Distribution, Facies, Ages, and Proposed Tectonic Associations of Regionally Metamorphosed Rocks in East- and South-Central Alaska

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REGIONALLY METAMORPHOSED ROCKS OF ALASKA

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By Cynthia Dusel-Bacon, Béla Csejtey, Jr., Helen L. Foster, Elizabeth O. Doyle, Warren J. Nokleberg, and George Plafker

ABSTRACT

Most of the exposed bedrock in east- and south-central Alaska has been regionally metamorphosed and deformed during Mesozoic and early Cenozoic time. All the regionally metamorphosed rocks are assigned to metamorphic-facies units on the basis of their temperature and pressure conditions and metamorphic age. North of the McKinley and Denali faults, the crystalline rocks of the Yukon-Tanana upland and central Alaska Range compose a sequence of dynamothermally metamorphosed Paleozoic and older(?) metasedimentary rocks and metamorphosed products of a Devonian and Mississippian continental-margin magmatic arc. This sequence was extensively intruded by postmetamorphic mid-Cretaceous and younger granitoids. Many metamorphic-unit boundaries in the Yukon-Tanana upland are low-angle faults that juxtapose units of differing metamorphic grade, which indicates that metamorphism predated final emplacement of the fault-bounded units. In some places, the relation of metamorphic grade across a fault is best explained by contractional faulting; in other places, it is suggestive of extensional faulting.

Near the United States-Canadian border in the central Yukon-Tanana upland, metamorphism, plutonism, and thrusting occurred during a latest Triassic and Early Jurassic event that presumably resulted from the accretion of a terrane that had affinities to the Stikinia terrane onto the continental margin of North America. Elsewhere in the Yukon-Tanana upland, metamorphic rocks give predominantly late Early Cretaceous isotopic ages. These ages are interpreted to date either the timing of a subsequent Early Cretaceous episode of crustal thickening and metamorphism or, assuming that these other areas were also originally heated during the latest Triassic to Early Jurassic and remained buried, the timing of their uplift and cooling. This uplift and cooling may have resulted from extension.

South of the McKinley and Denali faults and north of the Border Ranges fault system, medium-grade metamorphism across much of the southern Peninsular and Wrangellia terranes was early to synkinematic with the intrusion of tonalitic and granodioritic plutons of primarily Early and Middle Jurassic age in the Peninsular terrane and Late Jurassic age in the Wrangellia terrane. Areas metamorphosed during the Jurassic episode that crop out near the Border Ranges fault system were subsequently retrograded and deformed in Cretaceous and early Tertiary time during accretion of younger units to the south. North of the Jurassic metamorphic and plutonic complex, low-grade metamorphism affected the rest of the Wrangellia terrane sometime during Jurassic and (or) Cretaceous time.

North of the Wrangellia terrane and immediately south of the McKinley and Denali faults, flyschoid rocks, which were deposited within a basin that separated the Wrangellia terrane from the western margin of North America, form a northeastward-tapering wedge. Within the western half of the wedge, flysch and structurally interleaved tectonic fragments were highly deformed and weakly metamorphosed; much of the metamorphism and deformation probably occurred sometime during mid- to Late Cretaceous time. In the eastern half of the wedge, flyschoid rocks form an intermediate-pressure Barrovian sequence (Maclaren metamorphic belt). Metamorphism of the Maclaren metamorphic belt was synkinematic with the Late Cretaceous to earliest Tertiary intrusion of foliated plutons of intermediate composition. Isotopic data suggest metamorphism extended into the early Tertiary and was accompanied by rapid uplift and cooling. Low- to medium-grade metamorphism throughout the wedge was probably associated with the accretion of the outboard Wrangellia terrane, as has been proposed for the Maclaren metamorphic belt.

South of the Border Ranges fault system lie variably metamorphosed sequences of oceanic rocks that comprise the successively accreted Chugach, Yakutat, Ghost Rocks, and Prince William terranes. The Chugach terrane consists of three successively accreted sequences of differing metamorphic histories. Metamorphism in all the sequences was associated with north-directed underthrusting beneath either the combined Peninsular-Wrangellia terrane or the older and inner parts of the Chugach terrane. These sequences, from innermost to outermost are: (1) intermediate- to high-pressure, transitional greenschist- to blueschist-facies metabasalt and metasedimentary rocks that were metamorphosed during the Early and Middle Jurassic; (2) prehnite-pumpellyite-facies mélange that was metamorphosed sometime during the Jurassic and Cretaceous; and (3) low-pressure prehnite-pumpellyite- or greenschist-facies flysch and metavolcanic rocks that were initially

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metamorphosed during latest Cretaceous to early Tertiary time and, in the eastern Chugach Mountains, were subsequently overprinted by low-pressure amphibolite-facies metamorphism that accompanied widespread intrusion during Eocene time. A similar low-pressure-facies series also developed within mélange and flysch of the Yakutat terrane; these rocks are also intruded by Eocene plutons and are correlated with similar rocks of the Chugach terrane.

Seaward of the Chugach terrane are the strongly deformed but weakly metamorphosed (prehnite-pumpellyite-facies) deep-sea metasedimentary rocks and oceanic metavolcanic rocks of the Ghost Rocks and Prince William terranes. Metamorphism and deformation occurred during underthrusting of these terranes beneath the Chugach terrane in early Tertiary time and predated, perhaps by very little, intrusion by early Tertiary granitoids.

INTRODUCTION

This report identifies, describes, and interprets the major, regionally metamorphosed rocks of east- and south-central Alaska. It is one of a series of four reports on the metamorphic rocks of Alaska and their evolution (fig. 1). Metamorphic rocks are assigned to metamorphic-facies units, shown on a colored 1:1,000,000-scale map (pl. 1), on the basis of the occurrence of pressure- and temperature-sensitive minerals and the age of metamorphism. By means of detailed unit descriptions, this report summarizes the present state of knowledge (about late 1988, with the exception of the Yukon-Tanana upland, for which information published up to early 1991 is summarized) of the metamorphic grade, pressure and temperature conditions, age of protoliths and metamorphism, and speculated or known tectonic origin of regional metamorphism in east- and south-central Alaska. Metamorphic units are discussed in the same order as that used for the map explanation. Within each geographic area (fig. 2), units are discussed in order of decreasing metamorphic age.

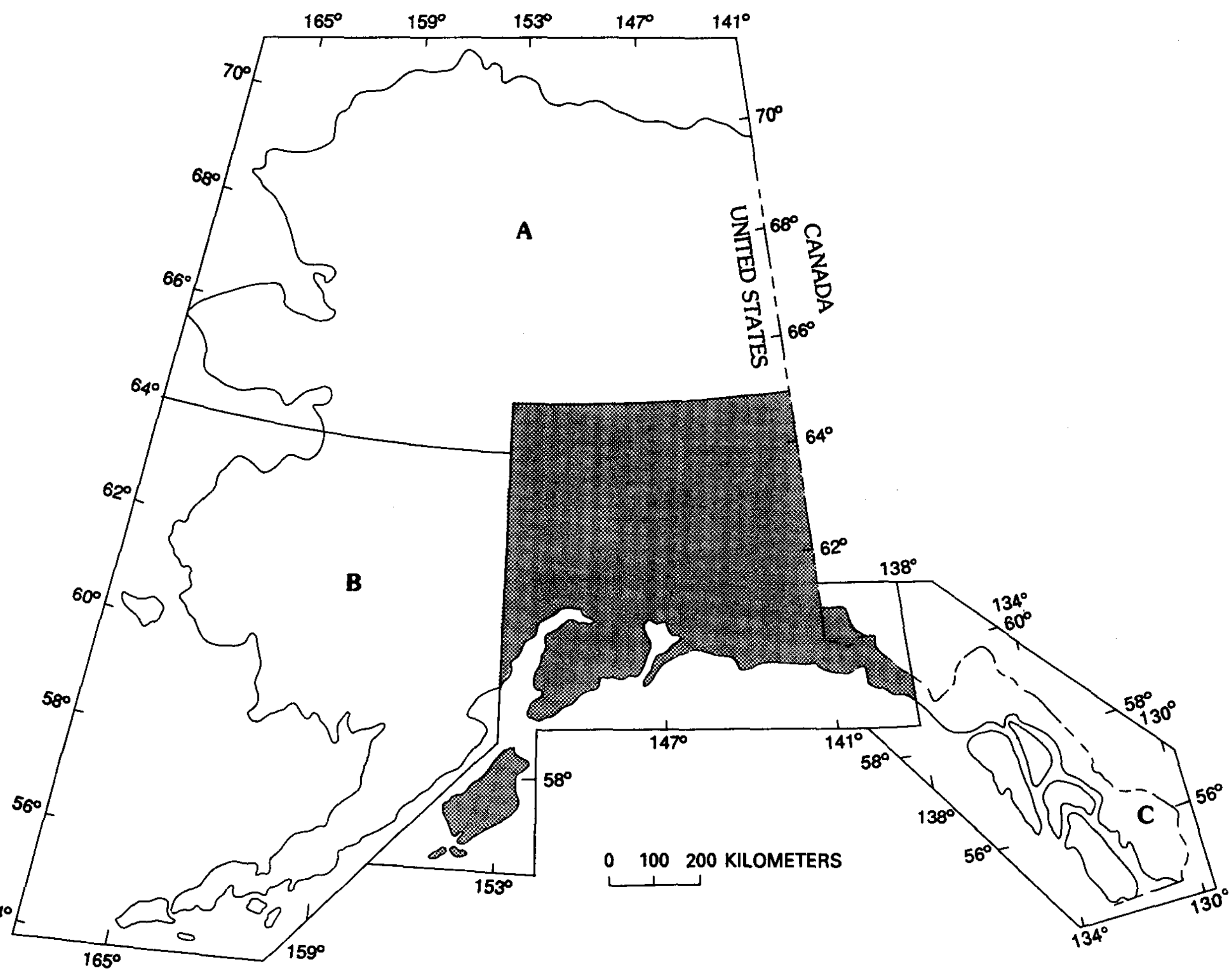

FIGURE 1.—Map showing area of this report (shaded) and other reports in the series of metamorphic studies of Alaska. A, Dusel-Bacon and others (1989); B, Dusel-Bacon, Doyle, and Box (in press); C, Dusel-Bacon, Brew, and Douglass (in press).

Units of the same metamorphic age or age range are generally discussed in order of increasing metamorphic grade.

Within the last two geographic areas, units are further subdivided into the lithotectonic terrane(s) of which they form a part. Except where otherwise indicated, the lithotectonic terrane designations west of long 141° are those proposed by Jones and others (1987) and the designations east of long 141° are those proposed by Monger and Berg (1987) (fig. 3). It should not be assumed that all authors of this report necessarily recognize the proposed terranes.

The metamorphic-facies determination scheme (fig. 4, table 1) on which the map (pl. 1) is based was developed by the Working Group for the Cartography of the Metamorphic Belts of the World (Zwart and others, 1967). This scheme is based on pressure- and temperature-sensitive metamorphic minerals that are petrographically identifiable by most geologists. Regionally metamorphosed rocks are divided into three facies groups based on increasing temperature: (1) laumontite and prehnite-pumpellyite facies (LPP), shown in shades of gray and tan; (2) greenschist facies (GNS), shown in shades of green; and (3) epidote-amphibolite and amphibolite facies (AMP), shown in shades of red and orange. Where possible, the greenschist-facies and the epidote-amphibolite- and amphibolite-facies groups are divided into three facies series on the basis of pressure. A high-, intermediate-, or low-pressure series is indicated by an H,

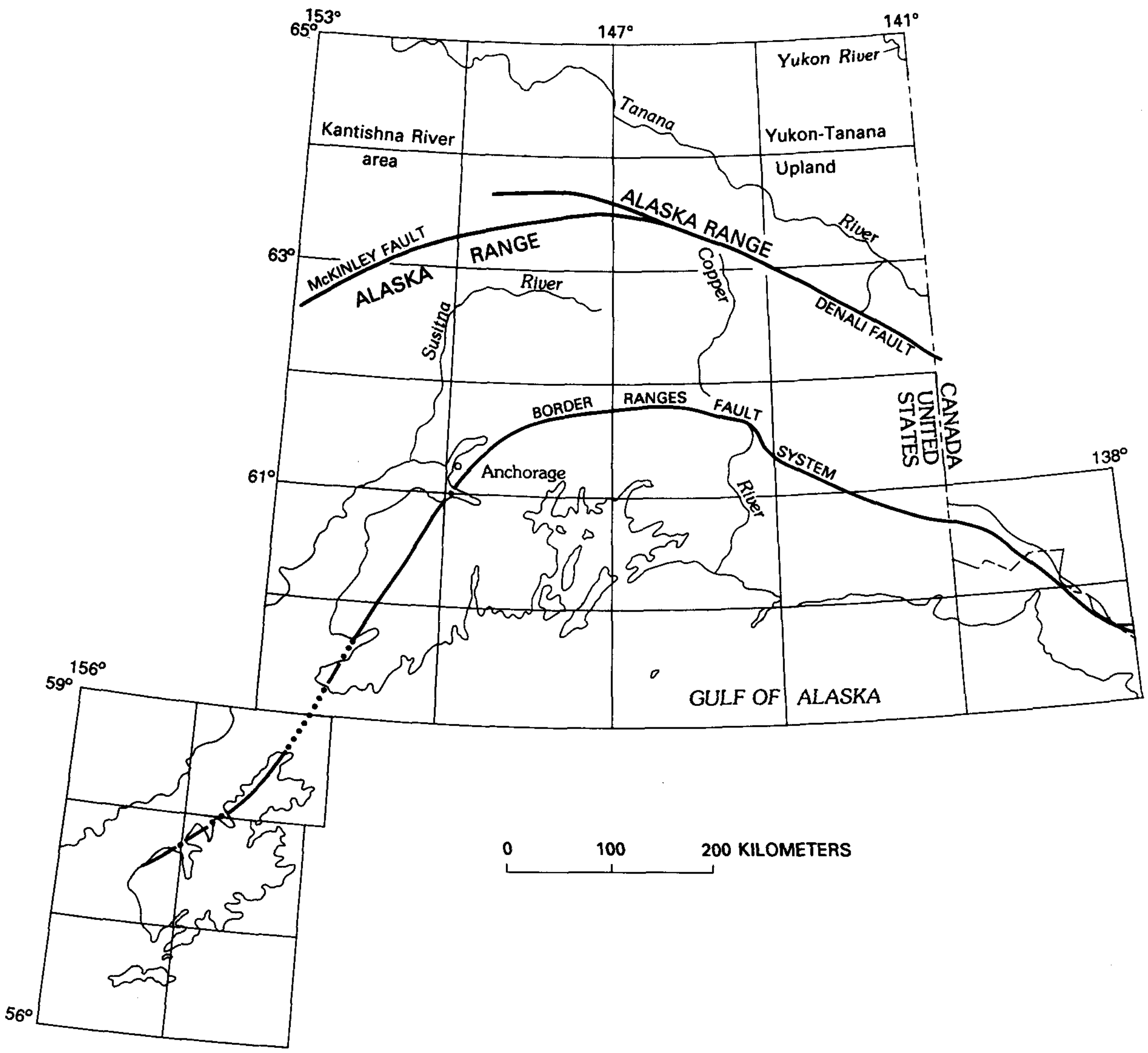

FIGURE 2.—Regional geographic areas in east- and south-central Alaska that are discussed in text. Boundaries of 1:250,000-scale quadrangles shown for reference. Fault dotted where covered by water.

