranes, overrode part of the Central CT and North American craton margin, and fragments of oceanic crust were obducted onto terranes along the eastern margin of the Yukon CT (Slide Mountain terrane) and were locally emplaced onto the Yukon CT in Alaska (Seventymile terrane). The Wrangellia CT was characterized by Middle and Late Triassic eruptions of tholeiitic basalt in the Wrangellia terrane, eruption of bimodal volcanic rocks in the Alexander and Peninsular terranes, and Late Triassic to early Middle Jurassic arc volcanism and formation of the accretionary prism of the Southern Margin composite terrane above an east-dipping subduction zone. Limestone with Tethyan faunas was offscraped into accretionary prisms of the Cache Creek terrane and the Southern Margin CT. There was probable major northward movement of Wrangellia CT between Late Triassic and Late Jurassic time. FAR, Farallon plate.

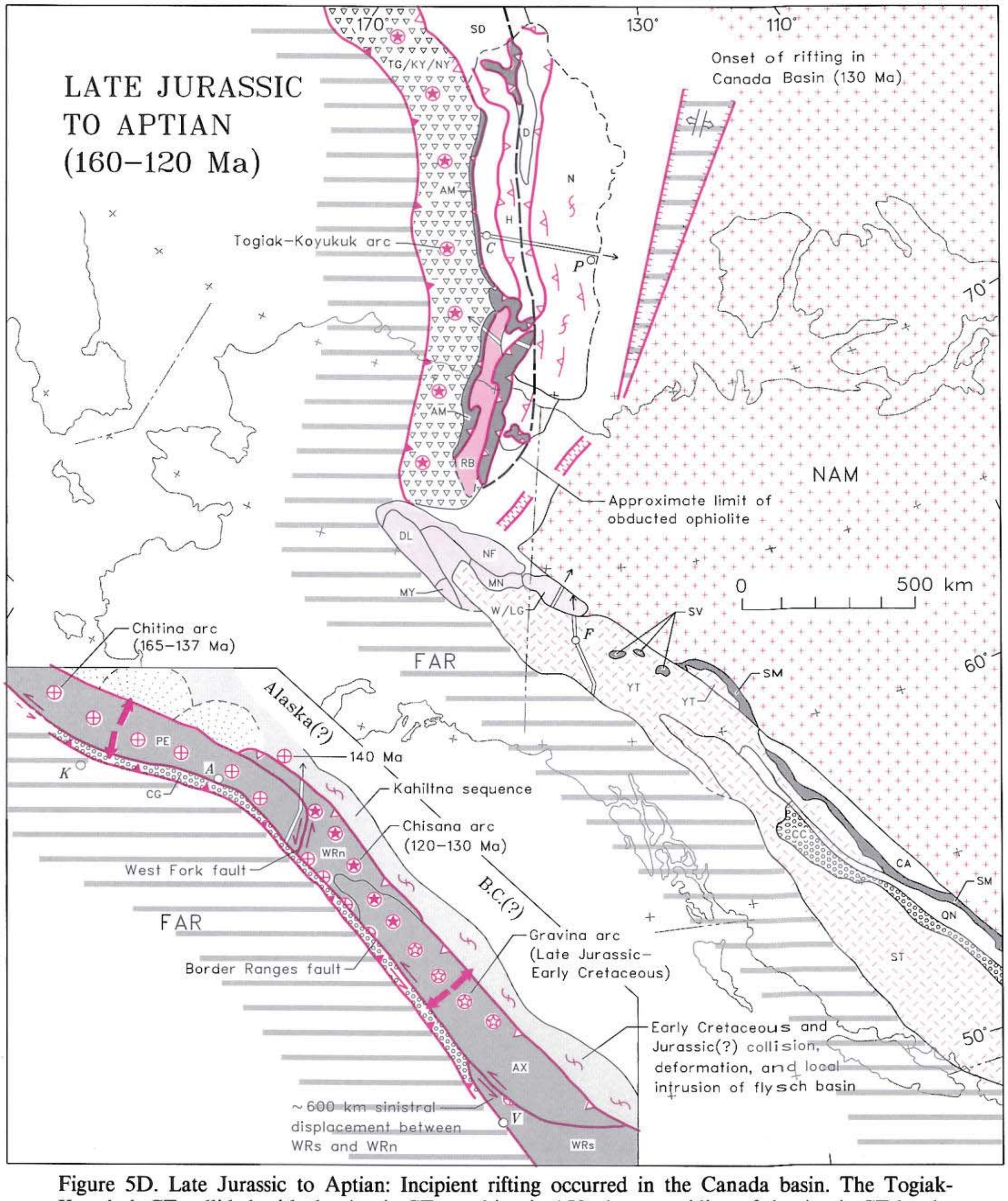

Figure 5D. Late Jurassic to Aptian: Incipient rifting occurred in the Canada basin. The Togiak-Koyukuk CT collided with the Arctic CT, resulting in 150+ km overriding of the Arctic CT by the oceanic crust of the closed Kobuk basin (Angayuchum, Tozitna, and Innoko terranes); there was major contractional deformation and regional high-pressure metamorphism in lower plate rocks and a probable flip in the subduction zone, above which arc magmatism continued through the Early Cretaceous. Arc magmatism and accretion occurred above the east-dipping subduction zone in the Wrangellia and Southern margin CTs. The Wrangellia terrane in Alaska was offset 600+ km from Wrangellia in British Columbia. There was deformation of flysch basins along the continentward margin of the Wrangellia CT by 140 Ma, probably by interaction with terranes along the continental margin. FAR, Farallon plate.

