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Chapter 10

Geology of south-central Alaska

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INTRODUCTION

Study area and major geologic units

South-central Alaska is defined as the region bounded by the Kuskokwim Mountains to the northwest, the basins north of the Alaska Range to the north, the Canadian border to the east, and the Chugach Mountains to the south (Fig. 1). This region, hereafter called the study area, includes the Alaska Range, the Wrangell, Nutzotin, and Talkeetna mountains, the Copper River and the Susitna basins, the northern flank of the Chugach Mountains, the Aleutian Range, and the Alaska Peninsula. This chapter describes and interprets the bedrock geology of the region, which consists mostly of a collage of Paleozoic and Mesozoic tectonostratigraphic terranes (hereafter referred to as terranes), Mesozoic flysch basin deposits, late Paleozoic and Mesozoic plutonic rocks, and younger late Mesozoic and Cenozoic sedimentary, volcanic, and plutonic rocks. Cited published sources and new data and interpretations of the authors are utilized for the descriptions and interpretations. The terranes, flysch basin deposits, and younger Mesozoic sedimentary, volcanic, and plutonic assemblages are described first in a general northwest to southeast order. Major faults or sutures are described second. Stratigraphic linkages and structural and tectonic relations between terranes are described last. Definitions of the various stratigraphic, structural, and tectonic terms are stated at the end of this introduction.

The three largest terranes in the study area are the Alexander, Peninsular, and Wrangellia terranes (Fig. 2) (Jones and others, 1981, 1984, 1987). Even though many boundaries between the three terranes are commonly faults, important stratigraphic linkages exist. These linkages suggest a common history since the Middle Pennsylvanian for the Alexander and Wrangellia terranes, and since at least the Late Triassic and possibly the late Paleozoic for the Peninsular and Wrangellia terranes (Plafker and others, 1989c; Plafker, 1990; Plafker and Berg, this volume, Chapter 33). As a result, this chapter interprets these three terranes as the Wrangellia composite terrane (WCT). An older name for the WCT is the Peninsular-Alexander-Wrangellia superterrane (Pavlis, 1983). The name of Wrangellia composite terrane is adopted in this chapter for conformity with Plafker and Berg (Chapter 33). A prior term, the Talkeetna superterrane, was used to describe the combined Wrangellia and Peninsular terranes by Csejtey and others (1982).

In addition to the major terranes in the study area, several small, narrow, highly deformed terranes occur adjacent to the Denali fault, south of the large masses of the Yukon-Tanana, Nixon Fork, and Dillinger terranes. These terranes are the Aurora Peak, Pingston, McKinley, Mystic, and Windy terranes, a terrane of ultramafic and associated rocks, and a fragment of the Dillinger terrane (Fig. 2). To the south, several other small terranes occur within highly deformed upper Mesozoic flysch assemblages, either as rootless nappes or as units bounded by steep faults (Jones and others, 1981, 1987). These terranes are the Broad Pass, Chulitna, Clearwater, Maclaren, Susitna, and West Fork terranes (Fig. 2). Two major late Mesozoic flysch basins, now tectonically collapsed, occur along the northern margin of the WCT (Fig. 2). To the northwest is the mainly Late Jurassic and Early Cretaceous flysch of the Kahiltna assemblage that probably originally depositionally overlapped the Peninsular terrane (Wallace and others, 1989). To the northeast is the partly coeval Late Jurassic and Early Cretaceous flysch and volcanic rocks of the Gravina-Nutzotin belt, which depositionally overlies the Wrangellia terrane in the study area and the Alexander terrane in southeastern Alaska (Berg and others, 1972).

Major faults or sutures are either known or are inferred to separate terranes. Along the northern boundary of the study area is the Denali fault and along the southern boundary is the Border Ranges fault (Fig. 2). Other important sutures are the Broxson Gulch thrust between the Maclaren and Wrangellia terranes, the Talkeetna thrust between the Peninsular and Wrangellia terranes, the West Fork fault between the southern Wrangellia and Peninsular terranes, and the Chitina Valley fault between the Wrangellia and southern Wrangellia terranes (Fig. 2). Major Cenozoic faults, such as the Castle Mountain, Hines Creek, and Totschunda faults, that occur mainly within terranes in the study area, are depicted and described by Plafker and others (Chapter 12).

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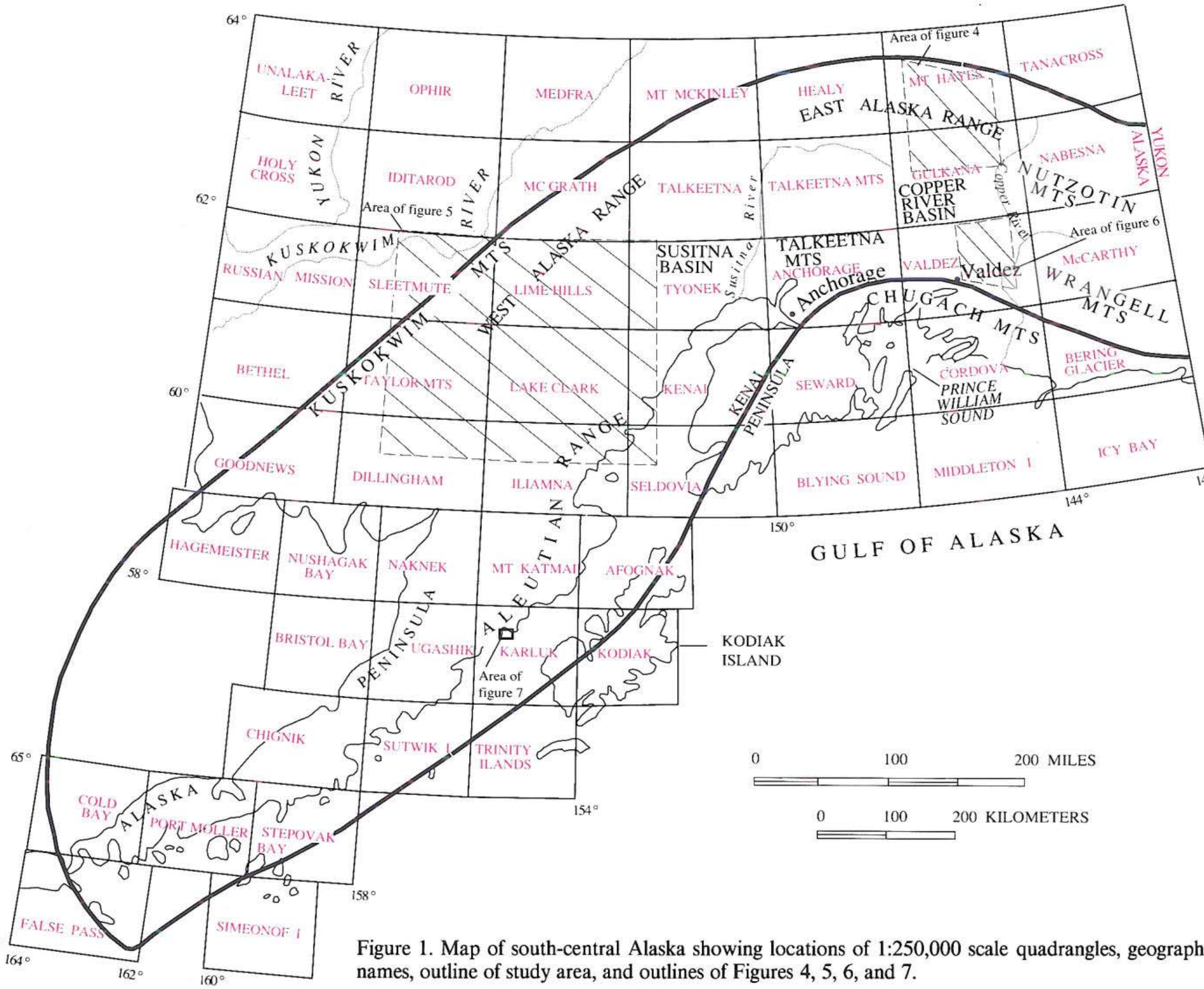


Figure 1. Map of south-central Alaska showing locations of 1:250,000 scale quadrangles, geographic names, outline of study area, and outlines of Figures 4, 5, 6, and 7.

Companion studies

Companion studies in this volume that describe the bedrock geology of areas adjacent to the study area are east-central Alaska by Foster and others (Chapter 6); southwestern Alaska by Decker and others (Chapter 9); southern Alaska continental margin by Plafker and others (Chapter 12); and the Aleutian arc by Vallier and others (Chapter 11). Other related topical studies in this volume that include data on the geology of the study area are accreted volcanic rocks by Barker and others (Chapter 17); metamorphic history of Alaska by Dusel-Bacon (Chapter 15); metallogenesis of Alaska by Nokleberg and others (Chapter 29); paleomagnetic data in Alaska by Hillhouse and Coe (Chapter 26); pre-Cenozoic plutonic history by Miller (Chapter 16); interior basins by Kirschner (Chapter 14); Late Cretaceous and Cenozoic magmatism in mainland Alaska by Moll-Stalcup (1990; Chapter 18); isotopic composition studies of igneous rocks of Alaska by Arth (Chapter 25); and volcanic rocks of the Aleutian and Wrangell arcs by Miller and Richter (Chapter 24).

Plates in this volume containing data relevant to the geology of the study area are geology of Alaska by Beikman; lithotectonic terrane map and columnar sections for Alaska by Silberling and others; metamorphic map of Alaska by Dusel-Bacon (Plate 4); map showing latest Cretaceous and Cenozoic magmatic rocks of Alaska by Moll-Stalcup and others; map showing selected pre-Cenozoic plutonic rocks and accreted volcanic rocks of Alaska by Barker and others; map showing sedimentary basins of Alaska by Kirschner (Plate 7); map and table showing isotopic age data in Alaska by Wilson and others; map showing locations of metalliferous lode deposits and placer districts of Alaska by Nokleberg and others (Plate 11); and neotectonic map of Alaska by Plafker and others (Plate 12).

Except where indicated, age designations used in this chapter are based on the Decade of North American Geology geologic time scale (Palmer, 1983); metamorphic facies are after Turner (1981); plutonic rock classifications are after Streckeisen (1976); volcanic rock classifications are after Streckeisen (1980); sandstone classifications are after Dickinson and Suczek (1979); deformed rock nomenclature is after Higgins (1971) and Wise and others (1984); terrane designations are modified from Jones and others (1987), Monger and Berg (1987), Silberling and others (this volume), Nokleberg and others (1994), and the authors; and older K-Ar isotopic ages are recalculated using the newer decay constants of Steiger and Jäger (1977).

Definitions

The following definitions are adapted from Coney and others (1980), Jones and others (1983), Howell and others (1985), Monger and Berg (1987), Wheeler and others (1988), and Nokleberg and others (1994).

Accretion. Tectonic juxtaposition of two or more terranes, or tectonic juxtaposition of a terrane(s) to a continental margin.

Accretionary wedge terrane. Fragment of a mildly to intensely deformed complex of turbidite deposits and lesser amounts of oceanic rocks. Formed adjacent to zones of thrusting and subduction along the margin of a continental or an island arc. Commonly associated with subduction zone terranes. May include large, fault-bounded units with coherent stratigraphy.

Assemblage. A group of stratigraphically or structurally related sedimentary and/or igneous rocks.

Belt. A regional linear group of geologic units.

Composite terrane. An aggregate of terranes that is interpreted to share either a similar stratigraphic kindred or affinity, or a common geologic history (Plafker, 1990; Plafker and Berg, this volume, Chapter 33). An approximate synonym is *superterrane* (Moore, 1992).

Continental margin arc terrane. Fragment of an igneous belt of coeval plutonic and volcanic rocks, and associated sedimentary rocks that formed above a subduction zone dipping beneath a continent. Inferred to possess a sialic basement.

Island (intraoceanic) arc terrane. Fragment of an igneous belt of plutonic rocks, coeval volcanic rocks, and associated sedimentary rocks that formed above an oceanic subduction zone. Inferred to possess a simatic basement.

Metamorphic terrane. Fragment of a highly metamorphosed and/or deformed assemblage of sedimentary, volcanic, and/or plutonic rocks that cannot be assigned to a single tectonic environment because original stratigraphy and structure are obscured. Includes highly deformed structural melanges that contain intensely deformed pieces of two or more terranes.

Overlap assemblage. A sequence of sedimentary and/or igneous rocks deposited on, or intruded into, two or more adjacent terranes. The sedimentary and volcanic parts depositionally overlie, or are interpreted to have originally depositionally overlain, two or more adjacent terranes, or terranes and the craton margin. Overlap plutonic rocks in some areas are coeval and genetically related to overlap volcanic rocks, and weld or stitch together adjacent terranes, or a terrane and a craton margin.

Oceanic crust, seamount, and ophiolite terrane. Fragment of part or all of a suite of eugeoclinal, deep-marine sedimentary rocks, pillow basalts, gabbros, and ultramafic rocks that are interpreted as oceanic sedimentary and volcanic rocks, and upper mantle. Includes both inferred offshore ocean and marginal ocean basin rocks. Includes minor volcaniclastic rocks of magmatic arc derivation. Mode of emplacement onto continental margin uncertain.

Postaccretion rock unit. Suite of sedimentary, volcanic, or plutonic rocks that formed in the late history of a terrane, after accretion. May occur also on an adjacent terrane(s) or on craton margin as an overlap assemblage unit. A relative term denoting rocks formed after juxtaposition of one terrane to an adjacent terrane.

Preaccretion rock unit. Suite of sedimentary, volcanic, or plutonic rocks that formed in the early history of a terrane, before accretion. Constitutes the stratigraphy inherent to a terrane. A relative term denoting rocks formed before juxtaposition of one terrane to an adjacent terrane.

Seamount and oceanic plateau. Major marine volcanic accumulations formed at a hot spot, fracture zone, or spreading center, or off the axis of a spreading center.

Subduction zone terrane. Fragment of variably to intensely deformed oceanic crust and overlying units, oceanic mantle, and lesser turbidite and continental margin rocks that were tectonically juxtaposed in a zone of major thrusting of one lithosphere plate beneath another. Many subduction zone terranes contain fragments of oceanic crust and associated rocks that exhibit a complex structural history, occur in a major thrust zone, and possess blueschist facies metamorphism. Commonly associated with accretionary wedge terranes. May include large, fault-bounded blocks with coherent stratigraphy.

Subterrane. Fault-bounded unit within a terrane that exhibits a similar, but not identical, geologic history to another fault-bounded unit in the same terrane.

Terrane. A fault-bounded assemblage or fragment that is characterized by a unique geologic history that differs markedly from that of adjacent terranes. Constitutes a physical entity, i.e., a stratigraphic succession bounded by faults, or an intensely deformed structural complex bounded by faults. Some terranes may be faulted facies equivalents of other terranes.

TERRANES ADJACENT TO DENALI FAULT

Several narrow terranes occur adjacent to the Denali fault in the central and eastern Alaska Range. These terranes are the Aurora Peak, McKinley, Mystic, Pingston, and Windy terranes, a terrane of ultramafic and associated rocks, and a fragment of the Dillinger terrane (Fig. 2). Some terranes, such as the Aurora Peak, Dillinger, McKinley, and Mystic terranes, extend along strike for only about 50 to 100 km, whereas others, such as the


160°
61°
Ks
TKv
DENALI FAULT
TKg
KH
CzV
mJg
Tg
PE
BRUIN BAY FAULT
CzS
JTru
JTru/PE
CG
BORDER RANGES FAULT
TG
mTv
55°
160°

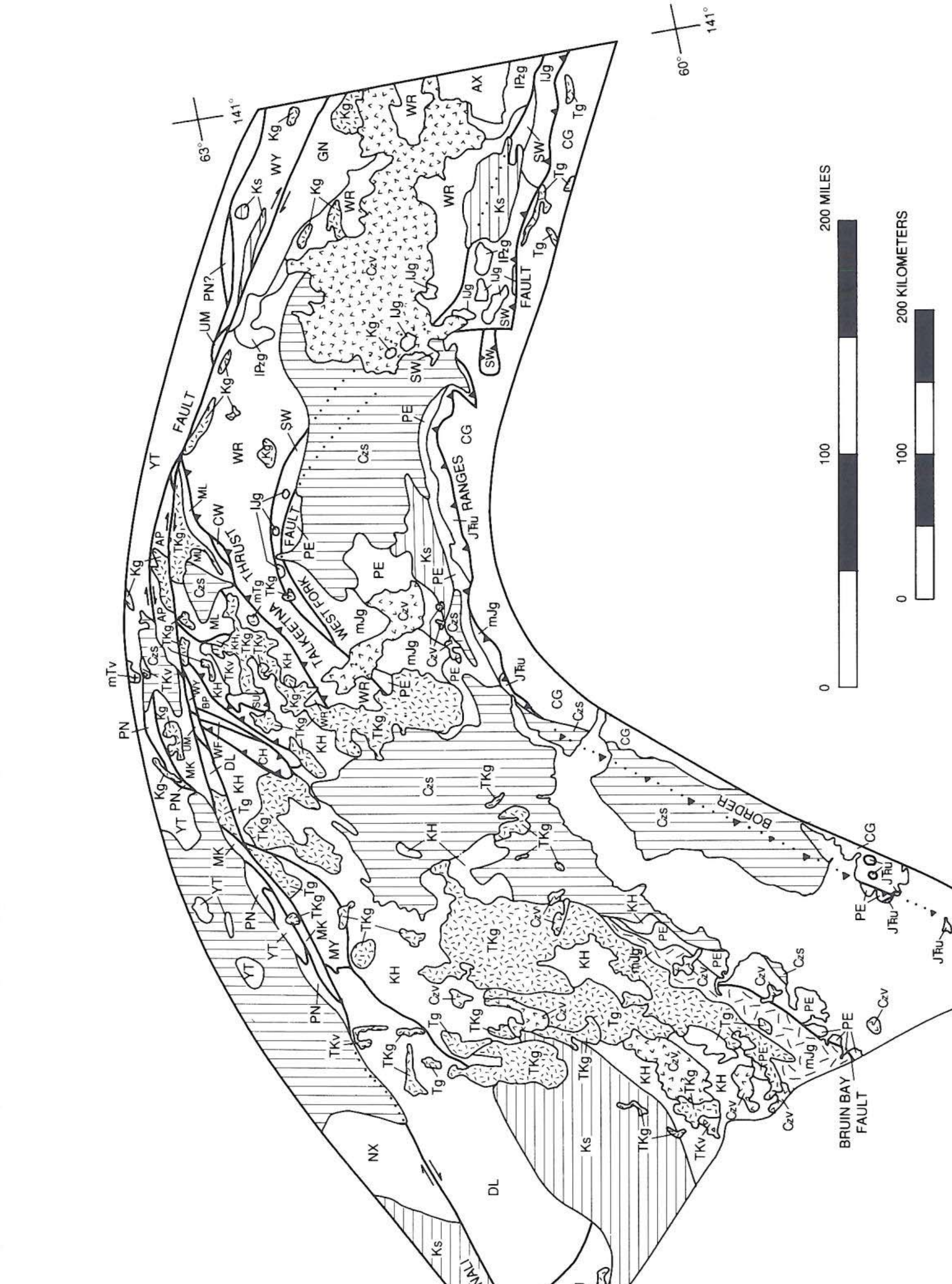


Figure 2. Generalized tectonic-magmatic map of south-central Alaska. Adapted from Jones and others (1987), Barker and others (this volume), Moll-Stalcup and others (this volume), and Nokleberg and others (1994). Explanation on following page.

EXPLANATION

CENOZOIC AND LATE CRETACEOUS SEDIMENTARY AND VOLCANIC ROCKS

- Czs — Cenozoic sedimentary rocks and unconsolidated deposits
- Czv — Cenozoic volcanic rocks
- mTv — Middle Tertiary volcanic rocks
- TKv — Late Cretaceous and early Tertiary volcanic rocks
- Ks — Cretaceous sedimentary rocks

TERTIARY AND CRETACEOUS GRANITOID ROCKS

- Tg — Early Tertiary granitoid rocks
- mTg — Middle Tertiary granitoid rocks
- TKg — Late Cretaceous and early Tertiary granitoid rocks
- Kg — Cretaceous granitoid rocks

EARLY CRETACEOUS AND LATE JURASSIC SEDIMENTARY AND VOLCANIC ASSEMBLAGES

- KH — Kahiltna assemblage
- GN — Gravina-Nutzotin belt

LATE JURASSIC AND OLDER PLUTONIC ROCKS

- lJg — Late Jurassic granitoid rocks: occur in Gravina-Nutzotin belt and Wrangellia terrane
- mJg — Middle Jurassic granitoid rocks: occur in Peninsular terrane
- JŦu — Late Triassic and Early Jurassic ultramafic. Mafic and granitoid rocks: occur in southern Peninsular terrane in Border Ranges ultramafic-mafic assemblage
- lPzg — Late Paleozoic granitoid rocks: occur in Wrangellia and Alexander terranes

TECTONO-STRATIGRAPHIC TERRANES

- AP — Aurora Peak Terrane
- AX — Alexander terrane
- BP — Broad Pass terrane
- CG — Chugach terrane
- CH — Chulitna terrane
- CW — Clearwater terrane
- DL — Dillinger terrane
- MK — McKinley terrane
- ML — Maclaren terrane
- MY — Mystic terrane
- NX — Nixon Fork terrane
- PE — Peninsular terrane
- PN — Pingston terrane
- SW — Southern Wrangellia terrane
- SU — Susitna terrane
- TG — Togiak and Goodnews terranes, undivided
- UM — Terrane of ultramafic and associated rocks
- WF — West Fork terrane
- WR — Wrangellia terrane
- WY — Windy terrane
- YT — Yukon-Tanana terrane

SYMBOLS

- Contact
- Fault—Dotted where concealed
- Thrust fault—Dotted where concealed. Teeth on upper plate
- Strike-slip fault—Dotted where concealed

Pingston and Windy terranes, and the terrane of ultramafic and associated rocks, occur discontinuously for several hundred kilometers. The terranes adjacent to the Denali fault are discussed in a general west to east order.

Pingston terrane

The Pingston terrane (Jones and others, 1981, 1982, 1983, 1984, 1987; Gilbert and others, 1984) occurs discontinuously along the Denali fault for several hundred kilometers north and northwest of the Dillinger, McKinley, and Mystic terranes in the Mount McKinley, Healy, and Mount Hayes quadrangles (Figs. 1, 2, and 3). The Pingston terrane consists of a weakly metamorphosed sequence of (1) Early Pennsylvanian and Permian phyllite, minor marble, and chert; (2) Late Triassic thin-bedded, laminated dark limestone, black sooty shale, calcareous sandstone, and minor quartzite; and (3) locally numerous bodies of gabbro, diabase, and diorite of Early Cretaceous(?) age (Reed and Nelson, 1980; Gilbert and others, 1984). The terrane is strongly folded and faulted, and displays a single slaty cleavage that parallels the axial planes of locally abundant isoclinal folds. A small lens of thin-bedded dark limestone, sooty shale, and minor quartzite, correlated with the Pingston terrane, occurs along the southern margin of the Windy terrane in the eastern Alaska Range (the unit is too thin to depict in Fig. 2) (W. J. Nokleberg, 1987, unpublished data). The Late Triassic stratified rocks are interpreted as a turbidite apron sequence deposited from deep-water turbidity currents that flowed from a cratonal source such as the Yukon-Tanana terrane to the north (Gilbert and others, 1984).

McKinley terrane

The McKinley terrane (Reed and Nelson, 1980; Jones and others, 1981, 1982, 1983, 1984, 1987; Gilbert and others, 1984) occurs adjacent to the Denali fault, north and northwest of the Mystic terrane, mainly in the McKinley quadrangle (Figs. 1, 2, and 3). The McKinley terrane consists mainly of (1) fine-grained Permian flysch, mainly graywacke, argillite, and minor chert; (2) Triassic chert; (3) a thick sequence of Late Triassic (Norian) pillow basalt; (4) Triassic(?) gabbro and diabase, interpreted as coeval with the pillow basalt; and (5) Late Jurassic(?) and Cretaceous flysch, mainly graywacke, argillite, minor conglomerate, and chert. Individual flows in the Late Triassic pillow basalt are commonly diabasic and locally have quenched margins; thickness ranges from 600 to 1,700 m. Discontinuous beds of fine-grained clastic sedimentary rocks are locally intercalated with the basalt. Also included in the McKinley terrane is Mississippian to Late Triassic chert that is thrust over, and folded with, the late Mesozoic flysch. The terrane is complex, thick, strongly folded and faulted, and weakly metamorphosed. On the basis of basalt whole-rock chemistry, the McKinley terrane was interpreted by Gilbert and others (1984) as a fragment of one or more Late Triassic seamounts possibly built on continental slope or rise crust.

Mystic and Dillinger terranes

The Mystic and Dillinger terranes (Jones and others, 1982, 1984, 1987) occur adjacent to the Denali fault, north and northwest of the Kahiltna assemblage, mainly in the McKinley and Healy quadrangles (Figs. 1, 2, and 3). The Dillinger terrane also forms a major unit beyond the western edge of the study area in southwestern Alaska (Decker and others, this volume).

The Mystic terrane (Figs. 2, and 3) (Reed and Nelson, 1980; Jones and others, 1982, 1983) consists of (1) Ordovician graptolitic shale and associated(?) pillow basalt; (2) massive Silurian limestone and Late Devonian sandstone, shale, conglomerate, and reefal limestone; (3) latest Devonian to Pennsylvanian radiolarian chert; (4) flysch, chert, argillite, and Permian conglomerate (locally plant bearing); and (5) associated Triassic(?) pillow basalt and gabbro. The terrane is a complexly deformed but partly coherent assemblage, and it is interpreted as a displaced fragment of the Paleozoic and early Mesozoic North American Cordillera continental margin (Jones and others, 1982; Decker and others, this volume).

The Dillinger terrane (Figs. 2 and 3) (Jones and others, 1982; Gilbert and Bundtzen, 1984; Patton and others, 1989; this volume, Chapter 7) consists chiefly of (1) Cambrian(?) and Ordovician calcareous turbidite, shale, and minor greenstone; (2) Early Ordovician and Early Silurian graptolitic black shale and chert; (3) Early and Middle Silurian laminated limestone and graptolitic black shale; (4) Middle to Late Silurian sandstone turbidites and shale; and (5) Late Silurian and Early Devonian limestone, breccia, sandstone, and shale that is complexly folded and faulted. The unit is interpreted as a displaced fragment of the Paleozoic and early Mesozoic North American Cordillera continental margin (Jones and others, 1982; Decker and others, this volume).

In southwest Alaska, the Dillinger, Nixon Fork, Mystic, and Minchumina terranes are interpreted by Decker and others (this volume) as various facies of the continental shelf and slope rocks of the Farewell terrane. In contrast, the related Minchumina and Nixon Fork terranes are interpreted by Patton and others (this volume, Chapter 7) as discrete fault-bounded units. Because of the distinctive, fault-bounded stratigraphy and structure in the study area, the Mystic and Dillinger rocks are herein interpreted as separate terranes within the study area. As originally interpreted by Jones and others (1982), the Dillinger, Nixon Fork, and Mystic terranes may have originally formed as facies of one another and were subsequently tectonically displaced several hundred kilometers from the northwestern part of the Canadian Cordillera.

Windy terrane

The Windy terrane (Figs. 2 and 3) (Jones and others, 1984, 1987; Nokleberg and others, 1985, 1989a, 1992a, 1992b) occurs in several narrow, discontinuous slivers within branches of the Denali fault, north of the Maclaren terrane, and south of the