I, or L in place of the final letter in the symbol used for the previously mentioned facies group. Transitional, intermediate-pressure greenschist- to high-pressure greenschist- (blueschist-) facies rocks are shown in blue and green diagonal stripes.

In this compilation, the scheme of Zwart and others (1967) is expanded. Specifically, combinations of letters and symbols are used to indicate metamorphic conditions transitional between different facies groups and series. Where the metamorphic grade of a unit is transitional between two facies groups or facies series, the lower grade or pressure designation is given first, and the two designations are separated by a slash. Where two facies groups occur together but have not been differentiated, the designation of the more abundant facies is given first, and the two designations are separated by a comma. As a further expansion, a symbol for either the met-

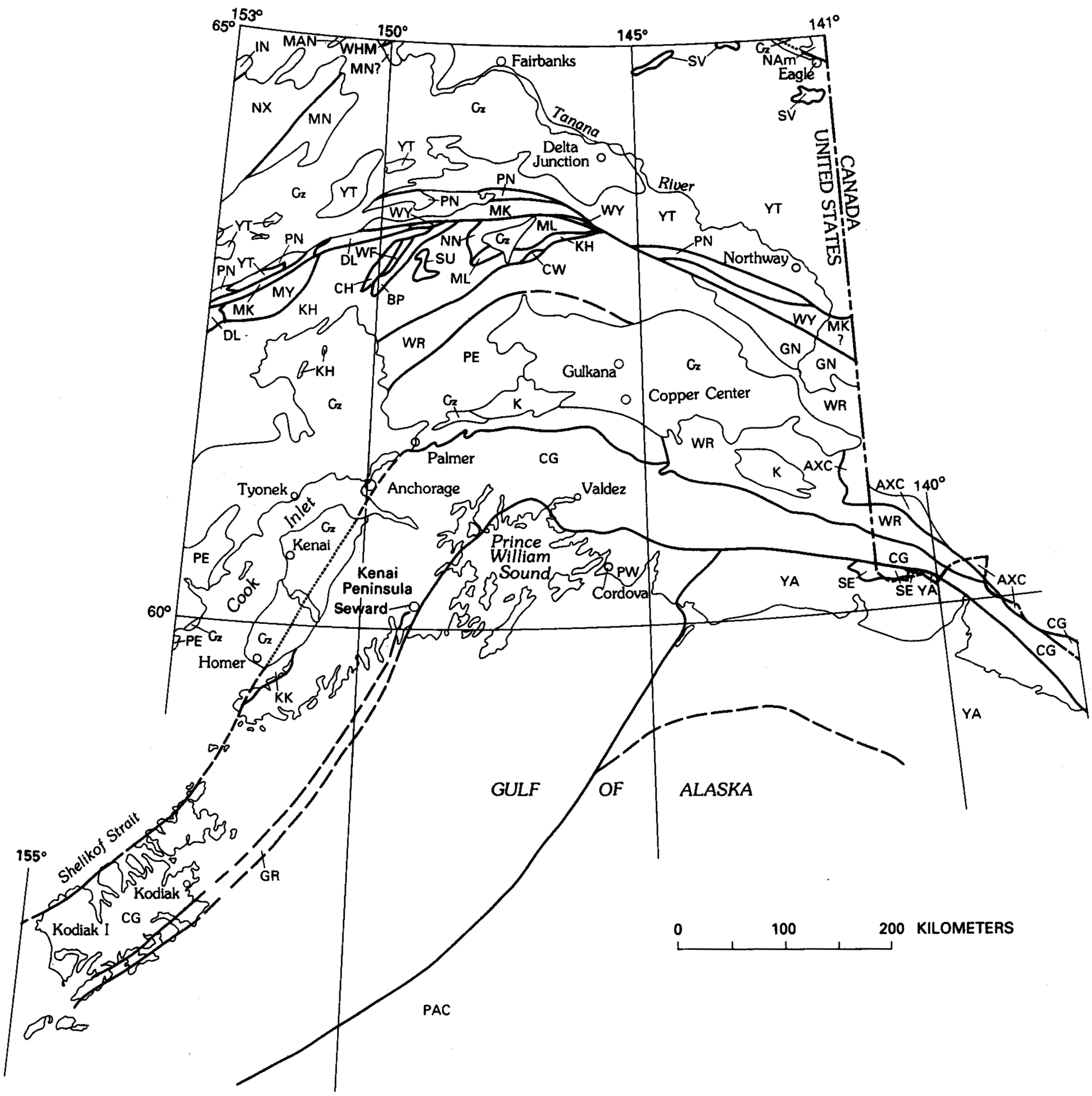

FIGURE 3.—Lithotectonic terrane map and abbreviated terrane names. West of long 141°, modified from Jones and others (1987); east of long 141°, from Monger and Berg (1987). Most, but not all, terranes shown are referred to in the text.

amorphic age or the minimum and maximum limits of the metamorphic age is given in parentheses following the facies symbol. Where two metamorphic episodes have affected the rocks, the symbol gives the facies and age of each metamorphic episode, beginning with the older episode. In several instances, numerical subscripts are used to differentiate between map units that have the same metamorphic grade and metamorphic age but that have different protoliths and are thought to have different metamorphic histories.

Protolith- and metamorphic-age designations are based on the Decade of North American Geology Geologic Time Scale (Palmer, 1983). Isotopic ages cited herein have been calculated or recalculated using the decay constants of Steiger and Jäger (1977).

Metamorphic mineral assemblages for most metamorphic-facies units (table 2) follow the detailed descriptions of the metamorphic units and are keyed to the metamorphic-mineral locality map (pl. 2).

General sources of metamorphic data used to compile the metamorphic facies map (pl. 1) are shown on figure 5. Complete citations for published sources are given in the references. Additional sources are referred to in the detailed unit descriptions.

EXPLANATION

——— Terrane-bounding fault–Dashed where approximately located; dotted where concealed beneath postaccretion Cenozoic deposits

——— Postaccretion or postamalgamation contact—Includes depositional faults and contacts that are not terrane boundaries

Terranes

AXC	Craig subterrane of Alexander terrane
BP	Broad Pass terrane
CG	Chugach terrane
CH	Chulitna terrane
CW	Clearwater terrane
DL	Dillinger terrane
GR	Ghost Rocks terrane
IN	Innoko terrane
KH	Kahiltna terrane
KK	Kachemak terrane
MAN	Manley terrane
MK	McKinley terrane
ML	Maclaren terrane
MN	Minchumina terrane
MY	Mystic terrane
NN	Nenana terrane
NX	Nixon Fork terrane
PE	Peninsular terrane
PN	Pingston terrane
PW	Prince William terrane
SE	Saint Elias terrane
SU	Susitna terrane
SV	Seventymile terrane
WF	West Fork terrane
WHM	White Mountains terrane
WR	Wrangellia terrane
WY	Windy terrane
YA	Yakutat terrane
YT	Yukon-Tanana terrane

OTHER SYMBOLS

Cz	Cenozoic deposits
GN	Gravina-Nutzotin belt
K	Upper Cretaceous deposit
NAm	North America
PAC	Pacific plate

FIGURE 3.—Continued

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SUMMARY OF THE METAMORPHIC HISTORY OF EAST- AND SOUTH-CENTRAL ALASKA

The metamorphic history of east- and south-central Alaska is best viewed in terms of the thermal and structural evolution of three separate, roughly east-west-trending areas that are separated by arcuate faults and primarily reflect the successive accretion of major terranes to the western margin of North America. The northern area is located north of the McKinley and Denali faults and includes the Kantishna River area, the Yukon-Tanana upland, and part of the Alaska Range. The central area is bordered by the McKinley and Denali faults to the north and the Border Ranges fault system to the south and includes part of the Alaska Range, the Talkeetna Mountains, and the Wrangell Mountains. The southern area is located seaward of the Border Ranges fault system and includes the Kodiak, Kenai, Chugach, and Saint Elias Mountains.

Within the northern area, the age and origin of regional low-grade metamorphism in the Kantishna River area is poorly known; metamorphism is bracketed between the middle Paleozoic age of the youngest protoliths and the Cretaceous and (or) Tertiary age of postmetamorphic granitoids. Metamorphism throughout the Yukon-Tanana upland predates the widespread intrusion of undeformed mid-Cretaceous granitoids. Many of the metamorphic-unit boundaries in the Yukon-Tanana upland are also terrane or subterrane boundaries that are defined by low-angle faults. Metamorphic grade changes abruptly across many of the faults, which indicates that major metamorphism predated final emplacement of the fault-bounded units. Some of the low-angle faults place higher grade over lower grade rocks, whereas other faults place lower grade over higher grade rocks; this suggests a complex synmetamorphic or postmetamorphic structural evolution.

Near the United States-Canadian border in the central Yukon-Tanana upland, metamorphism, plutonism, and thrusting occurred during a latest Triassic and Early Jurassic event that presumably resulted from the accretion of a terrane that had affinities to the Stikinia terrane onto the continental margin of North America. Elsewhere in the Yukon-Tanana upland, metamorphic rocks give predominantly late Early Cretaceous isotopic ages. These ages are interpreted to date either the timing of a subsequent Early Cretaceous episode of crustal thickening and metamorphism or, assuming that these areas were also originally heated during the latest Triassic to Early Jurassic and remained buried, the timing of their uplift and cooling, perhaps as a result of extension.

South of the Tanana River, most metamorphic rocks yield Early Cretaceous isotopic ages, similar to those determined for the contiguous Yukon-Tanana terrane to the north. A polymetamorphic and polydeformational history has been proposed for two units of the Yukon-Tanana terrane within the Alaska Range. In the western part of the Alaska Range near the McKinley River, the first metamorphic episode occurred under greenschist- to amphibolite-facies conditions and was associated with the development of northwest-trending folds. The second metamorphic episode occurred under lower greenschist-facies conditions and was synchronous with the development of northeast-trending folds and

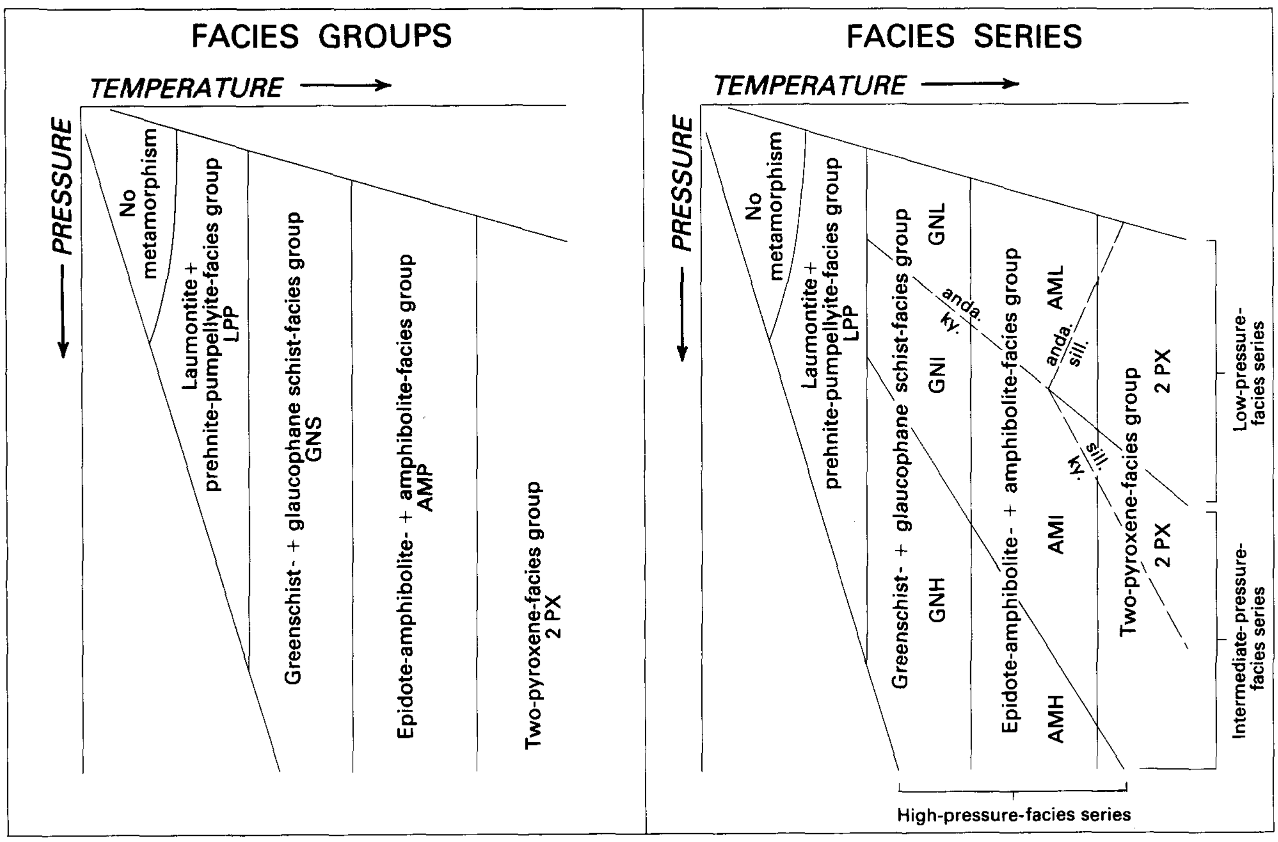

FIGURE 4.—Schematic representation of metamorphic-facies groups and series in pressure-temperature space and their letter symbols used in this report (modified from Zwart and others, 1967). Stability fields of Al_2SiO_5 polymorphs andalusite (anda.), kyanite (ky.), and sillimanite (sill.) shown by dashed lines.