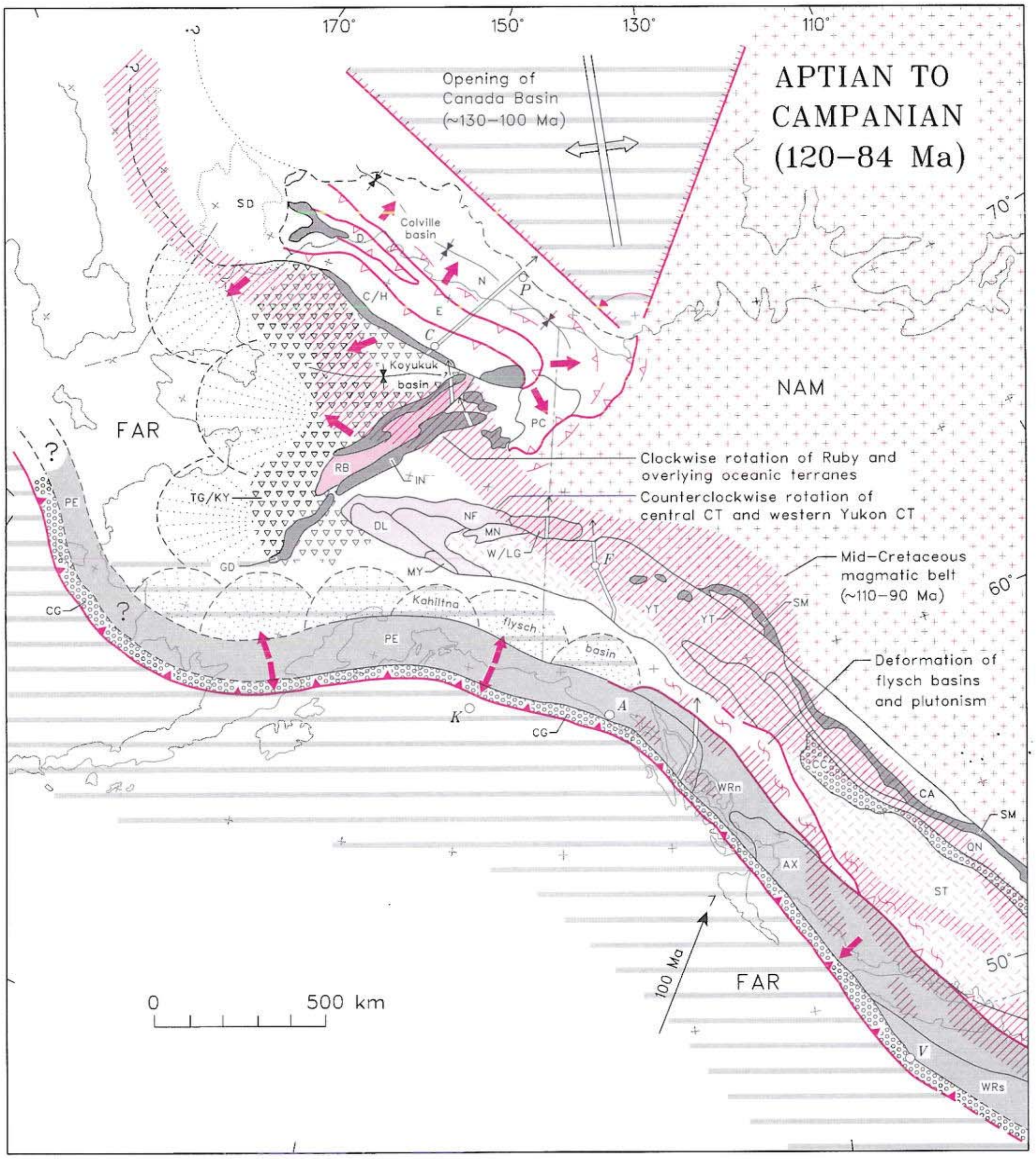

Figure 5E. Aptian to Campanian: The Canada basin opened, driving counterclockwise rotation of the Arctic CT and attached parts of the Togiak-Koyukuk and Oceanic CTs, and clockwise rotation of the Ruby terrane and attached parts of the Oceanic CT. The Wrangellia CT was emplaced against continental margin terranes with the collapse of flysch basins. A major magmatic belt (diagonal red lines) overprinted all major terranes in Alaska and adjacent parts of Canada; it is inferred to be related to east-dipping subduction along continental margin. Magmatism was accompanied by thermal metamorphism throughout much of Alaska and by at least local extension in the Yukon CT. FAR, Farallon plate.

on the inference that it was originally continuous with the southern part of the Arctic CT. There is no control on the latitudinal position of the Yukon CT; by Devonian time it was part of a continental margin magmatic arc.

The Cambrian through Early Devonian (Fig. 5A) continental margin in Alaska was characterized by (1) continued subsidence and local rifting in the miogeocline and deposition of carbonate rocks and of clastic sediments derived mainly from the craton; (2) local extension(?) with emplacement of ultramafic and mafic igneous rocks of the Livengood terrane on the ocean floor adjacent to the continental margin in latest Precambrian to Early Cambrian time; (3) local early Paleozoic extension and bimodal volcanism in parts of the Central and Yukon CTs; (4) possible early Paleozoic subduction and arc volcanism along the Arctic