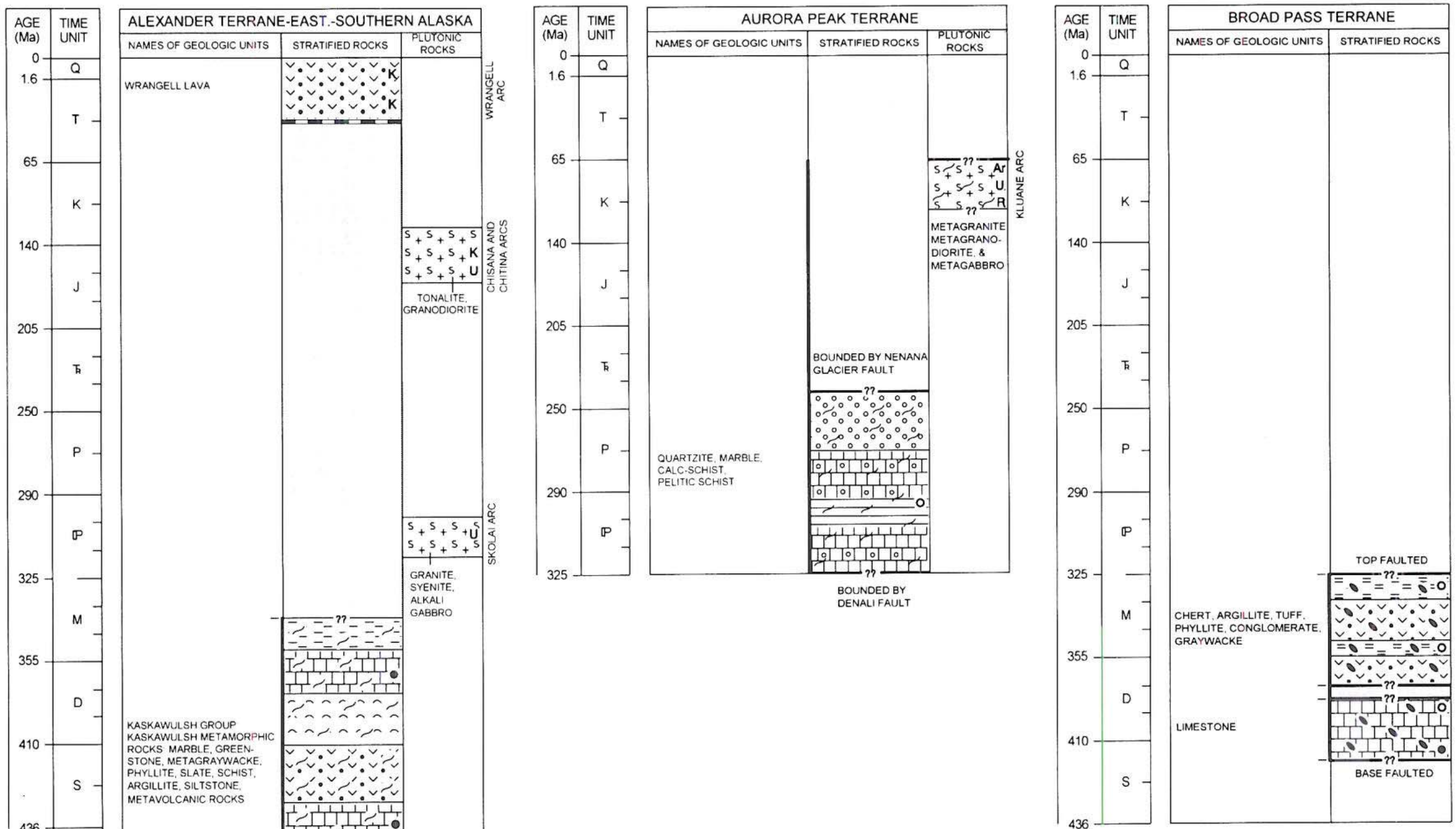
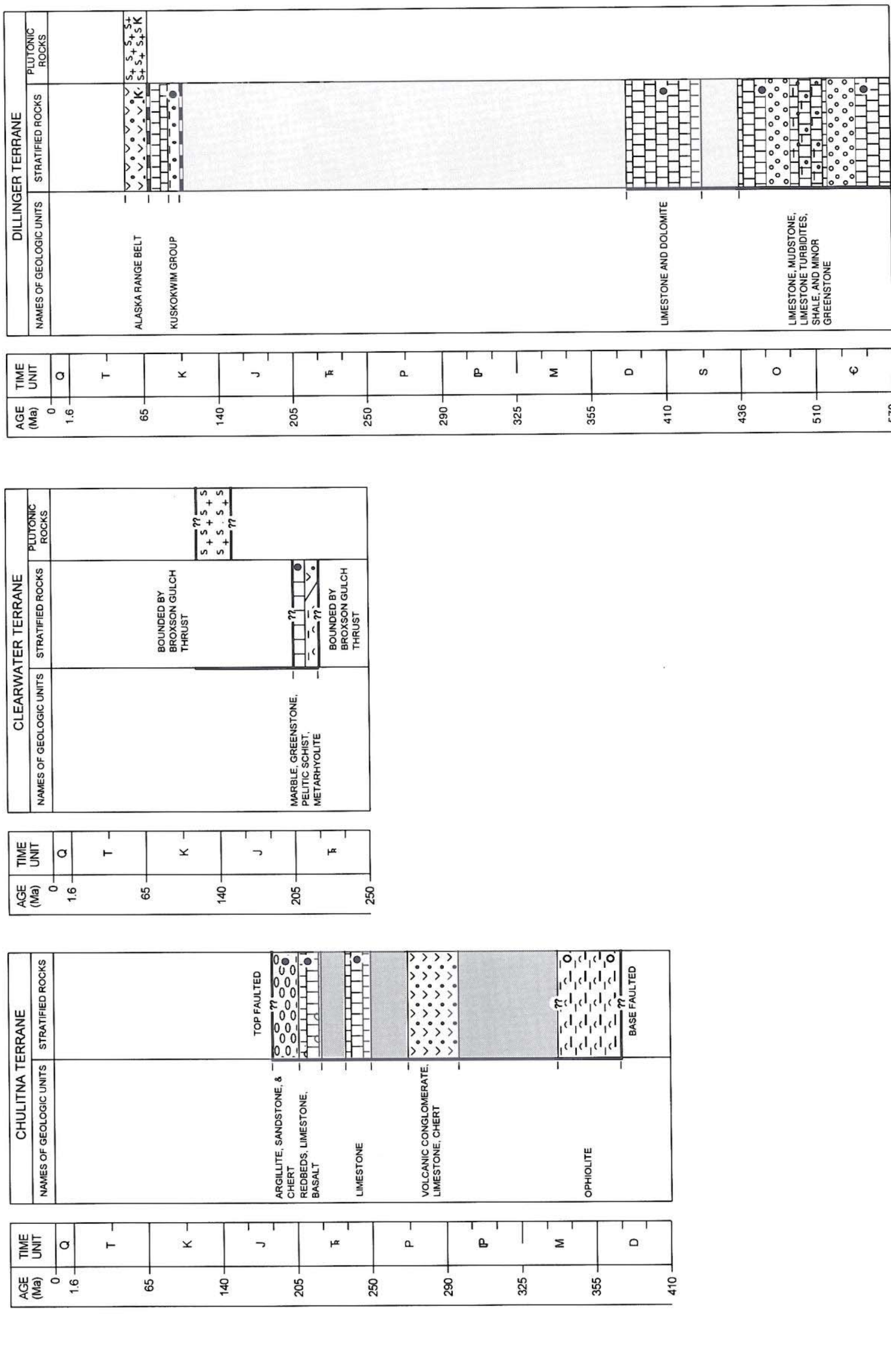
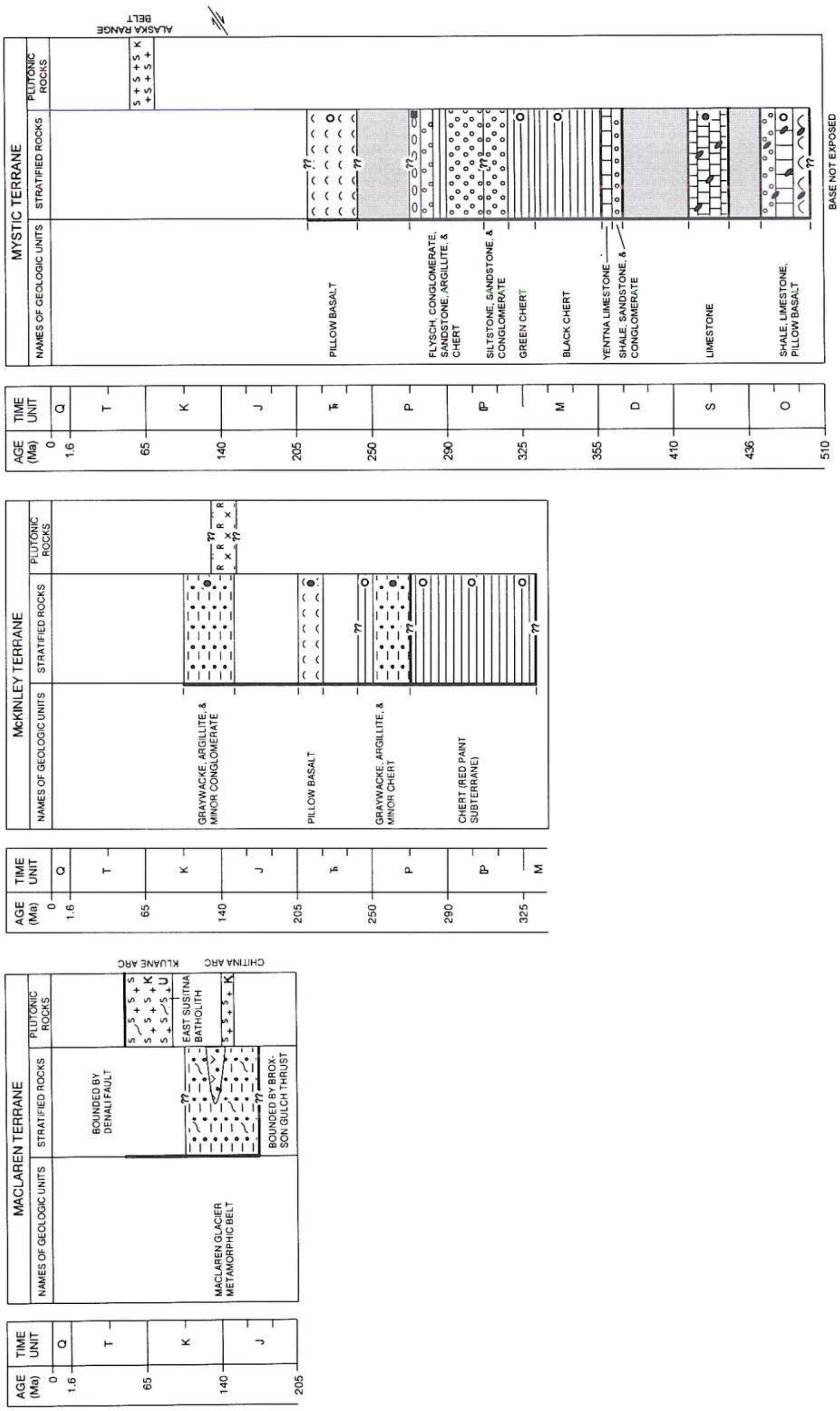


Figure 3 (on this and following six pages). Schematic stratigraphic columns for terranes in south-central Alaska. Columns listed in alphabetical order: Alexander terrane; Aurora Peak terrane; Broad Pass terrane; Chulitna terrane; Clearwater terrane; Dillinger terrane; Maclaren terrane; McKinley terrane; Mystic terrane; Peninsular terrane; Pingston terrane; southern Wrangellia terrane; Susitna terrane; terrane of ultramafic and associated rocks; West Fork terrane; Windy terrane; and Wrangellia terrane. Adapted from Richter (1976), Richter and others (1977), MacKevett (1978), Winkler and others (1981a), Jones and others (1981, 1982, 1984), Wilson and others (1985b), Nokleberg and others (1982, 1985, 1989a, 1992b, 1993), Csejtey and others (1986), Gardner and others (1988), Plafker and others (1989c), Wallace and others (1989), Winkler (1992), Silberling and others (this volume, Plate 3), and Wilson and others (1994). Geologic time scale from Decade of North American Geology geologic time scale (Palmer, 1983).


DILLINGER TERRANE
NAMES OF GEOLOGIC UNITS
STRATIFIED ROCKS
PLUTONIC ROCKS
ALASKA RANGE BELT
KUSKOKWIM GROUP
LIMESTONE AND DOLOMITE
LIMESTONE, MUDSTONE, LIMESTONE TURBIDITES, SHALE, AND MINOR GREENSTONE
BASE NOT EXPOSED
AGE (Ma)
TIME UNIT
CLEARWATER TERRANE
BOUNDED BY BROXSON GULCH THRUST
MARBLE, GREENSTONE, PELITIC SCHIST, METARHYOLITE
BOUNDED BY BROXSON GULCH THRUST
CHULITNA TERRANE
TOP FAULTED
ARGILLITE, SANDSTONE, & CHERT
REDBEDS, LIMESTONE, BASALT
LIMESTONE
VOLCANIC CONGLOMERATE, LIMESTONE, CHERT
OPHIOLITE
BASE FAULTED


MYSTIC TERRANE
AGE (Ma)
TIME UNIT
NAMES OF GEOLOGIC UNITS
STRATIFIED ROCKS
PLUTONIC ROCKS
ALASKA RANGE BELT
PILLOW BASALT
FLYSCH, CONGLOMERATE, SANDSTONE, ARGILLITE, & CHERT
SILTSTONE, SANDSTONE, & CONGLOMERATE
GREEN CHERT
BLACK CHERT
YENTNA LIMESTONE
SHALE, SANDSTONE, & CONGLOMERATE
LIMESTONE
SHALE, LIMESTONE, PILLOW BASALT
BASE NOT EXPOSED
McKINLEY TERRANE
GRAYWACKE, ARGILLITE, & MINOR CONGLOMERATE
PILLOW BASALT
GRAYWACKE, ARGILLITE, & MINOR CHERT
CHERT (RED PAINT SUBTERRANE)
MACLAREN TERRANE
MACLAREN GLACIER METAMORPHIC BELT
BOUNDED BY DENALI FAULT
BOUNDED BY BROXSON GULCH THRUST
EAST SUSITNA BATHOLITH
KLUANE ARC
CHITINA ARC
0
1.6
65
140
205
250
290
325
355
410
436
510
Q
T
K
J
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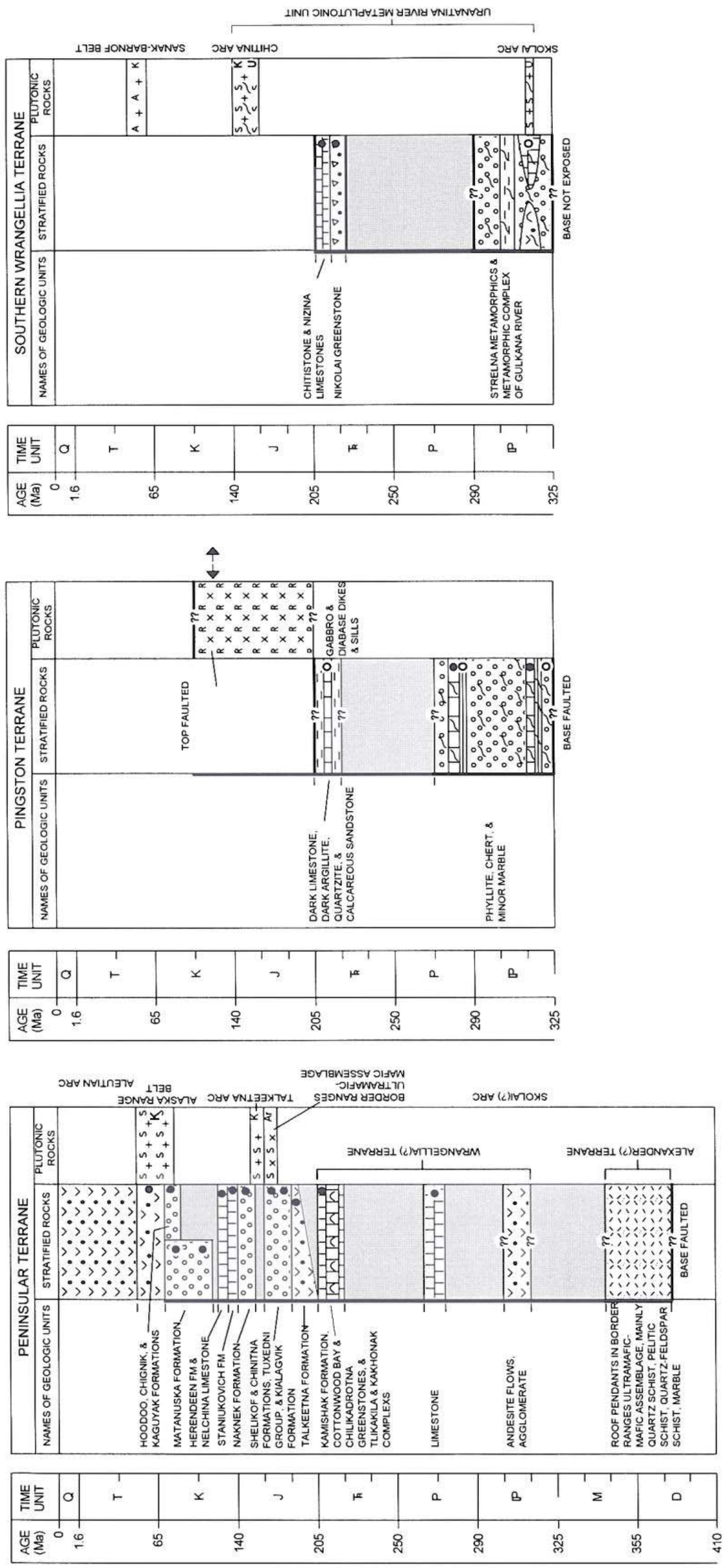
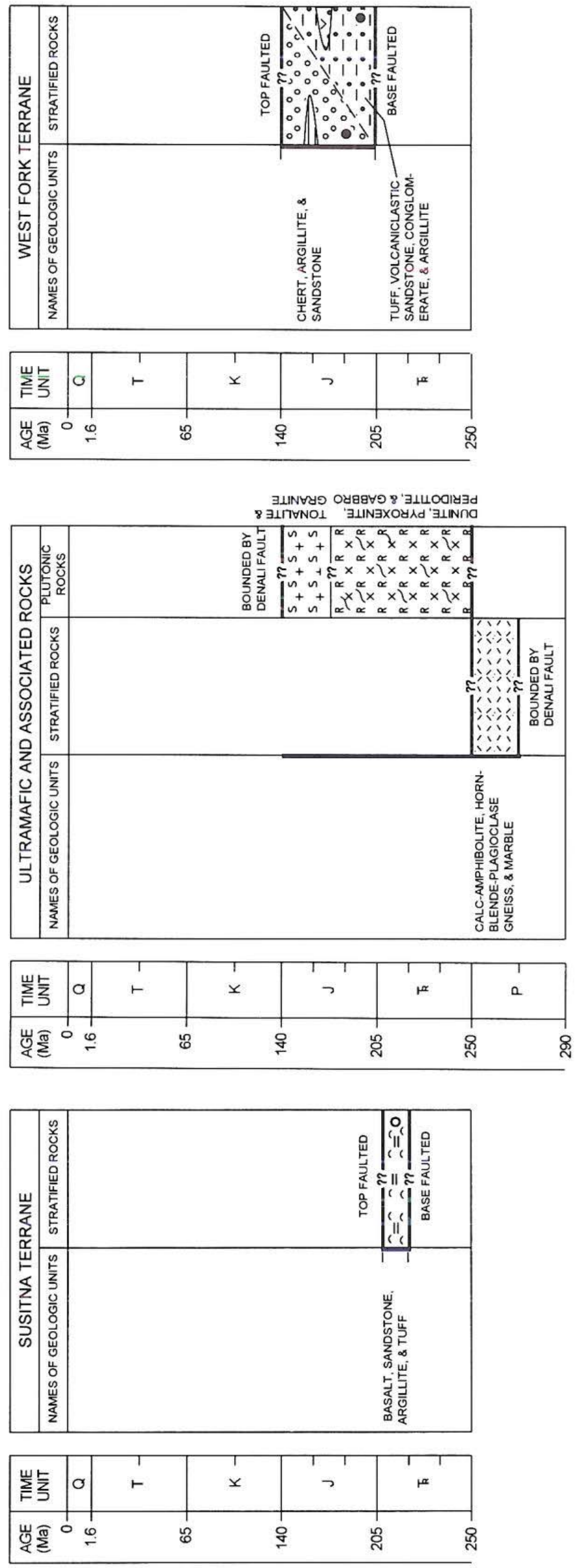

PENINSULAR TERRANE
PINGSTON TERRANE
SOUTHERN WRANGELLIA TERRANE
AGE (Ma)
TIME UNIT
NAMES OF GEOLOGIC UNITS
STRATIFIED ROCKS
PLUTONIC ROCKS
HOODOO, CHIGNIK, & KAGUYAK FORMATIONS
MATANUSKA FORMATION
HERENDEEN FM & NELCHINA LIMESTONE
STANIUKOVICH FM
NAKNEK FORMATION
SHELIKOF & CHINITNA FORMATIONS, TUXEDNI GROUP, & KIALAGVIK FORMATION
TALKEETNA FORMATION
KAMISHAK FORMATION, COTTONWOOD BAY & CHILIKADROTNA GREENSTONES, & TLIKAKILA & KAKHONAK COMPLEXS
LIMESTONE
ANDESITE FLOWS, AGGLOMERATE
ROOF PENDANTS IN BORDER RANGES ULTRAMAFIC-MAFIC ASSEMBLAGE, MAINLY QUARTZ SCHIST, PELITIC SCHIST, QUARTZ-FELDSPAR SCHIST, MARBLE
BASE FAULTED
WRANGELLIA(?) TERRANE
ALEXANDER(?) TERRANE
ALEUTIAN ARC
ALASKA RANGE BELT
TALKEETNA ARC
BORDER RANGES ULTRAMAFIC-MAFIC ASSEMBLAGE
SKOLAI(?) ARC
TOP FAULTED
GABBRO & DIABASE DIKES & SILLS
DARK LIMESTONE, DARK ARGILLITE, QUARTZITE, & CALCAREOUS SANDSTONE
PHYLLITE, CHERT, & MINOR MARBLE
CHITISTONE & NIZINA LIMESTONES
NIKOLAI GREENSTONE
STRELNA METAMORPHICS & METAMORPHIC COMPLEX OF GULKANA RIVER
BASE NOT EXPOSED
SANAK-BARANOF BELT
CHITINA ARC
SKOLAI ARC
URANATINA RIVER METAPLUTONIC UNIT


WEST FORK TERRANE
AGE (Ma)
TIME UNIT
NAMES OF GEOLOGIC UNITS
STRATIFIED ROCKS
CHERT, ARGILLITE, & SANDSTONE
TUFF, VOLCANICLASTIC SANDSTONE, CONGLOMERATE, & ARGILLITE
TOP FAULTED
BASE FAULTED
ULTRAMAFIC AND ASSOCIATED ROCKS
PLUTONIC ROCKS
BOUNDED BY DENALI FAULT
TONALITE & GRANITE
DUNITE, PYROXENITE, PERIDOTITE, & GABBRO
CALC-AMPHIBOLITE, HORNBLENDE-PLAGIOCLASE GNEISS, & MARBLE
BOUNDED BY DENALI FAULT
SUSITNA TERRANE
BASALT, SANDSTONE, ARGILLITE, & TUFF
TOP FAULTED
BASE FAULTED
0
1.6
65
140
205
250
290
Q
T
K
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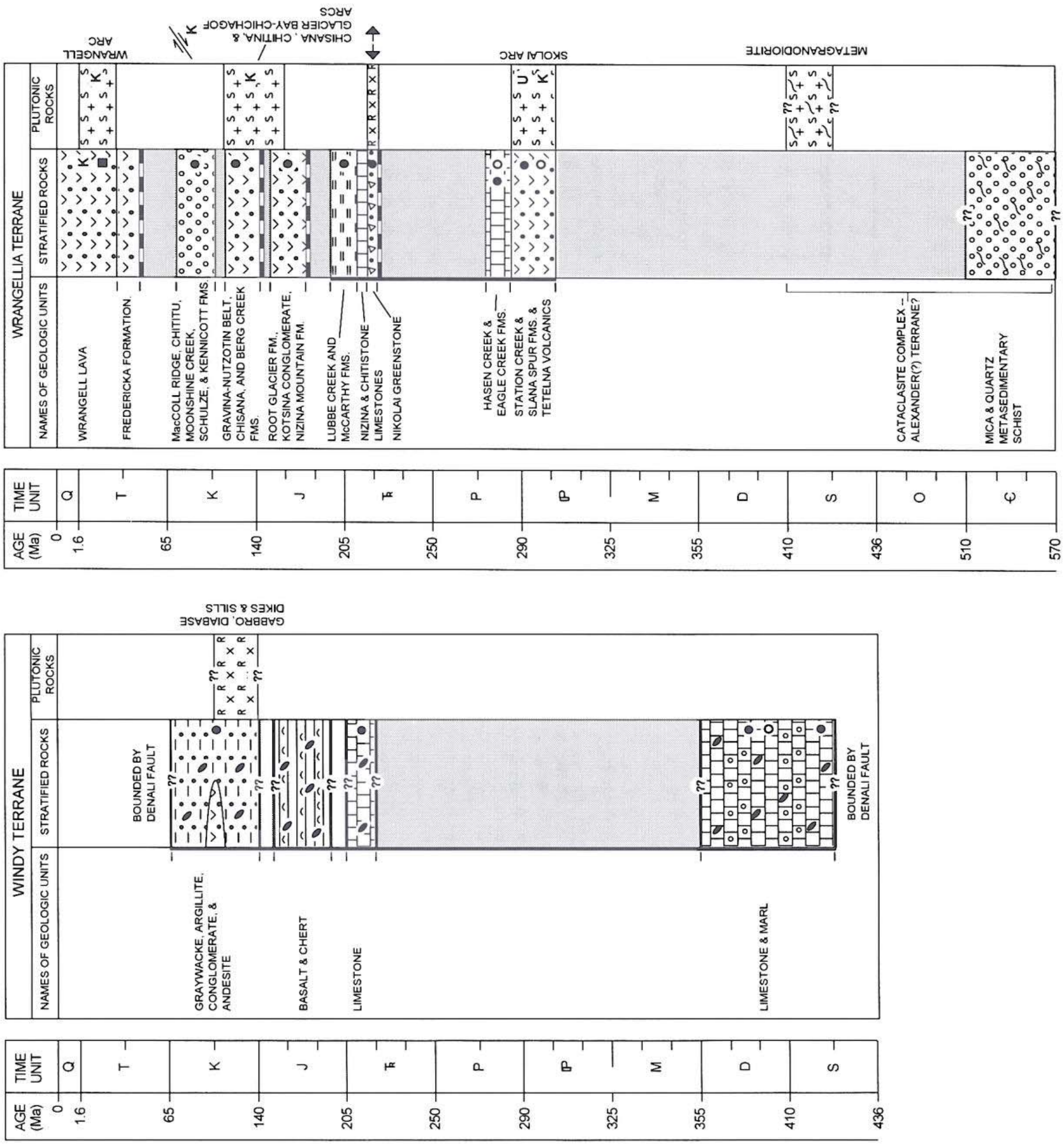
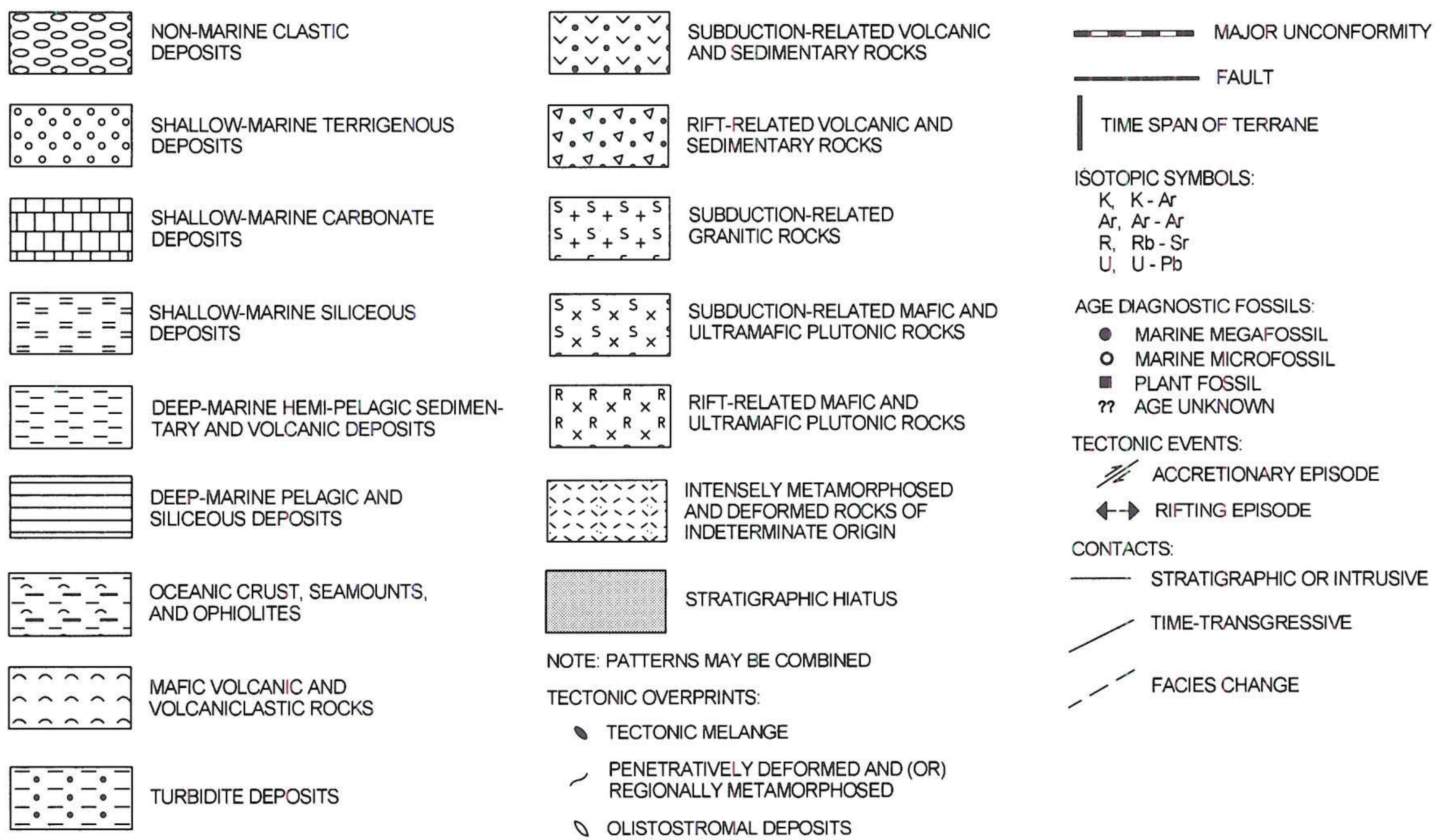
Ŧ
P


WRANGELLIA TERRANE
AGE (Ma)
TIME UNIT
NAMES OF GEOLOGIC UNITS
STRATIFIED ROCKS
PLUTONIC ROCKS
WRANGELL LAVA
FREDERICKA FORMATION
MacCOLL RIDGE, CHITITU, MOONSHINE CREEK, SCHULZE, & KENNICOTT FMS.
GRAVINA-NUTZOTIN BELT, CHISANA, AND BERG CREEK FMS.
ROOT GLACIER FM., KOTSINA CONGLOMERATE, NIZINA MOUNTAIN FM.
LUBBE CREEK AND McCARTHY FMS.
NIZINA & CHITISTONE LIMESTONES
NIKOLAI GREENSTONE
HASEN CREEK & EAGLE CREEK FMS.
STATION CREEK & SLANA SPUR FMS. & TETELNA VOLCANICS
CATACLASITE COMPLEX -- ALEXANDER(?) TERRANE?
MICA & QUARTZ METASEDIMENTARY SCHIST
WRANGELL ARC
CHISANA, CHITINA, & GLACIER BAY-CHICHAGOF ARCS
SKOLAI ARC
METAGRANODIORITE
WINDY TERRANE
GRAYWACKE, ARGILLITE, CONGLOMERATE, & ANDESITE
BASALT & CHERT
LIMESTONE
LIMESTONE & MARL
BOUNDED BY DENALI FAULT
GABBRO, DIABASE DIKES & SILLS
0
1.6
65
140
205
250
290
325
355
410
436
510
570
Q
T
K
J
TR
P
PP
M
D
S
O
Є

EXPLANATION FOR STRATIGRAPHIC COLUMNS



Aurora Peak and Yukon-Tanana terranes, mainly in the Healy and Mount Hayes quadrangles. The Windy terrane is a structural melange of diverse rock types that includes (Figs. 2, 3, and 4) (1) small to large fault-bounded lenses of limestone and marl of Silurian or Devonian age (Richter, 1976; Csejtey and others, 1986; Nokleberg and others, 1985, 1992a, 1992b); (2) Late Triassic limestone; (3) Jurassic basalt and chert; and (4) Cretaceous ammonite-bearing flysch and volcanic rocks composed mainly of argillite, quartz-pebble siltstone, quartz sandstone, metagraywacke, chert pebble and polymictic metaconglomerate, and lesser andesite and dacite (J. H. Stout, 1976, written commun.; Csejtey and others, 1986; Nokleberg and others, 1985, 1992a, 1992b).

Unlike adjacent terranes to the north and locally to the south, the Windy terrane exhibits mainly protolith textures and structures. Relict sedimentary structures include bedding, graded bedding, and crossbedding. The Windy terrane is intensely faulted and sheared and locally exhibits phyllonite and protomylonite with an intense schistosity formed at incipient lower greenschist facies metamorphism. The maximum structural thickness of the Windy terrane is about 5 km. The Windy terrane is interpreted as a structural melange that formed during tectonic mixing that occurred during Cenozoic dextral slip along the Denali fault. The Mesozoic flysch and associated volcanic rocks are interpreted as fragments of the Kahiltna assemblage and associated Chisana arc rocks (Stanley and others, 1990). The source for the Silurian or Devonian limestone and marl might be from the Mystic, Dillinger, and/or Nixon Fork terranes.

Aurora Peak terrane

The Aurora Peak terrane (Brewer, 1982; Nokleberg and others, 1985, 1989a, 1992b) occurs north of the Denali fault, west of the Richardson Highway, in the western Mount Hayes and eastern Healy quadrangles (Figs. 1, 2, and 3). The terrane consists of an older sequence of mainly metasedimentary rocks and a younger sequence of metaplutonic rocks (Fig. 4). Because of intense deformation, the stratigraphic thickness of the Aurora Peak terrane cannot be estimated. The maximum structural thickness is several thousand meters. Unless otherwise noted, the following description of the Aurora Peak terrane is after Aleinikoff (1984), Nokleberg (1985, 1989a, 1992), Brewer (1982), and Aleinikoff and others (1987).

The older sequence of metasedimentary rocks consists of mainly fine- to medium-grained and polydeformed calc-schist, marble, quartzite, and pelitic schist. One fragment of a conodont from marble indicates a Silurian to Triassic age. Protoliths for the metasedimentary rocks include marl, quartzite, and shale. The younger metaplutonic sequence consists of regionally metamorphosed and penetratively deformed, schistose quartz diorite, granodiorite, and granite, and sparse amphibolite derived from gabbro and diorite. U-Pb zircon isotopic analysis of a metamorphosed quartz diorite indicates an age of igneous intrusion of 71 Ma; isotopic analysis of lead from samples of metagranitic rocks suggests derivation from an ~1.2 Ga source.

The Aurora Peak terrane was twice metamorphosed and ductilely deformed. The core of the terrane exhibits an older, upper amphibolite facies metamorphism and associated mylonitic schist. Because of similar and parallel fabrics in the metasedimentary and metaplutonic rocks, the upper amphibolite facies metamorphism of both units is interpreted as having occurred during syntectonic intrusion of Late Cretaceous and early Tertiary granitic rocks. The margins of the terrane exhibit a younger middle greenschist facies metamorphism and formation of blastomylonite along an intense younger schistosity. A K-Ar biotite age of 27 Ma suggests that retrograde metamorphism occurred at least into the middle Tertiary. The younger, greenschist facies metamorphism is interpreted as having formed during dextral-slip transport of the terrane along the Nenana Glacier and Denali faults.

The Aurora Peak terrane and the Maclaren terrane to the south are interpreted as displaced continental margin arc fragments that were tectonically separated from the Kluane schist and the Ruby Range batholith that occur on the northeast side of the Denali fault some 400 km to the southeast in the Yukon Territory (Nokleberg and others, 1985; Plafker and others, 1989c). Between the Aurora Peak and Maclaren terranes is a structural melange of Paleozoic and Cretaceous sedimentary and volcanic rocks that constitutes the Windy terrane (Figs. 3 and 4). The Aurora Peak terrane is interpreted as having been tectonically transported to a position against the southern Yukon-Tanana terrane before transport of the Maclaren terrane and resultant formation of the structural melange of the Windy terrane between the Maclaren and Aurora Peak terranes.