TABLE 1.—*Scheme for determining metamorphic facies*

[Modified from Zwart and others, 1967]

Facies symbol	Diagnostic minerals and assemblages	Forbidden minerals and assemblages	Common minerals and assemblages	Remarks
		LAUMONTITE AND PREHNITE-PUMPELLYITE FACIES		
LPP	Laumontite + quartz, prehnite + pumpellyite.	Pyrophyllite, analcime + quartz, heulandite.	"Chlorite", saponite, dolomite + quartz, ankerite + quartz, kaolinite, montmorillonite, albite, K-feldspar, "white mica".	Epidote, actinolite, and "sphene" possible in prehnite-pumpellyite facies.
		GREENSCHIST FACIES		
GNS		Staurolite, andalusite, cordierite, plagioclase (An>10), laumontite + quartz, prehnite + pumpellyite.	Epidote, chlorite, chloritoid, albite, muscovite, calcite, dolomite, actinolite, talc.	
		Low- and intermediate-pressure greenschist facies		
GNL and GNI		Hornblende, glaucophane, crossite, lawsonite, jadeite + quartz, aragonite.		Biotite and manganiferous garnet possible; stilpnomelane mainly restricted to intermediate-pressure greenschist facies.
		High-pressure greenschist (blueschist) facies		
GNH	Glaucophane, crossite, aragonite, jadeite + quartz.		Almandine, paragonite, stilpnomelane.	Subcalcic hornblende (barroisite) may occur in highest temperature part of this facies.
		Low-temperature subfacies of high-pressure greenschist facies		
GNH (with stipple, pl. 1)	Above minerals plus pumpellyite and (or) lawsonite.			
		EPIDOTE-AMPHIBOLITE AND AMPHIBOLITE FACIES		
AMP	Staurolite.	Orthopyroxene + clinopyroxene, actinolite + calcic plagioclase + quartz, glaucophane.	Hornblende, plagioclase, garnet, biotite, muscovite, diopside, K-feldspar, rutile, calcite, dolomite, scapolite.	
		Low-pressure amphibolite facies		
AML	Andalusite + staurolite, cordierite + orthoamphibole.	Kyanite.	Cordierite, sillimanite, cummingtonite.	Pyralspite garnet rare in lowest possible pressure part of this facies.
		Intermediate- and high-pressure amphibolite facies		
AMI and AMH	Kyanite + staurolite.	Andalusite.		Sillimanite mainly restricted to intermediate-pressure amphibolite facies.
		TWO-PYROXENE FACIES		
2PX	Orthopyroxene + clinopyroxene.	Staurolite, orthoamphibole, muscovite, epidote, zoisite.	Hypersthene, clinopyroxene, garnet, cordierite, anorthite, K-feldspar, sillimanite, biotite, scapolite, calcite, dolomite, rutile.	Hornblende possible. Kyanite may occur in higher pressure part of this facies and periclase and wollastonite in low-pressure part.

with low-grade metamorphism in the adjacent metamorphic unit.

An eastward-increasing metamorphic sequence developed during Early(?) to Late Cretaceous time within several relatively small terranes that crop out in the Alaska Range just north of the McKinley fault. Metamorphism in that area may have been related to the accretion of the Peninsular and Wrangellia segments of a composite terrane, which was composed of the Peninsular, Wrangellia, Alexander, and northern Taku terranes in mid- to Late Cretaceous time (Csejtey and others, 1982; Nokleberg and others, 1985a). This composite terrane, defined by Plafker and others (1989), is herein referred to as the southern Alaska composite terrane.

Within the central area, bounded by the McKinley and Denali faults to the north and the Border Ranges fault system to the south, medium-grade metamorphism occurred across much of the southern Peninsular and Wrangellia terrane segments of the southern Alaska composite terrane. This metamorphic episode was early to synkinematic with the in-

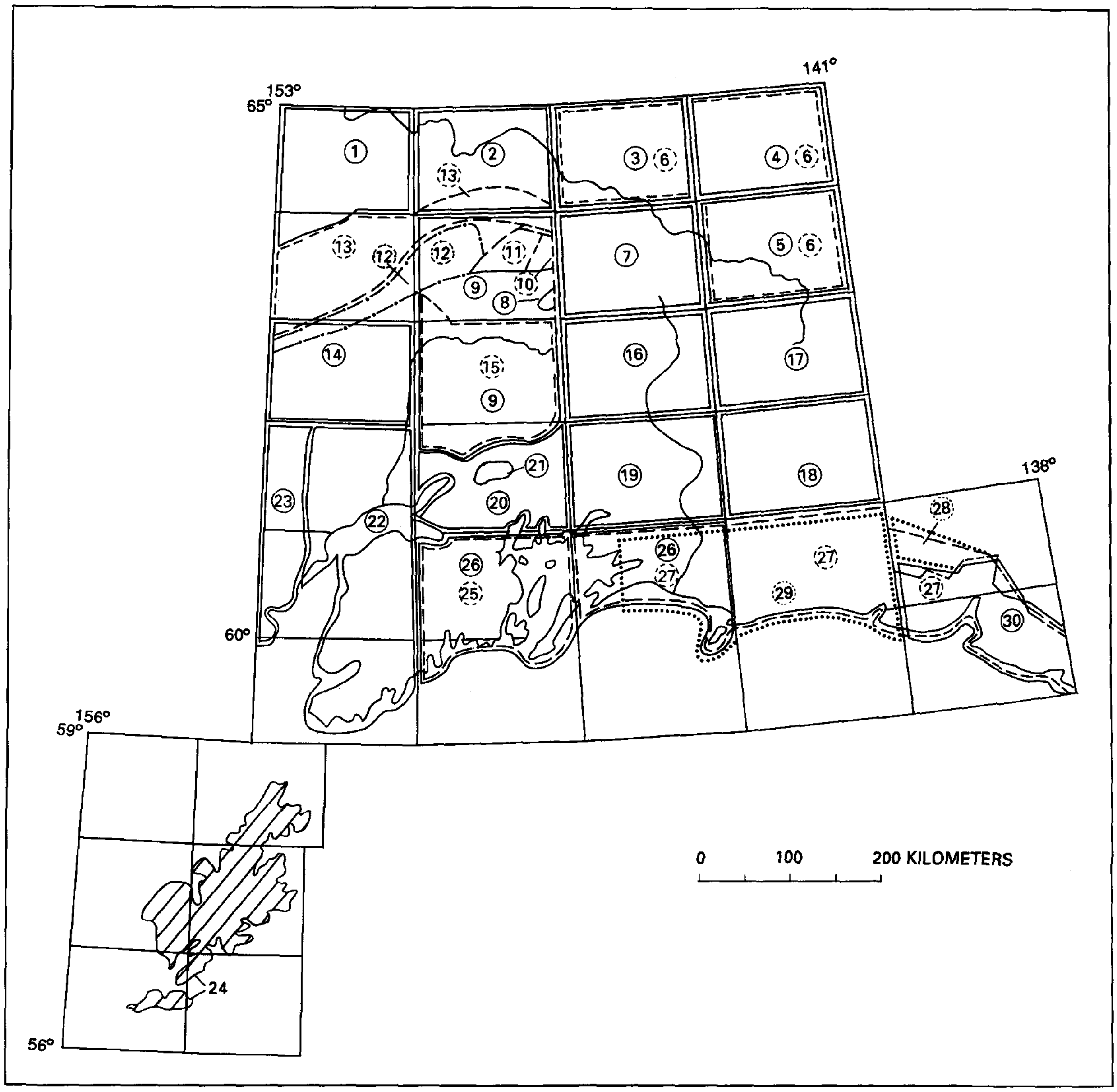

FIGURE 5.—General sources of metamorphic data for the metamorphic facies map of east- and south-central Alaska (pl. 1). Numbers refer to sources of data listed in explanation. Boundaries of 1:250,000-scale quadrangles shown for reference. Ring patterns around numbers correspond to boundary patterns used to delineate that area.

trusion of tonalitic and granodioritic plutons of primarily Early and Middle Jurassic age in the Peninsular terrane and Late Jurassic age in the Wrangellia terrane. The parts of the Jurassic metamorphic and plutonic complex that crop out near the Border Ranges fault system were subsequently retrograded and deformed in Cretaceous and early Tertiary time during the accretion of the younger Chugach terrane to the south. North of the Jurassic metamorphic and plutonic complex, low-grade metamorphism affected the rest of the Wrangellia terrane sometime during Jurassic and (or) Cretaceous time.

North of the Wrangellia terrane and immediately south of the McKinley and Denali faults, flyschoid rocks, which were deposited within a basin that separated the Wrangellia terrane from the western margin of North America, form a northeastward-tapering wedge. Low-grade metamorphism and intense deformation affected the flysch and structurally interleaved tectonic fragments within the western half of the wedge sometime during mid- to Late Cretaceous time. Low- to medium-grade intermediate-pressure (Barrovian) metamorphism took place in the eastern half of the wedge. Metamorphism and deformation of the intermediate-pressure sequence, referred to as the Maclaren metamorphic belt, was

EXPLANATION

1. R.M. Chapman and S.L. Douglass, unpublished metamorphic facies map
2. Péwé and others (1966); Forbes and Weber, 1982
3. Weber and others (1978)
4. Foster (1976)
5. Foster (1970)
6. H.L. Foster, unpublished metamorphic facies map
7. W.J. Nokleberg, unpublished metamorphic facies map; Nokleberg and others (1985a)
8. Smith (1981)
9. Béla Csejtey, Jr., unpublished metamorphic facies map
10. Brewer (1982)
11. Sherwood (1979)
12. Jones and others (1983)
13. T.K. Bundtzen, unpublished metamorphic facies map
14. Reed and Nelson (1980)
15. Csejtey and others (1978)
16. W.J. Nokleberg, unpublished metamorphic facies map
17. Richter (1976); D.H. Richter, unpublished metamorphic facies map
18. MacKevett (1978)
19. Winkler and others (1981b); G.R. Winkler, unpublished metamorphic facies map
20. G.R. Winkler, unpublished geologic map
21. T.L. Pavlis, unpublished metamorphic facies map; Pavlis (1983)
22. Magoon and others (1976)
23. Reed and others (1983); Detterman and others, 1976
24. S.M. Roeske and J.C. Moore, unpublished metamorphic facies map
25. Tysdal and Case (1979)
26. M.L. Miller and S.W. Nelson, unpublished metamorphic facies map
27. George Plafker, unpublished metamorphic facies map
28. Campbell and Dodds (1985)
29. Hudson and Plafker (1982)
30. Hudson and others (1977b)

FIGURE 5.—Continued

synkinematic with the Late Cretaceous to earliest Tertiary intrusion of foliated plutons of intermediate composition. Metamorphism extended into the early Tertiary and was accompanied by rapid uplift and cooling. Metamorphism throughout the wedge was probably associated with the accretion of the outboard Wrangellia terrane.

The southern area, which lies south of the Border Ranges fault system, is composed of variably metamorphosed sequences of oceanic rocks that comprise the successively accreted Chugach, Yakutat, Ghost Rocks, and Prince William terranes. The Chugach terrane lies between the steeply dipping to north-dipping Border Ranges and Contact fault systems. It comprises three successively accreted sequences of differing metamorphic histories that are separated by vertical- to north-dipping faults. Metamorphism in all the sequences was associated with north-directed underthrusting beneath either the combined Peninsular-Wrangellia terrane or the older and inner parts of the Chugach terrane. The innermost sequence is a discontinuous belt of transitional intermediate-pressure greenschist-facies to high-pressure greenschist- (blueschist-) facies metabasalt, metachert, and metasedimentary rocks that were metamorphosed during Early and Middle Jurassic time. Strongly sheared rocks within the parts of this unit near the Tazlina glacier and adjacent to the Copper River yield late Early Cretaceous K-Ar mineral ages that probably indicate partial resetting of Jurassic isotopic ages during emplacement of the adjacent seaward mélange complex (Plafker and others, 1989).

The middle sequence of the Chugach terrane is a prehnite-pumpellyite-facies mélange complex that consists of oceanic sedimentary and igneous rocks and offscraped fragments of continental margin or older subduction assemblages. Initial metamorphism and deformation of the mélange complex probably occurred during active underthrusting within an accretionary prism and was followed by late fracturing and cataclasis during uplift of the complex. Accretion of the mélange complex postdates the Late Triassic age of the oldest matrix in the mélange and may have taken place over a long time span that extended throughout the Jurassic and into the Late Cretaceous.

The outermost and most extensive part of the Chugach terrane is an accretionary prism made up of uppermost Cretaceous metamorphosed flysch and metavolcanic rocks. These rocks underwent prehnite-pumpellyite- to lower greenschist-facies low-pressure metamorphism that probably accompanied north-directed underthrusting beneath the older and inner parts of the Chugach accretionary prism and the combined Peninsular and Wrangellia terranes during latest Cretaceous to early Tertiary time. In the eastern Chugach Mountains, these rocks were subsequently affected by low-pressure amphibolite-facies metamorphism that accompanied widespread intrusion during Eocene time. A similar low-pressure-facies series also developed within mélange and flysch of the Yakutat terrane; these rocks are also intruded by Eocene plutons and are correlated with similar rocks of the Chugach terrane.

South of the Contact fault system, the deep-sea metasedimentary rocks and oceanic metavolcanic rocks of the Ghost Rocks and Prince William terranes were strongly deformed and weakly metamorphosed under prehnite-pumpellyite-facies conditions. Metamorphism and deformation occurred in early Tertiary time, not long after the youngest strata were deposited, and probably took place during underthrusting of these terranes beneath the Chugach terrane. Metamorphism predated, perhaps by very little, the intrusion of the early Tertiary plutons that stitch the Ghost Rocks and Prince William terranes to the Chugach terrane landward of them.

DETAILED DESCRIPTION OF METAMORPHIC MAP UNITS

AREA NORTH OF THE McKINLEY AND DENALI FAULTS

KANTISHNA RIVER AREA (NIXON FORK, MINCHUMINA, AND WHITE MOUNTAINS TERRANES)

GNS (eKMPz)

The phyllite, greenschist, pelitic schist, quartzite, calcareous schist, greenstone, and metalimestone of Proterozoic(?) to middle(?) Paleozoic age that compose this unit are included in the Nixon Fork terrane. These rocks crop out in the western Kantishna River quadrangle, where rocks of pelitic composition typically contain chlorite, quartz, white mica, and, locally, calcite, epidote, and actinolite. More varied and diagnostic metamorphic mineral assemblages have been described for correlative rocks to the southwest in the Ruby, Nulato, and Ophir quadrangles (Dusel-Bacon and others, 1989; Dusel-Bacon, Doyle, and Box, in press).

Metamorphism is known to postdate the middle(?) Paleozoic protolith age of the youngest rocks and predate the Cretaceous or Tertiary intrusive age of crosscutting granitoids. On the basis of geologic reasoning, the age and origin of metamorphism of this unit may be related to Late Jurassic to Early Cretaceous tectonic overthrusting of oceanic rocks, which were rooted in the Yukon-Koyukuk basin, onto the Precambrian and Paleozoic rocks of the Ruby geanticline (Patton and others, 1977).

LPP (lKD)

This unit comprises an undifferentiated assemblage of weakly metamorphosed Ordovician through Devonian argillite, shaly, slaty, or phyllitic mudstone, semischist, and quartzite; Devonian metalimestone; and complexly folded Ordovician through Devonian(?) metachert and minor argillite that crops out in and adjacent to the Kantishna River quadrangle (Chapman and Yeend, 1981). These rocks are included in the Nixon Fork, White Mountains, and Minchumina terranes. Bulk compositions are not suitable for the development of metamorphic mineral assemblages that have easily definable P-T ranges, but the development of quartz, chlorite, white mica, albite, and locally zoisite, as well as a semischistose fabric in some rocks, suggests low-grade metamorphic conditions of the prehnite-pumpellyite facies. The age of metamorphism is bracketed between the Devonian protolith age of the youngest rocks and the early Late Cretaceous (91-Ma) age of a granitoid that crops out near the northwest margin of the shaly rocks and probably intrudes that unit (Silberman and others, 1979).