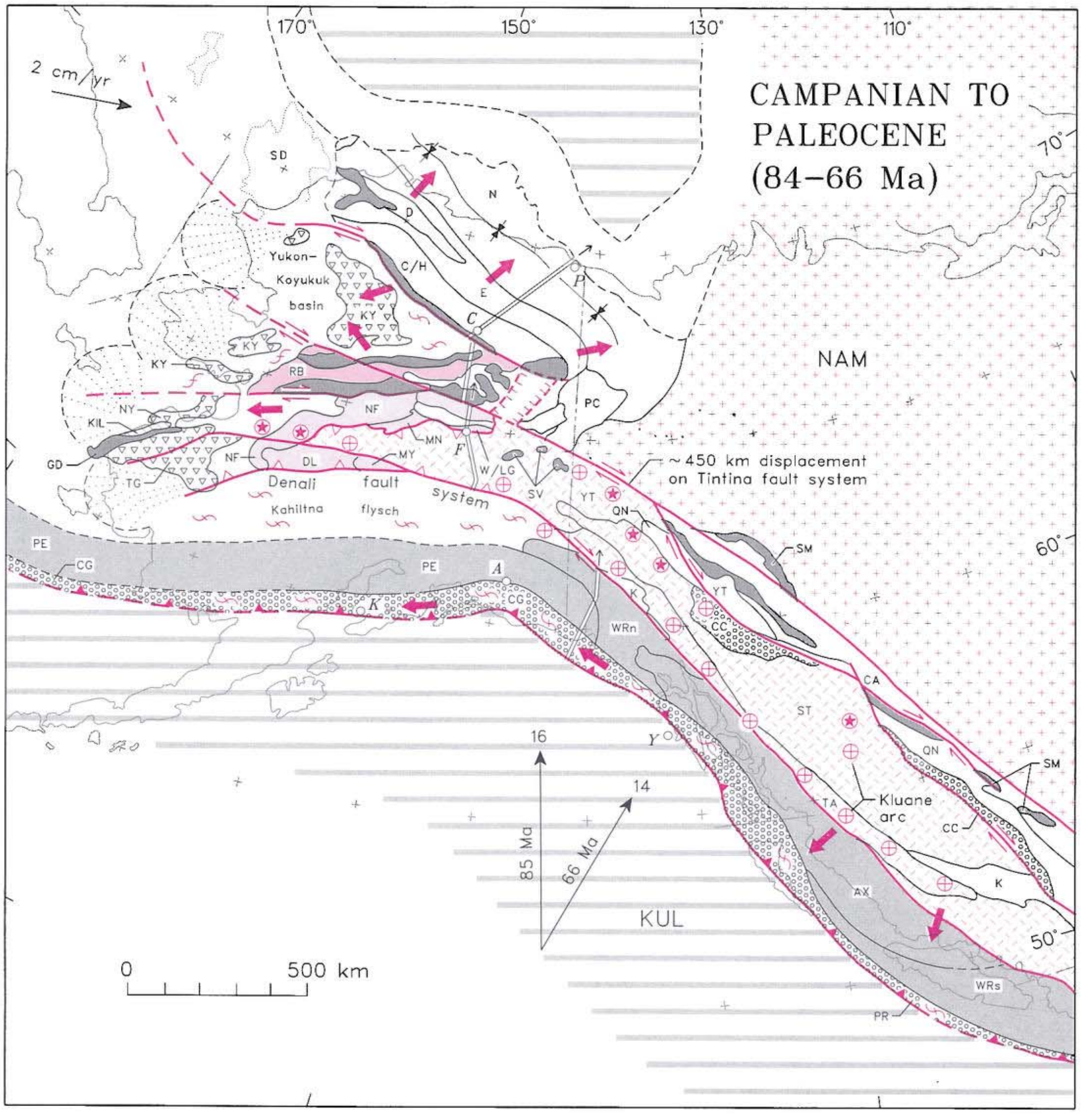

Figure 5F. Campanian to Paleocene: Dextral transpression along the continental margin resulted in northwestward movement of the Yukon CT along the Tintina and related faults, driving further clockwise rotation of the Ruby terrane and attached Oceanic CT to close the Yukon-Koyukuk basin. Kluane arc magmatism was active above the landward-dipping subduction zone, and there was large accretion of arc-derived sediments in the Southern Margin CT. KUL, Kula plate.

CT part of the continental margin or on an accreted continental fragment; and (5) Silurian (Franklinian orogeny) deformation of the inboard part of the Arctic CT.

The late Early Devonian to earliest Mississippian interval was characterized along the continental margin of Alaska and contiguous regions by compressional deformation and dominantly coarse clastic sedimentation (Ellesmerian orogeny of Arctic Alaska and Antler orogeny in the southern Cordillera). During this period, there was granitoid plutonism and local comagmatic(?) andesitic to felsic volcanism in the Arctic CT (Hammond, Coldfoot, and western North Slope subterranes), the Ruby terrane, and the Yukon CT (Yukon-Tanana terrane). Magmatism of this age has not been recognized in the Central CT. The Devonian to Early Mississippian magmatic belt is generally coeval and coextensive with granitoid plutonism that extends southward through Yukon Territory in Canada, and with plutonism and volcanism in the Klamath Mountains and Sierra Nevada of Oregon and California (see summary by Rubin and others, 1991).

The Wrangellia CT was a primitive oceanic arc or oceanic arc complex throughout much of the early Paleozoic (and probably the Late Proterozoic). In the southern segment of the Wrangellia CT on Vancouver Island, volcanism and plutonism of the Sicker arc are poorly dated in the interval from the Middle Silu-