Terrane of ultramafic and associated rocks

A terrane of ultramafic and associated rocks (Richter, 1976; Richter and others, 1977; Nokleberg and others, 1982, 1985, 1989a, 1992b) occurs in the eastern Alaska Range in the Mount Hayes and Healy quadrangles (Figs. 1 and 2). Generally the terrane occurs in narrow, fault-bounded lenses within branches of the Denali fault that are up to a few kilometers wide and several kilometers long. The terrane also occurs in a few small klippen south of the Denali fault in the eastern Mount Hayes quadrangle (Fig. 4).

The ultramafic rocks are mainly fine- to medium-grained pyroxenite and peridotite, and dunite, along with local hornblende gabbro (Fig. 3). The ultramafic rocks are largely altered to serpentinite and are generally highly sheared. The associated rocks are amphibolite, hornblende-plagioclase gneiss, and marble that host the ultramafic rocks. The associated rocks are interpreted as a suite of calcareous metasedimentary rocks metamorphosed to amphibolite facies. Sparse, small, elongate plutons of tonalite and granite locally intrude the ultramafic rocks and calcareous metasedimentary rocks. The ultramafic and associated rocks are moderately to intensely ductily deformed with a strong schistosity that is subparallel to contacts and enclosing faults. A weak schistosity occurs in the tonalite and granite that is subparallel to intrusive contacts. No isotopic age data exist for the terrane.

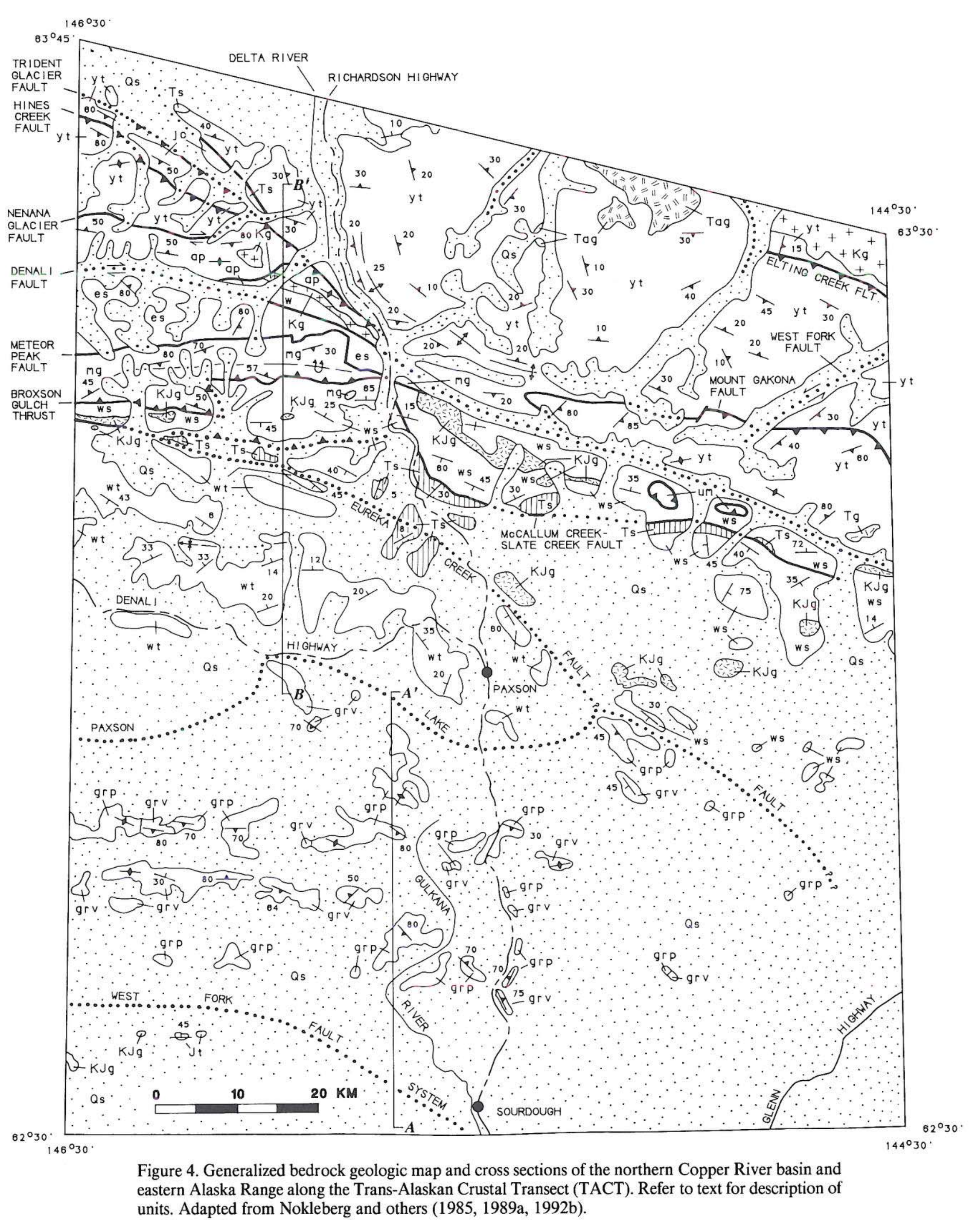
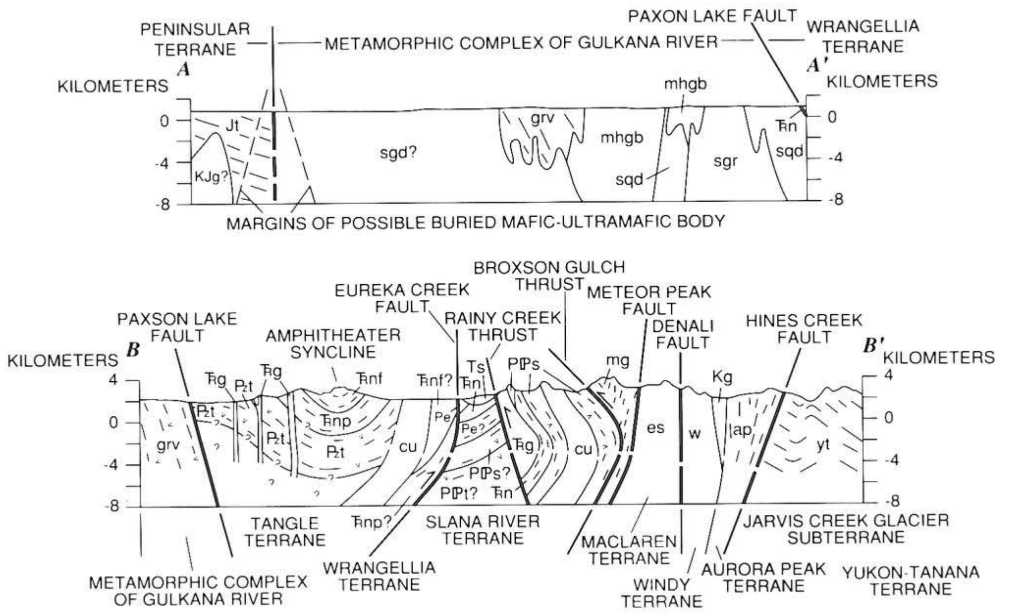


Figure 4. Generalized bedrock geologic map and cross sections of the northern Copper River basin and eastern Alaska Range along the Trans-Alaskan Crustal Transect (TACT). Refer to text for description of units. Adapted from Nokleberg and others (1985, 1989a, 1992b).



Notes: Surficial deposits omitted
No vertical exaggeration
All but one contact covered by surficial deposits in section *A-A'*

0 10 20 KILOMETERS

EXPLANATION

CENOZOIC SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

Qs — Quaternary surficial deposits

Ts — Tertiary sedimentary rocks

PLUTONIC ROCKS

Tg, Tag
- Tg - Early Tertiary granitic rocks
- Tag - Early Tertiary alkalic gabbro

Kg — Cretaceous granitic rocks

KJg — Early Cretaceous and Late Jurassic granitic rocks

YUKON-TANANA TERRANE

yt

AURORA PEAK TERRANE

ap

WINDY TERRANE

w

MACLAREN TERRANE

es — East Susitna batholith

mg — Maclaren Glacier metamorphic belt

TERRANE OF ULTRAMIFIC AND ASSOCIATED ROCKS

um

WRANGELLIA TERRANE

Slana River subterrane

ws	TRg	cu
	TRn	
	Pe	
	PIPs	
	PIPt	

ws - undifferentiated. On cross sections, divided into:
- TRg - Gabbro and diabase;
- cu - cumulate mafic & ultramafic rocks;
- TRn - Nikolai Greenstone;
- Pe - Eagle Creek Formation;
- PIPs - Slana Spur Formation; and
- PIPt - Tetelna Volcanics

Tangle subterrane

wt	TRg	cu
	TRnf	
	TRnp	
	Pzt	

wt - Undifferentiated. On cross sections, divided into:
- TRg - Gabbro and diabase;
- cu - cumulate mafic and ultramafic rocks;
- Nikolai Greenstone—
  - TRnf - Subaerial basalt flow member and
  - TRnp - Pillow basalt flow member; and
- Pzt - tuff, argillite, and chert

METAMORPHIC COMPLEX OF GULKANA RIVER

Metaplutonic rocks

grp	sgr
	sgd
	sqd
	mhbd

grp - Undifferentiated. On cross sections, divided into:
- sgr - Schistose granite;
- sgd - Schistose granodiorite;
- sqd - Schistose quartz diorite; and
- mhgb - Metamorphosed hornblende gabbro

Metavolcanic and metasedimentary rocks

grv

PENINSULAR TERRANE

Jt — Talkeetna formation

SYMBOLS

- Contact—Dotted where concealed
- Fault—Dotted where concealed
  - Strike-slip
  - Thrust—Teeth on upper plate
- Antiform—Dashed where approximately located; dotted where concealed
  - Anticline
  - Overturned anticline
  - Syncline—showing plunge
- Strike and dip of beds
  - 35 Inclined
  - Vertical
- Strike and dip of schistosity and parallel compositional layer
  - 75 Inclined
  - Vertical

The tonalite and granite are assumed to be Mesozoic in age (Richter and others, 1977); the other units of the terrane are therefore assumed to be Mesozoic or older.

The near-vertical lenses of the terrane along the Denali fault may be fragments emplaced from a source of depth during Late Cretaceous and Cenozoic dextral slip along the Denali fault. The two klippen of the terrane south of the Denali fault may represent remnants of amalgamation along the ancestral Denali fault, where substantial south-verging thrusting has been interpreted (Stanley and others, 1990). The terrane has been interpreted (1) as a crustal suture belt (Richter, 1976; Richter and others, 1977) or (2) as having uncertain, but possible, ophiolitic affinity (Patton and others, 1992; this volume, Chapter 21). Alternatively, because of the assemblage of high-grade metasedimentary rocks, metamorphosed ultramafic and mafic rocks, and metagranite plutons, the terrane might be a fragment of the deep levels of an igneous arc.

LATE JURASSIC AND EARLY CRETACEOUS FLYSCH BASINS

Two major tectonically collapsed flysch basins occur across the northern part of the study area, south of the Denali fault (Fig. 2) (Jones and others, 1982). To the northwest is the Late Jurassic and Early Cretaceous Kahiltna assemblage, and to the northeast is the Late Jurassic and Early Cretaceous Gravina-Nutzotin belt (Berg and others, 1972). These two assemblages of flysch and locally associated coeval volcanic and plutonic rocks form a major belt that is several thousand kilometers long and extends discontinuously from the Alaska Peninsula to the west, to the southern part of southeastern Alaska to the southeast (Berg and others, 1972; Rubin and Saleeby, 1991; Gehrels and Berg, this volume; Silberling and others, this volume). In the study area, the Kahiltna assemblage occurs discontinuously for more than 800 km along the northwestern margin of the Peninsular and Wrangellia terranes and is divided into southern and northern segments. The companion Gravina-Nutzotin belt occurs mainly along the northeastern margins of the Wrangellia and Alexander terranes for about 1,500 km in the study area.

Southern Kahiltna assemblage

The southern segment of the Kahiltna assemblage, hereafter called the southern Kahiltna assemblage for the sake of brevity, occurs along the northwestern margin of the Peninsular terrane in the northwestern Aleutian Range, mainly in the Lake Clark quadrangle (Figs. 1, 2, and 5). Almost everywhere in this area, the Kahiltna assemblage is separated from the main mass of the Peninsular terrane to the south by the Alaska-Aleutian Range batholith (Figs. 2 and 5) (Nelson and others, 1983; Wallace and others, 1989). In this area, the Kahiltna assemblage was defined as the informally named Koksetna River sequence and the Chilikadrotna Greenstone (Hanks and others, 1985; Wallace and others, 1989). The Koksetna River sequence is composed of widespread Late Jurassic and Early Cretaceous clastic rocks that are best exposed in the area drained by the Koksetna River. Conformably beneath the Koksetna River sequence is the Chilikadrotna Greenstone (Bundtzen and others, 1979; Wallace and others, 1989), which is interpreted below to be part of the Peninsular terrane. Unlike otherwise noted, the following description of the southern Kahiltna assemblage is from Eakins and others (1978) and Wallace and others (1989).

Koksetna River sequence. The Koksetna River sequence is generally poorly exposed, although a few excellent exposures occur in river gorges and the more rugged foothills west of the Alaska Range. The sequence consists mainly of complexly deformed volcanic-lithic turbidites that have no distinctive marker horizons. Only two localities with datable megafossils have been discovered, one each of Late Jurassic (Kimmeridgian) age and Early Cretaceous (Valanginian) age. Isolated outcrops of poorly exposed pebble and cobble conglomerate may occur in part of the sequence. Clast types in the conglomerate include intermediate to silicic volcanic and plutonic rocks, and subordinate chert and argillite. The depositional environments range from slope and inner fan (Mutti and Ricci Lucchi, 1978) in the southeast to middle fan and outer fan in the northwest; regional sediment transport was probably to the northwest or north. Clast compositions of the sandstones suggest derivation from a magmatic-arc provenance that was dominated by volcanic rocks, but with local exposures of plutonic rocks, fine-grained clastic rocks, regionally metamorphosed rocks, and contact-metamorphosed rocks.

Bedding generally dips steeply to the northwest. Upright and overturned beds indicate that the Koksetna River sequence has been isoclinally folded and faulted. The sequence is locally intruded and metamorphosed by latest Cretaceous to early Tertiary plutons of the Aleutian-Alaska Range batholith (Fig. 5). The sequence is progressively unconformably overlapped toward the southeast by latest Cretaceous to early Tertiary volcanic rocks preserved in a regional northeast-trending structural low. Contacts between the Koksetna River sequence and the stratigraphically subjacent Chilikadrotna Greenstone generally are not exposed. In the few places where exposed, the contact is intensely deformed. However, the Chilikadrotna Greenstone is exposed in the cores of a series of antiforms, indicating that it underlies the Koksetna River sequence. The Chilikadrotna Greenstone was probably both the depositional basement and a local sediment source for the overlying Koksetna River sequence.

Units adjacent to southern Kahiltna assemblage. The southern Kahiltna assemblage is bounded to the northwest by the sedimentary rocks ofthe Kuskokwim Group (Fig. 5), which consists of Late Cretaceous, deep-marine, shallow-marine, and local nonmarine sedimentary rocks (Patton and others, 1989; this volume, Chapter 7). Farther northwest, the Kuskokwim Group depositionally overlaps several major terranes, including the Nixon Fork, Dillinger, and Mystic terranes (Fig. 2). In the study area, the southern Kahiltna assemblage and the Kuskokwim Group are juxtaposed along the sharp Chilchitna fault (Fig. 5), which dips steeply northwest and is locally marked by a zone of phyllitic rocks. The fault may be a depositional contact that was structurally modified. However, more recent studies in this area indicate that the contact between the southern Kahiltna assemblage and the Kuskokwim Group may be gradational (D. C. Bradley, 1991, oral commun.). To the south, the southern Kahiltna assemblage may grade upward into the post-Turonian Kuskokwim Group. One locality within the southern Kahiltna assemblage in the Tyonek quadrangle has yielded the Late Cretaceous (Turonian) fossil *Inoceramus* (W. P. Elder, 1989, written commun. to D. C. Bradley).

Northern Kahiltna assemblage

The northern segment of the Kahiltna assemblage, hereafter called the northern Kahiltna assemblage for the sake of brevity, occurs in the northern Talkeetna Mountains and the central Alaska Range in the Talkeetna, Talkeetna Mountains, Healy, and adjacent quadrangles (Figs. 1 and 2) (Reed and Nelson, 1980; Csejtey and others, 1978, 1982, 1986). The assemblage consists of mainly monotonous, intensely deformed and locally highly metamorphosed flysch of Late Jurassic and Early Cretaceous age with a structural thickness of probably several thousand meters. The flysch consists of intercalated dark-colored argillite, phyllite, fine- to coarse-grained lithic graywacke, dark gray polymictic pebble conglomerate, subordinate chert-pebble conglomerate, a few thin beds of radiolarian chert, limy mudstone, and impure limestone. In the easternmost narrow lens of the northern Kahiltna assemblage in the eastern Healy and western Mount Hayes quadrangles, sparse andesite flows and volcanic metagraywacke are important components (Nokleberg and others, 1982, 1992b; Csejtey and others, 1986). The Late Jurassic and Early Cretaceous age of the northern Kahiltna assemblage is established by sparse microfossils and megafossils of Hauterivian to Barremian or Early Cretaceous age (Reed and Nelson, 1980; Csejtey and others, 1978, 1986). The flsych of the northern Kahiltna assemblage may be the protolith for the metasedimentary and metavolcanic rocks of the Maclaren terrane, discussed below. The flysch sequence is compressed into tight or isoclinal folds and is complexly faulted. Many areas are sheared and exhibit a pervasive axial plane cleavage. Because of the lithologically monotonous nature of the flysch sequence, faults are difficult to detect.

Gravina-Nutzotin belt

The Gravina-Nutzotin belt (Berg and others, 1972; Richter and Jones, 1973; Richter, 1976) occurs in the eastern Alaska Range and Nutzotin Mountains and is deposited on the Wrangellia terrane in the Mount Hayes, Nabesna, and McCarthy quadrangles (Figs. 1 and 2). The belt consists of more than 3,000 m of Late Jurassic and Early Cretaceous argillite, mudstone, and graywacke, and sparse conglomerate, limestone, volcanic flows, and volcaniclastic rocks and tuff deposited under shallow-marine to deep-marine conditions. Graded bedding is locally abundant and well developed, and turbidite deposits are common. The flysch sequence contains abundant intermediate-composition volcanic detritus (Berg and others, 1972; Richter, 1976; Nokleberg and others, 1982, 1985, 1992b). Rare fossils in the belt, mainly Buchia in the Nabesna quadrangle, indicate an Oxfordian through Barremian (Late Jurassic through Early Cretaceous) age. The rocks of the belt are locally highly deformed, particularly near the central part of the belt where isoclinal, overturned folds and companion thrust and reverse faults are common. The belt is faulted against the Yukon-Tanana terrane along the Denali fault to the north and east.

In the Nabesna quadrangle (Figs. 1 and 2), the Gravina-Nutzotin belt includes the Chisana Formation, which consists of marine and subaerial volcanic and volcaniclastic rocks, mainly andesite and basaltic andesite flows, and associated breccias, graywacke, and conglomerate that is more than 2,500 m thick (Richter, 1976). In this area, the Chisana Formation contains Early Cretaceous megafossils and locally grades downward through a tuffaceous unit into the stratigraphically subjacent part of the Gravina-Nutzotin belt (Richter, 1976). In the eastern Mount Hayes quadrangle, andesitic volcanic rocks are interlayered with flysch that contains Early Cretaceous megafossils (Nokleberg and others, 1992a, 1992b). The Chisana Formation is locally unconformably overlain by as much as 90 m of Late Cretaceous continental sedimentary rocks (Richter, 1976).

The Chisana Formation, the non-Chisana part of the Gravina-Nutzotin belt, and the Kahiltna assemblage are locally intruded by weakly deformed to nondeformed Late Jurassic and Early Cretaceous granitic plutons (Fig. 2) (Berg and others, 1972; Miller, this volume, Chapter 16). The source of the andesite flows and related rocks of the Chisana Formation, the volcanic detritus in the Gravina-Nutzotin belt, and the granitic plutons intruding these two units and the Kahiltna assemblage is interpreted as an extensive, coeval igneous arc flanked by the volcanic-derived flysch. The igneous arc was first recognized by Berg and others (1972) as the Gravina-Nutzotin basinal arc, and was named the Chisana arc by Plafker and others (1989c). Rare earth element (REE) whole-rock analyses suggest a transitional tholeiitic and calc-alkaline island-arc origin for the volcanic rocks (Barker and others, this volume; see also microfiche).

This island arc and companion flysch basin deposits of the Kahiltna assemblage are interpreted as having formed along the northern edge of the WCT prior to emplacement along the Alaskan continental margin (Berg and others, 1972; Plafker and others, 1989c; Barker, this volume). The main evidence for deposition of the flysch and associated rocks on the accreting margin of the WCT is the derivation of clasts in conglomerate from both the Wrangellia terrane and from continental sources (Berg and others, 1972; Richter, 1976).

TERRANES WITHIN KAHILTNA ASSEMBLAGE

Tectonically intermixed with the Kahiltna assemblage in the area south of the Denali fault are several small terranes, including the Chulitna, Susitna, West Fork, Broad Pass, Maclaren, and

Clearwater terranes (Fig. 2) (Jones and Silberling, 1979; Silberling and others, this volume).

Chulitna terrane

The Chulitna terrane (Nichols and Silberling, 1979; Jones and Silberling, 1979; Jones and others, 1980) occurs in the central Alaska Range (Figs. 1, 2, and 3). The terrane contains a number of thrust slivers, folded into a large southeastward-overturned syncline, that are tectonically underlain by flysch. A wide variety of rock sequences of different ages and depositional environments occurs in the terrane, which consists mainly of (1) a tectonically dismembered Late Devonian ophiolite composed of serpentinite, gabbro, pillow basalt, and red radiolarian chert; (2) Pennsylvanian chert and Permian limestone, argillite, and

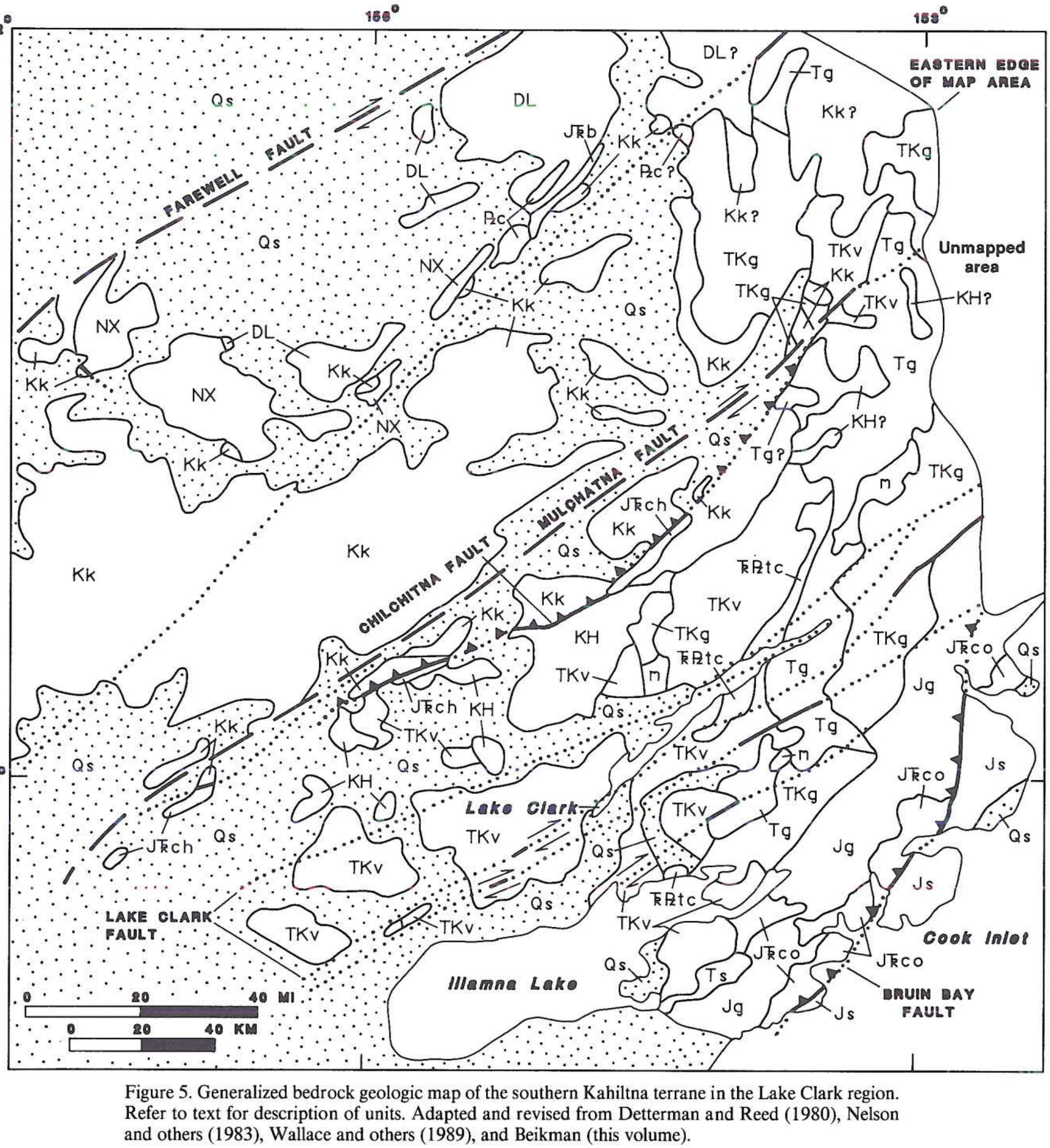


Figure 5. Generalized bedrock geologic map of the southern Kahiltna terrane in the Lake Clark region. Refer to text for description of units. Adapted and revised from Detterman and Reed (1980), Nelson and others (1983), Wallace and others (1989), and Beikman (this volume).

volcaniclastic rocks; (3) Early Triassic limestone; and (4) Late Triassic redbeds with minor interbedded limestone. Depositional contacts and/or reworked clastic detritus from underlying rocks indicate a stratigraphic continuity for this diverse package. For example, abundant Devonian ophiolite clasts occur with polycrystalline quartz pebbles in the Late Triassic redbeds. The ophiolitic clasts consist of serpentinite, basalt, and red radiolarian chert that contains the same distinctive radiolarians that are found in the main belt of Devonian ophiolitic rocks. Likewise, clasts of Mississippian chert occur in the basal Permian conglomerate, and clasts of Permian limestone are found in the Triassic redbeds. None of these sequences is known to occur elsewhere in Alaska. The terrane is highly folded and thrust faulted, but displays an internally coherent stratigraphy.

The geologic history of the Chulitna terrane commenced with formation of oceanic crust in Late Devonian time (Jones and others, 1980). Deposition of pelagic chert in an oceanic setting continued into the Mississippian; in late Paleozoic time, coarse volcanic conglomerates and flows covered the older cherts and incorporated ripped-up chert clasts in their basal beds. These late Paleozoic rocks are heterogeneous in character, and their internal stratigraphic relations are poorly known, mainly because of complex structure and lack of fossils throughout the section. The distinctive Triassic redbeds overlie ammonite-bearing cherty limestone of Early Triassic age (Nichols and Silberling, 1979). Fossils from this limestone show strong affinities with faunas from California, Nevada, and Idaho, and differ from assemblages known farther north in Canada. This relation implies a lower latitude position for the Chulitna terrane in the Early Triassic. The Late Triassic redbeds formed along a continental margin, as indicated by abundant polycrystalline quartz in some conglomeratic beds; however, no comparable sequence has been located along the western margin of North America that would indicate the position of the Chulitna terrane in Late Triassic time.

Susitna terrane

The Susitna terrane (Jones and others, 1980, 1982) occurs in the northern part of the Talkeetna Mountains (Figs. 1, 2, and 3) and consists of thick piles of pillow basalt, deep-marine tuffaceous sedimentary rocks, sandstone, and tuff. The fossils *Monotis subcircularis* and *Heterastridium* sp. are locally abundant in argilite interbedded with the volcanic rocks and indicate a Late Triassic (Norian) age. The Susitna terrane is a rootless nappe engulfed in the highly deformed Mesozoic flysch of the Kahiltna assemblage. The upper contact of basalt with flysch originally may have been depositional, but relations are now obscured by subsequent shearing along the contact. The Susitna terrane is herein interpreted as a possible fragment of an oceanic seamount and/or a fragment of the Peninsular terrane, possibly equivalent to either the Cottonwood Bay Greenstone or the Chilikadrotna Greenstone, that was tectonically decoupled from its basement and faulted into the flysch of the Kahiltna assemblage during the middle or Late Cretaceous. This interpretation would require at least moderate tectonic displacement from the core of the Peninsular terrane.

EXPLANATION

CENOZOIC AND LATE CRETACEOUS SEDIMENTARY ROCKS

Qs — Quaternary surficial deposits

Ts — Early Tertiary sedimentary rocks

Kk — Late Cretaceous Kuskokwim Group

CENOZOIC AND LATE CRETACEOUS GRANITOID ROCKS

Tg — Early Tertiary granitoid rocks

TKv — Early Tertiary and Late Cretaceous volcanic rocks

TKg — Early Tertiary and Late Cretaceous granitoid rocks

EARLY CRETACEOUS AND LATE JURASSIC SEDIMENTARY ROCKS

KH — Kahiltna assemblage

TECTONO-STRATIGRAPHIC TERRANES

Mystic terrane

JTRb — Pillow basalt, minor clastic rocks

PzC — Clastic rocks, carbonate rocks, and chert

Dillinger terrane

DL

Nixon Fork terrane

NX

Peninsular terrane

Js — Sedimentary rocks, Tuxedni Group, Chinitna Formation, and Naknek Formation

Jg — Middle Jurassic granitic rocks

JTRch — Chilikadrotna Greenstone

JTRco — Cottonwood Bay Greenstone, Kamishak Formation, and Talkeetna Formation

TRPztc — Tlikakila complex. Mainly metamorphosed and tectonically disrupted sedimentary rocks and mafic and ultramafic rocks of uncertain age and local Triassic limestone

m — Metamorphosed rocks in roof pendants

SYMBOLS

Contact

Fault—Dotted where concealed

Thrust fault—Dashed where approximately located, dotted where concealed

Strike-slip fault—Dashed where approximately located, dotted where concealed

West Fork and Broad Pass terranes

The West Fork and Broad Pass terranes occur in the central Alaska Range structurally below the Chulitna terrane along its southeastern margin (Figs. 1, 2, and 3). The West Fork terrane consists of two separate lithologic units (Jones and others, 1982; Csejtey and others, 1986). The upper unit is chert, argillite, and sandstone ranging in age from Early to Late Jurassic. The lower unit is crystal tuff and volcaniclastic sandstone and argillite. The lower unit is mainly undated, but one occurrence of fossiliferous sandy conglomerate of Early Jurassic age is known. The West Fork terrane is interpreted as a fragment of a turbidite basin formed adjacent to the volcanic part of a Jurassic island arc (Jones and others, 1982).

The Broad Pass terrane (Jones and others, 1982; Csejtey and others, 1986) occurs in the central Alaska Range and is a poorly exposed structural melange of (1) chert, argillite, tuffaceous rocks, phyllite, conglomerate, and graywacke with Late Devonian to middle Mississippian radiolarians in chert; (2) blocks of Silurian and Devonian limestone; and (3) very minor serpentinite. No internal stratigraphy is known, and the basic structure is chaotic. The terrane extends northeastward beyond the known limits of both the Chulitna and West Fork terranes and terminates against the Denali fault (Fig. 2). The terrane is interpreted to be a structural mixture of diverse sedimentary rocks.