YUKON-TANANA UPLAND (YUKON-TANANA AND SEVENTYMILE TERRANES)

AMH,I (eJIT̶R)

This unit comprises intermediate-pressure amphibolite-facies biotite gneiss and schist, amphibolite, marble, quartzite, metachert, and pelitic schist. Poorly preserved crinoid columnals indicate a Paleozoic age for at least some of the sedimentary protoliths. The rocks are well foliated; they were first deformed into northeast-trending isoclinal recumbent to vertical folds, and later they were deformed into north-trending open folds (Foster and others, 1985).

These rocks are in fault contact with the adjacent metamorphic units, and they are intruded by latest Triassic to earliest Jurassic plutons (Taylor Mountain batholith) and by Cretaceous plutons. Foster and others (1987a) assign the rocks of this unit to a subterrane (Y4) of the Yukon-Tanana terrane and postulate that the rocks could either be a part of the Stikinia terrane of Jones and others (1984, 1987) or, more likely, a comparable but different part of the composite Terrane I of Monger and others (1982) that includes the Stikinia terrane and that was accreted to the margin of North America. Correlation with the Stikinia terrane is based on the fact that the latest Triassic to earliest Jurassic granitoids that intrude this unit are similar in age to those in the Stikinia terrane of Yukon Territory, Canada (Tempelman-Kluit, 1976; Jones and others, 1984). Plutons of this age are not known to occur in any other part of the Yukon-Tanana terrane in Alaska. More recently, these metamorphic and plutonic rocks have been assigned to the Teslin-Taylor Mountain terrane by Hansen (1990).

Garnet is a common constituent of many rocks. Amphibolite commonly contains the assemblage hornblende+calcic plagioclase+epidote+sphene±biotite±garnet±chlorite±quartz. Most schists and gneisses are fairly quartzose and contain quartz+plagioclase+biotite±epidote±garnet±white mica±amphibole. Pelitic rocks are fairly rare, but where these rocks occur a common mineral assemblage is quartz+white mica+biotite±plagioclase±staurolite±garnet±kyanite.

Geothermobarometric analysis of rocks from this unit indicates high- to intermediate-pressure and medium temperature conditions during metamorphism. Application of multiple geobarometers and geothermometers yields the following results: biotite-garnet amphibolite, 10 to 12.5 kb, 635° to 685°C, and 7 to 10 kb, 560 to 645°C; staurolite-kyanite-garnet-quartz schist, 6 to 7 kb, 560 to 605°C (Dusel-Bacon and Douglass, 1990; Dusel-Bacon and Hansen, 1992).

Metamorphism of this unit was part of a Late Triassic through Early Jurassic orogenic episode that consisted of metamorphism, plutonism, folding, and thrusting and affected the Y4 subterrane in the eastern part of the Yukon-Tanana upland (Cushing and others, 1984; Foster and others, 1985; Hansen, 1990). Timing of these events is based on $^{40}Ar/^{39}Ar$ incremental-heating experiments. Amphibolite-facies metamorphism reached its peak about 213±2 Ma, synmetamorphic intrusion of the Taylor Mountain batholith (unit JŦRg) followed at about 209±3 Ma, and cooling took place over a period of about 36 m.y. years (Cushing and others, 1984). Northward thrusting (along south-dipping faults within unit AMH,I (eJIŦR) and by inference also along the fault that separates this unit from unit GNS (eKPz) to the north) of the amphibolite-facies rocks and obduction of low-grade oceanic rocks (units LPP/GNS (eJIŦR) and MzPzu) onto units AMH,I (eJIŦR) and GNS (eKPz) took place during cooling and was over by about 185 Ma, as indicated by a $^{40}Ar/^{39}Ar$ integrated plateau age of 187±2 Ma on biotite formed within a thrust zone (Cushing and others, 1984; Foster and others, 1985). Rapid uplift and cooling during accretion is indicated by two $^{40}Ar/^{39}Ar$ mineral pairs from garnet-biotite amphibolite gneiss from the central area of unit AMH,I (eJIŦR), which give ages of 188 Ma (hornblende) and 186 Ma (biotite), and nearby of 187 Ma (hornblende) and 185 Ma (biotite) (Hansen and others, 1991). These near-coincident mineral-pair ages suggest a rapid cooling rate of about 100°C/m.y. from 500 to 300°C from both localities.

All these related events occurred as a result of subduction beneath a northeast-facing arc developed on a continental fragment (Stikinia), subsequent closure of the intervening ocean basin that separated the arc from the western margin of North America, and accretion of the arc and fragments of the ocean basin onto the North American margin (Tempelman-Kluit, 1979; Monger and others, 1982; Foster and others, 1985; Hansen, 1990). Hansen (1990), Hansen and others (1992), and Dusel-Bacon and Hansen (1992) propose that the rocks of this unit were metamorphosed within the south- to southwest-dipping subduction system that separated the outboard composite terrane, of which this unit formed a part, from underlying parautochthonous North America. Some workers (Hansen, 1990; Hansen and others, 1991; and Dusel-Bacon and Hansen, 1992) interpret the adjacent unit AMP (eK), described below, which lies to the south of unit AMH,I (eJIŦR), as part of the North American footwall plate, and propose that high-pressure metamorphism documented in at least the eastern part of unit AMP (eK) occurred during imbrication of the North American margin and continentward overthrusting of the accreted terrane in Early Jurassic time. Early Cretaceous cooling ages recorded in the eastern part of unit AMP (eK) are interpreted to date the time of unroofing of lower plate rocks caused by crustal extension (Hansen, 1990; Hansen and others, 1991; and Dusel-Bacon and Hansen, 1992). It is on this basis that the ductile shear zone that separates unit AMH,I (eJIŦR) from unit AMP (eK) is shown as a low-angle normal fault (pl. 1)

GNS (eJIŦR)

This unit includes primarily quartz-chlorite-white mica schist, quartz-actinolite schist, feldspar quartz-sericite schist containing minor interlayered phyllite, calcareous schist, and mafic and felsic metavolcanic rocks. These rocks are included in the Yukon-Tanana terrane. Protolith ages are unknown but they are probably Paleozoic. In the southeastern Eagle quadrangle, unit GNS (eJIŦR) structurally overlies a sequence of greenschist-facies rocks (unit GNS (eKPz)) characterized by carbonaceous quartzite and is structurally overlain by thrust sheets of amphibolite-facies rocks (unit AMH,I (eJITR)) and ultramafic rocks (unit MzPzu) (Foster and others, 1985, 1987a). Farther to the south, in the eastern Tanacross quadrangle, we interpret unit GNS (eJITR) to structurally overlie unit AMP (eK) along a low-angle normal fault.

Metamorphic mineral assemblages generally contain combinations of chlorite, quartz, white mica, and albite and less commonly contain actinolite and epidote; biotite occurs locally in the Tanacross quadrangle. Foliation is well developed and rocks are multiply folded and commonly lineated. Mylonitic and partly to completely recrystallized mylonitic textures, which are characterized by porphyroclastic quartz augen, are common in these rocks and attest to their complex structural history.

These rocks are correlated with the Klondike Schist of McConnell (1905) and unit B of Green (1972) that crop out across the Canadian border (Foster, 1970; Green, 1972; Foster and others, 1985). A Late Triassic to Early Jurassic metamorphic age is suggested by a 175±14-Ma K-Ar muscovite age (Tempelman-Kluit and Wanless, 1975) and by a 202±11-Ma Rb-Sr whole rock age (Metcalfe and Clark, 1983) determined for the Klondike Schist in Canada. Metamorphism of this unit may have been part of the Late Triassic through Early Jurassic orogenic episode that consisted of metamorphism, plutonism, folding, and thrusting that affected the rocks in the eastern part of the Yukon-Tanana upland (Cushing and others, 1984; Foster and others, 1985, 1987a; Hansen, 1990).

LPP/GNS (eJITR)

The weakly to moderately metamorphosed, massive, and locally pillowed greenstone and associated metasedimentary and metavolcanic rocks, including argillite, metatuff, quartz-sericite schist, quartz-actinolite schist, quartzite, carbonaceous metalimestone, metachert, and metagraywacke (Foster, 1970, 1976; Foster and others, 1987a; Weber and others, 1978), that make up this unit are included in the Seventymile terrane. Most protolith ages are unknown, but conodonts and radiolarians of Permian age occur in weakly metamorphosed chert in the Big Delta quadrangle (Weber and others, 1978), and radiolarians of Mississippian age, brachiopods of Permian age, and conodonts of Triassic age occur in the northern Eagle quadrangle (Foster, 1976; Foster and others, 1987a). This unit consists of a number of isolated thrust remnants that are themselves broken by internal high-angle and thrust faults. Greenstone, metachert, and metavolcanic rocks are associated with ultramafic and gabbroic rocks (unit MzPzu). In the north-central part of the Eagle quadrangle, this entire package of rocks is considered to be part of a dismembered ophiolitic assemblage (Keith and others, 1981).

Metamorphic grade differs between individual thrust remnants. Greenstone in the Eagle quadrangle contains prehnite+pumpellyite+albite±epidote±chlorite±white mica±quartz in the northernmost exposure of this unit, and it contains chlorite+albite+epidote+pumpellyite+calcite+sphene+ironoxides and chlorite+albite+epidote+actinolite+calcite elsewhere in the quadrangle. Glaucophane+epidote+zoisite+garnet+albite+chlorite+white mica+sphene+chloritoid+hematite+calcite occurs in a small exposure of metabasalt just south of the Tintina fault in the Eagle quadrangle (Keith and others, 1981). Greenstone in the Big Delta quadrangle is characterized by light-green to bluish-green amphibole and minor epidote, zoisite, chlorite, sericite, and sphene (Weber and others, 1978), indicating that it was metamorphosed under the slightly higher temperature conditions that are characteristic of the greenschist facies. Metasedimentary rocks in all areas generally contain white mica and quartz together with various combinations of chlorite, plagioclase, epidote, actinolite, carbonaceous material, and calcite.

Metamorphic mineral assemblages indicate temperature conditions were transitional between those of the prehnite-pumpellyite facies and the greenschist facies. In the Eagle quadrangle, the coexistence of prehnite and pumpellyite in one area indicates a possible range in temperature between about 200 and 300°C; the more widespread occurrence of coexisting pumpellyite and epidote and epidote and actinolite indicates that temperatures were more likely in the low 300°C range (Nitsch, 1971). In other areas, particularly in the Big Delta quadrangle, the absence of prehnite and pumpellyite and the presence of epidote and actinolite indicates metamorphic temperatures were greater than about 350°C (Nitsch, 1971).

An Early Jurassic metamorphic age is indicated by a 201±5-Ma $^{40}Ar/^{39}Ar$ integrated plateau age on actinolite from greenstone in the southeastern Eagle quadrangle near Chicken (G.W. Cushing, unpub. data, 1984). Metamorphism of these low-grade rocks may have begun in latest Triassic time and may have been part of the Late Triassic through Early Jurassic tectonic and thermal episode that resulted in metamorphism of unit AMH,I (eJITR) (Cushing and others, 1984). The lithology of unit LPP/GNS (eJITR) and its association with ultramafic rocks (unit MzPzu) suggest that it formed in an ocean basin that may have separated either a subterrane of the Yukon-Tanana terrane (Foster and others, 1985, 1987a) or the margin of North America from a terrane(s) to the south or southeast that included unit AMH,I (eJIT̄R). As the ocean basin closed, remnants of the telescoped ocean basin were obducted southward onto the rocks of unit AMH,I (eJIT̄R), where they were affected by the late stages of the Late Triassic to Early Jurassic metamorphic episode. Other parts of the telescoped ocean basin were thrust northward (Foster and others, 1985, 1987a). The outcrop of glaucophane-bearing greenstone probably is part of a fault sliver that was dragged to a greater depth in a subduction zone or transpressive boundary along the convergent margin.

LPP (eKPz)

The small part of this unit that crops at the northern edge of the Big Delta quadrangle consists of incipiently metamorphosed dark-gray quartzite, argillite, and phyllite (Weber and others, 1978). In the adjacent Circle quadrangle, just north of the area discussed in this report, the extension of this unit includes these rock types as well as calcareous phyllite, metalimestone, and medium- to coarse-grained grit and quartzite (Foster and others, 1983). Protoliths are Proterozoic and (or) Paleozoic in age. Most rocks are thin layered but some quartzites are massive; argillite is locally slaty. This unit makes up the northern, lowest grade part of one of the thrust sheets within the Yukon-Tanana terrane (Foster and others, 1987a). The southern boundary between this unit and the slightly higher grade (undifferentiated prehnite-pumpellyite- and greenschist-facies) rocks that compose the rest of this thrust sheet is located only approximately.

In general, the rocks of this unit are poorly exposed and have bulk compositions that are inappropriate for the development of diagnostic P-T- (pressure-temperature-) sensitive mineral assemblages. Metamorphic minerals in quartzose rocks include quartz, white mica, chlorite, and calcite; calcareous phyllite contains the assemblage quartz+calcite+white mica+magnesium–chlorite±plagioclase. Vitrinite reflectance measurements on dark-gray quartzite and phyllite in correlative rocks in the Circle quadrangle to the north indicate temperatures of 180±50 and 230±50°C (Laird and others, 1984).

Metamorphism of this unit occurred sometime during Paleozoic to Early Cretaceous time. A Paleozoic maximum metamorphic age is proposed on the basis of the probable age of the youngest protoliths. A late Early Cretaceous minimum metamorphic age is established by the fact that metamorphism in the Yukon-Tanana upland predates the late Early Cretaceous intrusion of the oldest postmetamorphic plutons that intrude the region. Metamorphism also predates the emplacement of several thrust sheets of differing metamorphic grade, including the one in which this unit occurs (Foster and others, 1987a). These thrust sheets are considered by Foster and her coworkers (1987a) to be subterranes of the Yukon-Tanana terrane. With the exception of the area near the United States-Canadian border in which thrusting occurred during Early Jurassic time as a late stage of the Late Triassic to Early Jurassic metamorphic episode that occurred in that area (discussed above), timing of thrusting in the rest of the Yukon-Tanana upland is unknown. A maximum age of thrusting is provided by the early Tertiary age of plutons that stitch the faults. Thrusting probably also predates the intrusion of the postmetamorphic late Early Cretaceous plutons; although none of these plutons is known to stitch the thrust faults, these plutons do occur in many different thrust sheets.

Low-grade metamorphism of this unit may have been caused by burial due to overthrusting of this unit and its slightly higher grade equivalent (unit LPP,GNS (eKPz)) by greenschist-facies semischist (unit GNS (eKPz)) sometime between Paleozoic and late Early Cretaceous time. An Early Cretaceous age of metamorphism is considered likely for this unit on the basis of two K-Ar age determinations from its higher grade equivalent, discussed immediately below.