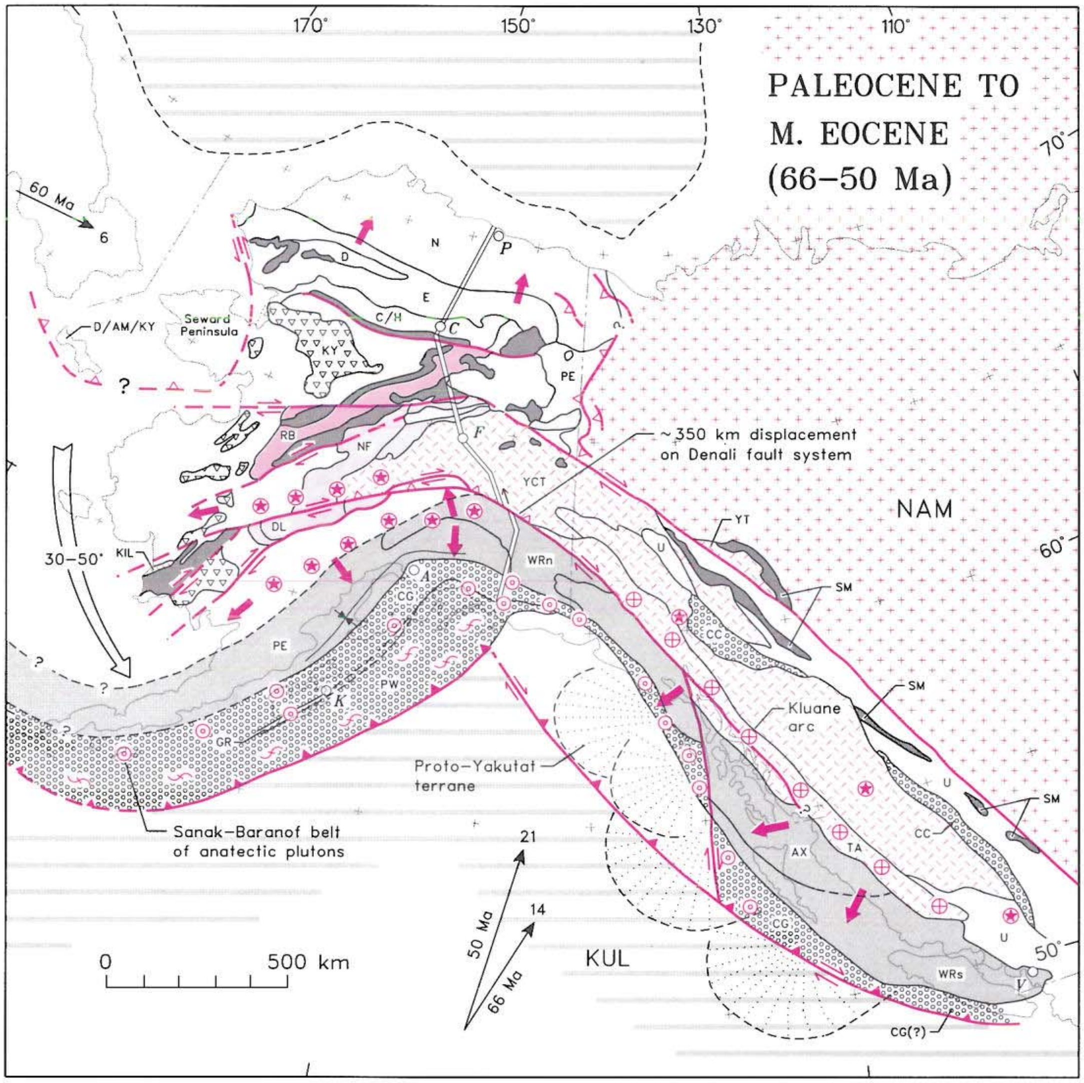

Figure 5G. Paleocene to middle Eocene: Large-scale counterclockwise rotation of western Alaska and displacement of the western Arctic CT (Seward Peninsula) was driven by compression between Eurasia and North America. Dextral displacement on the Denali fault system formed the proto-Yakutat terrane, and further dispersed terrane fragments in western Alaska. There was continued Kluane arc magmatism above landward-dipping subduction zones, and major volumes of arc-derived sediment were offscraped into western part of the Southern Margin composite terrane accretionary prism, followed by widespread anatectic magmatism along the southern Alaska margin. KUL, Kula plate.

rian to the Late Devonian (Brandon and others, 1986). The relation of this arc to the Late Devonian magmatism that characterized much of the western continental margin is unknown: one possibility is that it was an intraoceanic equivalent of the Devonian continental margin magmatic belt (Plafker, 1990).

Assuming the Northern Hemisphere option, the Ordovician to Devonian paleolatitude of the Wrangellia CT was 0°–15° south relative to the craton, depending upon the reference poles chosen (Van der Voo and others, 1980; Hillhouse and Coe, this volume). Its longitude relative to the craton is unknown. An intriguing alternative hypothesis assumes a Southern Hemisphere interpretation of the paleomagnetic data and suggests that the Alexander terrane part of the composite terrane was adjacent to eastern Australia until at least Middle Devonian time (Gehrels and Saleeby, 1987). This option is incompatible with Devonian faunal data from the Alexander terrane, which suggest North American affinities (Savage, 1988). Furthermore, magmatism of the Skolai and Talkeetna arcs indicates relative convergence between the Wrangellia CT and adjacent oceanic plates during most of the late Paleozoic and early Mesozoic. As a consequence, the Wrangellia CT could not have been transported passively on oceanic plates across the paleo-Pacific Ocean during this time