Maclaren terrane

The Maclaren terrane occurs in the central and eastern Alaska Range north of the Broxson Gulch thrust and south of the Denali fault (Figs. 2, 3, and 4) (Nokleberg and others, 1982, 1985, 1992b). The terrane consists of the Maclaren Glacier metamorphic belt to the south and the East Susitna batholith to the north. Included with the Maclaren terrane is the Nenana terrane of Jones and others (1984, 1987). Unless otherwise noted, the following description of the Maclaren terrane is after Smith and Lanphere (1971), Turner and Smith (1974), Smith (1981), Nokleberg and others (1982, 1985, 1989a, 1992a, 1992b), and Csejtey and others (1986).

Maclaren Glacier metamorphic belt. The Maclaren Glacier metamorphic belt is an inverted, prograde, Barrovian-type metamorphic belt (Smith, 1981; Nokleberg and others, 1985; Dusel-Bacon, 1991; this volume, Chapter 15; Dusel-Bacon and others, 1994) (Figs. 3 and 4). From south to north and structurally from bottom to top, the major fault-bounded units are pre–Late Jurassic argillite and metagraywacke, phyllite, and schist and amphibolite units. The argillite and metagraywacke unit consists predominantly of volcanic graywacke and siltstone, sparse andesite and basalt, and lesser calcareous and quartz siltstone metamorphosed at lower greenschist facies. The phyllite unit consists of interfoliated phyllite, metagraywacke, meta-andesite, and sparse marble metamorphosed at upper greenschist facies. The schist and amphibolite unit consists of interfoliated garnet amphibolite, garnet schist, amphibolite, mica schist, and calc-schist metamorphosed at amphibolite facies. The minimum structural thickness for the belt in the western Mount Hayes quadrangle is estimated to be several thousand meters.

A flysch protolith is interpreted for the argillite and metagraywacke unit. The only nearby data for the age of the argillite and metagraywacke unit are a 146 Ma K-Ar hornblende age and a 133 Ma K-Ar biotite age from an alkali gabbro stock that intrudes the argillite in the central Alaska Range. The alkali gabbro stock exhibits the same degree of lower greenschist facies metamorphism as the enclosing argillite and metagraywacke unit, indicating that both were metamorphosed together. This relation and the discordant ages for hornblende and biotite indicate that this part of the argillite and metagraywacke is Late Jurassic or older in age. This age, and a flysch protolith for the Maclaren Glacier metamorphic belt, suggests a correlation with the flysch of the Kahiltna assemblage to the west, which is faulted against the Maclaren terrane.

A general increase in metamorphic grade occurs from the lower greenschist facies argillite and metagraywacke unit, the lowest structural unit to the south, to the amphibolite facies schist and amphibolite unit, the highest structural unit to the north. The highest grade part of the metamorphic belt occurs in the Healy quadrangle to the west and is defined by the occurrence of sillimanite and kyanite. A Late Cretaceous and early Tertiary age of regional metamorphism for the schist and amphibolite unit of the Maclaren Glacier metamorphic belt is indicated by K-Ar hornblende and biotite ages ranging from 64.1 to 28.5 Ma.

East Susitna batholith. The East Susitna batholith (Fig. 4) consists of a suite of regionally metamorphosed and deformed, small to large plutons of gabbro, quartz diorite, granodiorite, and lesser quartz monzonite (Nokleberg and others, 1982, 1985, 1992b). Locally abundant migmatite, migmatitic schist, and schist and amphibolite, derived from older gabbro and diorite, also occur in the batholith. The schistose granitic rocks locally grade over a distance of a few centimeters to meters into migmatite, migmatitic schist, and schist and amphibolite.

The East Susitna batholith is ductilely deformed into mylonitic gneiss and schist, and regionally metamorphosed at middle amphibolite facies; there is local retrograde metamorphism to lower greenschist facies (Nokleberg and others, 1985). The batholith is separated from the Maclaren Glacier metamorphic belt by the Meteor Peak fault (Fig. 4). Isotopic studies indicate syntectonic intrusion of the East Susitna batholith from the middle Cretaceous through the early Tertiary. A sample of schistose quartz diorite from the batholith yields a U-Pb zircon age of 70 Ma, and various, abundnt K-Ar ages for metamorphic biotite and hornblende range from 87.4 to 29.8 Ma.

Coeval metamorphism of the East Susitna batholith and the Maclaren Glacier metamorphic belt (Nokleberg and others, 1985, 1989a) is indicated by (1) a regional relation of prograde units to the north, toward the East Susitna batholith; (2) a parallel fabric formed at amphibolite facies between the higher grade parts of the belt and the batholith; and (3) coeval K-Ar and U-Pb sphene isotopic ages for metamorphic minerals in both units. The increase of metamorphic grade in the Maclaren Glacier metamorphic belt toward the East Susitna batholith is interpreted as metamorphism that occurred in response to emplacement of the igneous magmas forming the batholith structurally above the metamorphic belt, thereby creating the inverted metamorphic sequence. A similar and subsequent interpretation is that the Maclaren terrane is an exhumed part of a deep crustal shear zone, where hot upper amphibolite facies rocks of the East Susitna batholith were emplaced over cooler lower grade rocks of the Maclaren Glacier metamorphic belt (Davidson and others, 1992). These relations are very similar to those observed for correlative units in the Gravina-Nutzotin belt and adjacent terranes, west of the foliated tonalite sill in the informally named Coast plutonic-metamorphic complex of Brew and Ford (1984) (Crawford and others, 1987; Gehrels and others, 1991).

The East Susitna batholith and companion Maclaren Glacier metamorphic belt are interpreted as having formed in a continental margin arc setting on the basis of (1) being a composite batholith intruding a quartz-rich flysch sequence; and (2) isotopic analysis of feldspar lead from samples of the East Susitna batholith, indicating derivation from a cratonal source of about 1.2 Ga (Aleinikoff and others, 1987). The Maclaren terrane is truncated to zero thickness where the Broxson Gulch thrust to the south abuts against the Denali fault to the north (Figs. 2 and 4). These relations strongly suggest that the Maclaren terrane is a displaced fragment, and that the rest of the Maclaren terrane may occur on the opposite side of the Denali fault (Forbes and others, 1973; Smith and others, 1974; Eisbacher, 1976; Stout and Chase, 1980; Smith, 1981; Nokleberg and others, 1985). The nearest rocks correlative with the Maclaren terrane are about 400 km away to the southeast in the Ruby Range batholith and associated metamorphic rocks of the Kluane Lake–Ruby Range area in the southwestern Yukon Territory, part of the Coast plutonic-metamorphic complex, Gravina-Nutzotin belt, and adjacent terranes.

Clearwater terranes

The Clearwater terrane (Jones and others, 1984) occurs in the eastern Alaska Range as a narrow, fault-bounded lens along the Broxson Gulch thrust (Figs. 1, 2, and 3). The terrane is a structurally complex assemblage of argillite, greenstone (metapillow basalt), shallow-water limestone and marble containing Late Triassic (late Norian) fossils, and sparse metarhyolite (Fig. 3) (Nokleberg and others, 1985, 1992b; Csejtey and others, 1986). Each lithology is fault bounded. The terrane is weakly metamorphosed and penetratively deformed at lower greenschist facies and locally contains a single intense schistosity (Nokleberg and others, 1982, 1985, 1992b; Dusel-Bacon and others, 1993). The Clearwater terrane is unique because it contains Late Triassic sedimentary rocks and presumably coeval basalt and rhyolite. Because it contains a bimodal suite of greenstone or metabasalt and metarhyolite, shallow-marine sedimentary rocks, and possibly a coeval granitic pluton, the Clearwater terrane is herein interpreted as a fragment of an island arc.

WRANGELLIA TERRANE

The Wrangellia terrane (Jones and others, 1977, 1981, 1987; Nokleberg and others, 1982, 1985, 1992b; Plafker and others, 1989c) occurs in the northern and eastern parts of the study area in the Gulkana, Healy, McCarthy, Mount Hayes, Nabesna, and Talkeetna Mountains quadrangles (Figs. 1 and 2). The terrane consists of several sequences (Richter, 1976; MacKevett, 1978; Winkler and others, 1981c; Nokleberg and others, 1982, 1985, 1992b; Plafker and others, 1989c): (1) a pre–late Paleozoic assemblage of metasedimentary and metagranitic rocks; (2) Pennsylvanian and Permian marine volcanic rocks (Tetelna volcanics); (3) interlayered Pennsylvanian and Early Permian marine volcanic and sedimentary rocks (Slana Spur and Station Creek formations); (4) Permian nonvolcanogenic limestone and argillite (Eagle Creek and Hasen Creek formations); (5) sparse hypabyssal to deep-seated late Paleozoic plutonic rocks; (6) a thick sequence of Late Triassic submarine and subaerial basalt (Nikolai Greenstone) and associated mafic and ultramafic intrusive rocks; (7) disconformably overlying Late Triassic and Early Jurassic shallow- and deep-water calcareous sedimentary rocks (Nizina and Chitistone limestones, and McCarthy and Lubbe Creek formations); (8) unconformably overlying Middle Jurassic through Early Cretaceous volcaniclastic and clastic rocks (Root Glacier and Nizina Mountain formations, Kotsina Conglomerate, and Berg Creek and Chisana formations) and flysch (Gravina-Nutzotin belt); and (9) younger Cretaceous marine basin deposits (Chititu, Moonshine Creek, Schulze, and Kennicott formations). Overlapping units are the middle Tertiary through Holocene subaerial volcanic and associated clastic rocks of the Wrangell Mountains volcanic field and coeval hypabyssal intrusive rocks of the Wrangell continental margin arc (Miller and Richter, this volume). In contrast to the McCarthy quadrangle to the southeast, the Late Jurassic through Cretaceous strata in the Nabesna and and Mount Hayes quadrangles to the northwest consist mainly of the Gravina-Nutzotin belt and the Chisana Formation (Richter, 1976; Nokleberg and others, 1982, 1992b). Unless noted, the following descriptions of the stratified rocks of the Wrangellia terrane in the eastern Alaska Range and Nutzotin Mountains in the Mount Hayes and Nabesna quadrangles are from Richter and Dutro (1975), Richter (1976), Richter and others (1977), and Nokleberg and others (1982, 1985, 1992b); descriptions from the Wrangell Mountains in the Nabesna quadrangle are from MacKevett (1969, 1971, 1978) and Smith and MacKevett (1970).

Pre–late Paleozoic units of Wrangellia terrane

In the Wrangellia terrane in the Nutzotin Mountains are roof pendants of pre–middle Pennsylvanian age. These roof pendants occur in the late Paleozoic granitic plutons of the Skolai arc and constitute a cataclasite unit (Richter, 1976) of mica and quartz schist, derived from clastic sedimentary rocks, and relatively younger, gneissose metagranitic rocks (Fig. 3) (W. J. Nokleberg and D. H. Richter, 1986, unpublished data). No fossil or isotopic data exist for the ages of the sedimentary or granitic rocks. Both parts of the cataclasite unit contain a regional upper greenschist facies schistose fabric that is also relatively older than the late Paleozoic plutons. This metasedimentary and metagranitic basement might be part of the mainly early and middle Paleozoic Alexander terrane which, to the southeast in the eastern Wrangell Mountains, is stitched to the Wrangellia terrane by a Pennsylvanian granitic pluton that intrudes the contact between the Alexander and Wrangellia terranes (see discussion below, and Gardner and others, 1988).

The basement of the Wrangellia terrane may have a variable nature. In some areas, an island-arc origin is indicated for the late Paleozoic Skolai arc by isotopic and chemical data (Aleinikoff and others, 1987; Barker, this volume), whereas in other areas, pre–late Paleozoic arc rocks occur either in roof pendants in the late Paleozoic plutonic rocks or, in the case of the northwestern Alexander terrane, are welded to the Wrangellia terrane by the late Paleozoic plutonic rocks. Analysis of seismic refraction data for the central part of the Wrangellia terrane in the Copper River Basin in the Gulkana quadrangle (Fig. 1) indicates a 35-km-thick, intermediate composition crust (Goodwin and others, 1989; Fuis and Plafker, 1991). Comparison of laboratory measurements of compression seismic velocities with modeled velocities indicates a seismically homogeneous middle crust and a thick and possibly more heterogeneous lower crust that together are likely composed of intermediate composition igneous rock and/or quartz-mica schist. Alternative interpretations for formation of the thick, intermediate composition crust are (Goodwin and others, 1989) (1) internal tectonic imbrication during accretion; (2) magmatic underplating after accretion of the Wrangellia terrane, possibly during formation of the late Cenozoic Wrangell Mountains volcanic field; or (3) buildup of at least the eastern part of the Wrangellia terrane on intermediate composition crust, possibly the Alexander terrane.

Late Paleozoic units of Wrangellia terrane

Tetelna volcanics, Slana Spur Formation, and Eagle Creek Formation. In the eastern Alaska Range and Nutzotin Mountains in the Mount Hayes and Nabesna quadrangles, the late Paleozoic stratified rocks of the Wrangellia terrane are the Tetelna volcanics, the Slana Spur Formation, and the Eagle Creek Formation (Figs. 3 and 4). The mainly Pennsylvanian or older Tetelna volcanics (Mendenhall, 1905; Richter, 1976; Richter and others, 1977; Nokleberg and others, 1982, 1992b) are dominantly andesite and lesser basalt flows, mud and debris avalanche deposits, and tuffs interbedded with fine- to coarse-grained volcaniclastic rocks that are more than 1,000 m thick. In one area in the Nabesna quadrangle (Fig. 1), Permian fossils and megafossils occur in part of the Tetelna volcanics (Richter, 1976). The base of the Tetelna volcanics is either not exposed or faulted. Conformably overlying the Tetelna volcanics is the middle Pennsylvanian to Early Permian Slana Spur Formation, which is mainly a thick sequence of marine calcareous and noncalcareous volcaniclastic rocks, including volcanic graywacke, volcanic breccia, and intermediate composition tuff, with subordinate limestone and argillite that are about 1,000 m thick. Conformably overlying the Slana Spur Formation is the Early Permian Eagle Creek Formation, which is mainly alternating units of shallow-marine argillite and limestone about 900 m thick.

Locally extensive hypabyssal dacite stocks, sills, and dikes and several large granitic plutons, including the Ahtell Creek pluton and a diorite complex (Richter and others, 1975; Barker and Stern, 1986; Beard and Barker, 1989; Barker, this volume), intrude only the Slana Spur Formation and the Tetelna volcanics. The hypabyssal and plutonic rocks are interpreted as being comagmatic with the volcanic rocks of the Slana Spur Formation, and together with this unit constitute part of the Skolai arc. U-Pb zircon isotopic analyses of the granitic rocks yield Pennsylvanian ages of 290 to 320 Ma.

Station Creek and Hasen Creek formations. In the Wrangell Mountains in the McCarthy quadrangle, the late Paleozoic stratified rocks of the Wrangellia terrane are the Station Creek and Hasen Creek formations (Figs. 2 and 3). The Pennsylvanian and Permian Station Creek Formation consists of altered andesite, basalt, volcanic breccia,and graywacke that is approximately 2,000 m thick. The base of the unit is either faulted or not exposed. The lower volcanic member of this unit is lithologically correlated with the Tetelna volcanics, and the upper volcaniclastic member is lithologically correlated with the Slana Spur Formation in the eastern Alaska Range. The Station Creek Formation, along with local crosscutting granitoids, constitutes the Skolai arc in the Wrangell Mountains (Richter and others, 1975; Barker and Stern, 1986; Beard and Barker, 1989; Barker, this volume; Miller, this volume, Chapter 16).

The Early Permian Hasen Creek Formation also occurs in the McCarthy quadrangle and is mainly fossiliferous limestone and argillite and lesser sandstone, chert, and conglomerate that is ~200 m thick. The unit is correlated with the Eagle Creek Formation in the eastern Alaska Range.

Mesozoic units of Wrangellia terrane

Nikolai Greenstone. In the eastern Alaska Range and Nutzotin Mountains, the Late Triassic Nikolai Greenstone, first described by Rohn (1900), consists mainly of massive, subaerial, amygdaloidal basalt flows, lesser pillow-basalt flows, and thin beds of argillite, chert, and mafic volcaniclastic rocks that are up to 4,350 m thick. The flows are predominantly intermixed aa and pahoehoe; individual units range from 5 cm to more than 15 m thick. Locally extensive gabbro dikes and cumulate mafic and ultramafic sills intrude the Nikolai Greenstone and older rocks in the subterrane; these dikes and sills are probably comagmatic with the basalt that formed the Nikolai Greenstone. Locally underlying the Nikolai is a unit of Permian through Middle Triassic shale, limestone, and chert that is up to 600 m thick (Silberling and others, 1981).

In the Wrangell Mountains, the Late Triassic Nikolai Greenstone is mainly altered, amygdaloidal, tholeiitic basalt ~3,000 m thick. Pillow basalt and argillite occur locally near the base. The unit occurs in intermixed pahoehoe and aa flows in units between 15 cm and 15 m thick. The basal part of the Nilolai is generally a volcanic conglomerate as much as 70 m thick.

The Nikolai Greenstone consists throughout of clinopyroxene and former calcic plagioclase. The unit is pervasively metamorphosed to a granoblastic suite of lower greenschist facies minerals, mainly chlorite, epidote, albite, zeolite, and prehnite. Amygdules are generally filled by calcite, chlorite, quartz, and epidote; some amygdules contain zeolites, prehnite, native copper, or Cu-sulfides.

Chitistone and Nizina limestones, McCarthy Formation, and Lubbe Creek Formation. The Late Triassic Chitistone and Mizina limestones occur mainly in the McCarthy quadrangle and consist of limestone, dolomite, algal-mat chips, and lesser chert that are ~1,100 m thick. In addition, the Nizina Limestone contains sparse tuffaceous detritus, mainly plagioclase and pyroxene crystals, and andesite or basalt fragments M. Mullen, 1991, written commun.). Similar unnamed limestone units occur stratigraphically above the Nikolai Greenstone in the Nutzotin Mountains and eastern Alaska Range. These dolomites and limestones are interpreted to have formed in supratidal settings; some beds have diagenetic features characteristic of sabkha facies (Armstrong and MacKevett, 1982).

The McCarthy and Lubbe Creek formations occur mainly in the McCarthy quadrangle and are primarily impure chert and limestone and radiolarian-rich siliceous shale that are as thick as 300 m. As with the Nizina Limestone, the McCarthy Formation contains sparse tuffaceous detritus (M. Mullen, 1991, written commun.). These deposits are interpreted as having formed in an open marine environment that gradually evolved upward to basinal limestone and siltstone (McCarthy Formation of Late Triassic and Early Jurassic ages) that was rich in pelagic mollusks and siliceous organisms. The tuffaceous material suggests proximity of an active volcanic arc in the Late Triassic and Early Jurassic, possibly the Talkeetna arc of the Peninsular terrane.

Nizina Mountain Formation, Kotsina Conglomerate, and Root Glacier, Berg Creek, Chisana, Kennecott, Chititu, Moonshine Creek, Schulze, and MacColl Ridge formations. The Jurassic and Cretaceous Nizina Mountain Formation, Kotsina Conglomerate, and Berg Creek, Chititu, Lubbe Creek, Kennecott, MacColl Ridge, Moonshine Creek, Root Glacier, and Schulze formations occur mainly in the McCarthy quadrangle and are primarily shallow-marine clastic rocks that compose a section more than 2,000 m thick. The dominant lithologies in each unit are spiculite and minor coquina (Lubbe Creek); graywacke (Nizina Mountain); conglomerate (Kotsina); siltstone, sandstone, shale, and conglomerate (Root Glacier); conglomerate, sandstone, siltstone, and calcarenite (Berg Creek); andesite flows, tuffs, and volcanic flysch (Chisina); sandstone, siltstone, and minor conglomerate (Kennecott); mudstone, shale, and subordinate porcellanite (Chititu); siltstone, sandstone, and minor conglomerate (Moonshine Creek); porcellanite with minor sandstone and conglomerate (Schulze); and coarse sandstone and minor conglomerate (MacColl Ridge). The Early Jurassic strata are basinal organic-rich siliceous limestone, cherty argillite, and shale, whereas the Middle and Late Jurassic strata are dominantly fine- to medium-grained clastic rocks; conglomerate is locally abundant in the upper part of the section. Locally abundant fossils throughout this sequence indicate deposition in water depths ranging from moderately deep (about 500–1,000 m) to shelfal (about 100–200 m). These Middle Jurassic to Late Cretaceous basinal strata contain many interformational disconformities and local intraformational hiatuses, and they vary markedly in thickness and distribution. An episode of strong north-verging folding and faulting occurred after deposition of the Late Jurassic strata; Early Cretaceous strata were deposited unconformably on these deformed strata.

Late Paleozoic and Mesozoic plutons and igneous arcs, and regional metamorphism of the Wrangellia terrane

The Wrangellia terrane contains remnants of four epochs of igneous activity: the late Paleozoic Skolai arc, Late Triassic mafic magmatism, the Late Jurassic Chitina arc, and the Early Cretaceous Chisana arc and Late Cretaceous Kluane arc. In addition, a period of middle Cretaceous regional metamorphism occurred throughout most of the terrane and the superjacent Gravina-Nutzotin belt.

Late Paleozoic Skolai arc. The Skolai arc forms a lithologically variable belt that is discontinuously exposed in the Wrangellia and Alexander terranes (Fig. 2), and in adjacent parts of Canada to the east. In the study area, the plutonic part of this belt consists of compositionally diverse early to middle Pennsylvanian plutons (unit lPzg, Fig. 2) that are mainly (1) the Ahtell pluton (diorite-gabbro-tonalite-anorthosite suite and diorite complex) in the eastern Alaska Range (Richter and others, 1975) with U-Pb ages of 290 to 316 Ma (Barker and Stern, 1986); (2) metagranite and metagranodiorite with U-Pb zircon ages of 308 to 310 Ma (Aleinikoff and others, 1988) in the Uranatina River metaplutonic unit of the southern Wrangellia terrane, and correlative units in the Chitina Valley, Chugach Mountains, and western Wrangell Mountains (Plafker and others, 1989c); and (3) the Bernard Glacier pluton with a U-Pb zircon age of 308 Ma (Gardner and others, 1988) intruding both the Wrangellia and Alexander terranes in the southeastern Wrangell Mountains. Possibly correlative rocks to the east in Canada include the alkalic Iceland Ranges plutonic suite of Pennsylvanian age in adjacent parts of Canada (Campbell and Dodds, 1982a, 1982b; Dodds and Campbell, 1988). This arc constitutes the lowermost widespread unit of the Wrangellia terrane. A south-facing arc is suggested by the increase in carbonate rock and chert contents in bedded sequences from the Wrangell Mountains southward across the Chitina Valley.

The origin of the Skolai arc was first discussed in two early studies. (1) In the Nabesna quadrangle, Richter and Jones (1973) interpreted the late Paleozoic volcanic and sedimentary rocks of the Wrangellia terrane as forming in an island arc developed on oceanic crust; and (2) to the west in the Mount Hayes quadrangle, Bond (1973, 1976) interpreted the late Paleozoic volcanic and sedimentary rocks of the Wrangellia terrane as forming in a marine volcanic chain on continental crust above a subduction zone. The main pieces of evidence for a marine origin for the Skolai arc are (1) submarine deposition of the volcanic flows, tuff, and breccia, and associated volcanic graywacke and argillite; and (2) locally abundant features that indicate deposition of sedimentary and volcanic debris from turbidity currents to form volcanic graywacke. The main supporting observations for an (oceanic) island-arc origin are (1) the absence of abundant continental crustal detritus in late Paleozoic stratified rocks; (2) little or no quartz in the volcanic rocks and associated shallow intrusive bodies; (3) common lead isotopic compositions for late Paleozoic granitic rocks, indicating low radiogenic lead values and derivation from a mixture of oceanic mantle and pelagic sediment leads, without an older continental component (Aleinikoff and others, 1987); and (4) Rb-Sr isotopic data and REE volcanic and plutonic whole-rock chemical analyses and petrologic data indicating an intra-oceanic island-arc origin (Barker and Stern, 1986; Beard and Barker, 1989; Arth, this volume; Barker, this volume; Miller, this volume, Chapter 16).

Late Triassic mafic magmatism and formation of Nikolai Greenstone and related rocks. A voluminous but short-lived period of mafic magmatism occurred in the Late Triassic and resulted in eruption of the widespread basalt of the Nikolai Greenstone and correlative units, such as the Karmutsen Formation in British Columbia, during a 7–8 m.y. interval (Richter and Jones, 1973; MacKevett, 1978; Jones and others, 1977; Silberman and others, 1981; Winkler and others, 1981a; Nokleberg and others, 1985; Plafker and others, 1989c). Coeval with the eruption was intrusion of gabbro and diabase dikes and sills, and of cumulate mafic and ultramafic sills.

The mafic magmatism resulting in the Nikolai Greenstone was first interpreted as forming in a rift setting (Jones and others, 1977; Nokleberg and others, 1985; Barker and others, 1989; Barker, this volume). Evidence cited for a rift setting is (1) a vast extent, occurrence in a linear belt, and a great thickness throughout the Wrangellia terrane; (2) a relatively constant igneous texture, petrology, and average chemical composition, approximating a typical high-Al tholeiite; and (3) REE analyses compatible with (back-arc) spreading.

The mafic magmatism resulting in the Nikolai Greenstone has been interpreted as forming in a mantle plume setting (Richards and others, 1991). Evidence cited for a plume origin consists of (1) the lack of any recognized sheeted dikes, rift facies, and rift structures; and (2) no indication of large amounts of crustal extension and graben formation usually associated with normal faulting. According to this interpretation, a buoyant rise of a large plume head would cause rapid dynamic uplift that preceded volcanism. Partial melting of the plume beneath oceanic lithosphere would result in an enormous volume of basalt being erupted quickly throughout the area centered on the head of the plume. The basaltic eruption would be a much shorter period compared with known rifted arcs. A rapid change would occur from deep water to shallow, near sea-level conditions immediately before basalt eruption.

Several features of the observed geology fit the plume model (Richards and others, 1991). In the submerged parts of the Skolai arc, thermal expansion and uplift resulted in surfacing of the Wrangellia terrane and formation of a vast thickness of marine and subaerial basalt with Nd and Sr isotopic compositions characteristic of oceanic plume basalt, up to 6,000 m thick, within about 7 to 8 m.y. in the Late Triassic. This upwelling also explains the lack of rift facies beneath the Nikolai Greenstone, as well as the absence of linear dike swarms that generally occur in rifted crust. Instead, widespread emplacement of gabbroic sills and cumulate mafic and ultramafic rocks occurred. Afterward, cooling and thermal subsidence controlled the post-basalt sedimentation in the stratigraphic sequence overlying the Nikolai, with a change from shallow-water carbonate facies of the Chitistone Limestone to the basinal deposits of the McCarthy Formation. This change may reflect thermal contraction induced by cooling of the underlying basaltic pile.

However, some problems exist with the plume origin. First, the Wrangellia terrane differs from modern oceanic plateaus in that the basalt of the Late Triassic Nilolai Greenstone was built on an inactive, late Paleozoic (Skolai) island arc and was locally succeeded by Early Jurassic arc volcanism that occurred no more than 10–15 m.y. later. Modern-day plateaus are not similar. Second, a serious problem may exist with the size and shape of the Nikolai Greenstone and correlative units in the Wrangellia terrane versus the size and shape of mantle plumes. The Wrangellia terrane is about 2,500 km long and less than 200 km wide. In contrast, plumes tend to be circular, and a very large one is only about 1,000 km in diameter (Richards and others, 1991). Additional studies are needed to resolve the origin of the basalts of the Nikolai Greenstone and coeval mafic and ultramafic plutonic rocks.

Late Jurassic Chitina arc. Late Jurassic granitic plutons of the Chitina arc (unit 1Jg, Fig. 2) intrude the older rocks of the Wrangellia and southern Wrangellia terranes in the southern Wrangell Mountains and Chitina Valley (Hudson, 1983; Miller, this volume, Chapter 16). The granitic rocks are mainly strongly foliated tonalite and granodiorite, and lesser granite and quartz diorite (MacKevett, 1978). The plutons extend from the southwestern Wrangell Mountains southeastward to Chichagof Island in southeastern Alaska and are interpreted as the roots of the Chitina arc (Plafker and others, 1989c).

The Chitina arc is interpreted as an island arc that formed during the Late Jurassic stage of subduction of the McHugh Complex and correlative units of the Chugach terrane to the south along the southern margin of the WCT (Plafker and others, 1989c). North to northeast subduction for the Chitina arc and the Chisana arc (described below) is inferred from the presence of coeval volcanic detritus of Late Jurassic to Early Cretaceous age in the adjacent McHugh Complex of the Chugach terrane (Plafker and others, 1989c). The axis of the Chitina arc is parallel to, and about 100 km south of, the Early Cretaceous Chisana arc.

The Late Jurassic plutons in the Chitina Valley were intensely penetratively deformed during a major regional orogeny that began in the Late Jurassic (MacKevett, 1978). In addition, the position of the Jurassic plutons along the southern margins of the Wrangellia terrane and the southern Wrangellia terrane, virtually at the Border Ranges fault system, requires that a substantial segment of the southern Wrangellia terrane margin has been tectonically removed since the Jurassic (MacKevett, 1978; Plafker and others, 1989c). Sinstral displacement may have offset the missing segment of the terrane margin that may be the part of the Wrangellia terrane in British Columbia (Plafker and others, 1989c).

Early Cretaceous Chisana arc and Late Cretaceous Kluane arc. The Chisana arc consists of a belt of Early Cretaceous volcanic and plutonic rocks in the Wrangell and Nutzotin Mountains and along the southern flank of the eastern Alaska Range (Barker, 1987; Plafker and others, 1989c). In the eastern Alaska Range, the volcanic unit is the Chisana Formation that overlies the Gravina-Nutzotin belt. Local andesite flows and volcaniclastic rocks occur within the Gravina-Nutzotin belt (Nokleberg and others, 1982, 1992b). In the Wrangell Mountains in the McCarthy quadrangle, the volcanic-detritus–rich unit is the Berg Creek Formation. These and subjacent units in the Wrangellia terrane are also intruded by coeval Early Cretaceous granitic plutons (older, Cretaceous part of unit TKg, Fig. 2). The Chisana arc is interpreted as an island arc that formed on the leading edge of the WCT during the Early Cretaceous stage of subduction of the McHugh Complex and correlative units of the Chugach terrane to the south along the southern margin of the WCT (Plafker and others, 1989s).

The Kluane arc consists of a widely spaced belt of Late Cretaceous granitic plutons that occurs mainly in the Gravina-Nutzotin belt and correlative units in Canada in the Wrangellia and Maclaren terranes (older, Late Cretaceous part of unit TKg, Fig. 2) (Plafker and others, 1989c). The younger Maastrichtian volcaniclastic sedimentary rocks of the MacColl Ridge Formation in the Wrangell Mountains (Fig. 3) are interpreted as a fore-arc basin sequence that was in part coeval with the younger Late Cretaceous Kluane arc. The Kluane arc is interpreted as a continental margin arc that formed during latest Cretaceous accretion of the Valdez Group and correlative units of the Chugach terrane to the south along the southern margin of the WCT (Plafker and others, 1989c). Regional geologic data indicate that the Kluane arc formed after accretion of the WCT to North America during the middle Cretaceous (Plafker and others, 1989c; Plafker, 1990).

Succeeding the Kluane arc is the Late Cretaceous and early Tertiary part of the Alaska-Aleutian Range batholith and coeval volcanic rocks (Miller, this volume, Chapter 16; Moll-Stalcup, 1990, and this volume. This vast array of voluminous plutons and volcanic rocks occurs in a belt 700 km long and 130 km wide that extends from the northwestern part of the Alaska Peninsula through the Talkeetna Mountains to the central Alaska Range (unit TKg, Fig. 2). This plutonic belt is interpreted as having formed during the early stages of rapid northward subduction in the latest Cretaceous and early Tertiary (Miller, this volume, Chapter 16; Moll-Stalcup, 1990, and this volume).