LPP,GNS (eKPz)

The undifferentiated prehnite-pumpellyite- and greenschist-facies dark-gray quartzite, argillite, phyllite, calcareous phyllite, and minor metalimestone (Weber and others, 1978) that compose this unit crop out primarily in the Big Delta quadrangle. They make up the major part of the thrust sheet of low-grade rocks within the Yukon-Tanana terrane; the previously described metamorphic unit also forms a part of this thrust sheet (Foster and others, 1987a). Protoliths are Proterozoic and (or) Paleozoic in age.

Characteristic metamorphic mineral assemblages in these rocks are quartz+white mica+chlorite± feldspar and rarely biotite and garnet in pelitic rocks and calcite+quartz+mica±chlorite±epidote±sphene in impure metalimestone. Parts of this unit are commonly thermally upgraded near contacts with

Tertiary intrusions. The presence of biotite and garnet locally in this unit can be attributed in part to contact metamorphism. However, some of the occurrences of these minerals may be due to regional metamorphism, indicating that locally metamorphic conditions reached those of the upper greenschist facies. Many rocks of this metamorphic unit contain mineral assemblages that are stable over a wide range of P-T conditions.

Paleozoic and Early Cretaceous metamorphic-age constraints are assigned to this unit on the basis of the same regional relations as those described above for unit LPP (eKPz). An Early Cretaceous metamorphic age is considered most likely at present on the basis of a K-Ar whole-rock age of 124.9 Ma on muscovite-quartz schist collected southeast of Fairbanks (W.J. Nokleberg and D.L. Turner, unpub. data, 1988) and a K-Ar age of 140 Ma on hornblende from schist collected from a deep drill hole on Eielson Air Force Base, also southeast of Fairbanks (Forbes and Weber, 1975).

GNS (eKPz)

The greenschist-facies quartz-chlorite-white mica schist, mylonitic schist, semischist, greenschist, quartzite, carbonaceous quartzite, marble, greenstone, phyllite, and graphitic schist (Weber and others, 1978; Foster, 1976) that make up this unit are considered to be one of several thrust sheets within the Yukon-Tanana terrane (Foster and others, 1987a). Greenstone and particularly marble are abundant in the northeastern part of this unit in the Eagle quadrangle. Fossils from the Eagle quadrangle (Foster, 1976) indicate that sedimentary protoliths are Paleozoic in age. No fossils have been found in this unit in the Big Delta quadrangle. A U-Pb analysis on zircon from a meta-andesite from the northeastern part of the Big Delta quadrangle yields an age of 375 Ma (Devonian) which is interpreted as the age of extrusion (J.N. Aleinikoff and W.J. Nokleberg, unpub. data, 1989).

With the exception of the more massive quartzite and greenstone, most rocks are well foliated, and the foliation has been folded at least once. Mylonitic textures are present to various degrees in most rocks. These textures are particularly well developed in schists in which fine-grained white mica, chlorite, and strained quartz are deflected around porphyroclasts (small augen) of quartz or potassium feldspar.

Characteristic metamorphic mineral assemblages are quartz+white mica+chlorite±feldspar±biotite±garnet in pelitic rocks; calcite+quartz±white mica±chlorite±epidote±sphene in impure marble; and plagioclase+chlorite+epidote±calcite±sphene in mafic rocks. Rocks are commonly thermally upgraded near contacts with Tertiary intrusions. Although most of the biotite and garnet present in this unit can be attributed to contact metamorphism, some of the occurrences of these minerals are due to regional metamorphism and indicate that, locally, metamorphic conditions reached those of the upper greenschist facies. Many rocks contain mineral assemblages that are stable over a wide range of P-T conditions, and some lowermost greenschist-facies or prehnite-pumpellyite-facies rocks may be included in this unit.

Paleozoic and Early Cretaceous metamorphic-age constraints are assigned to this unit on the basis of the same regional relations as those described above for unit LPP (eKPz). A minimum metamorphic age that is specific to the thrust sheet that constitutes this unit is provided by a 93-Ma K-Ar age on biotite from the pyroxene diorite that makes up the oldest dated undeformed pluton that intrudes this unit (Foster and others, 1979).

Recent structural and metamorphic study of this unit, during investigations of the Trans-Alaskan Crustal Transect (TACT) in the central Big Delta quadrangle, indicates that the low-grade, upper-plate metamorphic rocks of unit GNS (eKPz) are separated from high-grade, lower-plate metamorphic rocks (gneiss dome of unit AMP (eK)) by a low-angle ductile shear zone (Pavlis and others, 1988b, 1993). This juxtaposition of lower grade rocks of the hanging wall on higher grade rocks of the footwall suggests a major extensional episode that resulted in elimination of as many as 10 km of crustal section (Pavlis and others, 1993). Kinematic analysis of the ductile shear zone yields a consistent hanging-wall transport direction of east-southeast (Pavlis and others, 1988b, 1993), resulting in the map pattern on plate 1 in which the northwestern part of the ductile shear zone is shown as a thrust fault and the southeastern part as a low-angle normal fault. Final metamorphism of unit GNS (eKPz) probably accompanied ductile deformation during regional extension in mid-Cretaceous time, as proposed by Pavlis and others (1988b, 1993).

GNI (eKPz)

The quartzite, muscovite-quartz schist, and lesser amounts of interlayered pelitic schist, felsic schist, chloritic or actinolitic greenschist, calc-silicate rocks, and rare marble (Bundtzen, 1982; Foster and others, 1983) that make up this unit constitute the informally designated Fairbanks schist unit and Cleary sequence of Bundtzen (1982). These rocks are included in the Yukon-Tanana terrane. A U-Pb analysis on zircon from a metarhyolite in the Cleary sequence in the north Fairbanks area indicates an extrusive age of 369 Ma (Devonian) (J.N. Aleinikoff and W.J. Nokleberg, unpub. data, 1989). Other protoliths are probably Paleozoic and perhaps Proterozoic in age.

Metamorphic grade ranges from the chlorite zone of the greenschist facies to the garnet zone of the upper greenschist or epidote-amphibolite facies. The grade generally increases southeastward within this unit and continues to increase within the adjacent amphibolite-facies unit AMI (eKPz), which is interpreted to be a higher grade part of this metamorphic sequence (Foster and others, 1987a). Intermediate-pressure metamorphic conditions are assumed for both these units on the basis of the presence of abundant kyanite in the correlative, higher grade rocks of unit AMI (eKPz), described below. Quartzites and quartzitic schists contain rare to abundant megacrysts of quartz and feldspar in a matrix of quartz, feldspar, white mica, and, locally, minor chlorite, biotite, and small garnets. Pelitic schist is characterized by the assemblage quartz+plagioclase+muscovite+chlorite±carbonate and, commonly, either biotite±garnet or chloritoid±garnet. Mafic schist contains the assemblage actinolite or actinolitic hornblende+plagioclase+quartz+chlorite+epidote+sphene±carbonate and rare biotite or stilpnomelane. A locally mappable quartz-white mica-chlorite-magnetite schist, commonly containing plagioclase, biotite, or garnet, also is present (Foster and others, 1983).

Four distinct deformational events are recognized in the continuation of this unit to the north (shown on Dusel-Bacon and others, 1989) in the Circle quadrangle (Cushing and Foster, 1984). In that area, retrogressive metamorphism is found locally as a result of contact metamorphism around Tertiary plutons, but polymetamorphism of regional extent has not been identified by Foster and others (1983; 1987a). On the basis of work in the Fairbanks quadrangle (pl. 1), other workers propose that regional retrogressive metamorphism did affect this unit and that this metamorphic episode accompanied penetrative deformation that deformed earlier northwest-trending folds into northeast-trending folds (Forbes, 1982; Hall, 1984).

Metamorphism and folding postdate the thrusting of the dominantly pelitic assemblage that makes up most of unit AMI (eKPz) over the dominantly quartzitic assemblage that makes up most of unit GNI (eKPz). This relation is indicated by the facts that these two metamorphic units appear to have a similar metamorphic and deformational history and that biotite, garnet, and staurolite isograds and folds mapped in the Circle quadrangle to the north are unrelated to lithologic contacts between the pelitic and quartzitic assemblages (Foster and others, 1987a). Additional thrusting of these two units took place after the major metamorphic and deformational episodes. Metamorphism predates the thrusting of the prehnite-pumpellyite- and greenschist-facies unit LPP,GNS (eKPz) that overlies the southern margin of the related amphibolite-facies unit.

Paleozoic and Early Cretaceous metamorphic-age constraints are assigned to this unit on the basis of the same regional relations as those described above for unit LPP (eKPz). K-Ar mica ages from greenschist at three localities and one whole-rock age from another locality within this unit in either the Fairbanks quadrangle or the Livengood quadrangle to the north range from about 138 to 100 Ma (Forbes and Weber, 1982) and may indicate an Early Cretaceous age of metamorphism.

AMI (eKPz)

The penetratively polydeformed and regionally metamorphosed pelitic schist and gneiss and subordinate quartzite, quartzitic schist, augen gneiss, orthogneiss, calc-silicate rocks, marble, and amphibolite (Weber and others, 1978; Foster and others, 1983) that compose this unit form the higher grade part of the metamorphic sequence formed by this unit and unit GNI (eKPz), described above. Orthogneiss in the northeastern part of the Big Delta quadrangle has yielded a Late Proterozoic (671±34-Ma) U-Pb age on zircon (J.N. Aleinikoff, written commun., 1986), which is interpreted as its protolith age and provides a minimum protolith age for the metasedimentary and probable metavolcanic wallrocks. A Mississippian (340-Ma) U-Pb age on zircon has been determined for the granitic protolith of augen gneiss within the extension of this metamorphic unit in the southeastern Circle quadrangle, which is located north of the area shown on this map and adjacent to the Big Delta quadrangle (Foster and others, 1987b). This age indicates that at least some of the areas of augen gneiss within this unit are correlative with the larger augen gneiss bodies to the south (within unit AMP (eK), described below) that form a belt across east-central Alaska and the Yukon Territory, Canada (Dusel-Bacon and Aleinikoff, 1985).

The area of this unit in the northeastern Big Delta quadrangle that is thrust bounded and circular in plan view consists of high-grade pelitic schist and gneiss. These rocks have many lithologic and metamorphic similarities to the rocks that compose the sillimanite gneiss dome of unit AMP (eK) (described below) and may form another gneiss dome. This area of high-grade rocks continues into the Circle quadrangle, north of the map boundary, where the major part of the area is exposed (Foster and others, 1983; Dusel-Bacon and others, 1989). The metamorphic grade of these rocks ranges from the garnet zone of the epidote-amphibolite facies to the sillimanite zone of the amphibolite facies. Characteristic mineral assemblages in the highest grade pelitic rocks are (in addition to quartz, white mica, and plagioclase) biotite+garnet+staurolite±kyanite, biotite+garnet+kyanite±sillimanite and biotite+sillimanite±potassium feldspar±garnet. High-grade mafic schist contains hornblende+plagioclase+quartz±biotite±diopside and, locally, garnet or carbonate. Metamorphic conditions in the highest grade rocks of this complex in the southeastern Circle quadrangle were near those of the second sillimanite isograd (Foster and others, 1983), indicating metamorphic temperatures between about 600 and 700°C (Chatterjee and Johannes, 1974). The coexistence of kyanite and sillimanite in the part of this high-grade area that is exposed in the Circle quadrangle is indicative of an intermediate-pressure-facies series, but the occurrence of coexisting kyanite and andalusite (shown by letter symbols, pl. 1) in comparable pelitic schist in the northeastern Big Delta quadrangle suggests either that the P-T gradient was transitional between intermediate- and low-pressure-facies series, or that low-pressure metamorphism followed intermediate-pressure metamorphism, as has been proposed for the sillimanite gneiss dome of unit AMP (eK) (Sisson and others, 1990).

Farther to the west, along a 12-km transect in Goldstream Valley in the northeastern Fairbanks quadrangle, amphibole compositions from marbles, metabasalt, and calc-silicate rocks suggest intermediate pressure conditions. Petrogenetic grids for the calcareous and metabasaltic systems suggest peak metamorphic conditions of 550±50°C at 4 to 5 kb, indicative of the epidote-amphibolite to lower amphibolite facies (Keskinen, 1989). Replacement of amphibole by chlorite±biotite, growth of coarse tremolite along fractures in marbles, and complex interactions involving titanium oxides and silicates, suggest that peak metamorphism was followed by extensive flow of lower temperature, water-rich, oxidizing fluids (Keskinen, 1989).

The deformational and metamorphic history of this unit (thrusting, followed by metamorphism and folding, followed by postmetamorphic thrusting) and the Paleozoic and late Early Cretaceous metamorphic-age constraints assigned to it are the same as those described above for the lower grade part of the metamorphic sequence (unit GNI (eKPz)). The Mississippian protolith age of the augen gneiss has not been used to establish a maximum metamorphic age for this unit because, according to Foster and others (1987a), the augen gneiss that was dated may be in thrust contact with the associated metasedimentary rocks rather than intrusive into them. Monazite, separated from the orthogneiss in the northeastern Big Delta quadrangle that yielded a Late Proterozoic protolith age, gave a concordant U-Pb age of 115 Ma (J.N. Aleinikoff, written commun., 1987), indicating an Early Cretaceous thermal event that may have included greenschist- and amphibolite-facies metamorphism. Muscovite from garnet-mica gneiss and hornblende from amphibolite in the Fairbanks quadrangle (near Fox) gave K-Ar ages of about 124 Ma and 240 Ma, respectively (Forbes and Weber, 1982).

AMP (eK)

This unit is characterized by large bodies of augen gneiss (indicated on pl. 1 by the symbol for strongly metamorphosed pluton) that form a discontinuous belt of metamorphosed Mississippian plutons, which are interpreted to have developed underneath, or inland from, a continental margin magmatic arc (Dusel-Bacon and Aleinikoff, 1985). Other rocks types, interpreted to be wallrocks to the augen gneiss protolith, are amphibolite-facies quartz-mica schist, biotite and biotite-hornblende gneiss, quartzite, amphibolite, augen gneiss, sillimanite gneiss, and minor marble, calc-schist, and felsic gneiss. Protoliths include quartzose and, locally, pelitic sedimentary rocks, felsic and intermediate plutonic rocks, basalt, and minor limestone, marl, and felsic to intermediate volcanic rocks. These rocks compose the Y1 subterrane of the Yukon-Tanana terrane of Foster and others (1987a).