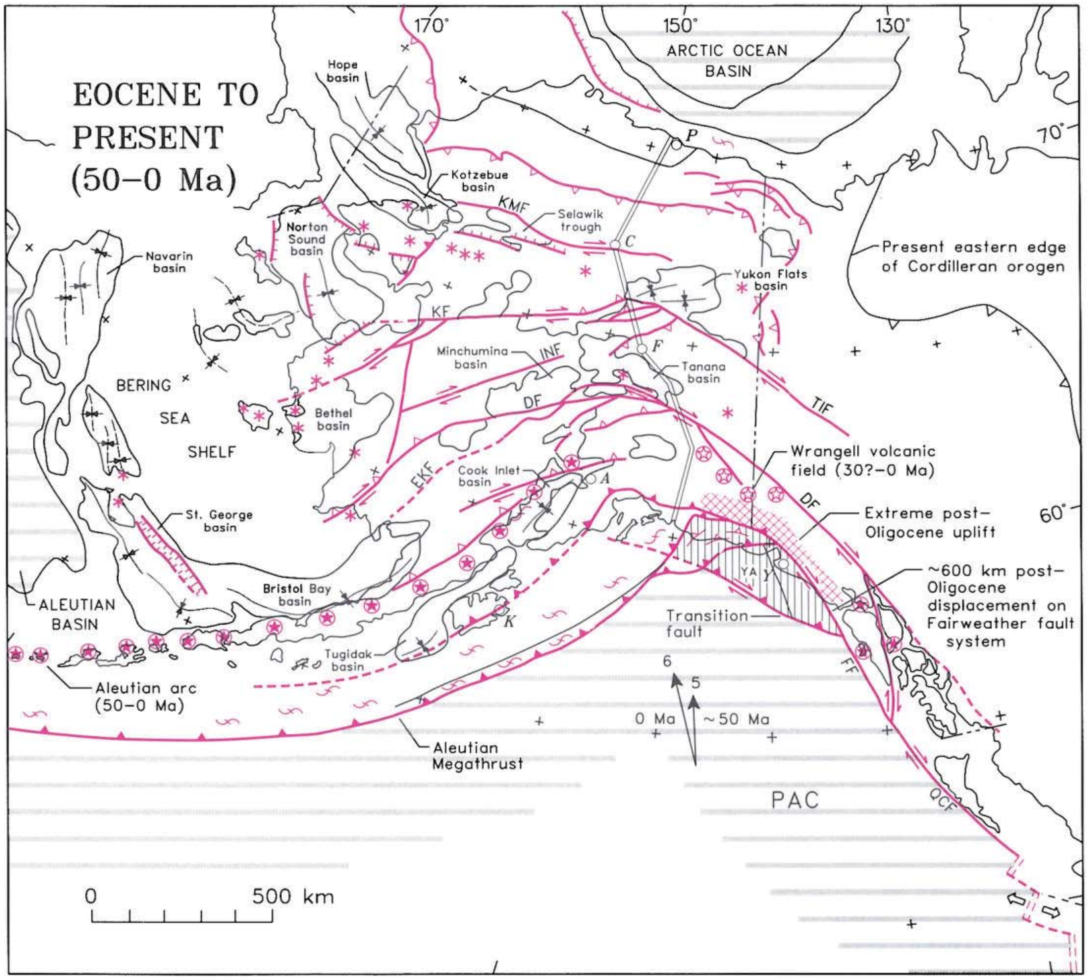

Figure 5H. Eocene to present: Onset of northwestward Pacific plate relative motions resulted in the formation of the present Aleutian–Alaska Peninsula arc, displacements on intraplate faults, and the formation of basins on land and on the contiguous continental shelves. At about 30 Ma, the Fairweather–Queen Charlotte transform boundary stepped northward to its present position, the Yakutat terrane began to move ~600 km northwestward along the transform boundary, and subduction of combined western Yakutat terrane and Pacific plate resulted in arc volcanism in the Wrangell Mountains and major uplift of eastern Chugach and Saint Elias mountains. Fault abbreviations are the same as for Figure 4. PAC, Pacific plate.

interval (Plafker and others, 1989; Nokleberg and others, this volume, Chapter 10).

Early Mississippian to Middle Triassic (360–230 Ma)

The Mississippian to Middle Triassic interval (Fig. 5B) in northern Alaska was characterized by deposition of the Ellesmerian sequence of continental clastic rocks, carbonate rocks, and chert on the subsiding ocean-facing shelf and rise of the Artic CT. Coeval rocks in the Central CT are scarce, but include Mississippian through Lower Jurassic carbonate rocks, chert, and volcaniclastic rocks (Innoko terrane) and Upper Permian and Upper Triassic sandy and spiculitic carbonate rocks (Nixon Fork terrane).

To the south, Devonian to earliest Mississippian orogeny in eastern Alaska, Yukon Territory, and British Columbia appears to have been immediately followed by extension and subsidence of the continental margin and rifting of fragments, including the Yukon CT, to open the Cache Creek Sea. Upper Paleozoic carbonate rocks were deposited on the Quesnellia terrane and the subsiding shelf. Relative motion between the seaward-moving Yukon CT and the oceanic plate resulted in Carboniferous and Permian arc magmatism in the southern part of the composite terrane (Stikine terrane); comparable magmatism has not been found in the Yukon-Tanana terrane to the north. The position of the Yukon CT relative to the craton during this time interval is unknown.

In the Wrangellia CT, late Paleozoic arc volcanic rocks and comagmatic plutons (Skolai arc) resulted from an inferred craton-dipping subduction zone. The Skolai arc is roughly coeval with arc rocks in the collage of accreted terranes within the Blue Mountains, eastern Klamath Mountains, and northern Sierra Nevada of the conterminous United States (Saleeby, 1983; Miller, 1987) and may have been part of this same arc system.

Late Triassic to Middle Jurassic (about 230–160 Ma)

During most of the Late Triassic to Middle Jurassic interval (Fig. 5C), convergence prevailed between the Farallon plate and the continental margin. As a consequence, fringing intraoceanic arcs developed within the Farallon plate from Alaska to southern California. In what is now western Alaska, the southern part of the Togiak-Koyukuk CT (Togiak arc) became active in Middle Jurassic time above a west-dipping subduction zone. To the south, in Canada, the Late Triassic and Early Jurassic Quesnellia magmatic arc (Fig. 3) and its associated accretionary complex (Cache Creek terrane) developed along the continental margin above an east-dipping subduction zone. In the Yukon CT, the Late Triassic to Middle Jurassic Stikine arc was active above a probable west-dipping subduction zone.

Subduction beneath the Quesnellia and Stikine arcs ended with closure of the Cache Creek basin by Middle Jurassic time, after which these arc and oceanic assemblages were tied to terranes of continental margin affinities (Monger and Berg, 1987). Collision of the Yukon CT with the continental margin resulted in accretion and east-directed overthrusting of the Late Triassic to Middle Jurassic complex of arcs (Stikine and Quesnellia terranes), accretionary prisms (Cache Creek terrane), and oceanic crust (Seventymile and Slide Mountain terranes). Devonian to Late Triassic ages of the oceanic rocks and associated sedimentary cover suggest a very long-lived sea that may have been 1000–5000 km wide (Tempelman-Kluit, 1979). Accretion was accompanied by intense deformation and metamorphism that included local formation of blueschist and eclogite facies rocks (Hansen, 1990).

In the Wrangellia CT, the early part of the Late Triassic was characterized by rifting and the eruption of voluminous sequences of marine and subaerial dominantly tholeiitic basalt flows and pillow lavas and by local bimodal volcanic rocks (Nokleberg and others, this volume). Rift-related magmatism was followed by latest Triassic to early Middle Jurassic Talkeetna arc volcanism above an east-dipping subduction zone and by subduction and local blueschist facies metamorphism in the associated accretionary prism of the Southern Margin CT. Much of the northward movement of the Wrangellia CT may have occurred during the lull in arc volcanism from earliest Middle Jurassic to Late Jurassic time.