Middle(?)-Cretaceous regional metamorphism. The Wrangellia terrane, including the Gravina-Nutzotin belt, generally exhibits weak, prehnite-pumpellyite to lower greenschist facies metamorphism (Nokleberg and others, 1985; Dusel-Bacon and others, 1994). The texture is generally granoblastic, but local incipient development of cleavage occurs. Abundant relict igneous or sedimentary minerals and textures remain. Locally asymmetric folds and companion axial plane faults accompany the regional metamorphism (Csejtey and others, 1982). The regional deformation and metamorphism is interpreted as having occurred in the middle(?) Cretaceous because (1) the structural fabric and metamorphic minerals generally occur in Early Cretaceous and older units (Dusel-Bacon and others, 1994); (2) sparse middle Cretaceous K-Ar whole-rock metamorphic ages are determined for the Wrangellia terrane (Silberman and others, 1980, 1981; Nokleberg and others, 1985, 1992a; Dusel-Bacon and others, 1994); and (3) relatively undeformed Late Cretaceous intrusive rocks of the Kluane arc, discussed above, locally intrude the highly deformed Late Jurassic and Early Cretaceous flysch and older bedrock of the Wrangellia terrane (Csejtey and others, 1982; Nokleberg and others, 1985; Plafker and others, 1989c). This regional deformation and metamorphism is interpreted as having occurred during the accretion of the WCT to the North American continental margin (Csejtey and others, 1982; Nokleberg and others, 1985; Plafker and others, 1989c).

Late Paleozoic and Mesozoic regional differences in Wrangellia terrane

Regional variations occur in the late Paleozoic and Mesozoic stratigraphy of the Wrangellia terrane. Two subterranes in the eastern Alaska Range, the Slana River and Tangle subterranes, exhibit significant differences in late Paleozoic and Late Triassic strata (Nokleberg and others, 1985). In addition, in the eastern Alaska Range and Wrangell Mountains, Late Jurassic and Early Cretaceous strata exhibit significant differences (Richter, 1976; MacKevett, 1978).

Late Paleozoic and Triassic regional differences—Slana River and Tangle subterranes. In the eastern Alaska Range, the Wrangellia terrane is divided into northern Slana River and southern Tangle subterranes that are juxtaposed along the intervening Eureka Creek fault (Fig. 4) (Nokleberg and others, 1982, 1985, 1992b). Unless noted, the following descriptions and interpretations of the two subterranes are after Richter (1976), Stout (1976), Richter and others (1977), MacKevett (1978), Nokleberg and others (1982, 1985, 1992b).

The Slana River subterrane occurs south of the Denali fault along the southern flank of the eastern Alaska Range. The Slana River subterrane consists (relative to the Tangle subterrane) mainly of (Fig. 4) (1) a thick sequence of Pennsylvanian and Permian island-arc volcanic and associated sedimentary rocks (Tetelna volcanics, Slana Spur Formation, Eagle Creek Formation), part of the Skolai arc; (2) a thin, 1,500-m-thick sequence of disconformably overlying massive basalt flows of the Late Triassic Nikolai Greenstone and coeval gabbro and diabase dikes and sills; (3) Late Triassic limestone; and (4) Late Jurassic and Early Cretaceous flysch of the Gravina-Nutzotin belt. The Slana River subterrane is the variant of the Wrangellia terrane in the Nutzotin Mountains and Wrangell Mountains.

The Tangle subterrane occurs south of the Slana River subterrane mainly in the southern foothills of the eastern and central Alaska Range. The Tangle subterrane consists (relative to the Slana River subterrane) mainly of (Fig. 4) (1) a relatively thin, lower sequence of upper Paleozoic and Lower Triassic sedimentary and tuffaceous rocks; (2) a relatively thick, disconformably overlying section of the Nikolai Greenstone, about 4,500 m thick, that is locally intruded by extensive cumulate mafic and ultramafic rocks, and gabbro and diabase dikes and sills; and (3) locally a thin unit of Late Triassic limestone. The late Paleozoic and Early Triassic sedimentary rocks consist mostly of aquagene tuff, dark gray argillite, minor andesite tuff and flows, and sparse light gray limestone estimated to be a few hundred meters thick. Sparse late Paleozoic and Early Triassic megafossils and radiolarians occur in this sequence. The mafic volcanic and associated rocks of the Nikolai Greenstone constitute the upper part of the Amphitheater Group of Stout (1976). The flysch of the Gravina-Nutzotin belt is missing in the Tangle subterrane.

The differences in the upper Paleozoic and lower Mesozoic parts of the Tangle and Slana River subterranes indicate that the two units (1) represent distal and proximal parts, respectively, of the same late Paleozoic Skolai arc; (2) represent proximal and distal parts, respectively, of the same Late Triassic mafic magmatism system; and (3) have been considerably shortened tectonically and juxtaposed during terrane migration and accretion. A stratigraphy somewhat similar to the Tangle subterrane occurs in the Wrangellia terrane on Vancouver Island in Canada (Muller and others, 1974; Muller, 1977; Nokleberg and others, 1985). If the Tangle subterrane originally formed close to the variant of the Wrangellia terrane on Vancouver Island, then considerable tectonic dismemberment of the Wrangellia terrane has occurred since deposition of the Gravina-Nutzotin belt in the Late Jurassic and Early Cretaceous.

Late Jurassic and Cretaceous regional differences—eastern Alaska Range and Wrangell Mountains. Jurassic and Cretaceous strata also exhibit significant differences between the eastern Alaska Range and Nutzotin Mountains to the northwest (Richter, 1976; Nokleberg and others, 1982, 1992b) and the southern flank of the Wrangell Mountains to the southeast (MacKevett, 1978). Three main differences occur. (1) The eastern Alaska Range and Nutzotin Mountains do not contain Middle Jurassic strata, whereas the southern Wrangell Mountains contain the Middle Jurassic Nizina Mountain Formation and Kotsina Conglomerate. (2) The eastern Alaska Range and Nutzotin Mountains contain a thick sequence of the flysch and volcanic rocks of the Late Jurassic and Early Cretaceous Gravina-Nutzotin belt, whereas the southern Wrangell Mountains contain the progradational clastic rocks of the Berg Creek and Chisana Formations. (3) Units similar to the younger marine clastic Cretaceous rocks of the southern Wrangell Mountains (Chititu, Moonshine Creek, Schulze, and MacColl Ridge formations) do not exist in the eastern Alaska Range and Nutzotin Mountains to the north. These stratigraphic differences, which persisted from the Middle Jurassic into the Cretaceous, suggest that vertical movements oscillated between the northern and southern areas of the Wrangellia terrane, with subsidence in one area being matched by uplift in the other.

Origin of Wrangellia terrane. The allochthonous origin of the Wrangellia terrane was first recognized during paleomagnetic investigations of the Late Triassic Nikolai Greenstone, which displays shallow paleomagnetic pole inclinations indicating eruption of the basalt near the Triassic paleoequatorial (Hillhouse, 1977; Hillhouse and Grommé, 1984; Jones and others, 1977). Field relations discussed below indicate that the Wrangellia terrane was attached to the Alexander terrane in the southeastern Wrangell Mountains by the middle Pennsylvanian (Gardner and others, 1988). Paleomagnetic and stratigraphic data suggest that the Wrangellia terrane in Alaska and the Peninsular terrane may have shared a common geologic history since the Late Triassic, and possibly since the late Paleozoic.

Five major tectonic events characterize the Wrangellia terrane, according to Richter and Jones (1973), Csejtey and others (1982), Nokleberg and others (1985), and Plafker and others (1989c): (1) eruption of volcanic rocks and intrusion of coeval hypabyssal and plutonic rocks of the late Paleozoic Skolai arc (Bond, 1973, 1976; Jones and others, 1977; Nokleberg and others, 1985; Jones and Silberling, 1979; Barker, this volume; Miller, this volume, Chapter 16); (2) extrusion of the basalt of Late Triassic Nikolai Greenstone and intrusion of coeval mafic intrusive rocks in either a rift or plume environment in a near-equator setting (Jones and others, 1977; Nokleberg and others, 1985; Plafker and others, 1989c; Richards and others, 1991); (3) formation of a major Late Jurassic and Early Cretaceous flysch basin on the northern or leading edge of the WCT during migration toward the North American continental margin, and formation of the coeval Chisana arc (Nokleberg and others, 1985; Plafker and others, 1989c); (4) accretion, deformation, and low-grade regional metamorphism in the middle Cretaceous (Nokleberg and others, 1985; Plafker and others, 1989c); and (5) Cenozoic dextral-slip movement along the Denali fault and internal dismemberment.

SOUTHERN WRANGELLIA TERRANE

The southern Wrangellia terrane (Plafker and others, 1989c) occurs south of the Wrangellia terrane in the northern Copper River basin, southern Wrangell Mountains, and northern

Chugach Mountains in the Gulkana, McCarthy, Talkeetna Mountains, and Valdez quadrangles (Figs. 1 and 2). The terrane is mainly a suite of generally highly deformed and metamorphosed late Paleozoic or older sedimentary and volcanic rocks, Late Triassic basalt and limestone, and Pennsylvanian and Late Jurassic metaplutonic rocks. The southern Wrangellia terrane contains some of the most structurally and petrologically complex rocks in the study area. In the northern Copper River basin, the terrane consists of the metamorphic complex of Gulkana River and is bounded to the north by the Paxson Lake fault and to the south by the West Fork fault and Peninsular terrane (Fig. 2). In the southern Wrangell Mountains and northern Chugach Mountains, the terrane consists of the Strelna metamorphics of Plafker and others (1989c) and the Urantina River metaplutonic unit, and is bounded to the north by the Chitina Valley fault and to the south by various splays of the Border Ranges fault and the Chugach terrane (Fig. 2). Unless noted, the following descriptions of the southern Wrangellia terrane in the Gulkana and Talkeetna Mountains quadrangles are from Csejtey and others (1978) and Nokleberg and others (1986, 1989a); descriptions from the Valdez and McCarthy quadrangles are from MacKevett (1978), Winkler and others (1981a), Nokleberg and others (1989b), and Plafker and others (1989c).

Metamorphic complex of Gulkana River

The metamorphic complex of Gulkana River along the southern flank of the central and eastern Alaska Range consists of three rock sequences (Fig. 4) (Nokleberg and others, 1986; Kline and others, 1990). The oldest sequence is an unfossiliferous unit of (1) chlorite schist derived from generally massive, locally pillowed hornblende andesite, lesser clinopyroxene basalt, and agglomerate; (2) metamorphosed felsic tuff and metarhyolite to metadacite flows; (3) sparse medium- to thin-foliated calc-schist, pelitic schist, and metachert; and (4) rare calcite and dolomite marble. The mafic metavolcanic rocks are interpreted to be comagmatic with the relatively younger metamorphosed mafic plutonic rocks, discussed below, which are interpreted to be late Paleozoic in age. The metamorphic complex of Gulkana River was first recognized by Csejtey and others (1978) in the northern Talkeetna Mountains as an unnamed unit consisting mainly of amphibolite, greenstone, and locally schistose granitic rocks.

The next younger sequence consists of schistose hornblende diorite and lesser schistose gabbro that occur in dikes, sills, and small plutons. K-Ar hornblende ages for these metamorphosed mafic rocks are 130, 131, 233, 282, 295, 306, and 1,369 Ma (W. J. Nokleberg, T. E. Smith, and D. L. Turner, 1986, unpublished data). The oldest age of 1,369 Ma may represent a younger plutonic rock containing excess argon. The intermediate ages of 282 to 306 Ma may be a late Paleozoic age of intrusion. The younger ages of 130 and 131 Ma are interpreted as minimum ages of regional metamorphism, as discussed below.

The youngest sequence consists of schistose granitic plutons, mainly biotite granodiorite and granite, with lesser biotite-muscovite trondhjemite and quartz diorite. Locally abundant relict igneous biotite and muscovite occur in some of the metagranitic plutons. K-Ar metamorphic biotite and white mica ages, discussed below, are interpreted as the age of synkinematic intrusion of the plutons in the Late Jurassic. The structural thickness of the metamorphic complex is estimated as several kilometers, although the base is not exposed.

The dominant major structure in the metamorphic complex of Gulkana River is an east-west–striking, steeply dipping to vertical structural homocline of metavolcanic and metasedimentary rocks (Fig. 4). The dominant minor structure is a locally intensely developed mylonitic schistosity in all three units that strikes generally east-west and dips steeply to vertically, parallel to the regional strike of major units and bounding faults (Fig. 4). Locally intense ductile deformation occurs along the schistosity, and there is formation of mylonitic schist in metasedimentary and metavolcanic rocks and mylonitic gneiss in metaplutonic rocks. Lower greenschist facies minerals, mainly chlorite, actinolite, epidote, albite, and white mica, occur along the schistosity away from the metamorphosed granitic plutons of the metamorphic complex. In more highly metamorphosed and deformed areas, hornblende, clinopyroxene, calcic plagioclase, and biotite in the metaigneous rocks are mostly to completely replaced by metamorphic minerals, whereas in lesser deformed areas, hornblende, clinopyroxene, calcic plagioclase, and biotite are only partly replaced by metamorphic minerals.

The grade of regional metamorphism of the country rocks adjacent to the metamorphosed plutons increases to lower amphibolite facies with the occurrence of hornblende, garnet, calcic plagioclase, and biotite in place of lower grade minerals farther away. In these areas, the schistose fabric of the country rocks continues into the metagranitic rocks. These relations are interpreted as regional metamorphism occurring during syntectonic intrusion of the metagranitic plutons. Schistose biotite-muscovite granodiorite and quartz diorite from three metagranitic plutons have K-Ar metamorphic biotite ages of 139, 142, 143, 146, and 149 Ma, and metamorphic white mica ages of 146 and 148 Ma (W. J. Nokleberg, T. E. Smith, and D. L. Turner, 1986, unpublished data). These K-Ar ages are interpreted as a Late Jurassic age of regional metamorphism, deformation, and syntectonic intrusion of the metamorphosed plutonic rocks. The Late Jurassic ages also provide a minimum age for the wall rocks.

Strelna metamorphics and Uranatina River metaplutonic unit

In the northern Chugach and southern Wrangell Mountains, the southern Wrangellia terrane is composed of the Strelna metamorphics of Plafker and others (1989c) and the Uranatina River metaplutonic unit. The Strelna metamorphics include the metasedimentary rocks of the Dadina River area that occur to the northwest in the southwestern Wrangell Mountains, and the Uranatina River metaplutonic unit includes the metagranitic rocks of the Dadina River area. In the area west of the Copper

River and south of Tonsina, the term "Haley Creek metamorphic assemblage" is adapted from Wallace (1981a) to include both the metamorphosed stratified and plutonic rocks of the southern Wrangellia terrane (Fig. 6). For a discussion of previous names for these units, refer to Plafker and others (1989c).

Most rocks assigned to the Strelna metamorphics and the Uranatina River metaplutonic unit occur in an east-west–striking belt of moderately to steeply dipping, highly deformed lithologies. However, west of the Copper River and south of Tonsina, the Haley Creek metamorphic assemblage occurs in a large, folded thrust sheet and small outlying klippen in an area up to 10 km wide in a north-south direction and more than 20 km long in an east-west direction (Fig. 6). The base of this thrust sheet is the part of the Border Ranges fault, which defines the boundary of the Chugach terrane (Fig. 2). Locally the thrust sheet is eroded to expose the underlying Valdez Group of the Chugach terrane in windows (Fig. 6) (Nokleberg and others, 1989b; Plafker and others, 1989b, 1989c). This maximum structural thickness of the thrust sheet is estimated to be 1 to 2 km.

Strelna metamorphics. The Strelna metamorphics of Plafker and others (1989c) comprise five main lithologies: greenschist, marble, schistose marble, quartzofeldspathic mica schist, and micaceous quartz schist. One body of carbonate rocks contains recrystallized crinoids and brachiopods (Moffit, 1938), indicating deposition in a relatively shallow marine environment. Intercalated marbles have yielded conodonts of early Pennsylvanian (Bashkirian) age (Plafker and others, 1985). The quartzofeldspathic mica schist is probably derived from a quartzofeldspathic sandstone with minor intercalated argillaceous sediment. The high silica content of the quartz schist and its intimate intercalation with micaceous layers indicate a probable protolith of banded argillaceous and tuffaceous chert. Field relations indicate that the greenschist is derived from massive flow units, pillow lavas, and thinner bedded units that were probably tuff or breccia intercalated with sedimentary rocks. The metavolcanic rocks are probably the southernmost extrusive part of the Skolai arc.

Intense deformation of the Strelna metamorphics has destroyed most primary textures except for primary layering, relict graded bedding, and sparse relict clastic textures. Metamorphic grade is mainly lower greenschist facies, but increases to amphibolite facies adjacent to Late Jurassic metaplutonic rocks of the Uranatina River metaplutonic unit (Nokleberg and others, 1989b). In these areas, the schistose fabric of the country rocks continues into the metaplutonic rocks. The Strelna is interpreted, on the basis of lithology and sparse megafauna and conodont microfauna, to represent a former marine sequence composed dominantly of quartzofeldspathic, pelitic, calcareous, and cherty rocks with subordinate volcanic rocks that were deposited in a shelf or upper slope basin.

Uranatina River metaplutonic unit. The metasedimentary rocks of the Strelna metamorphics of Plafker and others (1989c) are extensively intruded by compositionally diverse, strongly schistose to blastomylonitic metaplutonic rocks of the Pennsylvanian and Jurassic Uranatina River metaplutonic unit (Fig. 3) (Plafker and others, 1989c). This unit was defined for the area southeast of Tonsina in the northern Chugach Mountains (Fig. 6) by Plafker and others (1989c), but it is herein extended to include all late Paleozoic and early and middle Mesozoic plutonic rocks in the southern Wrangellia terrane. The Uranatina River unit is exposed in the southwestern Wrangell Mountains and northern Chugach Mountains (Winkler and others, 1981a), and it may correlate with metamorphic rocks to the west in the Anchorage quadrangle in the informally named Knik River terrane of Pavlis (1983). Wallace (1981a, 1981b) referred to these rocks informally in the vicinity of the Richardson Highway as the Uranatina River complex.

The Uranatina River metaplutonic unit consists of volumetrically minor amounts of Pennsylvanian metagranodiorite, metagranite, metagabbro, and interlayered gabbro and orthogneiss. U-Pb zircon isotopic ages for the Pennsylvanian metaplutonic rocks range from 309 to 310 Ma (Aleinikoff and others, 1988). The Pennsylvanian plutonic rocks are interpreted as the deeper levels of the southern margin of the Skolai arc (Plafker and others, 1989c). The relatively more abundant Jurassic metaplutonic rocks are compositionally variable, ranging from ultramafic to trondhjemitic, but are dominantly gneissic hornblende diorite, tonalite, and amphibolite, and they constitute the southern margin of the Late Jurassic Chitina arc (Plafker and others, 1989c). One U-Pb zircon age is 153 Ma, and K-Ar isotopic ages range from 138 to 157 Ma (MacKevett, 1978; Winkler and others, 1981a; Plafker and others, 1989c). The Jurassic metaplutonic rocks of the Uranatina River metaplutonic unit are correlated with the Chitina Valley batholith east of the Taral fault and in the Wrangellia terrane on the basis of similar ages, lithologies, geochemistry, and structural style. Sparse Early Cretaceous K-Ar ages from the Uranatina River metaplutonic unit (Winkler and others, 1981a) are tentatively interpreted as having been reset by a Late Cretaceous thermal event and by early Tertiary plutonism.

Correlation of metamorphic complex of Gulkana River with the Strelna metamorphics and Uranatina River metaplutonic unit

The metamorphic complex of Gulkana River is correlated with both the Strelna metamorphics of Plafker and others (1989c) and the Uranatina River metaplutonic unit because of (1) similar stratified protoliths; (2) similar suites of Late Jurassic metamorphosed plutonic rocks; and (3) a similar strongly mylonitic fabric that is interpreted in both units as forming during the late stages of, or immediately subsequent to, syntectonic plutonism (Nokleberg and others, 1986, 1989b; Pavlis and Crouse, 1989). The major differences between the metamorphic complex of Gulkana River and the units to the southeast are the occurrence of more abundant metasedimentary rocks and sparse Pennsylvanian plutonic rocks in the latter.

Origin of the southern Wrangellia terrane

The southern Wrangellia terrane was interpreted by Plafker and others (1989c) as a deeper and more metamorphosed equivalent of the type Wrangellia terrane that has been exposed by uplift along the Chitina fault system. The lithologic differences between the units may be explained by sedimentary facies changes and/or differences in level of exposure. Several relations appear to link the southern Wrangellia terrane with the Wrangellia terrane. (1) Similar protolith suites of upper Paleozoic sedimentary and intermediate composition volcanic rocks (Plafker and others, 1989c) and similar late Paleozoic plutonic rocks occur in both units (Aleinikoff and others, 1988; Gardner and others, 1988). (2) Spatial association of the southern Wrangellia and Wrangellia terranes for several hundred kilometers suggests a genetic link. (3) The southern Wrangellia terrane appears to contain Late Triassic Nikolai Greenstone and limestone, distinctive units of the Wrangellia terrane (Winkler and others, 1981a; Plafker and others, 1989c). (4) The Late Jurassic plutons of the Chitina Valley batholith occur in both the Wrangellia terrane and southern Wrangellia terrane close to the Chitina fault, but they are more abundant in the uplifted southern Wrangellia terrane. (5) Similar common lead crustal isotopic compositions for feldspar occur in both units (Aleinikoff and others, 1987).

Alternatively, D. L. Jones (1990, oral commun.), Grantz and others (1991), and Nokleberg (this chapter) interpret the southern Wrangellia terrane as a separate unit. Important differences occur between the southern Wrangellia terrane to the south and the Wrangellia terrane to the north. (1) The southern Wrangellia terrane contains a penetrative fabric and an amphibolite facies grade of metamorphism that is generally lacking in the Wrangellia terrane. (2) The southern Wrangellia terrane contains suites of syntectonic, two-mica granitic rocks of mainly Late Jurassic age that generally do not occur in adjacent parts of the Wrangellia terrane. (3) The late Paleozoic or younger stratified rocks of the Wrangellia terrane are not observed to stratigraphically overlie either the metamorphic complex of Gulkana River or the Strelna metamorphics. (4) The Late Triassic carbonate rocks and associated undated greenstone, mapped in the Strelna metamorphics (Plafker and others, 1989c), locally occur in fault-bounded blocks that are interpreted to have originally stratigraphically overlain the older, late Paleozoic stratified rocks of the Strelna. Because of these differences, the southern Wrangellia terrane in this chapter is designated as a unique unit. For similar reasons, this unit was also designated as a separate terrane, the Strelna terrane, by Grantz and others (1991). Additional studies are needed to resolve these differing interpretations.

ALEXANDER TERRANE

The Alexander terrane occurs southeast of the Wrangellia terrane in the southeastern Wrangell Mountains in the McCarthy and Bering Glacier quadrangles near the border between Alaska and the Yukon Territory of Canada (Figures 1, 2). The terrane was originally defined in, and comprises much of, southeastern Alaska (Berg and others, 1972; Gehrels and Saleeby, 1987; Jones and others, 1987; Monger and Berg, 1987; Gehrels and Berg, this volume).

In the study area, the Alexander terrane consists mainly of rocks informally referred to as the Kaskawulsh metamorphic rocks by Gardner and others (1988), which are equivalent to the Kaskawulsh Group that occurs in adjacent parts of Canada (Figure 3) (Kindle, 1953; MacKevett, 1978; Campbell and Dodds, 1982a, 1982b; Gardner and others, 1988). The early to middle Paleozoic Kaskawulsh metamorphic rocks are an intensely multiply folded and schistose sequence of marble, greenstone, metagraywacke, phyllite, slate, schist, argillite, metasiltstone, mafic volcanic rocks, and volcaniclastic rocks that are probably a few thousand meters thick. Numerous Devonian and older megafossils occur in the unit on structural strike in the Yukon Territory to the southeast (Campbell and Dodds, 1982a, 1982b). Metamorphic grade ranges from upper greenschist to amphibolite facies. To the east in Canada, the Alexander terrane also contains younger, late Paleozoic and early Mesozoic rocks that are correlated with the Wrangellia terrane (Gardner and others, 1988).

In the southeastern Wrangell Mountains, the Middle Pennsylvanian Barnard Glacier pluton stitches the Alexander and Wrangellia terranes (Gardner and others, 1988). This pluton intrudes both the Kaskawulsh metamorphic rocks of the Alexander terrane and the adjacent Pennsylvanian and Lower Permian Station Creek Formation of the Wrangellia terrane. The nature of the contact between the Pennsylvanian and Lower Permian Station Creek Formation and the Kaskawulsh metamorphic rocks is not exposed. Gardner and others (1988) suggested that the Station Creek Formation was deposited unconformably on the metamorphic rocks.

Intrusion of the Middle Pennsylvanian Bernard Creek pluton into both terranes requires juxtaposition by the Early Pennsylvanian and suggests that the Kaskawulsh metamorphic rocks of the northwestern Alexander terrane either may be basement for part of the Wrangellia terrane in the study area or may have been faulted against adjacent parts of the Wrangellia terrane, a suggestion originally made by Muller (1977). The roof pendants of pre–late Paleozoic metasedimentary and metagranitic rocks in the Nutzotin Mountains, described above, may be part of this basement.

The Alexander terrane in the study area and in southeastern Alaska is interpreted as a fragment of a long-lived, early and middle Paleozoic island arc (Gehrels and Saleeby, 1987; Gehrels and Berg, this volume). The above field relations indicate that this arc either was tectonically juxtaposed against the Wrangellia terrane by the middle Pennsylvanian or was the stratigraphic basement to at least part of the Wrangellia terrane. Similarly, the unit of unnamed Paleozoic(?) metamorphic rocks along the southern margin of the Peninsular terrane, discussed below, may be part of an Alexander terrane basement for part of the Peninsular terrane.

PENINSULAR TERRANE

The Peninsular terrane, originally defined by Jones and others (1977) and Jones and Silberling (1979, 1982), occurs along the southern edge of the study area, from the Alaska Peninsula to

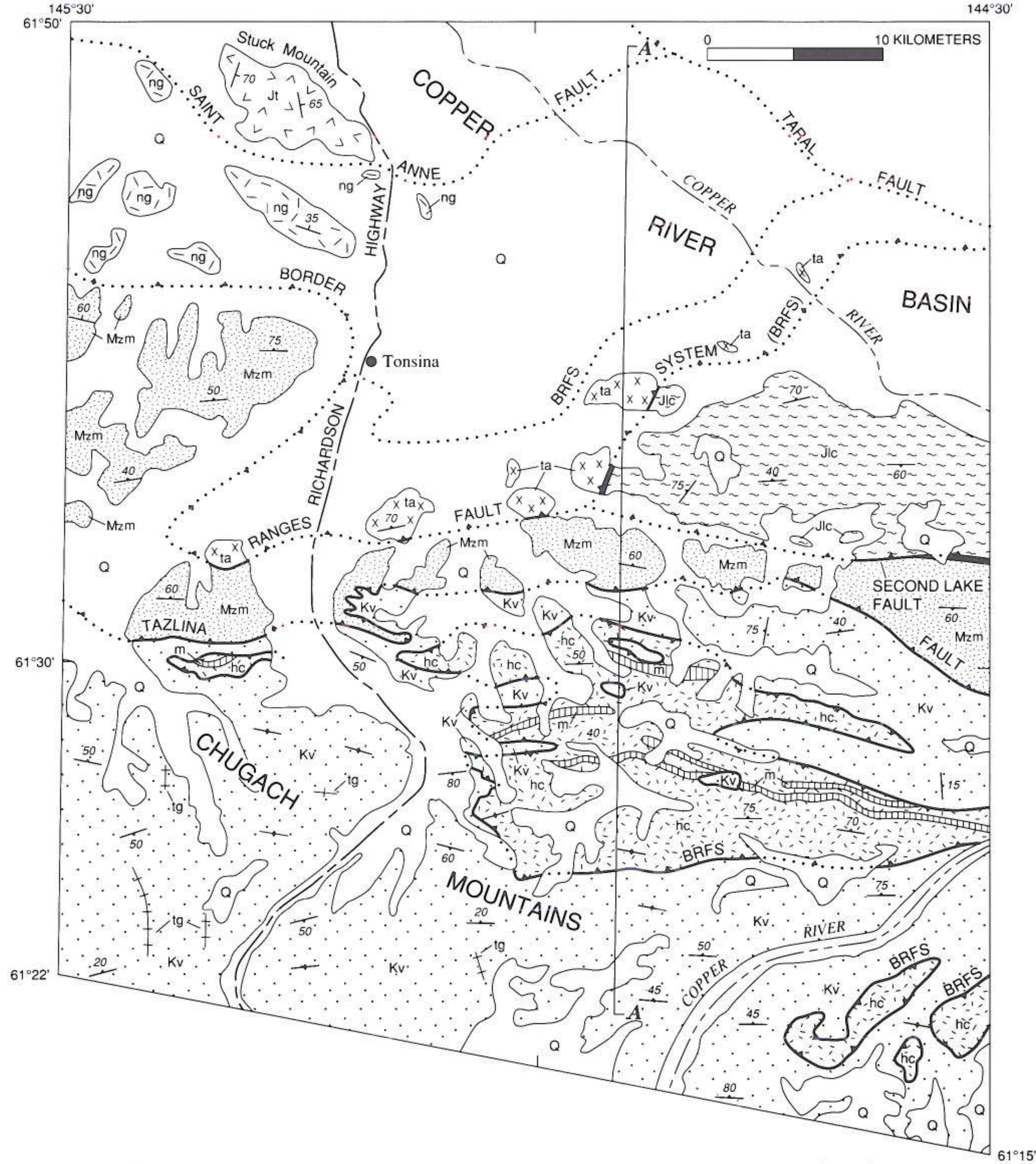
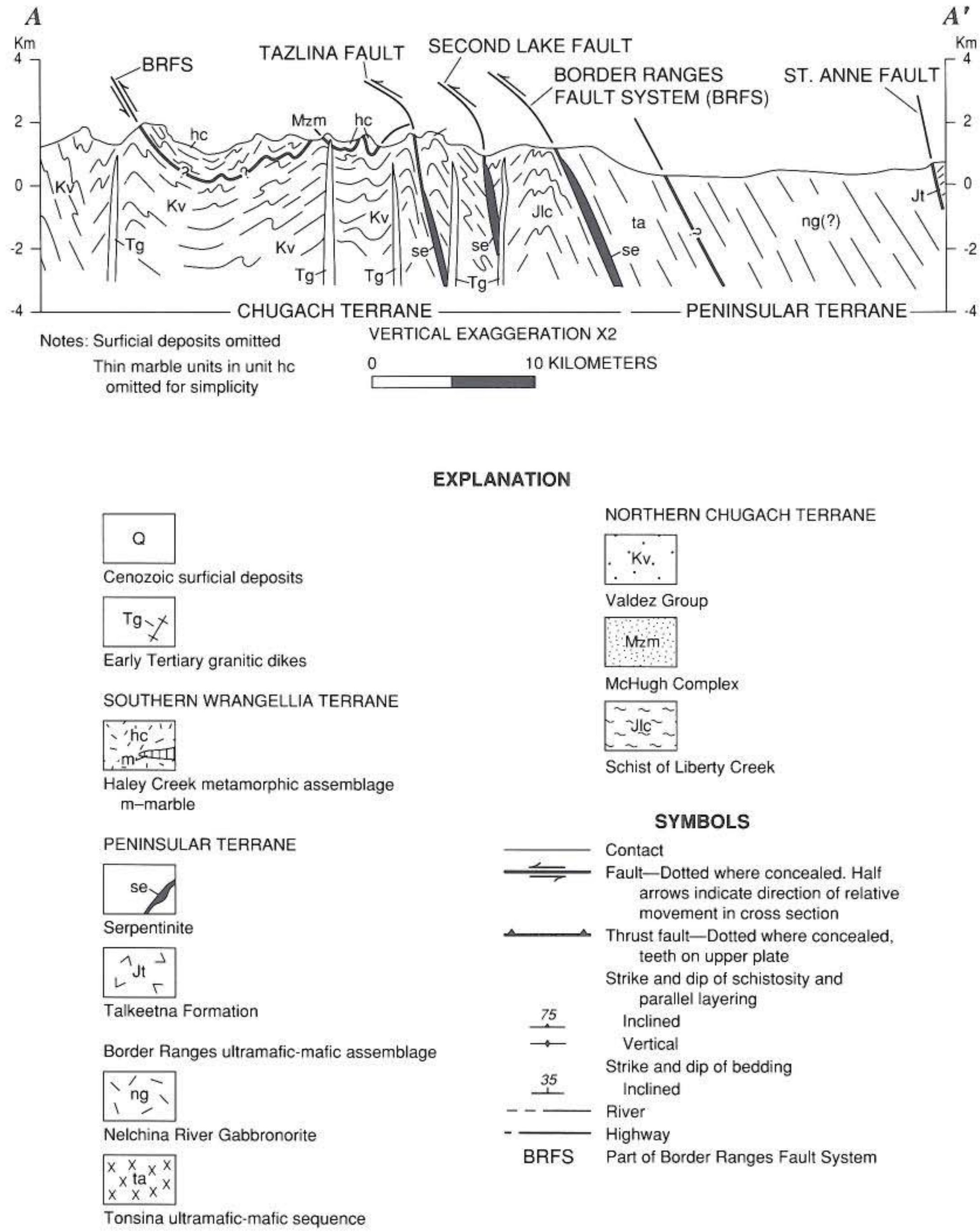


Figure 6. Generalized bedrock geologic map and cross section of the northern Chugach Mountains and southwestern Copper River basin along the Trans-Alaskan Crustal Transect (TACT). Refer to text for description of units. Adapted from Winkler and others (1981a), Nokleberg and others (1989b), and Plafker and others (1989c).



the southwest to the southeastern Copper River Basin to the northeast (Figs. 1 and 2). The terrane occurs south of the Wrangellia terrane, north of the Chugach terrane, and is bounded by the Talkeetna thrust and West Fork fault to the north and by the Border Ranges fault to the south (Fig. 2). The principal syntheses of geologic studies of the rocks and structures of the terrane are by Burk (1965), Wilson and others (1985b, 1994), Plafker and others (1989c), Detterman and others (1994), and Vallier and others (this volume). As defined by Plafker and others (1989c), the Peninsular terrane consists of (1) unnamed Paleozoic(?) metamorphic rocks that occur mainly as roof pendants in the Border Ranges ultramafic-mafic assemblage; (2) sparse late Paleozoic limestone and volcanic rocks; (3) Late Triassic limestone and basalt; (4) the Late Triassic to Middle(?) Jurassic Border Ranges ultramafic-mafic assemblage; (5) Early Jurassic marine andesite flows and related rocks; (6) Middle Jurassic granitic rocks that compose the older part of the Alaska-Aleutian Range batholith; (7) Middle Jurassic through Cretaceous fossiliferous clastic, volcaniclastic, and calcareous rocks; and (8) metamorphosed Permian to Late Jurassic stratified assemblages that occur either as roof pendants in, or occur adjacent to, the Alaska-Aleutian Range batholith. The original definition of the Peninsular terrane by Jones and others (1977) was expanded by Plafker and others (1989c) to include the Border Ranges ultramafic-mafic assemblage and the unnamed metamorphic rocks that are discontinuously exposed along the southern margin of the terrane. Large parts of the Peninsular terrane are also intruded by the Late Cretaceous through Tertiary part of the Alaska-Aleutian Range batholith, and the plutonic part of the Late Cretaceous and early Tertiary Alaska Range–Talkeetna Mountains igneous belt (unit TKg, Fig. 2) (Miller, this volume, Chapter 16; Moll-Stalcup, 1990, and this volume).