U-Pb ages on zircon from metavolcanic rocks suggest a Devonian (360- to 380-Ma) age for their protoliths (Aleinikoff and others, 1986). A protolith age of 341±3 Ma is indicated for the augen gneiss on the basis of its lower intercept age of U-Pb zircon discordia and on its Rb-Sr whole-rock isochron age (Aleinikoff and others, 1986). The closeness in age between metavolcanic and metaplutonic protoliths suggests that they were products of the same magmatic episode; it was probably part of a prolonged Devonian to Mississippian episode that occurred throughout much of Alaska and western Canada (Dusel-Bacon and Aleinikoff, 1985, and references contained therein). The upper intercept ages of U-Pb zircon discordia for augen gneiss, metasedimentary rocks, and metavolcanic rocks are consistently about 2.3 Ga, indicating that an Early Proterozoic source terrain provided detritus for the sedimentary protoliths and a crustal component to the parental magmas of the granitoid and volcanic protoliths.

Rocks are well foliated, and the foliation is multiply folded into isoclinal folds on several scales. Paracrystalline microfolding of foliation, indicated by the development of polygonal arcs in fold hinges (Misch, 1969), has been observed in amphibolite, but whether the formation of foliation and its folding took place during the same or separate metamorphic episodes is not known. Many rocks exhibit a well-developed stretching lineation, and most show some degree of mylonitization followed by varying degrees of recrystallization.

Few geothermobarometric studies have been made of this unit, but where such studies have been conducted, metamorphic pressure conditions range from low to high in different areas (discussed below). Because P-T data are not sufficient to adequately subdivide this unit into areas of differing barometric histories, this unit is shown with the nonspecific amphibolite-facies designation, AMP.

Amphibolite generally contains hornblende, plagioclase, epidote, and minor biotite, chlorite, or garnet, and marble locally contains diopside. Schist bulk compositions are generally low in alumina relative to ferromagnesian components and to silica; therefore, aluminum silicate minerals are somewhat restricted in occurrence. However, some fairly large areas of pelitic rocks occur in the Big Delta quadrangle.

One of these areas in the central Big Delta quadrangle consists of a 600 km^2 body of sillimanite gneiss and flanking pelitic schist (approximately outlined by the circular outline of the sillimanite isograd on plate 1) that has been interpreted as a gneiss dome (Dusel-Bacon and Foster, 1983). Work by Dusel-Bacon and Foster (1983) has shown that the metamorphic grade increases from that of pelitic schist on the flanks of the dome, where P-T conditions locally were those under which all three Al_2SiO_5 polymorphs (kyanite, andalusite, and sillimanite) are stable (determined to be approximately 3.8 kb and 500°C; Holdaway, 1971), to that of gneiss in the core of the dome, where P-T conditions were near those of the second sillimanite isograd (defined by the breakdown of muscovite+quartz to form sillimanite+potassium feldspar+water). Characteristic metamorphic mineral assemblages in the pelitic schist contain biotite+muscovite+quartz+plagioclase±garnet±staurolite±sillimanite±kyanite±andalusite. Metamorphic assemblages in the higher grade rocks of the core consist of sillimanite+biotite+quartz+orthoclase+plagioclase±garnet±muscovite and biotite+sillimanite+quartz+cordierite+orthoclase+plagioclase+muscovite. Garnet-biotite geothermometry (using the calibration of Ferry and Spear (1978)) indicates equilibration temperatures of 535 to 600±30°C for pelitic schist north of the dome and 655 to 705±30°C for sillimanite gneiss (Dusel-Bacon and Foster, 1983).

Subsequent study of the gneiss dome by Sisson and others (1990) indicates that the occurrence of staurolite-kyanite-sillimanite schist and garnet-bearing amphibolite in the northwest edge of the dome, garnet-cordierite geobarometry in the core of the dome, and geobarometry on plagioclase inclusions in garnet, all suggest intermediate pressures of about 5 kb. Later, low-pressure metamorphic conditions within the gneiss dome accompanied mylonitization that was associated with greenschist-facies metamorphism and extension of structurally overlying rocks (unit GNS (eKPz)) (Sisson and others, 1990; Pavlis and others, 1988b, 1993). Low-pressure conditions of about 2 to 3 kb during mylonitization and extension were proposed by Sisson and her coworkers (1990) on the basis of geothermobarometry, the occurrence of andalusite-bearing quartz veins, and the growth of texturally late andalusite in pelitic schist of the gneiss dome.

Farther to the east in the northeastern Tanacross quadrangle, pelitic schist locally contains kyanite, indicative of intermediate- to high-pressure conditions. Geothermobarometry indicates pressures and temperatures of 8.2 to 12.5 kb, 625 to 725°C for garnet-staurolite-quartz-mica schist and 8.7 to 12.5 kb, 600 to 730°C for garnet amphibolite (Dusel-Bacon and Douglass, 1990). Shear-sense indicators within this same area record dominantly top-to-the-northwest displacement and locally subsequent top-to-the-southeast displacement (Hansen and others, 1991; Dusel-Bacon and Hansen, 1992).

Petrographic evidence of a regional retrogressive metamorphic episode is minimal in most of this unit. In the southwestern part of this unit in the Mt. Hayes quadrangle, however, Nokleberg and others (1986a) have noted that amphibolite-facies rocks are retrograded to greenschist-facies assemblages and that the degree of retrogression increases to the south (W.J. Nokleberg, unpub. data, 1984). This retrogressive metamorphism is shown on the map as the second greenschist-facies episode in the adjacent unit GNS (eKD)+GNS (eK) to the south. However, because low-grade metamorphic minerals also occur in Late Cretaceous plutons that intrude the polymetamorphic greenschist-facies unit, and because these minerals are not found in the Cretaceous plutons that intrude the amphibolite-facies rocks of this unit, this retrograde episode apparently died out to the north and did not affect any but the most southerly part of this amphibolite-facies unit. Minor retrograde effects, such as the local chloritization of biotite and garnet, sericitization of feldspar and cordierite, and the development of actinolite from hornblende, are present locally in parts of this metamorphic unit. These replacement minerals are generally randomly oriented and developed prior to, or perhaps as a result of, Early Cretaceous plutonism.

Metamorphism of this unit postdates the Mississippian intrusive age of the augen gneiss protolith and predates the intrusion of Early and mid-Cretaceous plutons, which generally have K-Ar cooling ages of 105 to 85 Ma (Wilson and others, 1985). A 115-Ma U-Pb age on zircon from an unmetamorphosed (late metamorphic?) pluton that intrudes the sillimanite gneiss dome (Aleinikoff and others, 1984a) provides the most reliable minimum age of metamorphism. Abundant isotopic data from the metamorphic rocks of this unit yield Early Cretaceous ages between about 135 to 115 Ma: most conventional K-Ar mineral ages fall in the range of about 125-110 Ma; a Rb-Sr isochron age on minerals from augen gneiss is 115 Ma; sphene from augen gneiss gives a concordant U-Pb age of 134 Ma; U-rich zircon fractions from sillimanite gneiss and quartzite show Early Cretaceous lead loss (Aleinikoff and others, 1986); and hornblende from amphibolite associated with augen gneiss gives a $^{40}Ar/^{39}Ar$ incremental-heating plateau age of 119 Ma (T.M. Harrison, written commun., 1987) in the eastern part of the unit.

The high-pressure metamorphism documented in the eastern part of unit AMP (eK) in the Tanacross quadrangle (Dusel-Bacon and Douglass, 1992) is interpreted by Hansen (1990) and Dusel-Bacon and Hansen (1992) to have occurred as a result of tectonic burial caused by imbrication of the North American margin (of which they assume unit AMP (eK) formed a part) and overthrusting of the accreted arc, accretionary prism, and intervening ocean basin onto the North American margin in Early to early Middle Jurassic time. The Early Cretaceous cooling ages recorded in the eastern part of unit AMP (eK) are interpreted by Hansen (1990), Hansen and others (1991), and Dusel-Bacon and Hansen (1992) to date the time of unroofing of lower-plate unit AMP (eK) during crustal extension. The top-to-the-northwest displacement and the locally developed younger top-to-the-southeast displacement recorded in the ductile fabrics of schist and gneiss in the northeastern Tanacross quadrangle may correspond, respectively, with initial contractional and subsequent extensional tectonism (Hansen and others, 1992; Dusel-Bacon and Hansen, 1992). An alternative interpretation of the Early Cretaceous metamorphic cooling ages in unit AMP (eK) is that they record a second regional metamorphism and deformation, associated with underplating of Mesozoic flysch and the Gravina arc, and oblique collision of the Wrangellia and Peninsular terranes with the Yukon-Tanana terrane (Nokleberg and others, 1991).

Limited U-Pb data on zircon from quartzite (Aleinikoff and others, 1984b, 1986) and the gneiss dome (Aleinikoff and others, 1984a) and structural relations between augen gneiss and wallrocks in east-central Alaska and Yukon Territory suggest that an earlier metamorphic episode may have accompanied intrusion of the batholithic sheets of what is now augen gneiss (Dusel-Bacon and Aleinikoff, 1985). These structural relations are: (1) some areas of augen gneiss coincide with large structural and metamorphic culminations (Mortensen, 1983), and (2) the concordant contacts of the augen gneiss bodies and parallelism between lithologic contacts and the gently dipping regional penetrative fabric suggest that the augen gneiss bodies were intruded synkinematically into ductile crust (Dusel-Bacon and Aleinikoff, 1985). However, these structural relations could have developed instead during regional-scale crustal extension in mid-Cretaceous time, thus lessening the amount of permissive evidence for a mid-Paleozoic metamorphic event.

ALASKA RANGE (YUKON-TANANA, PINGSTON, McKINLEY, WINDY, AND DILLINGER TERRANES)

GNS (eKD)+GNS (eK)

This unit comprises polydeformed and partly or totally polymetamorphosed greenschist-facies pelitic schist, micaceous quartzite, phyllite, calc-phyllite, and lesser amounts of graphitic schist, chlorite-actinolite schist, greenstone, marble, metachert(?), and metavolcanic rocks and singly metamorphosed metadiorite and metagabbro dikes and sills. It is included in the Yukon-Tanana, Pingston, and McKinley terranes. U-Pb data on zircon indicate a Devonian protolith age for metavolcanic rocks of this unit in the Mount Hayes quadrangle (Nokleberg and others, 1983; Aleinikoff and Nokleberg, 1984), and Devonian conodonts have been identified north of the Hines

Creek fault in the eastern Healy quadrangle (Sherwood and Craddock, 1979). Upper Triassic carbonaceous and calcareous metasedimentary rocks and marble overlie the Paleozoic metamorphic rocks south of the Hines Creek fault in the eastern Healy quadrangle (Csejtey and others, 1982, 1986). The intrusive age of the singly metamorphosed gabbroic bodies is unknown in most areas and is assumed to be Paleozoic or Mesozoic. South of the Hines Creek fault, the intrusive age of metagabbro that crops out in the eastern Healy quadrangle is bracketed between the Late Triassic age of the carbonaceous rocks that the gabbro intrudes and the late Early Cretaceous (105-Ma) age of the pluton that intrudes the gabbro (Csejtey and others, 1986); farther east in the western Mount Hayes quadrangle, hornblende from the relatively undeformed core of a metagabbro sill gives a K-Ar age of 100 Ma, which also indicates an intrusive age of late Early Cretaceous or older (W.J. Nokleberg and D.L. Turner, unpub. data, 1987).

The metamorphic history of this unit is poorly known and may have differed in various parts of this unit. Although several detailed studies of these metamorphic rocks have been made, knowledge of the regional metamorphic history is not sufficient to define areas in which P-T conditions, the degree of synmetamorphic deformation, and the timing of metamorphic episodes differed. In many areas, particularly in the eastern part of this unit near its northern contact, it is difficult to identify more than one metamorphic episode and to determine whether the observed assemblages formed during the first or second episodes that have been identified elsewhere in the greenschist-facies metamorphic belt. Although this unit is shown to have been affected by two metamorphic episodes, in at least some areas, the two proposed episodes may have been phases of a single event; this possibility is reflected in the overlap of ages proposed for the two episodes.

In the area north of the Denali and Hines Creek faults, the first metamorphic episode (M_1) was dynamothermal and produced predominantly upper greenschist-facies assemblages. This episode produced steeply dipping northwest-trending folds in the western part of the Alaska Range (Bundtzen, 1981), east-west-trending folds near the Nenana River (approximately between long 148° and 150°) (Hickman and others, 1977), and east-west changing to west-northwest-east-southeast-trending folds (approximately parallel with the change in orientation of the trace of the Hines Creek and Denali faults) in the Mount Hayes quadrangle (W.J. Nokleberg, unpub. data, 1985). Typical metamorphic assemblages in these rocks include plagioclase+quartz+white mica+chlorite±biotite±epidote and actinolite+plagioclase+biotite+epidote±garnet±sphene in basic rocks and quartz+sericite+chlorite, white mica+plagioclase+biotite, or epidote+plagioclase+stilpnomelane+white mica in pelitic rocks. Prograde metamorphism of these rocks increases to the north: M_1 occurred under amphibolite-facies conditions in related unit AMP (eKD)+GNS (eK) north of the western part of this unit, and the occurrence of hornblende, biotite, and intermediate plagioclase in metagranitic rocks of intermediate composition within the northernmost part of unit GNS (eKD)+GNS (eK) in the western Mount Hayes quadrangle indicates local amphibolite-facies conditions in that area as well during M_1 (W.J. Nokleberg, unpub. data, 1985; Nokleberg and others, 1986a).

In the area south of the Hines Creek fault, the first metamorphic episode (tentatively interpreted as corresponding to the M_1 episode described above) occurred under lower temperature and possibly higher pressure conditions than those that affected the rest of this unit. A typical M_1 mineral assemblage produced in siliceous rocks in the Mount Deborah area is quartz+white mica±chlorite±albite±carbonate±opaques. Metamorphic temperatures of 250 to 350°C for this episode have been proposed on the basis of CAI (conodont alteration index of Epstein and others, 1977) data (Brewer, 1982), but the conodont data may indicate metamorphic temperatures during the second rather than the first metamorphic episode. Limited data in the eastern part of the Healy quadrangle indicate that, at least locally, M_1 may have occurred under relatively high-pressure conditions. Potassic white mica b_0 values determined for a small number of samples are comparable to those determined for Otago schists, suggesting that metamorphic pressures were in the range of about 5 to 7 kb (Brewer, 1982). The observation of biaxial carbonate (aragonite?) by K.W. Sherwood (1979) warrants further investigation and tentatively supports the possibility that high-pressure conditions may have occurred locally. East of the Mount Deborah area, temperature conditions were apparently higher because biotite coexists with chlorite+white mica+albite±actinolite assemblages in the Mount Hayes quadrangle.

The age of M_1 metamorphism is unknown. It postdates the extrusion of the Devonian volcanic protoliths and predates the late Early Cretaceous age proposed for M_2. Whether or not the Triassic metasedimentary rocks were metamorphosed during the proposed first or second metamorphic episode is not known, and, therefore, the protolith age of these rocks cannot be used to establish a maximum age for M_1. Bundtzen and Turner (1979) proposed that the oldest (194 Ma) of four K-Ar ages on hornblende from garnet amphibolite in related unit AMP (eKD)+GNS (eK), in which the grade of M_1 metamorphism was higher, indicates a minimum Jurassic age for M_1.