The occurrence of enigmatic Permian Tethyan faunas in rocks associated with these arcs has been the subject of considerable debate in tectonic reconstructions of the western Cordillera. In Alaska, Tethyan faunas occur mainly in Permian limestone blocks at localities within melange of the Southern Margin CT that is associated with the Talkeetna arc. At one locality near Anchorage, limestone containing Tethyan faunas occurs as a pod in schistose pelitic rocks, mafic volcanic rocks, and metachert that was interpreted as part of the Peninsular arc terrane (Clark, 1982). Late Triassic bivalve faunas in the Peninsular terrane, however, are endemic to the Americas and support an east Pacific origin (Newton, 1983), so autochthonous Tethyan faunas are unlikely. We suggest the alternative possibility that the limestone and associated rocks may be a metamorphosed facies of the same melange that contains limestone blocks of Tethyan affinity elsewhere in the Southern Margin CT. In adjacent parts of Canada, Permian limestone containing Tethyan faunas occurs as thick and extensive blocks in accretionary melange (Cache Creek terrane) associated with the Quesnellia arc. These blocks are interpreted to be disrupted limestone reefs capping guyots or plateaus that were rafted on oceanic crust from southern latitudes and were offscraped into the accretionary prism (Monger and Berg, 1987). In the conterminous United States, Tethyan faunas occur in coeval arc-related assemblages in a discontinuous belt that extends through the Blue Mountains, Klamath Mountains, and northern Sierra Nevada (Miller, 1987).

Late Jurassic to Aptian (about 160–120 Ma)

The Late Jurassic to Aptian interval (Fig. 5D) was characterized mainly by convergence accompanied by arc magmatism, accretion, and deformation along much of the western continental margin. In the Arctic, incipient rifting and sea-floor spreading of the Arctic Ocean basin is indicated by Late Jurassic to Early Cretaceous extensional structures along the present Canada basin margin of the Arctic CT (Grantz and others, this volume).

Beginning in the Late Jurassic and continuing through the Early Cretaceous, the Togiak-Koyukuk CT was accreted to the continental margin (Patton and others, this volume, chapter 7). This collision zone along ocean-facing parts of the Arctic and Central CTs was marked by subduction of the attenuated continental margin beneath the Togiak-Koyukuk accretionary prism and arc. As a consequence, Late Devonian to Early Jurassic oceanic basalt and ultramafic rocks derived from the closed Kobuk Sea (the Oceanic CT) were obducted onto the continental margin as extensive thrust sheets up to 150 km wide. As with the Cache Creek Sea, the considerable age span of the oceanic rocks and the scarcity of continent-derived detritus suggest that the width of the Kobuk Sea was on the scale of thousands of kilometers. Emplacement was accompanied by widespread metamorphism, including blueschist facies metamorphism in the lower continental plate, and by large-scale continent-verging thrusting and folding.

On the Wrangellia CT, magmatism occurred during much of Late Jurassic and Early Cretaceous time in the Chitina and Gravina-Nutzotin arcs above an east-dipping subduction zone. Magmatism in the Wrangellia CT could represent a southward continuation of the partly coeval Togiak-Koyukuk arc, which would imply that the Wrangellia CT was close to its present position at that time. Volcaniclastic flysch and melange, including olistostromal blocks derived from the Wrangellia and Peninsular terranes, were deposited in the trench and accreted to the Southern Margin CT at the same time that thick, dominantly volcaniclastic flysch sequences were deposited in basins along the backarc side of the composite terrane. Truncation and intense shearing of the southern margin of the Wrangellia CT in Alaska are inferred to have occurred during about 600 km of sinistral displacement of the British Columbia part of the Wrangellia CT relative to the Alaska part (Plafker and others, 1989; this volume, Chapter 12). Sinistral strike-slip offset along the boundary between the Wrangellia and Alexander terranes in British Columbia and along the Border Ranges fault or the West Fork fault in Alaska could explain abrupt truncation of both the Talkeetna and Chitina arcs in Alaska (Fig. 5D); however, structural evidence for the sense of movement along the boundary remains to be documented. The inferred displacement postdates Late Jurassic plutonism and predates Late Cretaceous accretion of the flysch and basalt assemblage of the Chugach terrane. Late Jurassic to Early Cretaceous sinistral displacements reported elsewhere in the Cordillera (Avé Lallemant and Oldow, 1988) are compatible with this hypothesis.

In what is now south-central Alaska, deformation of thick flysch basinal assemblages (Kahiltna sequence) along the inboard margin of the Wrangellia CT occurred before emplacement of postdeformational alkalic gabbro plutons that yield K-Ar dates of 140 Ma (Smith, 1981). McClelland and others (1992a) cited the presence of Late Jurassic to Early Cretaceous basinal assemblages along the inner margin of the Wrangellia CT from western Alaska to California, and the deformation within these basins, to postulate emplacement of the composite terrane against inboard terranes, mainly the Stikine and Yukon-Tanana terranes, by Middle Jurassic time. In Alaska and adjacent parts of Canada, however, the dominantly volcanogenic composition of the flysch in these basins and paleocurrent data reflecting westerly sources do not support close proximity to the continental margin (Berg and others, 1972; Eisbacher, 1976; Cohen and Lundberg, 1988; Plafker, 1985, unpublished data). Other models propose that the flysch basins were closed by a Late Jurassic and/or Early to mid-Cretaceous suture that migrated from south to north (Pavlis, 1989). Because there are no known direct geologic ties, the position of the Wrangellia CT relative to the continental margin has not been shown in Figure 5D.

Aptian to Campanian (about 120–84 Ma)

During the Aptian to Campanian interval (Fig. 5E), orthogonal to dextral oblique convergence characterized the boundary of the Farallon and North American plates, and most of northern, central, and western Alaska was affected by deformation and rotations related to opening of the Canada basin.