Alaska Peninsula terrane

Recent studies of the Mesozoic strata of the Alaska Peninsula lead to the definition of the Alaska Peninsula terrane (Wilson and others, 1985b, 1994). The Alaska Peninsula consists of (1) late Paleozoic through Late Triassic sedimentary and volcanic rocks that are correlated with the Wrangellia terrane; (2) Jurassic and Cretaceous sedimentary and volcanic rocks; and (3) Jurassic plutonic rocks of the Alaska-Aleutian Range batholith. The definitions of the Alaska Peninsula and Peninsular terranes differ principally in that the former excludes the unit of unnamed metamorphic rocks and the Border Ranges ultramafic-mafic assemblage. These latter two units were interpreted by Wilson and others (1985a, 1994) as a separate terrane.

The Alaska Peninsula terrane is composed of two distinct but related subterranes, the Chignik and Iliamna subterranes. These two subterranes share a partial common geologic history in that the Iliamna subterrane to the northwest has served at most times as a source area for the Chignik subterrane to the southeast. However, some rock units occur in both subterranes. The bedrock of the Alaska Peninsula terrane is overlapped by the upper Eocene to lower Miocene volcanic and volcaniclastic rocks of the Meshik arc (Wilson, 1985) and by the late Tertiary and Quaternary volcanic and associated sedimentary rocks of the Aleutian arc (Moll-Stalcup, 1990, and this volume; Vallier and others, this volume).

Iliamna subterrane. The Iliamna subterrane occurs northwest of the Bruin Bay fault and is named after exposures in the Iliamna quadrangle (Fig. 1). The unit is composed mainly of the Kakhonak Complex, the Late Triassic Cottonwood Bay Greenstone, the Upper Triassic Kamishak Formation, the Early Jurassic Talkeetna Formation, and the Middle Jurassic part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1969, 1972, 1973, 1974a, 1974b; Detterman and Reed, 1980). Each of these units is correlative with parts of the Chignik subterrane or, in the case of the Kamishak and Talkeetna formations, are actually part of both subterranes. The Iliamna subterrane is characterized by metamorphism up to amphibolite facies grade and folding that is most intense nearest the Alaska-Aleutian Range batholith.

The southernmost exposure of rocks of the Iliamna subterrane occurs in the vicinity of Becharof Lake, where Jurassic quartz diorite (Reed and Lanphere, 1972) is exposed on a small island on the south side of the lake and in the hills north of the lake in the Naknek quadrangle. Southwest of Becharof Lake, the Iliamna subterrane is covered by younger rocks, although its presence may be inferred from geophysical and drill data (Wilson and others, 1994). Interpretation of aeromagnetic data (Case and others, 1981) suggests that the Iliamna subterrane may continue at least as far south as Port Heiden. Pratt and others (1972) suggested continuation of the batholith into southern Bristol Bay, on the basis of interpretation of shipborne magnetic data. However, the nature of the data precludes determination with certainty that the anomalies can be specifically tied to the Jurassic part of the batholith.

Chignik subterrane. The Chignik subterrane occurs southwest of the Bruin Bay fault and is named after exposures in the Chignik quadrangle (Fig. 1). The unit is composed mainly of upper Paleozoic andesite flows, agglomerate, and limestone, the Late Triassic Kamishak Formation, the Early Jurassic Talkeetna Formation, and a long-lived succession of Middle Jurassic through Cretaceous clastic, volcaniclastic, and calcareous units. In much of the Chignik subterrane, the structural style is dominated by en echelon anticlines, normal faulting, and thrust and high-angle reverse faults that have minor displacement in a northwest to southeast direction. Structures are typically aligned subparallel to the general northeast-southwest trend of the peninsula. In general, compressional features are more common to the southwest in the Chignik subterrane. Metamorphism in the Chignik subterrane occurs only in narrow contact-metamorphic zones around plutons. Most of the Mesozoic rocks of the Alaska Peninsula are part of the Chignik subterrane.

Unnamed Paleozoic(?) metamorphic rocks along the southern margin of the Peninsular terrane

Various unnamed Paleozoic(?) metamorphic rocks are discontinuously exposed along the southern margin of the Peninsular terrane, mainly northeast of Anchorage (Clark, 1972; Carden and Decker, 1977; Pavlis, 1982, 1983, 1986; Burns and others, 1983, 1991; Pavlis and others, 1988; Winkler, 1992), possibly at Seldovia (Martin and others, 1915), and on the northwest side of the Kodiak Islands (Roeske and others, 1989). The metamorphic rocks, too small to depict in Figure 2, occur mainly along, and immediately north of, the Border Ranges fault system.

The metamorphic rocks include two units of the so-called Knik River schist terrane (Carden and Decker, 1977; Pavlis, 1983). The first unit consists mainly of highly metamorphosed and deformed quartz schist and lesser mica-quartz schist, garnet-mica schist, hornblende-biotite-quartz schist, calc-amphibolite, siliceous marble, and pelitic marble. Protoliths for this metasedimentary and metavolcanic unit (Pavlis, 1982; Burns and others, 1991) are shale, chert, tuffaceous arenite, quartz-rich graywacke, marl, shaley limestone, and possible minor basalt. Local fault-bounded lenses of limestone contain Permian fusulinids (Clark, 1972). The metamorphic grade ranges from amphibolite to greenschist facies; the lower grade may be retrogressive. Similar quartz-muscovite-albite-chlorite pelitic schist also occurs as roof pendants in granitic rocks in the southwestern Talkeetna Mountains (Csejtey and others, 1978), and may be related.

A second unit consists of Jurassic gabbro, diorite, quartz diorite, tonalite, and amphibolite that are intensely mixed by intrusion and faulting (Pavlis, 1983; Pavlis and others, 1988; Burns and others, 1991). This unit is interpreted to be part of the Border Ranges ultramafic-mafic assemblage. Both units are cut by steeply dipping zones of cataclasite composed of chlorite-rich, highly deformed and altered mafic and ultramafic plutonic and volcanic rocks. The zones may represent interconnected strands of the Border Ranges fault system, along which ductile (Pavlis, 1982) and Tertiary brittle (Little and Naeser, 1989) offset was concentrated.

The metasedimentary and metavolcanic rocks of the unnamed Paleozoic(?) metamorphic unit may correlate with the late Paleozoic metasedimentary and metavolcanic rocks in the southern Wrangellia terrane (Burns, 1985; Plafker and others, 1989c; Winkler, 1992) and are herein interpreted as representing the deeper structural levels of the Peninsular terrane upon which part of the Late Triassic(?) and Jurassic Talkeetna igneous arc was built. Alternatively, the unit of unnamed metamorphic rocks may constitute basement for a pre-Jurassic subduction complex (Pavlis, 1982, 1983; Pavlis and others, 1988). The origin of the unnamed Paleozoic(?) metamorphic rocks unit is a major problem because its age, lithologies, and structural fabric are dissimilar to the younger stratified and intrusive rocks that compose most of the terrane.

Late Paleozoic strata of Peninsular terrane—unnamed Permian limestone and Permian(?) volcanic rocks

The oldest dated rocks in the Peninsular terrane are unnamed fossiliferous, late middle Permian limestones and Permian(?) volcanic agglomerates and flows (Figs. 3 and 7). The limestone is a 40-m-thick succession of thin- to thick-bedded, medium-grained, crystalline tan to gray limestone with thin interbeds of chert that occurs on a small unnamed islet (100 by 200 m) at the entrance to Puale Bay. A late middle Permian (early

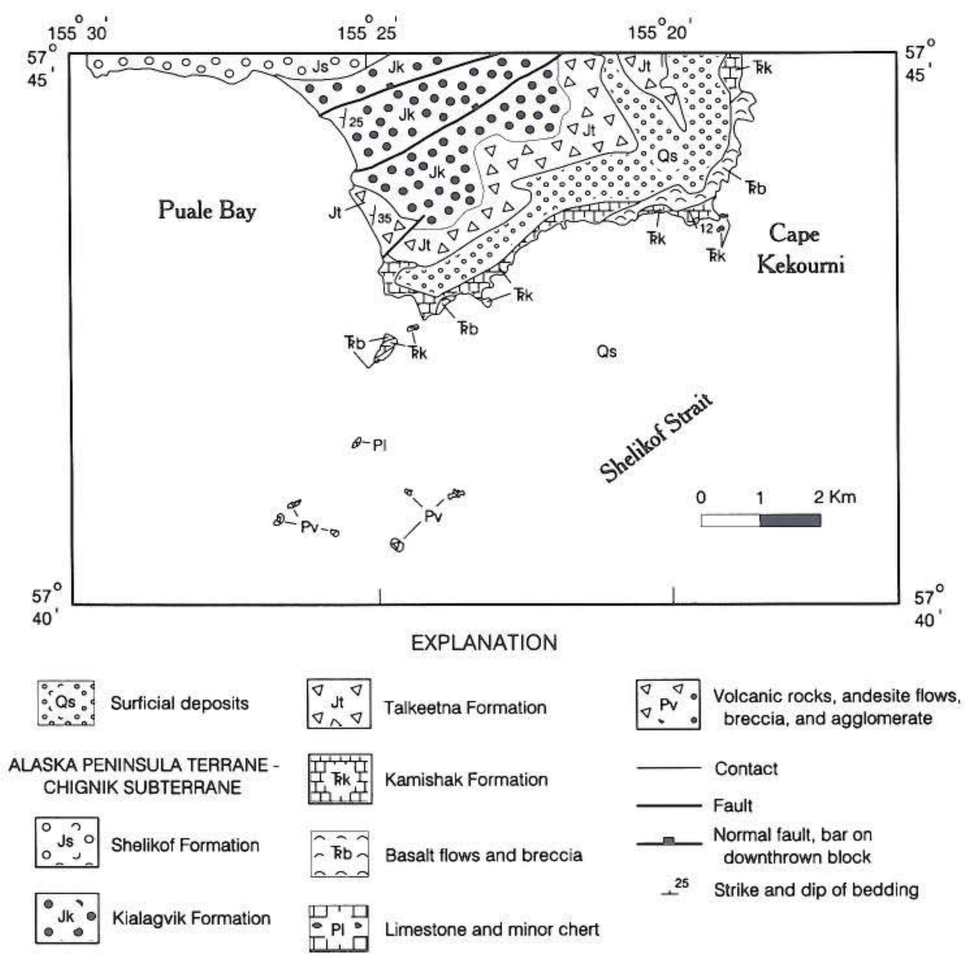


Figure 7. Generalized bedrock geologic map of the Puale Bay region on the Alaska Peninsula. Refer to text for description of units. Adapted from Wilson and others (1994).

Guadalupian) age is based on poorly preserved and silicified coral, brachiopod, and foraminifer fossils (Hanson, 1957). No contacts are exposed, although the highly contorted beds dip about 40° northwest, which places them apparently structurally beneath Triassic rocks on other islands about 1 km to the north.

Massive dark green to black volcanic breccia, agglomerate, and andesitic flows of unknown age and thickness are exposed on small islets southeast of Puale Bay and appear to be structurally beneath the Permian limestones (Figs. 3 and 7) (Hanson, 1957; Hill, 1979). Barring major faults between the islands, this volcanic sequence is assigned a Permian(?) age. Limited chemical data (Hill, 1979) suggest that these volcanic rocks are calc-alkaline. The Permian(?) volcanic rocks and Permian limestones may partially correlate with the Pennsylvanian and Early Permian volcanic and associated rocks of the Skolai arc, and overlying Permian limestone of the Wrangellia terrane.

Mesozoic strata of Peninsular terrane

Kakhonak and Tlikalika complexes. The Kakhonak Complex (Detterman and Reed, 1980) (Fig. 3) is a heterogeneous assemblage of metamorphic rocks of Permian(?) to Jurassic age exposed in the Iliamna quadrangle. The complex, unique to the Iliamna subterrane, is exposed mainly as roof pendants in the Alaska-Aleutian Range batholith, but it also crops out in areas surrounded by surficial deposits. The complex contains marble, quartzite, greenstone and other metavolcanic rocks, and schist. Most rocks are weakly metamorphosed to greenschist facies; relict bedding is often discernible. The maximum age of the enclosing batholith is about 155 Ma, placing a minimum age of early Late Jurassic on the metamorphic rocks. Lithologies indicate that the protoliths were similar to the Permian limestones and the overlying Cottonwood Bay Greenstone, Kamishak Formation, and Talkeetna Formation.

The informally named Tlikakila complex of Wallace and others (1989) occurs along the northwestern edge of the Alaska-Aleutian Range batholith in a narrow, northeast-trending, faulted belt along the southeastern margin of the Kahiltna assemblage (Fig. 5) (Wallace and others, 1989). The Tlikakila complex consists of a narrow belt of variably metamorphosed and highly deformed metasedimentary and mafic metavolcanic rocks, and mafic and ultramafic rocks. Sparse Late Triassic fossils occur in the complex. This unit is correlated with the Kakhonak Complex (Wilson and others, 1993).

Cottonwood Bay Greenstone. The Cottonwood Bay Greenstone (Detterman and Reed, 1980) (Fig. 3) is a sequence of metavolcanic rocks exposed on the west side of Cook Inlet that is unique to the Iliamna subterrane. The thickness may exceed 600 m; however, contact relations with other stratigraphic units are obscure. Bedding is locally discernible; in most areas, the rocks have been altered to hornfels or low-grade, schistose metamorphic rock. The least altered areas consist of massive, dark-green, amygdaloidal basalt flows. No isotopic age determinations exist for the greenstone, but a close association with the Kamishak Formation, described below, suggests a Late Triassic (Norian?) age. The lower pillowed greenstone member of the Shuyak Formation on northwest Kodiak Island was correlated by Moore and Connelly (1977) with the Cottonwood Bay Greenstone. A possible correlation of the Cottonwood Bay Greenstone with the Late Triassic Nikolai Greenstone of the Wrangellia terrane was suggested by Detterman and Reed (1980). On the basis of lithology, the Cottonwood Bay Greenstone has been interpreted as of oceanic affinity, possibly an ocean-island basalt (J. R. Riehle, 1991, oral commun.). On the basis of REE chemistry, the lower member of the Shuyak Formation is interpreted as an island-arc tholeiite (Hill, 1979).

Chilikadrotna Greenstone. The Chilikadrotna Greenstone occurs in the Lake Clark quadrangle in the southwestern Alaska Range (Figs. 3 and 5) (Eakins and others, 1978; Bundtzen and others, 1979; Wallace and others, 1989). The Chilikadrotna is poorly exposed in a series of discontinuous, northeast-trending antiformal exposures near the northwestern boundary of the southern Kahiltna assemblage, in low hills adjacent to the Chilikadrotna River (Eakins and others, 1978). The unit is composed principally of massive altered basalt that commonly is amygdaloidal, locally pillowed, and contains rare interpillow limestone and chert. Sparse pyroxene-bearing andesitic flows, tuff breccia, and crystal-lithic lapilli tuff also occur in the sequence. The volcanic rocks of the Chilikadrotna Greenstone commonly are metamorphosed to prehnite-pumpellynite facies. Penetrative deformational fabrics are developed only locally, but fault surfaces and shear zones are abundant.

Diverse metasedimentary rocks locally are spatially associated with the volcanic rocks (Wallace and others, 1989), although the stratigraphic relations with the volcanic rocks are obscure. The metasedimentary rocks include limestone, chert, cherty shale and tuff, and various metaclastic rocks, and they occur mainly in narrow, structurally concordant zones adjacent to the volcanic rocks. Conodonts from the limestone are Late Triassic (Norian) in age (T. R. Carr, 1983, written commun.; N. M. Savage, 1983, written commun.), and brachiopods from the limestone are also of probable Norian age (P. R. Hoover, 1984, written commun.). The metasedimentary rocks exhibit a weak slaty cleavage that dips steeply and mainly to the northwest. Locally, highly schistose zones occur. Much of the unit is highly imbricated.

The Chilikadrotna Greenstone was grouped with the Koksetna River sequence into the southern Kahiltna terrane by Wallace and others (1989). However, on the basis of lithology and association with the Norian sedimentary rocks, the Chilikadrotna Greenstone is herein interpreted as part of the Peninsular terrane that is depositionally overlain by the Koksetna River sequence that composes the southern Kahiltna assemblage. The Chilikadrotna Greenstone was correlated with the Cottonwood Bay Greenstone by Wallace and others (1989).

Kamishak Formation. The Kamishak Formation (Figs. 3 and 7), common to both the Iliamna and Chignik subterranes, consists of 1,200 m of thin-bedded to massive limestone, chert, minor calcareous siltstone and mudstone, and sparse tuff (Fig. 7). The depositional environment of the unit was shallow water and high energy intervals of the unit include both reefs and biohermal buildups. Fossils yield a Late Triassic (Norian) age (Detterman and Reed, 1980; C. D. Blome, U.S. Geological Survey, 1981, oral commun.).

The carbonate rocks of the Kamishak Formation and interbedded volcanic rocks are interpreted to overlie the Permian limestone and volcanic rocks that are exposed on the islands of Puale Bay (Fig. 7) (Detterman and others, 1994). Triassic rocks similar to the Kamishak Formation also occur in the subsurface in the Cathedral River area (McLean, 1977) at the southwest end of the Alaska Peninsula. Moore and Connelly (1977) suggested that the upper member of the Shuyak Formation, mainly tuff, volcaniclastic turbidite, massive sandstone, volcanic conglomerate, and mudstone (Connelly, 1978; Connelly and Moore, 1979), on northwestern Kodiak Island is a possible correlative of the Triassic volcanic and volcaniclastic rocks at Puale Bay. Limestone and volcanic rocks of the Kamishak Formation are herein interpreted as having formed in an island-arc environment (Moore and Connelly, 1977; Hill, 1979; Wang and others, 1988) at low latitude (Detterman, 1988; Hillhouse and Coe, this volume).

At Puale Bay, the upper contact of the Kamishak Formation is conformable and gradational with the overlying Talkeetna Formation (Figs. 3 and 7); Detterman and others (1994) arbitrarily placed the contact as the point where clastic sedimentary rocks replace limestone as the major constituent of the rock sequence. The Kamishak Formation is lithologically and faunally equivalent to the Nizina Limestone and the McCarthy Formation in the Wrangellia terrane (Detterman and Reed, 1980). The Port Graham sequence in the Seldovia area (Kelley, 1984) is also coeval with, and lithologically similar to the Kamishak Formation.

Talkeetna Formation. The Late Triassic(?) and Early Jurassic Talkeetna Formation (Fig. 3), common to both the Iliamna and Chignik subterranes, consists mainly of andesitic, basaltic, and volcaniclastic rocks (Paige and Knopf, 1907; Martin, 1926; Detterman and Hartsock, 1966; Csejtey and others, 1978; Winkler and others, 1981a; Detterman and others, 1983; Winkler, 1992). The unit crops out discontinuously from the southern Copper River basin, through the Talkeetna Mountains, to Puale Bay on the Alaska Peninsula. Stratigraphically and lithologically equivalent rocks are encountered in a drillhole at the southwest end of the Alaska Peninsula.

In the Talkeetna Mountains (the type area), and in the southern Copper River basin and northern Chugach Mountains, the Talkeetna Formation is mainly bedded andesitic volcaniclastic sandstone and tuff, ignimbrite, breccia, and agglomerate; andesite and lesser rhyolite and basalt flows; and shale (Csejtey and others, 1978; Plafker and others, 1989c; Burns and others, 1991; Winkler, 1992). On the Alaska Peninsula, the Talkeetna is mainly gray-green, coarse-grained tuffaceous sandstone; lesser green to red, massive coarse-grained tuff; and minor brownish-gray siltstone and gray to gray-brown limestone (Detterman and others, 1994). The thickness is variable throughout the area of outcrop, but is typically between 400 and 1,200 m. Apparently partly coeval shallow intrusive rocks (mainly dikes, sills, and plugs of andesite composition) and local compositionally diverse diorite, quartz diorite, and granodiorite plutons of Late Jurassic, Late Cretaceous, and early Tertiary age intrude the unit.

The Talkeetna Formation undergoes a gradual lithologic transition from predominantly volcanic lithologies in the northeast to predominantly sedimentary lithologies to the southwest. This transition suggests that the rocks of the unit become more distal from the arc volcanism to the southwest. Diagnostic Early Jurassic marine megafossils occur throughout, and Late Triassic fossils locally occur in the lower part of the unit on the southern Kenai Peninsula (Martin and others, 1915; Kelley, 1984; Detterman and others, 1994). The Talkeetna Formation was correlated by Plafker and others (1989c) with the lithologically and temporally equivalent andesitic arc sequence that includes the Bonanza Group in the Vancouver Island segment of the Wrangellia terrane and the Maude and Yakoun formations in the Queen Charlotte Island segments of the Wrangellia terrane (Sutherland-Brown, 1968; Jeletzky, 1976; Cameron and Tipper, 1985).

A shallow-marine to subaerial deposition for much of the Talkeetna Formation is indicated by fossil content and sedimentary facies (Grantz, 1960, 1960b; Imlay and Detterman, 1973; Detterman and Reed, 1980; Detterman and others, 1994). The Early Jurassic age (Hettangian and early Sinemurian) is based on an abundant megafauna. However, this megafauna is present in great abundance in only a few horizons and may represent mass kills as a result of volcanic eruptions (Detterman and others, 1994). At Puale Bay, the formation records an inner neritic to sublittorial environment (Detterman and others, 1994). The contact of the Talkeetna with the overlying Kialagvik Formation is disconformable, because rocks of the late Sinemurian, Pliensbachian, and most of the Toarcian stages are missing.

Kialagvik Formation and Tuxedni Group. The Early and Middle Jurassic (Callovian to Toarcian) Kialagvik Formation (Fig. 3) (Capps, 1923) overlies the Talkeetna Formation and is mainly cross-bedded sandstone, rhythmically bedded siltstone and sandstone, shale, conglomerate, and sparse limestone, and is about 400 m thick (Detterman and others, 1994). The Kialagvik Formation is exposed only in a limited area between Wide and Puale bays, and is interpreted as having formed in a gradually subsiding depositional basin. It records erosion of the volcanic part of the Talkeetna arc and incipient unroofing of the Jurassic plutonic root of the Talkeetna arc that forms the Jurassic part of the Alaska-Aleutian Range batholith (Reed and others, 1983).

The Middle Jurassic Tuxedni Group crops out from Iniskin Bay to the Talkeetna Mountains and is a 3,000-m-thick sequence of graywacke, sandstone, conglomerate, siltstone, and shale (Detterman and Hartsock, 1966; Imlay and Detterman, 1973; Imlay, 1984). The conglomerate of the Tuxedni is mainly composed of volcanic rocks in a graywacke matrix and, like the Kialagvik Formation, records erosion of the volcanic part of the Talkeetna arc. The lower part of the Tuxedni Group is correlated with the

Kialagvik Formation; the Tuxedni Group is a more complete sequence that ranges up to Bathonian(?) in age (Detterman and others, 1994).

Shelikof and Chinitna formations. The Middle Jurassic (Callovian) Shelikof and Chinitna formations (Fig. 3) (Capps, 1923) overlie the Kialagvik Formation and are composed of 1,400 m of volcaniclastic graywacke, conglomerate, and siltstone containing calcareous sandstone clasts. Deposition of these units reflects continued erosion of the volcanic part of the Talkeetna arc to the northwest (present-day coordinates). The sedimentary rocks record a shoaling depositional environment from bottom to top.

In the Cook Inlet area and in the Talkeetna Mountains, rocks similar in age to the Shelikof Formation are mapped as part of the Middle Jurassic (Callovian) Chinitna Formation (Detterman and Hartsock, 1966; Grantz, 1960a, 1960b). The Chinitna is divided into two members: a lower unit, the Tonnie Siltstone Member, and an upper unit, the Paveloff Siltstone Member. The Chinitna Formation consists dominantly of siltstone and concretionary siltstone. The upper part of the Chinitna is correlative with the Shelikof (Detterman and Hartsock, 1966). The Chinitna contains much less coarse volcanic debris than the Shelikof Formation. Both formations were deposited in similar quiescent marine depositional environments.

Naknek Formation. The Late Jurassic (Tithonian to Oxfordian) Naknek Formation (Fig. 3) consists of up to 3,200 m of arkosic sandstone, conglomerate, siltstone, and sparse limestone beds that occur within siltstone intervals. The unit was originally described by Spurr (1900) and was more thoroughly described and divided into five members by Detterman and others (1994). The Naknek is the most persistent and widespread unit on the Alaska Peninsula and possibly in southern Alaska. It crops out from the Talkeetna Mountains to the southwestern end of the Alaska Peninsula. The Naknek was deposited in a shallow-water shelf and nonmarine environment. Granitic lithic and mineral fragments are the dominant component and indicate unroofing and erosion of the Alaska-Aleutian Range batholith. Boulder conglomerate is developed in the Naknek adjacent to the Bruin Bay fault (Burk, 1965). The Naknek correlates with the Root Glacier Formation (MacKevett, 1969) of the Wrangellia terrane in the southern Wrangell Mountains.

Staniukovich and Herendeen formations and Nelchina Limestone. The Early Cretaceous (Valanginian and Berriasian) Staniukovich Formation (Fig. 3) (Detterman and others, 1994) conformably overlies the Naknek Formation in many areas. Lithologically, the Staniukovich is similar to the Naknek, although finer grained. The Staniukovich consists of siltstone, shale, and minor sandstone deposited in shallow-marine and nonmarine environments (Wilson and others, 1994). The sediment was derived from a source terrane composed in part of the Alaska-Aleutian Range batholith and in part from older sedimentary units.

The Early Cretaceous (Barremian and Hauterivian) Herendeen Formation (Fig. 3) (Detterman and others, 1994) conformably overlies the Staniukovich Formation; it is a thin, well-sorted calc-arenite that locally contains abundant *Inoceramus* prisms, and angular to subrounded quartz and feldspar grains. North of the Mount Katmai area, rocks of Early Cretaceous age are generally not known in the Chignik subterrane, although a thin (100 m thick) Early Cretaceous clastic unit that includes, in part, the Nelchina Limestone was mapped by Csejtey and others (1978) and Grantz (1960a, 1960b) in the Talkeetna Mountains quadrangle. The Nelchina Limestone is a lithologic and stratigraphic equivalent of the Herendeen Formation.

Uplift in middle Cretaceous time resulted in removal of much of the Herendeen and Staniukovich formations and parts of the Naknek Formation. The uplift appears to have been the most pronounced in the Puale Bay to Lake Iliamna area. However, in the Mount Katmai area, small patches of Albian rocks (Pedmar Formation) have been found that indicate deposition during Aptian to Santonian time.

Matanuska Formation. The stratigraphically uppermost part of the Chignik subterrane consists of the Matanuska, Chignik, Hoodoo, and Kaguyak formations, which were deposited in a short-lived marine transgression in the Early and Late Cretaceous (Fig. 3).

The Early and Late Cretaceous (Albian to Maastrichtian) Matanuska Formation (Martin, 1926; Grantz, 1961) was originally defined in the Matanuska Valley and in this area is the youngest part of the Chignik subterrane. The Matanuska also occurs in the Talkeetna Mountains and in the southern Copper River basin, mainly in the Anchorage, Valdez, and Talkeetna Mountains quadrangles (Figs. 1 and 3). The Matanuska is a flysch sequence of dark gray marine siltstone, sandstone, claystone, and minor conglomerate (Grantz and Jones, 1960; Grantz, 1964; Detterman and others, 1994). Several faunal gaps and unconformities divide the formation. The much longer depositional history of the Matanuska Formation, compared with older Late Cretaceous formations, indicates a return to a marine depositional basin sooner in the northeastern part of the subterrane than in more southwestern parts. However, the disconformities and unconformities within the Matanuska Formation indicate that the basin was not structurally stable. Conglomerate and coal throughout most of the underlying Chignik Formation indicate a nearshore to nonmarine environment, whereas conglomerate and coal seams are known only locally in the Matanuska Formation. The unit is interpreted as being deposited in a forearc apron adjacent to the Late Cretaceous and early Tertiary part of the Alaska-Aleutian Range batholith (Moore and Connelly, 1977; Winkler, 1992).

Chignik, Hoodoo, and Kaguyak formations. The Chignik and Hoodoo formations (Fig. 3) are of Late Cretaceous (Campanian and Maastrichtian) age and are exposed southwest of Puale Bay and Becharof Lake. The Chignik Formation consists of about 500 to 650 m of fluvial to shallow-marine sandstone, siltstone, and lesser coal and carbonaceous shale. The Hoodoo Formation consists of more than 600 m of rhythmically bedded sandstone and shale, and coarsens upward. The Kaguyak Formation is in the Mount Katmai area of the Alaska Peninsula, and is very similar lithologically to the Hoodoo, but is more than 1,200 m thick. The Hoodoo and Kaguyak formations were deposited in prograding submarine fans. The Chignik, Hoodoo, and Kaguyak formations are apparently in large part derived from the reworking of earlier, predominantly sedimentary strata of the area, although a volcanic-rock component was possibly added.

Younger Cenozoic assemblages. The Mesozoic rocks of the Peninsular terrane are overlain by more 6,000 m of Cenozoic volcanic and sedimentary rocks of the Aleutian arc on the Alaska Peninsula and to the northeast in the Talkeetna Mountains (Figs. 2 and 3) (Csejtey and others, 1978; Silberman and Grantz, 1984; Winkler, 1992; Detterman and others, 1994; Vallier and others, this volume; Miller and Richter, this volume) and the Meshik arc (Wilson, 1985). Thick, basinal coal-bearing rocks also occur in the Matanuska Valley, southern Talkeetna Mountains, Cook Inlet, Kenai Peninsula, and Copper River basin (Kirschner, this volume, Chapter 14).