The second greenschist-facies metamorphism (M_2) is only tentatively correlated between the various parts of this unit. Part of the uncertainty in correlating the M_2 episodes in this unit is due to the fact that gabbroic dikes do not occur in all parts of this unit, and the age of the dikes is generally unknown. The second greenschist-facies episode produced weak retrograde effects on M_1 assemblages and a weak metamorphic foliation that is axial planar to broad northeast-trending folds in the area northeast of the McKinley River (Bundtzen and Turner, 1979) and axial planar to gently dipping, east-west-trending folds in the central part of the unit near the Nenana River (Hickman and others, 1977). Metamorphic minerals produced during M_2 in these areas are albite+ chlorite+zoisite±calcite in basic rocks and albite+ chlorite+phengite+zoisite in pelitic rocks.

In the area south of the Hines Creek fault, M_2 metamorphism increases from west to east as indicated by mineral assemblages in metagabbroic rocks. Metagabbro contains pumpellyite-actinolite zone assemblages (+chlorite+albite+quartz+sphene± stilpnomelane±calcite±iron epidote) and actinolite-clinozoisite zone assemblages (+albite+quartz+ sphene±chlorite±stilpnomelane±calcite±iron epidote). Sericite, quartz, albite, calcite, chlorite, and rarely biotite characterize M_2 assemblages in siliceous metavolcanic rocks near the boundary between the Healy and Mount Hayes quadrangles. Phase equilibria of pertinent minerals in these rocks indicate temperatures in the range of 300 to 400°C and low or intermediate pressures. Elongate M_2 minerals produced in the Mount Deborah area during this episode are randomly oriented and formed under static conditions (Brewer, 1982).

Similar metamorphic textures are described for metagabbros that intrude the penetratively deformed greenschist-facies rocks of this unit north of the Denali fault in the eastern Alaska Range. In the Nabesna quadrangle, although metagabbros exhibit a marginal schistosity (W.J. Nokleberg, unpub. data, 1986), their interiors are unfoliated, contain well-preserved igneous textures, and have been only weakly metamorphosed, as evidenced by the presence of saussuritized calcic plagioclase, chloritized hornblende, and isolated segregations of chlorite (Richter, 1976). These relations indicate that the dikes (of indeterminate Paleozoic or Mesozoic age) were intruded after the main period of folding and metamorphism (Richter, 1976). Textural features in these rocks could have resulted from intrusion and metamorphism taking place either during late M_1 or during a subsequent M_2 episode.

The second greenschist-facies episode was more dynamothermal in correlative rocks to the northwest in the Mount Hayes quadrangle. In that area, metagabbroic rocks are locally more deformed, and M_2 is considered to have produced a south-dipping cataclastic schistosity and phyllonitic and blastomylonitic textures in metasedimentary and metavolcanic rocks (Nokleberg and others, 1986a). Detailed petrographic study of the greenschist-facies rocks in the Mount Hayes quadrangle indicates that M_2 metamorphism decreases in grade systematically from north to south and that M_2 chlorite-zone assemblages have almost completely replaced the higher grade M_1 mineral assemblages (Nokleberg and others, 1986a). This replacement is most evident in the northern part of this unit where the metamorphic grade of M_1 was highest.

Although the metamorphic conditions and degree of accompanying deformation during M_2 may have differed in various parts of this unit, available isotopic data indicate that M_2 in all areas occurred during late Early Cretaceous time. Near the westernmost part of this unit in the Mount McKinley quadrangle, two separates of muscovite from the slightly higher grade related schist of unit AMP (eKD)+GNS (eK) gave K-Ar ages of about 100 Ma (Bundtzen and Turner, 1979). On the basis of radiometric and structural similarities, the M_2 episode in that area has been correlated with the low-grade metamorphism of the Totatlanika Schist (Bundtzen and Turner, 1979) and the Devonian rocks described by Hickman and others (1977) (both of which are included in unit LPP/GNL (eK)). In the central part of this unit, in the northeastern Healy quadrangle, K-Ar ages of 115 and 107 Ma were determined for muscovite from phyllite just north of and south of the Hines Creek fault, respectively (Sherwood and Craddock, 1979). Farther east, Rb-Sr internal isochron ages and K-Ar white-mica ages determined for the greenschist-facies rocks of this unit that crop out in the eastern Mount Hayes quadrangle and for the amphibolite-facies rocks along the southern edge of unit AMP (eK) fall in the range of 102 to 119 Ma (Nokleberg and others, 1986a). The overlap in isotopic ages for the greenschist-facies rocks and the youngest ages from the amphibolite-facies rocks of unit AMP (eK) to the north (whose isotopic ages generally range from 115 to 134 Ma) suggests that M_2 greenschist-facies metamorphism, in at least the northeastern part of the

Mount Hayes quadrangle, occurred later during the same Early Cretaceous episode.

AMP (eKD)+GNS (eK)

The metamorphic history of the polymetamorphosed and polydeformed quartz-mica schist, micaceous quartzite, amphibolite, and granitic gneiss that make up this unit differs from that of the adjacent, lower grade polymetamorphosed greenschist-facies rocks, described immediately above, only in that metamorphic conditions during the M_1 episode reached amphibolite-facies grade. Protoliths in both areas are the same and both are included in the Yukon-Tanana terrane.

The southeastern boundary of this unit is defined by the first appearance of hornblende. Characteristic M_1 assemblages are hornblende+calcic plagioclase+biotite+epidote+garnet+sphene in mafic rocks and are biotite+muscovite+garnet+calcic plagioclase in pelitic rocks. A southeast to northwest increase in the metamorphic grade of M_1, beginning in the adjacent unit in which M_1 took place under greenschist-facies conditions and extending throughout this unit, is indicated by an increase in the grain size of garnet, mica, and feldspar and by a decrease in the unit-cell edge of garnets (Bundtzen, 1981; Bundtzen and Veach, 1984). Northwest-trending folds were produced during this metamorphic episode.

Retrograde effects produced by M_2 metamorphism are more pronounced in this unit than they are in the adjacent greenschist-facies unit, owing to the greater disparity in metamorphic grade between M_1 and M_2 episodes in the higher grade part of the M_1 sequence. Retrogressive metamorphism produced replacement of calcic plagioclase by albite+zoisite, garnet by chlorite or biotite, hornblende by actinolite, biotite by pennine and magnetite or rutile, and muscovite by phengitic white mica. M_2 metamorphism accompanied the development of northeast-trending folds (Bundtzen, 1981).

M_1 metamorphism postdates the Devonian(?) age of the youngest protolith (T.K. Bundtzen, oral commun., 1988) and predates the probable Early Cretaceous age of M_2. Four hornblende separates from garnet amphibolite yield K-Ar ages ranging from 195 to 104 Ma (Bundtzen and Turner, 1979). Bundtzen and Turner (1979) proposed that the oldest of these four ages probably represents a minimum age (Jurassic) for M_1 and that the younger ages probably represent varying amounts of radiogenic argon loss during a Cretaceous thermal event (M_2). A late Early Cretaceous age for M_2 is proposed on the basis of two K-Ar ages on muscovite (about 100 Ma) determined for these rocks; K-Ar ages on biotite of about 94 and 86 Ma suggest that M_2 may have continued into early Late Cretaceous time (Bundtzen and Turner, 1979). A K-Ar whole-rock age of 108 Ma from unit LPP/GNL (eK), whose metamorphism is interpreted to have been part of the M_2 episode that affected this unit, further supports an Early Cretaceous age for M_2.

LPP/GNL (eK)

The weakly metamorphosed and polydeformed quartzose and quartzofeldspathic semischist, metafelsite, metabasite, carbonaceous schist, phyllite, slate, metalimestone, and locally stretched metaconglomerate that compose this unit are included in the Yukon-Tanana terrane. In the central Alaska Range, the semischist and metamorphosed bimodal volcanic rocks constitute the Upper Devonian and Lower Mississippian Totatlanika Schist of Gilbert and Bundtzen (1979), and the underlying carbonaceous metasedimentary rocks and metaconglomerate constitute the Ordovician(?) to Middle Devonian(?) Keevy Peak Formation of Gilbert and Bundtzen (1979) (Warhaftig, 1968; Gilbert and Redman, 1977). A sliver of this unit north of the Hines Creek fault in the western Healy quadrangle has been named the Wyoming Hills sequence by Gilbert and Redman (1977). A narrow window of this unit, composed of lithologically similar rocks of unknown protolith age (Spruce Creek sequence), is exposed under higher grade rocks in the area north of the McKinley River (Bundtzen, 1981).

Characteristic mineral assemblages in metapelites and metafelsites are white mica+albite+chlorite+tourmaline. The occurrence of coexisting prehnite and clinozoisite (+chlorite+albite±calcite) and actinolite (+chlorite+epidote+albite+tourmaline) in metabasalt and epidote (+chlorite+albite+calcite) in metagraywacke suggests that P-T conditions were in the range of 2 to 3 kb and around 300°C, as defined by the general P-T range in which the univariant curves for the reactions prehnite+chlorite=pumpellyite+actinolite and pumpellyite+chlorite+quartz=epidote+actinolite approach one another (Nitsch, 1971). Metamorphic conditions in the Spruce Creek sequence locally reached up to biotite grade (Bundtzen, 1981).

Metamorphism was synkinematic with the development of northeast-trending folds (Bundtzen, 1981). A late Early Cretaceous age for this deformational and metamorphic episode is proposed on the basis of a whole-rock K-Ar age of 108.0±3.2 Ma on metarhyodacite from the Totatlanika Schist (Bundtzen and Turner, 1979).

GNS (KM)

This little studied sequence of regionally metamorphosed and isoclinally folded greenschist-facies metasedimentary and metavolcanic rocks crops out within and north of the western Alaska Range in the northwestern Talkeetna and southwestern Mount McKinley quadrangles. It includes both the basement and the overlying middle Paleozoic rocks of the Yukon-Tanana terrane. Basement rocks include Proterozoic and (or) Paleozoic maroon and green slate and phyllite and grit; overlying middle Paleozoic rocks include black slate and quartzite (probably correlative with the Ordovician(?) to Middle Devonian(?) Keevy Peak Formation of Gilbert and Bundtzen, 1979) and metavolcanic and semischistose rocks (probably correlative with the Upper Devonian and Lower Mississippian Totatlanika Schist of Gilbert and Bundtzen, 1979) (Reed and Nelson, 1980; T.K. Bundtzen, oral commun., 1984). Metamorphism of this unit postdated the Early Mississippian deposition and extrusion of the youngest protoliths and occurred before and (or) during the late Early Cretaceous episode. Part, or all, of this unit probably shared a common metamorphic history with either unit GNS (eKD)+GNS (eK) or unit LPP/GNS (eK) that crop out to the northeast.

GNS (lKD)

This unit primarily is made up of a regionally metamorphosed and isoclinally folded sequence of phyllite, metaconglomerate, quartz-mica schist, quartzite, calcareous mica schist, quartz-chlorite schist, intermediate to mafic metavolcanic and metavolcaniclastic rocks, massive volcanic greenstone, and metalimestone (Richter, 1976; Nokleberg and others, 1985a). Metalimestone contains fossils that are Middle Devonian (Richter, 1976) and Devonian (Nokleberg and others, 1985a) in age. Metasedimentary rocks exhibit well-defined axial plane schistosity that was deformed by a later period of kink folding. This metamorphic unit is included in the Windy terrane in the Mount Hayes quadrangle and the combined Windy and McKinley(?) terranes in the Nabesna quadrangle.

Metamorphic mineral assemblages in pelitic rocks typically include quartz+white mica±biotite±chlorite±albite±actinolite±calcite, and those in mafic volcanic rocks include actinolite+albite±chlorite±epidote±quartz. The metamorphic age of this unit can only be bracketed between the Middle Devonian protolith age of the meta-limestone and the early Late Cretaceous (94- to 89-Ma) age of unmetamorphosed plutonic rocks that intrude the metasedimentary rocks (Richter, 1976). Because these plutons tend to be concordant with the structural grain of the metamorphic rocks, are generally foliated, and lack xenoliths, they were emplaced at deeper levels in the crust than were the plutons south of the Denali fault (Richter and others, 1975; Richter, 1976). These same features may indicate that greenschist-facies metamorphism occurred as an early phase of this mid-Cretaceous thermal episode.

LPP/GNS (K)

This unit comprises a weakly metamorphosed sequence of prehnite-pumpellyite- and (or) greenschist-facies phyllite, metasandstone, metaconglomerate, metasiltstone, slate, metalimestone, greenstone, and metachert. Protoliths range in age from middle Paleozoic to mid-Cretaceous (Gilbert and Redman, 1977; Jones and others, 1983; Jones and others, 1984). These rocks are included in the Pingston, McKinley, Dillinger, and Windy terranes.

Very little study has been made of the metamorphism of these rocks. Gilbert and Redman (1977) describe this unit in the Toklat-Teklanika Rivers area as having been weakly metamorphosed by a single metamorphic episode. In that area, siliceous metalimestone consists of calcite, quartz, and minor carbonaceous material and sericite and displays prominent cleavage and isoclinal folds; slate consists of quartz, sericite, and carbonaceous material and displays fine sedimentary laminations and crossbedding and a phyllitic sheen; metasandstone contains metamorphic sericite, chlorite, calcite (commonly present in crosscutting veinlets), and partly annealed quartz grains; and weakly metamorphosed gabbro contains metamorphic epidote, chlorite, and serpentine (Gilbert and Redman, 1977). CAI values of 6 were determined for conodonts of Late Triassic age from three samples of metalimestone near the headwaters of the Teklanika River (Sherwood and Craddock, 1979), indicating metamorphic temperatures of over 400°C (Epstein and others, 1977). However, a CAI value of only 3 was determined for Triassic conodonts from a thin metalimestone bed about 20 km to the south in this same general area (A.G. Harris and Christine Carlson, unpub. data, 1983), indicating that these rocks were only raised to temperatures in the range of about 100 to 200°C (Epstein and others, 1977).

In the northwest corner of the Talkeetna quadrangle, this unit consists of metasiltstone, metalimestone, greenstone, and minor quartzite (Reed and Nelson, 1980) that are interpreted to have been metamorphosed under lower greenschist-facies conditions (S.W. Nelson, written commun., 1983). These rocks range in age from late Paleozoic to Late Triassic. Fine-grained clastic rocks generally lack a semischistose fabric and cleavage; greenstones have well-developed secondary chlorite, biotite, and amphibole (Reed and Nelson, 1980).

Metamorphism is known to predate the age of the overlying unmetamorphosed Paleocene Cantwell Formation (Wolfe and Wahrhaftig, 1970; Gilbert and Redman, 1977). The metamorphic-age constraints and uncertainties about the metamorphic history of this unit are the same as those for the adjacent greenschist-facies unit GNL/I (K) to the east just north of the McKinley fault in the central Healy quadrangle. The part of this metamorphic unit to the east of long 151° is tentatively considered to be a lower grade metamorphic equivalent of the adjacent low- to intermediate-pressure greenschist-facies unit and to have been part of a metamorphic complex in which metamorphic grade increased from west to east. Whether or not the area of this unit to the west of long 151° was involved in the eastward-increasing metamorphic episode is not known.