In northern Alaska counterclockwise rotation of the Arctic CT away from the craton from late Neocomian through Albian time resulted in the development of a passive margin along the Canada basin that persists to the present. Rotation was accompanied by continued thrusting and uplift of the southern part of the Arctic CT (O'Sullivan and others, 1993) and by continued clastic sedimentation in the Colville foredeep basin of the North Slope. Uplift of the Arctic CT may have been at least in part a consequence of postorogenic extension (Miller and Hudson, 1991). In the eastern Arctic CT, contractional deformation occurred in the hinge zone of rotation, and uplift is reflected in clastic sedimentation in the region (Howell and Wiley, 1987).

Rotation of the Arctic CT is inferred in our model to have driven clockwise rotation of the Ruby terrane, Togiak-Koyukuk CT, and contiguous oceanic terranes, and minor counterclockwise rotation of the Central and western Yukon CTs, to form the southern margin of the proto-Koyukuk basin. The basin was filled with synorogenic Lower to mid-Cretaceous marine flysch derived mainly from the uplifted Brooks Range orogen.

The Wrangellia CT was juxtaposed against the Yukon CT close to its present position during this interval with resulting intense deformation of intervening flysch basins and structural imbrication and continent-directed deep underthrusting, synorogenic plutonism, and metamorphism as high as kyanite grade in the tectonically thickened crust along the suture zone (Csejtey and others, 1982; Monger and others, 1982; Crawford and others, 1987; Rubin and Saleeby, 1992). In central Alaska, Stanley and others (1990) postulated large-scale mid-Cretaceous (about 115–95 Ma) underthrusting of flysch beneath the Yukon-Tanana terrane to the north to explain electrically conductive rocks at depth and lead isotope data (Aleinikoff and others, 1987) that suggest a flysch component in mid-Cretaceous plutons. In parts of the Yukon-Tanana terrane, crustal extension at about 130–110 Ma resulted in a "core-complex" style detachment, a regional subhorizontal metamorphic fabric, and elimination of as much as 10 km of crustal section (Pavlis and others, 1993). The tectonic mechanism for the extensional event is unknown. In western Alaska, the Wrangellia CT is inferred from dredge data to form the western boundary of what is now the Bering Sea shelf (Marlow and others, this volume). A major unknown is the nature of the crust between the outer Bering Sea shelf and the onshore terranes.

Mid-Cretaceous magmatism and associated thermal metamorphism occurred in a broad belt through much of Alaska (Miller, this volume, Chapter 16), the Canadian Cordillera (Armstrong, 1988), and the Russian far east (Parfenov and Natal'in, 1986). We believe that this magmatic belt is related mainly to continental margin arc magmatism above a shallow-dipping subduction zone, but it also includes many plutons probably formed by crustal melting (Crawford and others, 1987; Pavlis and others, 1993; Hudson, this volume; Miller, this volume, Chapter 16). Thermal metamorphism and magmatism of this age occurs in a belt as wide as 600 km that extends from the North American craton in Canada across all outboard terranes to the southern margin of the Wrangellia CT. This belt requires that the terranes were assembled in approximately their present relative positions by the end of this time interval, except for younger intraplate fault displacements.

Campanian to Paleocene (about 84–66 Ma)

From Campanian to Paleocene time (Fig. 5F), the terranes along the northeast Pacific Ocean margin assumed their present configuration. After formation of the Kula plate at about 85 Ma, relative motion north of the Kula–Farallon–North American plate triple junction was characterized by rapid dextral-oblique transpression.

Erosion of the north- and east-propagating thrust sheets in the Arctic CT continued to supply sediment to the Colville foreland basin (Howell and others, 1992; Dover, this volume; Moore and others, this volume). In central Alaska, northwestward displacement of the Yukon CT and the attached Central CT (Nixon Fork and related terranes) occurred mainly by dextral slip along the Tintina fault and its major splays in Alaska. This displacement resulted in additional clockwise rotation of the Ruby terrane and overlying oceanic terranes with resulting pervasive compressive deformation of the Yukon-Koyukuk basin fill. In southern Alaska, final suturing of the Wrangellia CT occurred upon closure of the intervening seaway, sometime after the Cenomanian. Closure was accompanied by deformation and metamorphism of the intervening Kahiltna flysch basin and associated miniterranes.

A continental margin magmatic arc (Kluane arc) was active during the Late Cretaceous to early Tertiary interval along and inboard of the Wrangellia CT–Yukon CT boundary and it extended westward into west-central Alaska. An enormous volume of volcaniclastic sediment was shed from the arc onto the ocean floor and this sediment was then offscraped to form a major part of the Southern Margin CT accretionary prism.

Although dextral offset along the Tintina fault is shown as occurring mainly in this interval, the actual age of offset in Alaska is uncertain. In contiguous areas of Canada, fault movement continued into late Eocene or Oligocene time (Gabrielse, 1985), and in Alaska a short segment was reactivated with vertical displacement as recently as Holocene time (Plafker and others, this volume, Plate 12). It is likely that at least some strike-slip movement occurred during this time interval on the Denali and other faults outboard of the Tintina fault, but there is no direct evidence for the timing or amount of these displacements.

Paleocene to Eocene (about 66–50 Ma)

During Paleocene to early Eocene time (Fig. 5F) large Kula–North American plate relative motions continued in Alaska and adjacent parts of Canada. At the same time there was up to 6 cm/yr compression between Eurasia and North America coincident with opening of the Labrador basin.

Compression between Eurasia and North America resulted in counterclockwise oroclinal bending, into about their present positions, of western Alaska and the Arctic CT. Possibly concurrent with rotation, the Seward Peninsula segment of the Arctic CT is inferred to have been offset to the south relative to the eastern Arctic CT; this offset is postulated as the result of faulting, rather than rotation, to maintain the subparallelism of coeval structures in the Seward Peninsula and nearby parts of the southern Brooks Range (Till and Dumoulin, this volume). Uplift in the eastern Arctic CT at about 60 Ma, indicated by fission-track data (O'Sullivan and others, 1993) and by thrusting of the eastern Arctic CT over the adjacent miogeocline, may be related to this compressional episode.

In interior Alaska, transpression along the southern continental margin resulted in major dextral strike slip on the Denali fault that preceded the main rotation of western Alaska, and resulted in continued minor dextral slip on other northwest-trending intraplate faults, such as the Tintina fault. The combination of dextral displacement on northwest-trending faults and oroclinal bending resulted in local development of extensional basins along these faults systems (Fig. 5H).