Border Ranges ultramafic-mafic assemblage

A discontinuous belt of plutonic rocks, informally named the Border Ranges ultramafic-mafic assemblage (Plafker and others, 1989c), is up to 20 km wide and extends for more than 1,600 km along the southern margin of the Peninsular terrane from the Taral fault near the Copper River to southwest of the Kodiak Islands (unit JTru, Fig. 2; Figs. 3 and 6) (Winkler and others, 1981b; Hudson, 1983; Burns, 1985, 1994; Burns and others, 1991). The assemblage is marked by a remarkably continuous, high positive aeromagnetic anomaly throughout its length (Grantz and others, 1963; Andreason and others, 1974; Fisher, 1981; Case and others, 1986). The Border Ranges ultramafic-mafic assemblage is the southernmost unit in the Peninsular terrane and is bounded to the south by the Border Ranges fault system, which forms the southern margin of the Peninsular terrane (Figs. 2 and 6). Smaller scattered ultramafic bodies occur for about 100 km east of Tonsina, and other ultramafic bodies, locally with associated layered gabbros, occur discontinuously for several hundred kilometers to the southwest, and include the Wolverine Complex of Carden and Decker (1977) and the Eklutna complex of Burns (1985) near Anchorage, bodies on the Kenai Peninsula and on western Kodiak Island (Burns, 1985, 1993; Plafker and others, 1989c; Burns and others, 1991). Locally, klippen of the Border Ranges ultramafic-mafic assemblage, such as at Klanelneechena Creek in the western Valdez quadrangle and at Red Mountain in the Seldovia quadrangle (Fig. 1), occur south of the Border Range fault and structurally above the Chugach terrane to the south (Fig. 2). The klippen are interpreted as erosional remnants of the structurally higher Border Ranges ultramafic-mafic assemblage (Burns, 1985).

The Border Ranges ultramafic-mafic assemblage is best exposed in the eastern Peninsular terrane, along the northern Chugach Mountains, where it consists predominantly of layered gabbro with minor ultramafic rocks (Fig. 6). In the central and western parts of the assemblage, tonalite and quartz diorite are also abundant and are complexly intermixed with minor mafic and ultramafic variants (Burns and others, 1991; Winkler, 1992). The ultramafic-mafic rocks may be as thick as 14 km. Contact relations between the Border Ranges ultramafic-mafic assemblage and rocks to the north are also best exposed in the northern Chugach Mountains, where it forms a north-dipping sequence structurally overlain mainly by Mesozoic bedded volcaniclastic rocks of the Talkeetna Formation and granitic rocks along the St. Anne fault (Figs. 2 and 6) (Nokleberg and others, 1989b; Plafker and others, 1989c). The fault displays late Cenozoic normal displacement and is interpreted as having formed along a former intrusive contact. Similar Cenozoic normal displacement is interpreted for the youngest period of movement along the Border Ranges fault system to the south and southwest (Little and Naeser, 1989; Nokleberg and others, 1989b; Plafker and others, 1989c).

Tonsina ultramafic-mafic sequence and Nelchina River Gabbronorite. Detailed studies of the Border Ranges ultramafic-mafic assemblage in the northern Chugach Mountains recognize two major subdivisions: the deeper level Tonsina ultramafic-mafic sequence, and the shallower level Nelchina River Gabbronorite (Burns, 1985, 1994; Burns and others, 1991). The Tonsina ultramafic-mafic sequence is discontinuously exposed in a belt 40 km long and up to 4 km wide west of the Copper River (Fig. 6). It is juxtaposed against the northern margin of the Chugach terrane along the Border Ranges fault system and dips generally north to northwest toward a concealed contact with the Nelchina River Gabbronorite. The Tosina ultramafic-mafic sequence and correlative sequences consist of distinctive high-pressure and high-temperature cumulate sequences of variably folded and faulted layered ultramafic and mafic rocks. The principal rock types are dunite and harzburgite, websterite, and an upper unit of predominantly spinel- and garnet-bearing gabbro. The transition from the ultramafic rocks to the garnet gabbros may represent a fossil Moho.

The Nelchina River Gabbronorite (Burns and others, 1991; Burns, 1994) extends westward along the southern margin of the Peninsular terrane as a continuous belt up to 12 km wide for at least 120 km along the northern margin of the Chugach Mountains. The Nelchina River Gabbronorite consists of gabbronorite, two-pyroxene gabbro, magnetite gabbronorite, anorthositic gabbronorite, norite, and lesser hornblende gabbro (Burns and others, 1991). The gabbroic rocks are either massive with little or no directional fabric, or occur in layers up to 20 m thick that are defined by modal variations in pyroxene and plagioclase. Similar units of mafic cumulate rocks occur to the southwest and constitute most of the Border Ranges ultramafic-mafic assemblage (Burns, 1985).

In the northern part of the Chugach Mountains near Tonsina, ^{40}Ar-^{39}Ar isotopic analysis of hornblende indicates an early Middle Jurassic age of 171–181 Ma for the Border Ranges ultramafic-mafic assemblage (Winkler and others, 1981a; Plafker and others, 1989c; Onstott and others, 1989). In the central

Chugach Mountains, K-Ar, ^{40}Ar-^{39}Ar, and U-Pb isotopic analyses of zircon, hornblende, and biotite from these rocks range from about 165 to 195 Ma (Winkler, 1992). To the southwest on Kodiak Island, U-Pb zircon isotopic analysis of the Afognak pluton yields an age of 217 ± 10 Ma or latest Triassic (Roeske and others, 1989). K-Ar hornblende ages throughout the Border Ranges ultramafic-mafic assemblage yield an age range mainly from the Late Triassic to Middle Jurassic (Roeske and others, 1989; Plafker and others, 1989c; Winkler and others, 1981a; Burns and others, 1991; Winkler, 1992).

Origin of the Border Ranges ultramafic-mafic assemblage. The structural position, continuity, and lithology of the Border Ranges ultramafic-mafic assemblage clearly tie it to the Peninsular terrane (Plafker and others, 1989c). Although generally separated by faults, two areas link the Border Ranges ultramafic-mafic assemblage to the rest of the Peninsular terrane to the north. (1) Locally on northwest Kodiak Island, the latest Triassic Afognak pluton intrudes the volcanic rocks in the upper member of the Upper Triassic Shuyak Formation (Roeske and others, 1989), which is correlated with the Kamishak Formation on the Alaska Peninsula (Moore and Connelly, 1977; Connelly, 1978). (2) To the northwest near Tonsina in the northern Chugach Mountains, the Nelchina River Gabbronorite contains one inclusion of contact-metamorphosed volcanogenic sandstone interpreted as derived from the Talkeetna Formation (Plafker and others, 1989c). These relations indicate that the Border Ranges ultramafic-mafic assemblage locally intruded either the volcanic part of the arc or the stratigraphic underpinnings of the arc.

The Border Ranges ultramafic-mafic assemblage has been interpreted as originating by fractionation of basaltic magma in the roots of the Talkeetna arc, on the basis of its composition and spatial relation to the andesitic flows and related volcaniclastic rocks of the Late Triassic(?) and Early Jurassic Talkeetna Formation (Burns, 1985; DeBari and Coleman, 1989; Plafker and others, 1989c; Burns and others, 1991). Emplacement of the ultramafic part of the Border Ranges ultramafic-mafic assemblage in an active orogenic belt is suggested by high-temperature granulite facies metamorphism and textures characteristic of high-grade, synkinematic plastic deformation (DeBari and Coleman, 1989; Nokleberg and others, 1989b). Mineral assemblages in the Tosina ultramafic-mafic sequence, together with olivine, pyroxene, and spinel compositions, indicate crystallization of the lower level gabbro at about 9.5–11 kbar (28–33 km), temperatures in the range 1100–1150 °C; the higher level gabbronorite crystallized at temperatures greater than 1150 °C at unconstrained pressures above 2 kbar (6 km) (DeBari and Coleman, 1989).

The origin of the hornblende-rich gabbronorite in the upper parts of the Border Ranges ultramafic-mafic assemblage is interpreted as volatile-rich magmas that further fractionated to calc-alkalic diorites and trondhjemites that erupted to form the subparallel Talkeetna volcanic arc (Burns, 1985). Available data for the Nelchina River Gabbronorite indicate lower pressure crystallization of a hydrous tholeiitic magma (Coleman and Burns, 1985; DeBari and Coleman, 1989). The metamorphic grade of schists and hornfels intruded by the gabbronorite suggests intermediate- to shallow-level emplacement. Plastic deformation both of gabbroic rocks and of the quartz diorite, trondhjemite, and tonalite suite suggests intrusion while the gabbroic rocks were still hot enough to deform by flow (Burns, 1985, 1993; DeBari and Coleman, 1989). Major element and trace element mass-balance calculations of the Border Ranges ultramafic-mafic assemblage and of the overlying Talkeetna Formation yield a high-Mg basaltic bulk and low-Al bulk composition that is compatible with derivation by partial melting of a mantle wedge source, and that is too low to have been derived by partial melting of subducted oceanic crust (DeBari and Sleep, 1991).

An alternative interpretation (proposed by F. H. Wilson) is that the Border Ranges ultramafic-mafic assemblage is not genetically linked to the Talkeetna arc. The correlation and assumed genetic association of the Border Ranges ultramafic-mafic assemblage with the Talkeetna arc on the basis of chemistry is reasonable at the eastern end of the arc. However, the increasing spatial separation of the Border Ranges ultramafic-mafic assemblage, the Talkeetna Formation, and the Jurassic part of the Alaska-Aleutian Range batholith southwest of the Kenai Peninsula argues against a close genetic association. Given the great depth of emplacement and presumably slow cooling of the ultramafic and mafic rocks of the Border Ranges ultramafic-mafic assemblage (Burns, 1985), it is unlikely that the mainly Middle Jurassic ages reported for the Border Ranges ultramafic-mafic assemblage (Onstott and others, 1989; Plafker and others, 1989c; Winkler and others, 1981b) reflect emplacement. The Late Triassic(?) and Early Jurassic age of the Talkeetna Formation and the Middle Jurassic cooling age of the Jurassic part of the Alaska-Aleutian Range batholith are both well established. The similarity of these ages and those for the Border Ranges ultramafic-mafic assemblage also argues against a genetic association. It is unlikely that the deepest roots of the arc would yield older cooling ages than the middle or upper parts of the arc. Uplift and emplacement of the Border Ranges ultramafic-mafic assemblage adjacent to its own volcanic arc, nearly contemporaneous with arc activity, require an unlikely series of tectonic events to occur within a convergent margin.

Middle Jurassic plutonic rocks on Alaska Peninsula

Middle Jurassic plutonic rocks, the older part of the Alaska-Aleutian Range batholith, form a spectacular north-northwest–striking magmatic belt about 740 km long and from 15 to 35 km wide (unit mJg, Fig. 2) (Lanphere and Reed, 1973; Reed and Lanphere, 1969, 1973, 1974a; Reed and others, 1983; Miller, this volume, Chapter 16). The plutons intrude the Late Triassic(?) and Early Jurassic Talkeetna Formation and consist of a calc-alkaline suite with relatively low initial Sr ratios (Reed and others, 1983). The dominant lithologies are diorite, quartz diorite, and tonalite. Some studies of chemical variations across the batholith suggest emplacement above a southeast-dipping subduction zone (Reed and Lanphere, 1974a; Reed and others, 1983), whereas other studies suggest emplacement above a northwest-dipping subduction zone (Moore and Connelly, 1977). These characteristics and the spatial association with the mainly Early Jurassic Talkeetna Formation were used by Reed and others (1983) to define the Talkeetna arc.

Talkeetna arc and origin of Peninsular terrane

The major tectonic event characterizing the Peninsular terrane is the early Mesozoic Talkeetna arc, represented by the deep-level igneous rocks of the Border Ranges ultramafic-mafic assemblage, the Late Triassic(?) and Early Jurassic Talkeetna Formation, and the Middle Jurassic part of the Alaska-Aleutian Range batholith. The Talkeetna arc is a major Mesozoic feature in the study area that extends for more than 1,500 km along the length of the Alaska Peninsula and northeastward to the eastern Copper River basin (Fig. 2). The arc was originally defined by Plafker and others (1989c) as an Early Jurassic feature composed of the deep-level ultramafic and mafic rocks of the Border Ranges ultramafic-mafic assemblage that formed the roots to the volcanic and related rocks of the Talkeetna Formation. Burns (1985) interpreted the deep-level ultramafic and mafic rocks of the Border Ranges ultramafic-mafic assemblage as the source of the andesitic volcanic and associated rocks of the Talkeetna Formation. Miller (this volume, Chapter 16) places the Talkeetna Formation and Middle Jurassic granitic rocks of the Alaska-Aleutian Range batholith into the Talkeetna arc and mentions the possibility of the Border Ranges ultramafic-mafic assemblage also being part of the arc.

Moderately different ages exist for the various components of the Talkeetna arc. Plafker and others (1989c) interpreted that the mainly Middle Jurassic isotopic ages for the Border Ranges ultramafic-mafic assemblage are cooling ages from Early Jurassic igneous activity. However, a wider age range may exist for the arc. Volcanism associated with the Talkeetna arc may have begun in the Late Triassic, as indicated by the occurrence of *Halobia* and *Pseudomonotis subcircularis* in tuffaceous strata 1,500 m thick at the base of the section in the Port Graham area of the southern Kenai Peninsula (Martin and others, 1915). A latest Triassic isotopic age (217 Ma) was reported for the Afognak pluton within the Border Ranges ultramafic-mafic assemblage on Kodiak Island (Roeske and others, 1989). With this range of fossil and isotopic ages and the above field relations, the Talkeetna arc is herein interpreted to consist of (1) Late Triassic tuffaceous strata and the Early Jurassic Talkeetna Formation; (2) the Early and/or Middle Jurassic Border Ranges ultramafic-mafic assemblage; and (3) the Middle Jurassic part of the Alaska-Aleutian Range batholith.

An island-arc origin for the Talkeetna arc is indicated by geochemical data. Andesite and basalt from the Talkeetna Formation in the Talkeetna Mountains show affinities with a medium-K, tholeiitic type of orogenic andesite; these data are compatible with an island-arc origin (Barker and Grantz, 1982; Barker, this volume, see microfiche). Compatible geochemical data were also obtained at the easternmost outcrops of the Talkeetna Formation along the Richardson Highway (Plafker and others, 1989c). The Middle Jurassic plutonic rocks exhibit relatively low initial Sr ratios (Reed and Lanphere, 1973; Reed and others, 1983; Barker, this volume, see microfiche; Miller, this volume, Chapter 16). The bulk composition of the Talkeetna arc was calculated by DeBari and Sleep (1991) assuming an igneous-arc linkage for the Border Ranges ultramafic-mafic assemblage and the Talkeetna Formation.

The polarity of the arc is interpreted as southeast on the basis of the occurrence of northward-dipping, coeval subduction-zone assemblages in the northern Chugach terrane that occur across the Border Ranges fault to the south (Plafker and others, 1989c; this volume, Chapter 12). Units constituting these subduction-zone assemblages are mainly (1) discontinuous outcrops of blueschist and locally interlayered greenschist that are exposed along the northern margin of the Chugach terrane from Kodiak Island to the eastern Chugach Mountains with metamorphic ages that range mainly from 204 to 154 Ma (see summaries in Roeske, 1986; Roeske and others, 1989; Plafker and others, 1989c; this volume, Chapter 12); and (2) the older parts of the subduction-zone melange of the McHugh Complex, which contains Late Triassic through middle Cretaceous radiolarian chert (Nelson and others, 1986; Winkler and others, 1981c; Plafker and others, 1989c; this volume, Chapter 12) that may have been accreted during the existence of Talkeetna arc. These relations indicate that the latest Triassic through Middle(?) Jurassic Talkeetna arc to the north and the Late Triassic through Middle Jurassic parts of the accretionary assemblages to the south are the remnants of a paired igneous arc and subduction-zone complex, now juxtaposed along the Border Ranges fault (Plafker and others, 1989c; this volume, Chapter 12). However, these structural relations require tectonic erosion of the intervening part of the arc (Pavlis, 1983; Nokleberg and others, 1989b; Plafker and others, 1989c; Roeske and others, 1989).

An alternative interpretation (proposed by F. H. Wilson) is that the arc faced northwest and the subduction zone dipped southeastward (using present-day coordinates). This interpretation is based largely on whole-rock chemical differentiation trends for Jurassic plutonic rocks on the Alaska Peninsula (Reed and others, 1983). Included with this interpretation is the Kahiltna assemblage as a coeval accretionary prism. Problems with this interpretation are (1) the Kahiltna assemblage is younger than the Talkeetna Formation and the Middle Jurassic plutonic rocks; (2) the Kahiltna assemblage does not include any oceanic rocks typical of arc-related accretionary prisms; (3) the occurrence of the coeval blueschists and subduction-zone melange of the northern Chugach terrane cannot be explained readily by a southeast-dipping subduction zone; and (4) some studies of chemical variation across the Middle Jurassic part of the Alaska-Aleutian Range batholith suggest emplacement above a northwest-dipping subduction zone (Moore and Connelly, 1977).

In the northern Chugach Mountains, the upward transition from cumulate ultramafic and mafic rocks of the Border Ranges ultramafic-mafic assemblage to supracrustal volcaniclastic rocks of the Talkeetna Formation within a sequence no more than 6 to 7 km thick clearly suggests crustal thinning. It is possible that this thinning occurred during post–Middle Jurassic, low-angle, listric movement along detachment faults between the major units (Nokleberg and others, 1989b).

MAJOR FAULTS

Denali faults

The Denali fault (Figs. 2 and 4), one of the major tectonic boundaries in North America, extends from northern southeastern Alaska through the Alaska Range to the Bering Sea, a distance of more than 2,000 km. The fault has been studied by Sainsbury and Twenhofel (1954), St. Amand (1954, 1957), Twenhofel and Sainsbury (1958), Grantz (1966), Richter and Matson (1971), Stout and others (1973), Brogan and others (1975), Wahrhaftig and others (1975), Packer and others (1975), Plafker and others (1977; 1989c; this volume, Plate 12), Lanphere (1978), Stout and Chase (1980), Csejtey and others (1982), and Nokleberg and others (1985). In this chapter, the Denali fault is restricted to the main trace or the McKinley strand of Csejtey and others (1982). The Hines Creek splay to the north, which was included as part of the Denali fault system by Wahrhaftig and others (1975) and Csejtey and others (1982), was interpreted by Nokleberg and others (1989a, 1992b) as a separate structure that is not a terrane boundary, but instead is a younger structure mostly within the southern Yukon-Tanana terrane.

Evidence for the extent of displacement on the Denali fault consists of high-quality data for smaller amounts of movement during the Quaternary and lower quality data for greater amounts of movement during the late Mesozoic and Tertiary. Evidence for Quaternary movement on the Denali fault in the eastern and central Alaska Range was summarized by Richter and Matson (1971), Stout and others (1973), and Plafker and others (1977). Estimates of Quaternary movement on the fault since early Wisconsin or Illinoisan time range from 1 to 6.5 km (Stout and others, 1973); probable rates of Holocene movement average about 1.5 cm/yr (Plafker and others, this volume, Plate 12). The sense of movement in all places is right lateral. Evidence for earlier Tertiary dextral displacement along the Denali fault, based on offset of the Foraker and McGonagal plutons near Mount McKinley, is about 38 km in 38 m.y. (Reed and Lanphere, 1974b).

Evidence for substantial Late Cretaceous and early Tertiary dextral displacement along the Denali fault consists of (1) a minimum of 300 km of offset of flysch of the Late Jurassic and Early Cretaceous Gravina-Nutzotin belt between the Nutzotin Mountains in the Wrangell Mountains and similar rocks to the southeast in the Dezadeash Basin near the Ruby Mountains (Eisbacher, 1976); (2) offset of the Maclaren and Aurora Peak terranes, which have early Tertiary granitic rocks and metamorphic fabrics, in the eastern Alaska Range, from similar rocks about 400 km to the southeast in the southwestern Yukon Territory (Forbes and others, 1973; Smith and others, 1974; Nokleberg and others, 1985, 1989a); (3) offset of the Broxson Gulch thrust, which offsets the Maclaren and Wrangellia terranes, from the same area (Eisbacher, 1976; Nokleberg and others, 1985); and (4) post-Triassic dextral offset of part of the Wrangellia terrane in the eastern Wrangell Mountains to a position at least 350 km to the southeast on the Chilkat Peninsula in northern southeastern Alaska (Plafker and others, 1989a).

In addition to offset units, the very distinct structural melange of the Paleozoic and Mesozoic Windy terrane occurs along the Denali fault between the Aurora Peak terrane and the Late Cretaceous and early Tertiary East Susitna batholith of the Maclaren terrane (Figs. 2 and 4). The occurrence of the Windy terrane for several hundred kilometers along the Denali fault indicates substantial offset between highly disparate bedrock units. Also in the central and eastern Alaska Range, significantly different terranes occur on opposite sides of the Denali fault (Hickman and Craddock, 1976; Richter, 1976; Sherwood and Craddock, 1979; Jones and others, 1987; Brewer, 1982; Sherwood and others, 1984; Nokleberg and others, 1985, 1992b). All of the above data are incompatible with the interpretations of Csejtey and others (1982), who indicated only a few kilometers offset along the Denali fault during the Cenozoic.

Nenana Glacier fault

The Nenana Glacier fault (Brewer, 1982; Nokleberg and others, 1985, 1989a, 1992b) occurs a few kilometers north of the Denali fault in the central and eastern Alaska Range in the Mount Hayes and Healy quadrangles (Figs. 1 and 2). The fault juxtaposes the Aurora Peak terrane to the south from the Yukon-Tanana terrane to the north (Figs. 2 and 4). The chief evidence for the fault includes (1) a narrow zone of ductile deformation and intense shearing with locally abundant retrogressive metamorphism of the high-grade rocks of the Aurora Peak terrane; (2) local formation of structural melange between the Aurora Peak and Yukon-Tanana terranes; and (3) juxtaposition of the amphibolite facies Cretaceous rocks of the Aurora Peak terrane against the low-grade Devonian rocks of the Hayes Glacier subterrane of the southern Yukon-Tanana terrane. The Nenana Glacier fault is interpreted as a slightly older Late Cretaceous or early Tertiary branch of the Denali fault (Brewer, 1982; Nokleberg and others, 1985, 1989a, 1992b).

Ancestral Denali fault

Geologic and geophysical data suggest that Mesozoic flysch along the northern margin of the Wrangellia terrane was thrust under the southern margin of the multiply metamorphosed and deformed Paleozoic Yukon-Tanana terrane in the middle to Late Cretaceous along the ancestral Denali fault. Magnetotelluric and seismic reflection data for the southern Yukon-Tanana terrane are interpreted as indicating that large volumes of conductive rocks exist beneath the southern Yukon-Tanana terrane in the eastern and central Alaska Range (Labson and others, 1988; Stanley and others, 1990). The highly conductive rocks are interpreted to be carbonaceous units that appear to dip northward under the highly resistive rocks of the southern Yukon-Tanana terrane. The carbonaceous units are probably a combination of (1) a formerly extensive, but now collapsed, Mesozoic flysch basin now partly preserved in the Kahiltna assemblage and the Gravina-Nutzotin belt; and (2) other carbonaceous sedimentary rocks in Paleozoic sedimentary terranes now preserved as remnants along the Denali fault. This flysch basin, described above, is interpreted as initially having formed on the leading or northern edge of the WCT (Nokleberg and others, 1985; Plafker and others, 1989c; Rubin and Saleeby, 1991). The docking of this terrane may have caused large-scale oblique underthrusting, folding, and metamorphism in the flysch basin, within which the Cenozoic strike-slip Denali fault subsequently developed.

Two geologic observations support a period of Cretaceous oblique-slip underthrusting along the ancestral Denali fault. A zone of intense retrograde metamorphism, with K-Ar mica ages of 100 to 110 Ma (Nokleberg and others, 1986), associated ductile deformation, and south-verging structures occurs along the southern margin of the Yukon-Tanana terrane. This zone occurs for several hundred kilometers adjacent to the Denali fault and is up to 20 km wide (Nokleberg and Aleinikoff, 1985; Nokleberg and others, 1986). The intensity of retrograde metamorphism and ductile deformation increases toward the fault, and lowest greenschist facies rocks and intensely deformed, mylonitic schist occur adjacent to the fault. South-verging, tightly appressed to isoclinal minor folds with axial plane zones of mylonite are also observed in the zone of mylonitic schist. This fabric indicates that retrograde metamorphism occurred during thrusting of the southern Yukon-Tanana terrane onto units to the south. The retrograde metamorphism was interpreted by Stanley and others (1990) as occurring during the underthrusting of cool, wet flysch of the Kahiltna assemblage. Dark colored argillite and metagraywacke of Cretaceous age form a major part of the melange of the Windy terrane that occurs for several hundred kilometers along the Denali fault in the central and eastern Alaska Range (Fig. 2). These lenses are interpreted as relicts of the flysch of the Kahiltna assemblage that remained after oblique underthrusting along the ancestral Denali fault and subsequent Cenozoic dextral strike-slip movement along the fault.

Talkeetna thrust

The Talkeetna thrust dips moderately to steeply southeastward along the northwestern margin of the Peninsular terrane in the central and western Alaska Range, mainly in the Healy, Mount McKinley, and Talkeetna quadrangles (Figs. 1 and 2) (Csejtey and others, 1978, 1982, 1986; Csejtey and St. Aubin, 1981). The thrust occurs between the Kahiltna assemblage to the north and the older bedrock of the Peninsular and Wrangellia terranes to the south (Csejtey and others, 1982, 1986). Toward the east in the western Mount Hayes quadrangle, the Talkeetna thrust terminates against the younger, north-dipping Broxson Gulch thrust (Nokleberg and others, 1985, 1989a).

There are complicated structural relations along the Talkeetna thrust (Csejtey and others, 1982). Subsidiary, southeastward-dipping imbricate faults along the thrust consistently bring older rocks of the Wrangellia terrane to the south on top of younger rocks of the Kahiltna assemblage to the north. Folds associated with the thrust are generally tight or isoclinal, and they range in size from small secondary folds to major folds having an amplitude of several kilometers. A northwestward tectonic transport is also indicated by drag folds in the upper plates of the subsidiary thrusts and by northwestward, overturned folds in the flysch north of the Talkeetna thrust. Series of complex and imbricate thrust faults with local reversals of structural vergence adjacent to the Chulitna terrane are interpreted as the result of local stress reversal during late orogenic folding. In other areas, major folds with amplitudes of at least 10 km are associated with the thrust.

Movement along the Talkeetna thrust and the intense deformation of the Peninsular and Wrangellia terranes and the Kahiltna assemblage, both above and below the thrust, are interpreted as occurring during the middle and Late Cretaceous emplacement of the WCT to Alaska (Csejtey and others, 1982; Nokleberg and others, 1985; Plafker and others, 1989c). The age of the orogeny is bracketed by the youngest deformed rocks (the Late Jurassic and Early Cretaceous flysch) and by the ages (Late Cretaceous and early Tertiary) of the oldest undeformed intrusive rocks (Csejtey and others, 1978, 1982). The orogeny involved complex thrusting and folding, low- to medium-grade regional metamorphism, subordinate high-angle faulting, and late tectonic plutonism. This deformation produced a prominent, generally northeast trending structural grain.

Broxson Gulch thrust

The Broxson Gulch thrust (Stout, 1976; Nokleberg and others, 1982, 1985, 1992b) occurs in the eastern Alaska Range between the Wrangellia terrane to the south and the Maclaren terrane to the north (Figs. 2 and 4). The thrust extends to the west from an acute termination against the Denali fault in the eastern Alaska Range. To the west, the thrust truncates the relatively older Talkeetna thrust (Csejtey and others, 1986). The main evidence for the Broxson Gulch thrust is (1) truncation of various units in both terranes; (2) locally abundant, highly sheared rocks; and (3) juxtaposition of units of diverse stratigraphy, age, and structure.

Like the Talkeetna thrust, the Broxson Gulch displays a complex history of movement (Nokleberg and others, 1985, 1989a). The first period of movement consisted of thrusting of the Wrangellia terrane onto the Maclaren terrane after deposition of the Late Jurassic and Early Cretaceous strata of the Gravina-Nutzotin belt. The thrust is interpreted as having dipped southward (oceanward) during this period. The second period of movement consisted of substantial strike-slip offset, which resulted in dislocation of a small fault-bounded wedge of the Triassic and Jurassic McCarthy Formation from the eastern Wrangell Mountains to the central Alaska Range. Similar strike-slip movement may have occurred along the Talkeetna thrust to the west (Csejtey and others, 1982). The third period of movement consisted of overturning of the fault to a north dip and reactivation with south-verging movement. South-vergent movement is indicated by (Nokleberg and others, 1982, 1985, 1989a, 1992b) (1) juxtaposition of older bedrock of the Wrangellia terrane over Tertiary sedimentary and volcanic rocks, and over Wisconsin glacial deposits along various north-dipping branches of the fault; and (2) refolding of schistosity and compositional layering in the southern part of the Maclaren terrane to north dips near the thrust.

Paxson Lake and Chitina Valley faults

The Wrangellia terrane is bounded on the south by the Paxson Lake fault in the northern Copper River Basin (Fig. 2) (Nokleberg and others, 1986) and by the Chitina Valley fault along the southern margin of the Wrangell Mountains (Fig. 2) (Plafker and others, 1989c). To the south of these faults is the southern Wrangellia terrane (Fig. 2).

The Paxson Lake fault occurs in the southern flank of the Alaska Range and in the northern flank of the Talkeetna Mountains. The fault is not exposed in the southern Alaska Range, where it strikes mainly east-west; a steep to vertical dip is suggested by a straight trace (Figs. 2 and 4) (Nokleberg and others, 1986, 1989a). Evidence for the fault consists of (1) the intensely deformed and steeply dipping rocks of the metamorphic complex of Gulkana River adjacent to the nonpenetratively deformed and gently dipping units of the Wrangellia terrane; and (2) the presence of thick and massive hornblende andesite and two-mica granitic plutons in the metamorphic complex of Gulkana River compared with few, if any, similar rocks in the Wrangellia terrane. The Paxson Lake fault is most narrowly constrained on the southwest flank of Paxson Mountain to a colluvium-covered zone about 500 m wide. The only unit covering the fault is composed of Quaternary glacial deposits. The Paxson Lake fault continues to the west in the Talkeetna Mountains quadrangle, where it is mapped in bedrock either as (1) a southeast-dipping zone of intense shearing that occurs along the southern boundary of the Wrangellia terrane (Csejtey and others, 1978); or (2) a northwest-dipping, faulted disconformity (Kline and others, 1990).

The Chitina Valley fault occurs in the southern Wrangell Mountains (MacKevett, 1978; Gardner and others, 1988; Plafker and others, 1989c). The fault strikes east-southeast and dips steeply southwest. It juxtaposes late Paleozoic metamorphic rocks, Triassic greenstone and marble, and Late Jurassic plutons of the southern Wrangellia terrane to the south against the weakly metamorphosed and less-intensely deformed sedimentary, volcanic, and plutonic rocks of the Wrangellia terrane to the north. Pre–Early Cretaceous deformation along the fault is indicated by strata of Albian age deposited unconformably across the fault. Structures in rocks north of the fault are north-verging, whereas south of the fault, the upper Paleozoic rocks of the southern Wrangellia terrane are deformed into south-verging, nearly recumbent folds that are cut by intensely deformed Late Jurassic granitoids of the Chitina Valley batholith (MacKevett, 1978). These relations indicate that at least two periods of penetrative deformation have affected the rocks along the southern margin of the Wrangellia terrane.

West Fork fault

The West Fork fault occurs between the southern Wrangellia terrane to the north and the Peninsular terrane to the south in the northern Copper River basin (Fig. 2). The fault is everywhere covered by surficial deposits, mainly glaciofluvial or glacial lake deposits, but generally strikes east-west to southeast, and appears to be near vertical based on a straight trace (Fig. 3) (Nokleberg and others, 1986). Geologic evidence for the fault consists of the extensive, nonmetamorphosed, gently dipping Late Triassic(?) and Early Jurassic Talkeetna Formation to the south occurring adjacent to locally highly metamorphosed and deformed, late Paleozoic(?) metamorphosed volcanic, sedimentary, and plutonic rocks of the metamorphic complex of Gulkana River to the north. Geophysical evidence for the fault consists primarily of the major east-west–striking Sourdough magnetic high that occurs along the fault (Andreasen and others, 1974; Campbell and Nokleberg, 1986). This magnetic high is interpreted as a near-vertical body of mafic or ultramafic rocks between the Peninsular terrane and the metamorphic complex of Gulkana River. The West Fork fault trends southeastward and may connect with the Taral fault underneath the unconsolidated Quaternary deposits of the Copper River basin and the Tertiary volcanic rocks of the Wrangell arc (Winkler and others, 1981a), where a similar magnetic high marks the concealed inferred trace of the fault (Case and others, 1986).