In southern Alaska, Kluane arc magmatism continued in southeastern Alaska and it extended into southwestern Alaska and probably the Bering Sea shelf, as a broad belt of arc-related volcanic rocks. Voluminous Paleocene and Eocene deep-sea fan and trench(?) deposits were derived from the Kluane arc and incorporated into the western limb of the Southern Margin CT. Accretion was followed by widespread early Eocene metamorphism and anatectic granitic plutonism in parts of the Southern Margin CT and adjacent Wrangellia CT inferred to have been related to subduction of the Kula-Farallon ridge. Along the southeastern margin of Alaska, the proto-Yakutat terrane was formed by early Eocene(?) oceanward stepping of the plate boundary following about 180 km of dextral displacement on the Chatham Strait segment of the Denali fault. During and immediately after faulting, lower 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 Chugach terrane and on oceanic crust to the west.

Eocene to present (about 50–0 Ma)

North to northwest motion of the Pacific plate relative to the continental margins of Alaska and most of Canada began by early middle Eocene time after subduction of the Kula plate and continues to the present. Figure 5G shows selected major structural features in Alaska and on the adjacent sea shelves; the present configuration of terranes and composite terranes is shown in Figures 1 and 2.

Nearly orthogonal to dextral-oblique convergence along most of the western Alaska margin resulted in development of the Aleutian arc as the Pacific–North American plate boundary from the Alaska Peninsula westward, thereby trapping a large segment of oceanic plate within the abyssal Bering Sea (Marlow and others, this volume; Vallier and others, this volume). Andesitic volcanism associated with the Aleutian arc (Fournelle and others, this volume; Kay and Kay, this volume) began on the Alaska Peninsula at about 50 Ma, a few million years after the onset of northwestward motion of the Pacific plate, and continues to the present. Subduction along the Aleutian megathrust beneath the arc was accompanied by accretion and underplating of deep-sea sediments and oceanic crust along the inner wall of the Aleutian Trench, which includes the Southern Margin CT. Along the western Aleutian ridge, a wide range of strike-slip, extensional, and rotational structures reflect the dextral-oblique to dextral relative motion across that part of the Aleutian arc (Vallier and others, this volume; Plafker and others, this volume, Plate 12). During this interval, some of the northeast- to east-trending intraplate strike-slip faults of western and central Alaska were reactivated as thrust or oblique thrust faults.

Dextral transpression characterized the transform plate margin off southeastern Alaska and British Columbia and resulted in dextral strike slip on northwest- to west-trending intraplate faults extending inland at least to the Kobuk and Tintina faults. Intermittent magmatism in southeastern Alaska and adjacent parts of British Columbia suggests a significant component of oblique underthrusting along that margin during Paleogene time (Brew, this volume). Throughout Alaska, continental sediment was deposited in interior basins formed as crustal sags, pull-aparts related to strike-slip faults, and half grabens (Kirschner, this volume, Chapter 14; Wahrhaftig and others, this volume), and dominantly marine sediment was deposited in shelf-margin and shelf basins (Kirschner, this volume, Plate 7). The larger basins of the Bering Sea shelf contain dominantly marine strata of post–middle Eocene age. Marlow and others (this volume) interpret the Norton and Bristol Bay basins as crustal sags that probably involve block faulting in basement rocks; they interpret the Navarin and St. George basins as grabens and half grabens formed by extensional collapse of the outer Bering shelf margin. An alternative view which emphasizes the scarcity of normal faults seen on seismic reflection profiles across many of these outer shelf basins, is that they are controlled by margin-parallel dextral shear zones along and near the continental shelf edge (Worrall, 1991).

At about 30 Ma, the transform margin stepped landward to its present position on the Queen Charlotte and Fairweather faults, and the Yakutat terrane began moving northwestward with the Pacific plate about 600 km to its present position (Plafker and others, this volume). Subduction of the leading edge of the Yakutat terrane beneath the Southern and Wrangellia CTs resulted in volcanism in the Wrangell arc beginning about 25 Ma and continuing to the present. Ongoing collision and subduction of the Yakutat terrane is marked by extreme uplift and topographic relief in the adjacent Chugach and Saint Elias mountains, by deposition of thick sequences of Miocene and younger clastic sediments (including abundant marine glacial diamictite) in continental shelf basins and the Aleutian Trench, by intense ocean-verging compressional deformation, and by high seismicity (Plafker and others, this volume, Chapter 12). Stress trajectories derived from neotectonic data (Plafker and others, this volume, Plate 12) suggest that late Cenozoic mountain-building deformation and seismicity throughout Alaska and adjacent parts of Canada and Neogene volcanism in the Aleutian arc and dominantly basaltic volcanism in large areas of interior and western Alaska, the Bering Sea shelf, and southeastern Alaska are driven mainly or entirely by interaction between the Pacific plate (and Yakutat terrane) with the southern margin of the continent.

Discussion

The tectonic model presented here is compatible with much of the geologic, geophysical, and paleomagnetic data for Alaska. There are two major differences between this model and previous interpretations of the tectonic evolution of Alaska (Plafker, 1990) and the southern Alaska margin (Plafker and others, this volume, Chapter 12). First, we have used geologic data to constrain the timing for northward movement and accretion of the Wrangellia CT to southern Alaska to Jurassic time, instead of the plate reconstructions of Engebretsen and others (1985), which preclude significant northward movement before Late Cretaceous time. Second, we postulate that clockwise rotation of the Central CT began in Early to mid-Cretaceous time, concurrent with opening of the Arctic basin, instead of late Paleozoic to early Mesozoic counterclockwise rotation indicated by paleomagnetic data (Plumley, 1984). Throughout this synthesis we have tried to highlight the inevitable problems that arise due to lack of data, to conflicting data from different studies, or to different interpretations of the same data. Resolution of these, and other major problems, should provide a fertile field for future geologic and geophysical research in Alaska.

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