Bruin Bay fault

The Bruin Bay fault separates the Iliamna and Chignik subterranes of the Peninsular terrane on the Alaska Peninsula. The fault occurs between the mainly Late Triassic and Early Jurassic strata of the Iliamna subterrane to the northwest from the mainly Middle and Late Jurassic strata of the Chignik subterrane on the southeast (Fig. 2). The fault strikes northeast, dips northwest, and displays high-angle reverse (northwest side up) movements with a total stratigraphic throw of as much as 3 km (Detterman and Reed, 1980). A component of left-lateral strike-slip motion is possible; however, the evidence is tenuous (Detterman and Reed, 1980, p. 69). Preferential development of conglomerate in the Naknek Formation adjacent to the Bruin Bay fault suggests that the fault may have been active in Late Jurassic (Oxfordian) time (Burk, 1965; Detterman and Reed, 1980). Displacement predates emplacement of Oligocene plutons across the fault. The Bruin

Bay fault has been inferred to extend south of Becharof Lake (Jones and Silberling, 1979; von Huene and others, 1985; Lewis and others, 1988). However, the available data are not conclusive because the faults along strike south off Becharof Lake dip in the opposite sense from the Bruin Bay fault and have the opposite sense of slip, i.e., northwest side downthrown.

LINKAGES BETWEEN WRANGELLIA, ALEXANDER, AND PENINSULAR TERRANES

As defined by Jones and others (1981), the terranes constituting the WCT were interpreted as structurally bound blocks with unique geologic and displacement histories. This interpretation was strongly influenced by early paleomagnetic data of variable reliability that suggested large relative motions between the Alexander, Peninsular, and Wrangellia terranes (Hillhouse, 1977; Hillhouse and Grommé, 1980, 1984; Stone and Packer, 1979; Stone and others, 1982). Geologic, paleontologic, and more recent paleomagnetic studies favor the alternative that these terranes have been a single terrane throughout much, if not all, of their decipherable histories, and that differences between them can be explained by differences in exposed structural level and/or facies variations. These available data suggest the following. (1) The Alexander terrane was amalgamated with the Wrangellia terrane and was the basement beneath at least part of the Wrangellia terrane by at least early Pennsylvanian time. (2) The northern part of the former Taku terrane of southeastern Alaska is a displaced fragment of Wrangellia. (3) The combined Wrangellia-Alexander terranes were amalgamated with the Peninsular terrane at least by Late Triassic time and possibly by the late Paleozoic. The various types of geologic linkages between sections of the Wrangellia, Alexander, Peninsular, and former northern Taku terranes are shown schematically in Figure 8 and are summarized briefly below.

Paleozoic linkages

A possible early Paleozoic linkage between the Wrangellia terrane in British Columbia and the Alexander terrane in southeastern Alaska is suggested by extensive arc magmatism in both terranes, followed by sporadic volcanism and deposition of thick carbonate and chert sequences in the late Paleozoic (Fig. 8, linkage A). Metamorphosed arc volcanic and plutonic rocks of the Sicker Group on Vancouver Island are dated at 370–420 Ma, although the age of the base of this sequence is not known (Brandon and others, 1986). In the southern Alexander terrane, the possibly coeval metamorphic arc complex is mainly of Early Ordovician to Early Devonian age; associated plutonic rocks range in age from 430–405 Ma (Gehrels and Saleeby, 1987). A difference between the two regions is that the coarse clastic rocks of the Early Devonian Klakas orogeny in the Alexander terrane (Gehrels and Saleeby, 1987) are not recognized on Vancouver Island. Paleomagnetic data suggest that the Alexander terrane was about 15° south of its present latitude relative to North America in Pennsylvanian time, assuming an origin in the Northern Hemisphere (Van der Voo and others, 1980); comparable paleomagnetic data are unavailable for the Wrangellia terrane in Alaska, where the abundant oldest known rocks are Pennsylvanian.

The Wrangellia terrane in Alaska and the northwestern part of the Alexander terrane in the southeastern Wrangell Mountains are stitched together by (1) a belt of gabbroic, granitic, and alkalic plutonic rocks with middle Pennsylvanian zircon ages of 315–305 Ma (Fig. 8, linkage B) (Gardner and others, 1988; Aleinikoff and others, 1988); and (2) volcanic rocks of the associated Pennsylvanian and Early Permian Skolai arc (Fig. 8, linkage C; Muller, 1967; Gardner and others, 1988). The southeastern limit of the late Paleozoic igneous complex is unknown; coeval andesitic volcanic rocks and syenitic intrusive rocks with a single K-Ar biotite minimum age of 277 Ma occur locally in the southern Alexander terrane in southeastern Alaska and could represent part of this arc (Fig. 8; Gehrels and Berg, 1992; this volume). Possibly equivalent schistose metavolcanic and metasedimentary rocks, locally associated with mainly Early Permian carbonate rocks, occur in the Peninsular terrane along the northern margin of the Chugach Mountains in the Seldovia area and on the Alaska Peninsula (Figs. 3 and 7) (Plafker and others, 1989c; Wallace and others, 1989).

Permian carbonate rocks also provide possible stratigraphic linkages between the Alexander, Peninsular, and Wrangellia terranes in the study area and the northern former Taku terrane (Fig. 8, linkage D) (Jones and others, 1987; Plafker and others, 1989a). The carbonate rocks are mainly Early Permian in age, except on the Alaska Peninsula, where a single Late Permian occurrence is known. Pennsylvanian and Permian megafaunas from these terranes at the species level show close ties among the terrane faunas and also between the terrane faunas and North America (Mackenzie Gordon, Jr. and J. T. Dutro, Jr., 1991, written commun.).

Middle and Late Triassic linkages

The Alexander, Peninsular, Wrangellia, and former northern Taku terranes are linked by distinctive thick Middle to Late Triassic eruptive sequences and overlying shallow-marine strata (Fig. 8; linkages E and F). The eruptive rocks in these terranes are dominantly basaltic in sequences up to several kilometers thick; those in the Alexander terrane are either entirely basaltic or bimodal basalt and felsic volcanic rocks that are interbedded with marine sedimentary rocks in sequences up to several hundred meters thick (Jones and others, 1977; Detterman and Reed, 1980; Gehrels and others, 1986; Plafker and others, 1989c; Winkler, 1992).

The Wrangellia terrane in Alaska is linked with the Wrangellia terrane in British Columbia by thick sequences of Ladinian to Carnian basalt (Nikolai Greenstone and Karmutsen Formation) and overlying Late Triassic marine strata (Fig. 8, linkages E and F) (Jones and others, 1977). A comparable sequence of Carnian and older(?) greenstone, overlain by thin carbonate rocks

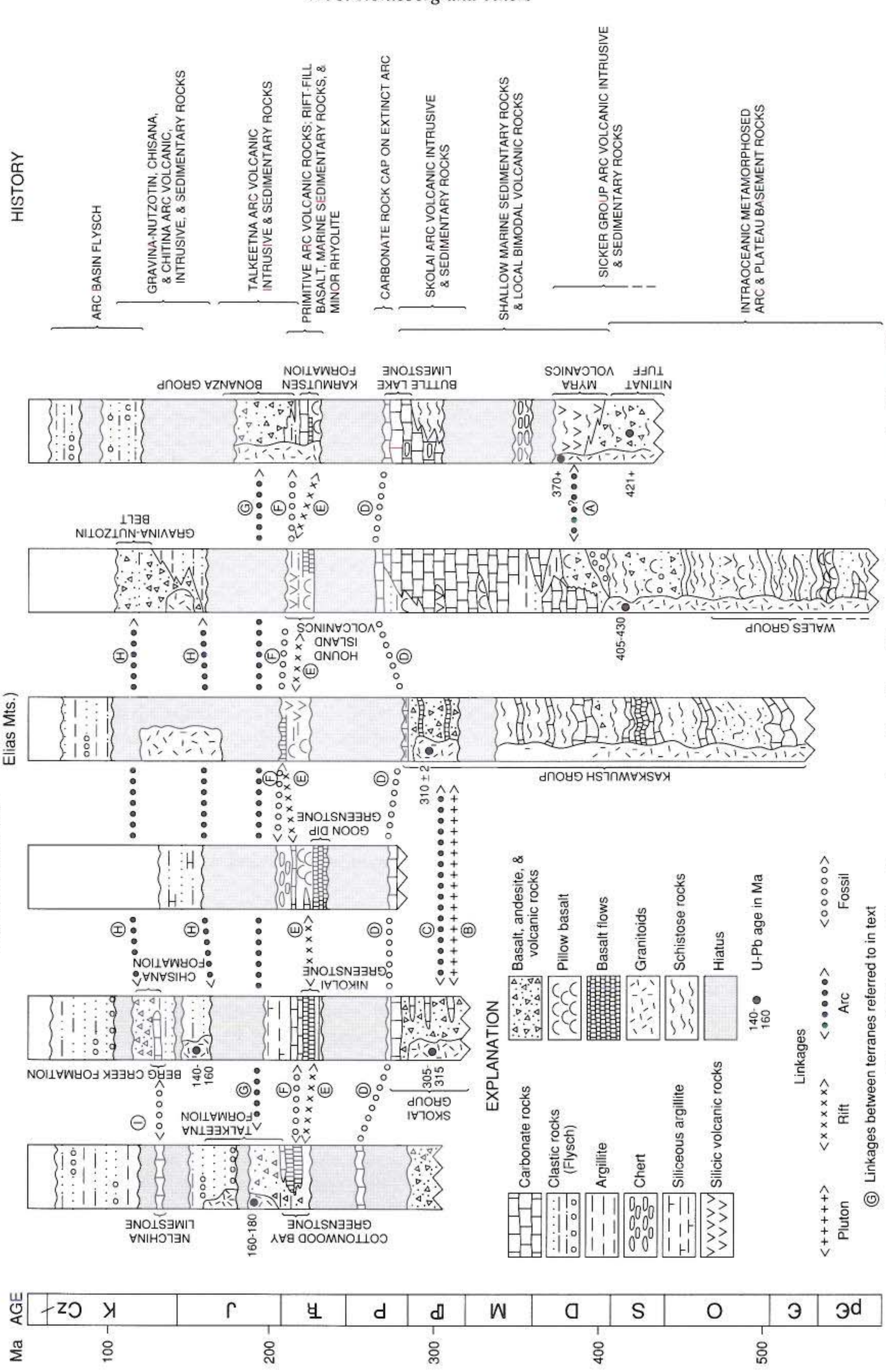


Figure 8. Diagram illustrating suggested stratigraphic and igneous linkages between the Wrangellia, southern Wrangellia, Peninsular, Alexander, and northern Taku (fragment of Wrangellia) terranes, south-central Alaska. Refer to text for discussion.

and chert of latest Carnian to late Norian age, occurs on the Chilkat Peninsula of southern Alaska in the Wrangellia terrane (former northern Taku terrane) (Plafker and others, 1989a). A similar, but slightly younger, sequence of basalt overlain by shallow-marine sedimentary rocks is also identified in the Peninsular terrane on the Alaska Peninsula, where both the Norian Cottonwood Bay Greenstone and the Kamishak Formation (limestone) have been correlated with the Nikolai Greenstone and Nizina Limestone, respectively, in the type area of the Wrangellia terrane (Detterman and Reed, 1980; Wilson and others, 1994). Undated greenstone and limestone in the southern Talkeetna Mountains area of the Peninsular terrane are tentatively correlated with the lithologically similar Nikolai Greenstone and overlying Chitistone Limestone of the Wrangellia terrane in the Wrangell Mountains (Winkler, 1992).

Reconstructions of paleogeographic distribution of the terranes based on studies of species endemism of Triassic bivalves suggest an ocean-island chain origin for the Wrangellia and Peninsular terranes (Newton, 1983), a scenario that is compatible with the paleomagnetically determined paleolatitude of about 30° south relative to the North American craton for the Alexander, Peninsular, and Wrangellia terranes (Hillhouse and Grommé, 1984; Haeussler and others, 1989; P. W. Plumley, 1990, oral commun.).

Late Triassic and Jurassic linkages

The Peninsular terrane and Wrangellia terrane of British Columbia are linked by major arc sequences, mainly of Early Jurassic age, but ranging in age from Late Triassic through early Middle Jurassic (Fig. 8, linkage G). These sequences are inferred (Plafker and others, 1989c; this volume, Chapter 12) to be a previously continuous arc that was disrupted by more than 600 km of sinistral strike-slip displacement. This correlation is based on the striking similarity in age and depositional environment of the two sequences, as well as the abrupt termination of continuous belts of the Talkeetna Formation and related intrusive rocks at the eastern end of the Peninsular terrane in Alaska (Jones and others, 1987) and the presence of coeval parts of the Bonanza Group and related units in the Wrangellia terrane of British Columbia (Muller and others, 1974; Cameron and Tipper, 1985). The Late Triassic and Early Jurassic section in the type area of the Wrangellia terrane in the Wrangell Mountains of Alaska is dominantly carbonate, but coeval arc volcanism in the region is inferred from the occurrence of lithic fragments of microlitic tuff throughout the Norian to Pleinsbachian Nizina Limestone and McCarthy Formation (M. Mullen, 1990, oral commun.). Faunal assemblages for both terranes are compatible with the paleomagnetic data in that they suggest deposition in subequatorial paleolatitudes (Imlay, 1984; Cameron and Tipper, 1985).

Late Jurassic and Cretaceous linkages

The Alaska segment of the Wrangellia terrane and the southern Alexander terrane are linked by the Chitina and Chisana magmatic arcs and associated sedimentary rocks during the latest Jurassic through Early Cretaceous (Fig. 8, linkage H). These sequences consist of distinctive arc-related volcanic, volcaniclastic, and intrusive rocks that compose the Gravina-Nutzotin belt (Berg and others, 1972; Gehrels and Berg, this volume) and probably the correlative Late Jurassic Tonsina-Chichagof and Early Cretaceous Nutzotin-Chichagof plutonic belts (Hudson, 1983; Miller, this volume, Chapter 16).

The Peninsular and Wrangellia terranes in Alaska are linked during the Valanginian to Hauterivian (early Early Cretaceous) by the distinctive fossiliferous Nelchina Limestone and Berg Creek Formation that extend discontinuously from the Alaska Peninsula to the southern Wrangell Mountains (Fig. 8, linkage I) (Plafker and others, 1989c). The two terranes may also be linked by the coeval and possibly originally connected sedimentary and lesser volcanic rocks of the Late Jurassic and Early Cretaceous Kahiltna assemblage and Gravina-Nutzotin belt.

WRANGELLIA COMPOSITE TERRANE

Stratigraphic relations and structural imbrication

The Alexander, Wrangellia, and Peninsular terranes exhibit stratigraphic, volcanic, and plutonic ties from the late Paleozoic through the Cretaceous. Because of these relations and linkages, the three terranes are interpreted as constituting the WCT (Plafker and others, 1989c). The chief differences between the three terranes are notable contrasts in the relative abundances of coeval strata. For example, in the study area, the Alexander terrane is mainly an early and middle Paleozoic volcanic arc terrane with only a thin expression of the late Paleozoic and early Mesozoic units of the Wrangellia terrane. Similarly, the Wrangellia terrane is mainly a late Paleozoic island-arc sequence and an early Mesozoic mafic magmatism sequence. Pre–late Paleozoic basement rocks, possibly of the Alexander terrane, which are interpreted to underlie the Wrangellia terrane or to have been juxtaposed against the Wrangellia terrane by the middle Pennsylvanian, are found locally in the eastern part of the study area in the Nutzotin Mountains and in the southeastern Wrangell Mountains. Similarly, the Peninsular terrane consists mainly of an Early and Middle Jurassic island-arc sequence. Only locally does a small part of the Peninsular terrane exhibit either (1) the volcanic and sedimentary rocks of the late Paleozoic Skolai island arc and the Late Triassic rift basalt that form the major part of the Wrangellia terrane or (2) possible fragments of metamorphosed Paleozoic or older metasedimentary and metavolcanic rocks that might be the early and middle Paleozoic part of the Alexander terrane.

The above relations indicate that, from east to west, the Alexander, Wrangellia, and Peninsular terranes exhibit successively higher levels of a structural-stratigraphic succession. The oldest part of the succession is mainly to the east in the predominantly early and middle Paleozoic Alexander terrane; the middle part of the succession in the central part of the predominately late Paleozoic and early Mesozoic Wrangellia terrane; and the youngest part of the succession is to the west in the predominantly middle and late Mesozoic Peninsular terrane.

Despite these linkages, substantial tectonic imbrication has occurred within the WCT (Plafker and others, 1989c). The abrupt termination of the Talkeetna arc and associated plutonic rocks in the eastern Peninsular terrane structurally against the very minor occurrence of this arc in the Wrangellia terrane requires extensive post–Middle Jurassic tectonic displacement of the Wrangellia terrane relative to the Peninsular terrane. This post-Jurassic displacement resulted in juxtaposition of different facies, and, therefore, in the original designation of the two units as separate terranes.

The timing of the suggested strike-slip displacement between the Peninsular and Wrangellia terranes cannot be determined more closely than the Late Jurassic to Late Cretaceous. The deformation affects Late Jurassic plutons and may have been synchronous with Late Jurassic Chitina arc magmatism. The displacement occurred prior to (mid[?]-Cretaceous) accretion of the younger parts of the melange of the McHugh Complex of Early Cretaceous (Berriasian to Valanginian) age to the southern Wrangellia terrane, because these rocks do not appear to be deformed by the strike-slip event. Along the northern margins of the Wrangellia and Peninsular terranes, geologic data indicate that the combined terranes were sutured to each other and to North America by the middle Cretaceous in mainland Alaska (Csejtey and St. Aubin, 1981; Nokleberg and others, 1985) and British Columbia (Monger and others, 1982).

Similar extensive tectonic imbrication has occurred within parts of the Wrangellia terrane. The tectonically juxtaposed Slana River and Tangle subterranes exhibit notable contrasts in the relative abundances and thicknesses from the late Paleozoic through the late Mesozoic. If, as suggested above, the Tangle subterrane formed originally close to the variant of the Wrangellia terrane on Vancouver Island, then considerable tectonic dismemberment and recombining of various elements of the Wrangellia terrane occurred in the late Mesozoic and Cenozoic.

Paleomagnetic studies indicate that the WCT was about 30° south of its present latitude relative to North America during the Late Triassic (Haeussler and others, 1989; Hillhouse and Coe, this volume). The WCT was juxtaposed against North America by the middle Cretaceous (Csejtey and others, 1982; Nokleberg and others, 1985; Plafker and others, 1989c; Grantz and others, 1991). The terrane is interpreted to have arrived at its present position between about the Cenomanian and the Eocene (Hillhouse and Coe, this volume). These studies suggest a long history of tectonic migration with ample opportunity for internal dismemberment of the WCT.

Structural and tectonic relations across the eastern Wrangellia composite terrane

The structural and tectonic relations across the eastern WCT, parallel to the Trans-Alaskan Crustal Transect (TACT) and the Richardson Highway, are displayed in three cross sections in Figures 4 and 6. In the following discussion, the three cross sections are described and interpreted from south to north.

Cross section A-A′ (Fig. 6) displays the important structural and tectonic relations between the northern Chugach, southern Peninsular, and southern Wrangellia terranes. To the south, the moderate-grade metamorphic rocks of the southern Wrangellia terrane, interpreted as a fragment of an island arc, occur in a major klippe that is floored by a splay of the Border Ranges fault. The klippe rests on the low-grade Late Cretaceous flysch of the Valdez Group in the northern Chugach terrane. Juxtaposition of the southern Wrangellia and Chugach terranes occurred in the early Cenozoic after accretion and underthrusting of the Valdez Group beneath the relatively older subduction-zone complex of the McHugh Complex (Nokleberg and others, 1989b; Plafker and others, 1989c). Farther north, the Border Ranges ultramafic-mafic assemblage to the north is thrust over the blueschist and greenschist unit of the schist of Liberty Creek along another splay of the north-dipping Border Ranges fault. If the deep-level island-arc rocks of the Border Ranges ultramafic-mafic assemblage are tectonically paired to the blueschists along the northern margin of the Chugach terrane, then the entire fore-arc basin that originally existed between the two units has been tectonically removed. Farther north, the Late Triassic(?) and Early Jurassic Talkeetna Formation is normally faulted along the St. Anne fault onto the Late Triassic through Middle(?) Jurassic Border Ranges ultramafic-mafic assemblage to the south. If both units are part of the Talkeetna arc, then juxtaposition of these two units requires moderate disappearance of stratigraphic section. Locally, one inclusion of volcaniclastic sandstone, interpreted as a part of the Talkeetna, is observed in the Nelchina River Gabbronorite (Plafker and others, 1989c).

Cross section A-A′ (Fig. 4) displays the important structural and tectonic relations between the northern Peninsular, southern Wrangellia, and Wrangellia terranes. To the south, the Talkeetna Formation of the Peninsular terrane is juxtaposed along the strike-slip (?) West Fork fault against the southern Wrangellia terrane to the north. The unmetamorphosed Jurassic or Cretaceous sedimentary, volcanic, and plutonic rocks of the Peninsular terrane contrast sharply with the regionally deformed and metamorphosed sedimentary, volcanic, and plutonic rocks of the southern Wrangellia terrane (Nokleberg and others, 1986, 1989a). Farther north, the southern Wrangellia terrane is juxtaposed along the strike-slip(?) Paxson Lake fault against the Wrangellia terrane to the north. In contrast to the southern Wrangellia terrane, the Wrangellia terrane exhibits a weak granoblastic, lower greenschist facies fabric. Strike-slip movement along both faults is poorly constrained because of poor exposure and extensive glacial deposits.

Cross section B-B′ (Fig. 4) displays the important structural and tectonic relations between the northern Wrangellia, Maclaren, Windy, Aurora Peak, and southern Yukon-Tanana terranes. To the south, the island-arc Wrangellia terrane is thrust under the continental margin arc Maclaren terrane along the north-dipping Broxson Gulch thrust. This fault is interpreted as the locus of middle Cretaceous accretion of the Wrangellia terrane onto the North American continental margin, and originally dipped south but was subsequently rotated to a north dip (Nokleberg and others, 1985). The low-grade metamorphism and broad folding of the Wrangellia terrane contrasts sharply with the high-grade and multiply deformed metamorphic rocks of the Maclaren terrane. Farther north, the high-grade metaplutonic rocks of the East Susitna batholith of the Maclaren terrane are juxtaposed against the low-grade metasedimentary rocks in the structural melange of the Paleozoic and Mesozoic sedimentary and volcanic rocks of the Windy terrane. Late Cretaceous and early Tertiary metamorphic ages for the Maclaren terrane require early to middle Tertiary juxtaposition against the Windy terrane. This relation and the occurrence of the Windy terrane for several hundred kilometers along the Denali fault are among several lines of evidence for substantial Cenozoic strike-slip displacement along the Denali fault. Farther north, the Windy terrane is juxtaposed against the continental margin arc Aurora Peak terrane which, like the Maclaren terrane, is interpreted as a fragment of the Mesozoic North American continental margin that migrated along the Denali and Nenana Glacier faults (west of the plane of section) from a site to the southeast (Nokleberg and others, 1985). Farther north, the Aurora Peak terrane is juxtaposed against the Paleozoic Yukon-Tanana terrane, which is interpreted as an older displaced fragment of the Paleozoic North American continental margin (Foster and others, 1987, and this volume; Nokleberg and others, 1989a). The Yukon-Tanana terrane occurs in east-central Alaska and discontinuously along the eastern side of southeastern Alaska to near Vancouver, Canada (Foster and others, 1987, and this volume; Gehrels and Berg, this volume).

CONCLUSIONS

The interpretations presented herein are compatible with most geologic data in the study area, paleomagnetic data for the Wrangellia terrane, and major aspects of plate reconstructions for the northeast Pacific region. These interpretations differ from previous ones (Coney and others, 1980; Jones and Silberling, 1982; Monger and others, 1982; Saleeby, 1983; Coney and Jones, 1985; Howell and others, 1985; Umhoefer, 1987) in that they require tectonic juxtaposition, by late Paleozoic time, of the Wrangellia and Alexander terranes, and by at least the Late Triassic of the Wrangellia and Peninsular terranes. These three terranes, interpreted as the WCT, may have been close to each other since the late Paleozoic, with younger and structurally higher units exposed from east to west. The mainly early and middle Paleozoic Alexander terrane to the east is interpreted as the stratigraphic basement for the mainly late Paleozoic and early Mesozoic Wrangellia terrane to the west. Similarly, the Wrangellia terrane is interpreted as the stratigraphic basement for the predominantly Mesozoic Peninsular terrane.

In addition to the WCT, a series of narrow and generally highly deformed terranes occur as discontinuous, fault-bounded lenses along the Denali fault, south of the Yukon-Tanana, Nixon Fork, and Dillinger terranes. These units are the Aurora Peak, Pingston, McKinley, Mystic, and Windy terranes; a terrane of ultramafic and associated rocks; and a fragment of the Dillinger terrane. Several small terranes also occur within highly deformed upper Mesozoic flysch assemblages, either as rootless nappes or as units bounded by steep faults. These units are the Chulitna, West Fork, Broad Pass, Susitna, Maclaren, and Clearwater terranes (Fig. 2). Diverse origins are interpreted for many of these units, including origins as displaced fragments of the Paleozoic and early Mesozoic North American continental margin, continental margin arcs, island arcs, ophiolites, seamounts, flysch basins, and structural melanges.

Two major late Mesozoic flysch basins, now tectonically collapsed, occur along the northern margin of the WCT. To the northwest is the Kahiltna assemblage, which probably originally depositionally overlapped the Peninsular terrane; to the northeast is the Gravina-Nutzotin belt, of mainly coeval flysch and volcanic rocks, which depositionally overlies the Wrangellia terrane. These major Late Jurassic and Early Cretaceous flysch basins, as well as the coeval Chitina and Chisana igneous arcs, extend for several thousand kilometers through southern and southeastern Alaska; they are interpreted as forming on the leading edge of the WCT during migration towards North America (Nokleberg and others, 1985; Plafker and others, 1989c).

Major faults or sutures are either known or are inferred to separate most terranes in the study area. Along the northern boundary is the Denali fault, and along the southern boundary is the Border Ranges fault (Fig. 2). Other important sutures are the Broxson Gulch thrust between the Maclaren and Wrangellia terranes, the Talkeetna thrust between the Kahiltna assemblage to the north and the Wrangellia terrane to the south, the West Fork fault between the southern Wrangellia and Peninsular terranes, and the Chitina Valley fault between the Wrangellia and southern Wrangellia terranes (Fig. 2). These faults are both the loci of accretion of adjacent terranes and the loci of tectonic erosion of the margins or marginal facies of terranes that existed before accretion.

FUTURE STUDIES

Many important questions remain for future studies.

1. What are the origins of the small terranes along the Denali fault and within the Kahiltna assemblage? The tectonic environments need further substantiation, because, if the interpretations are correct, they suggest migration from widely divergent loci.

2. What is the structural and tectonic setting of the Kahiltna assemblage? The occurrence of several small terranes, some possibly exotic, within the assemblage suggests substantial tectonic dismemberment. Is the assemblage a collage of various Mesozoic flysch units that formed in widely separated sites and were subsequently accreted together?

3. Significant discrepancies exist between geologic and paleomagnetic data indicating pre-Triassic amalgamation of the Wrangellia and Alexander terranes (Van der Voo and others,

1980; Yole and Irving, 1980; Hillhouse and Grommé, 1984; Haeussler and others, 1989; Gardner and others, 1988; Plafker and others, 1989c; P. W. Plumley, 1991, written commun.) and paleontologic data that indicate differing pre-Triassic displacement histories for these terranes (Newton, 1983; Silberling, 1985; Detterman, 1988).

4. An apparent contradiction exists between geologic data that indicate late Early to early Late Cretaceous (Albian to Cenomanian) docking of the WCT in about its present position relative to inboard terranes, and plate reconstructions (Engebretsen and others, 1985) indicating that northward displacement and docking of the WCT could not have occurred prior to the Campanian.

5. What was the nature of accretion of the island-arc assemblages of the WCT to the south against the displaced continental margin terranes of the Yukon-Tanana, Dillinger, Mystic, and Nixon Fork terranes to the north? Were substantial parts of the Mesozoic flysch and associated island-arc volcanic rocks along the northern margin of the WCT thrust under the southern margin of these displaced continental margin terranes to the north along the ancestral Denali fault (Stanley and others, 1990)? Were substantial parts of the WCT to the south and the Yukon-Tanana and other continental margin terranes to the north tectonically eroded during accretion?

6. The Paleozoic and early Mesozoic stratigraphic and igneous linkages between the various parts of the WCT rely mainly on comparative studies between generally widely separated occurrences of sedimentary and volcanic rocks, and on temporal, petrographic, and geochemical similarities between widely separated plutons in proposed arcs. Most of the definition of the WCT relies on these similarities. Currently, only one pluton, the Barnard Glacier pluton in the southeastern Wrangell Mountains, is observed to stitch together the Wrangellia and Alexander terranes. Abundant new data, particularly on the isotopic compositions of the volcanic and plutonic parts of arcs, are needed to clearly demonstrate the continuity of the interpreted arcs. Similarly, detailed stratigraphic and paleontologic studies are needed for the correlations of sedimentary rocks between the various parts of the WCT.

7. There is considerable debate on the origin of the mafic magmas that formed the Late Triassic basalts of the Nikolai Greenstone and coeval mafic and ultramafic plutonic rocks in the WCT. The available data appear to contradict formation in either a rift or plume setting.

8. Are the southern Wrangellia and Wrangellia terranes linked by stratigraphy and by igneous arcs? One major linkage between the two units is the occurrence of the Late Triassic limestone and undated greenstone in the southern Wrangellia terrane. However, these two units occur in fault-bounded fragments near the Chitina Valley fault and may be displaced from the Wrangellia terrane to the north. The igneous arc linkages rely mainly on petrologic and isotopic similarities of widely separated plutons.

9. Are parts of the Peninsular and Wrangellia terranes stratigraphically underlain by pre–late Paleozoic metasedimentary and metagranitic rocks of the Alexander terrane? Two possible occurrences of the Alexander terrane are the unit of unnamed Paleozoic(?) metamorphic rocks along the southern margin of the Peninsular terrane, and the pre–late Paleozoic metasedimentary and metagranitic rocks that occur as roof pendants in late Paleozoic granitic rocks in the Nutzotin Mountains in the Wrangellia terrane. Both areas need additional study.

10. Are the early Paleozoic Kaskawulsh metamorphic rocks equivalent to the Kaskawulsh Group of Canada, and are both part of the highly deformed and faulted Alexander terrane? More detailed studies, principally in western Canada, might establish this unit as a separate terrane. In that case, the Wrangellia and Alexander terranes would not be stitched together by late Paleozoic metagranitic rocks.

11. What was the nature of tectonic juxtaposition of the deep-level, low-temperature and high-pressure glaucophane blueschist and greenschist along the northern margin of the Chugach terrane, south of the Border Ranges fault, against the deep-level, high-temperature and high-pressure ultramafic rocks of the Border Ranges ultramafic-mafic assemblage to the north? These structural relations require substantial tectonic erosion of the intervening part of the arc.

12. Does a genetic linkage exist between the various parts of the Talkeetna island arc, the Late Triassic through Middle(?) Jurassic Border Ranges ultramafic-mafic assemblage, the Late Triassic(?) and Lower Jurassic Talkeetna Formation, and the Middle Jurassic part of the Alaska-Aleutian Range batholith? The present inferred linkage of the three units is based primarily on temporal data, level of emplacement of the three igneous units, and the apparent intrusion of the Border Ranges ultramafic-mafic assemblage into the Late Triassic and Early Jurassic stratified rocks of the Peninsular terrane in two widely separated areas. Additional isotopic data and field observations are needed to support this linkage.

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