GNL/I (K)

This unit comprises phyllite, quartzite, strained conglomerate, metamorphosed intermediate to felsic tuffs and flows, thin-bedded to massive metalimestone, and a minor amount of Jurassic and Cretaceous metagabbroic rocks (Sherwood, 1979) and forms the intermediate-grade part of the apparent eastward-increasing metamorphic sequence. It crops out north of the McKinley fault in the Healy quadrangle and is included in the McKinley terrane. Sedimentary protoliths are considered by Csejtey and others (1982) to be metamorphosed Jurassic and Cretaceous flysch.

A typical mineral assemblage in metasedimentary or metavolcanic rocks contains quartz+whitemica+albite+chlorite+stilpnomelane±sphene±epidote±actinolite±calcite (Sherwood, 1979). Metamorphic mineral assemblages in this unit and adjacent units north of the McKinley fault suggest an eastward increase in metamorphic grade. Low- to intermediate-pressure conditions during metamorphism are inferred on the basis of evidence presented below in the discussion of the amphibolite-facies rocks to the east (unit AML/I (K)), which are considered by Csejtey to be the higher grade metamorphic equivalent of this unit. Phyllites and quartzites generally possess a single foliation oriented subparallel to bedding. The crystallization of stilpnomelane postdates the formation of this foliation and formed late kinematically. A late strain-slip or crenulation cleavage postdates the formation of the foliation and the crystallization of stilpnomelane (Sherwood, 1979).

An Early Cretaceous maximum age of metamorphism is provided by the youngest protolith age proposed for the flysch (Csejtey and others, 1982). A latest Cretaceous minimum age of metamorphism is established by the Paleocene age of the overlying unmetamorphosed Cantwell Formation (Wolfe and Wahrhaftig, 1970).

AML/I (K)

Polydeformed pelitic schist, calc-schist, marble, quartzite, and lesser amounts of foliated intermediate metaplutonic rocks and orthoamphibolite make up most of this unit. Protoliths of calcareous metasedimentary rocks are Triassic in age (Csejtey and others, 1982, 1986). Metamorphosed gabbroic dikes and sills of presumed Jurassic and Cretaceous age (based on age relations for similar gabbroic rocks described for the adjacent unit to the north) and weakly metamorphosed intermediate plutonic rocks of Late Cretaceous (70 Ma) age (Aleinikoff, 1984; Nokleberg and others, 1985a) are also included in this unit. It forms the highest grade part of the apparent eastward-increasing metamorphic sequence that includes the two lower grade metamorphic units to the west (units LPP/GNS (K) and GNL/I (K), described above). This unit crops out north of the McKinley fault in the east-central Healy and west-central Mount Hayes quadrangles and is included in the McKinley terrane by Jones and others (1987) and the Aurora Peak terrane by Nokleberg and others (1985a).

Metamorphic grade increases from lower amphibolite facies in the west to upper amphibolite facies in the east. Progressive mineral assemblages in pelitic rocks that also contain quartz and plagioclase are muscovite+quartz; muscovite+quartz+garnet; and biotite+garnet+staurolite+muscovite±sillimanite. Andalusite coexists with sillimanite in one sample of pelitic schist in the Mount Hayes quadrangle (W.J. Nokleberg, unpub. data, 1984), and relict chiastolite occurs within prismatic sillimanite in the Mount Deborah area (Brewer, 1982). Amphibolites contain (in addition to quartz, calcic plagioclase, biotite, sphene, and calcite) the lower grade assemblage hornblende+clinozoisite+cummingtonite±garnet in the west and the higher grade assemblage hornblende+diopside or garnet in the east (Brewer, 1982; W.J. Nokleberg, unpub. data, 1984). The presence of sparse relict chiastolite and andalusite indicates a P-T path that passed through or below the aluminum silicate triple point. Although kyanite has not yet been identified, the presence of garnet in both metabasic and metapelitic rocks suggests that metamorphic pressures were more likely intermediate than low (Brewer, 1982). The fact that sillimanite coexists with muscovite but not with potassium feldspar indicates that maximum metamorphic temperatures remained below those required to produce the reaction quartz+muscovite=sillimanite+potassium feldspar+water and, therefore, probably did not exceed about 700°C (Chatterjee and Johannes, 1974). However, the presence of migmatitic textures in the highest grade parts of this unit and the coexistence of forsterite+ enstatite+tremolite in ultramafic rocks within this unit suggests that locally temperatures were as much as 725°C (Brewer, 1982).

Geologic observations in the Healy quadrangle indicate that metamorphism either preceded or was synchronous with the intrusion of the large batholith that crops out just west of long 147° and yields a $^{40}Ar/^{39}Ar$ plateau age of about 105 Ma (Csejtey and others, 1986). The fact that this pluton generally crosscuts the metamorphic fabric, that, locally, igneous contacts are migmatitic, and that, in places, the pluton is foliated is permissive evidence that plutonism occurred during the latter part of a regional metamorphism that may have begun in the Early Cretaceous. A latest Cretaceous minimum metamorphic age is proposed on the basis of the Paleocene age of the unmetamorphosed Cantwell Formation that overlies what we interpret as the lower grade rocks (LPP/GNS (K) and GNL/I (K) to the west) of the eastward-increasing metamorphic sequence.

Retrogressive metamorphism at greenschist-facies grade, characterized by late development of chlorite, biotite, white mica, and actinolite, overprints amphibolite-facies assemblages near major faults. Greenschist-facies minerals are also weakly to moderately developed in granitoid rocks of Late Cretaceous age (W.J. Nokleberg, unpub. data, 1986). In the absence of petrologic evidence that indicates a hiatus between amphibolite- and greenschist-facies metamorphism, we consider that greenschist-facies minerals developed during the waning stages of the amphibolite-facies episode as P-T conditions decreased along the return path of a P-T loop (Spear and others, 1984).

AREA SOUTH OF THE McKINLEY AND DENALI FAULTS AND NORTH OF THE BORDER RANGES FAULT SYSTEM

MEDIUM-GRADE ROCKS OF THE PENINSULAR, WRANGELLIA, AND ALEXANDER TERRANES

AMP,GNS (meJ)

This unit comprises intermixed amphibolite and variably altered, sheared, or foliated diorite or quartz diorite as well as minor biotite-quartz-feldspar gneiss in the northwestern Anchorage quadrangle, sheared granodiorite and associated migmatite and subordinate pelitic schist and greenstone in the southwestern Talkeetna Mountains quadrangle, and subordinate greenschist and marble in the northeastern Talkeetna Mountains quadrangle (Csejtey and others, 1978). These rocks are included in the Peninsular terrane. Possible protoliths for the amphibolite of this unit are any or all of the nearby volcanic formations consisting of the Lower Jurassic Talkeetna Formation, Upper Triassic basaltic sequence, or upper Paleozoic volcanogenic sequence; marble protoliths have the same age possibilities (Csejtey and others, 1978).

Metamorphic mineral assemblages in amphibolite include hornblende and calcic plagioclase; minor garnet, quartz, sphene, and opaque minerals; and rare epidote and biotite. Amphibolite in the northwestern Anchorage quadrangle and the northeastern Talkeetna Mountains quadrangle most strongly resemble one another, except the segregation layering of mafic and felsic components is more prevalent in the amphibolite in the former area than it is in the latter one. Marble in the northeastern Talkeetna Mountains quadrangle contains minor amounts of garnet and diopside. Pods of greenschist are intercalated with amphibolite in the marble-bearing exposure of the unit in the northeastern Talkeetna Mountains quadrangle, suggesting that metamorphism may not have been of uniform intensity (Csejtey and others, 1978).

Metamorphism of this unit appears to have been part of a Jurassic plutonic and metamorphic episode that began after the extrusion and deposition of the Lower Jurassic Talkeetna Formation (Csejtey and others, 1978). Intrusion of tonalitic to granodioritic plutons probably took place from late Early Jurassic to Late Jurassic time and overlapped in part with metamorphism and deformation. An Early and (or) Middle Jurassic metamorphic age is suggested by a K-Ar age of 177 Ma determined on hornblende from diorite or amphibolite in the northeastern Talkeetna Mountains quadrangle (Csejtey and others, 1978). Csejtey and his coworkers (1978) propose that the 177-Ma age should be considered a minimum metamorphic age because many of the Jurassic plutons in the Talkeetna Mountains appear to postdate major metamorphism.

On the basis of geologic and geophysical data, Plafker and others (1989) propose that the synmetamorphic plutons and roughly coeval metavolcanic rocks of this unit form part of the Late Triassic to Middle Jurassic seaward-facing Talkeetna magmatic arc that developed as a result of left-oblique subduction of the Farallon plate beneath the southern Alaska composite terrane. According to our interpretation, metamorphism of unit AMP,GNS (meJ) occurred in that same tectonic setting.

AMP (meJ)+GNS (eTeK)

The retrograded pelitic schist of unknown protolith age that composes this unit crops out near the headwaters of Willow Creek in the northwestern Anchorage quadrangle and is part of the Peninsular terrane. We consider the initial amphibolite-facies metamorphism to be Early and (or) Middle Jurassic in age (Csejtey and others, 1978) and to have been part of the same synplutonic metamorphic episode that affected nearby unit AMP,GNS (meJ) in the Talkeetna Mountains and perhaps unit GNS,AMP (eKJ) south of the Matanuska River. Relict amphibolite-facies minerals (biotite, garnet, and probable hornblende) are partly to totally replaced by the greenschist-facies assemblage quartz+muscovite+albite+chlorite.

Retrograde metamorphism (M_2) predates the Paleocene depositional age of the overlying sedimentary rocks (G.R. Winkler, written commun., 1984), but its age and origin are unknown. K-Ar ages on muscovite from this unit range from about 66 to 59 Ma (Csejtey and others, 1978). These ages are close to the K-Ar mineral ages from the adjacent tonalitic to granitic composite pluton (unit TKg), suggesting either that the metamorphic ages were reset during intrusion and, thus, do not date the timing of M_2 or that, if the ages were not reset subsequent to M_2, M_2 may have been associated with intrusion of the pluton. Alternatively, M_2 may have occurred during an enigmatic Early Cretaceous thermal episode, discussed below, that resulted in plutonism and possible associated metamorphism of unit GNS,AMP (eKJ) south of the Matanuska River.

GNS,AMP (eKJ)

This unit comprises a diverse sequence of greenschist- and epidote-amphibolite-facies tectonized metaplutonic, metasedimentary, and metavolcanic oceanic rocks, including argillite, metachert, quartz schist, amphibolite, actinolite schist, marble, calc-silicate, and blocks of metachert and metabasalt in a foliated argillaceous matrix. These rocks have been informally called the Knik River schist terrane by Carden and Decker (1977) and are described in detail by Pavlis (1983); they crop out north of the Border Ranges fault in the Anchorage quadrangle and are included in the Peninsular terrane. Protolith ages are unknown except for marble, which is known to be of Permian age (Clark, 1972).

Foliated metamorphic rocks occur as discrete large bodies, as small slices within a disrupted zone, and as roof pendants or screens adjacent to both Early to Middle Jurassic (about 195- to 170-Ma) plutons and Early Cretaceous (about 135- to 110-Ma) plutons (Pavlis and others, 1988a). The Early to Middle Jurassic plutons (unit Jmu, pl. 1) are made up of intermediate, mafic, and ultramafic rocks that are included in the Border Ranges ultramafic-mafic complex of Burns (1985). The Early Cretaceous plutons (unit Kg, pl. 1) are tonalitic to trondhjemitic and intrude only the southern part of the Knik River schist terrane northeast of the Knik River.

Amphibolites contain hornblende+plagioclase (albite to andesine)+opaque minerals±chlorite±quartz±epidote and rarely biotite or garnet. Calc-silicate rocks consist of diopside+garnet+zoisite±amphibole±quartz±calcite. Micaceous schists contain biotite+muscovite+garnet. The assemblage wollastonite+calcite+quartz in calcareous metacherts at upper greenschist- or epidote-amphibolite-facies grade suggests a fairly low total pressure during metamorphism of these rocks (Pavlis, 1983). Metamorphic and deformational fabrics are quite variable within this unit; rocks range from well foliated to weakly foliated and ductilely deformed to brittlely deformed. In many areas, metamorphic textures indicate that the peak of metamorphism was post kinematic. Local retrograde metamorphism occurred within fault zones less than 1 km wide and produced veins of prehnite±quartz, epidote+quartz, and scapolite; replacement of biotite and plagioclase by chlorite and sericite; and serpentinite in ultramafic rocks (Pavlis, 1982).

The metamorphic history of this unit is uncertain and available data suggest that metamorphism may have occurred at a different time(s) in different parts of this unit. In at least the northern part of this unit, the spatial association of the proposed low P/T metamorphism of this unit with the large Early to Middle Jurassic plutonic belt suggests that metamorphism was Early Jurassic in age and was an early stage of Jurassic plutonism (Pavlis, 1983). This interpretation is supported by a single K-Ar age of 173±7 Ma on actinolite from an actinolite-epidote schist collected at the mouth of the Knik River (Carden and Decker, 1977). In the southern part of this unit, however, epidote-amphibolite- and greenschist-facies rocks are spatially associated with the Early Cretaceous plutons. Two hornblende ages (121-Ma K-Ar age and 117-Ma $^{40}Ar/^{39}Ar$ age) from mafic schists are virtually indistinguishable from the cooling ages of the Cretaceous plutons, indicating that the argon clocks were either set or reset in the metamorphic rocks during the Early Cretaceous (Pavlis, 1983; Pavlis and others, 1988a).

Pavlis and others (1988a) propose that metamorphism in at least the southern part of this unit, was associated with the Early Cretaceous intrusive episode. According to their hypothesis, intrusion was late kinematic with respect to ductile evolving to brittle deformation that accompanied metamorphism. They further propose that this near-trench thermal event was coeval with underthrusting of the mélange (McHugh Complex) of the Chugach terrane beneath the southern margin of the Peninsular and Wrangellia segments of the southern Alaska composite terrane (Pavlis and others, 1988a). However, as mentioned below in our discussion of the metamorphic history of the Chugach terrane mélange (unit LPP (eTJ)), underthrusting of the mélange may have occurred intermittantly throughout much of the Jurassic and Cretaceous and was not restricted to a single interval. The tectonic mechanism for the Early Cretaceous localized episode of near-trench plutonism, like that of the early Tertiary widespread episode of near-trench plutonism within the Chugach terrane flysch (discussed below in the overview section of this paper), is problematic and unresolved.

GNS,AMP (lJ)

This unit consists of two areas of undifferentiated greenschist- and amphibolite-facies metasedimentary, metavolcanic, and metaplutonic rocks: one group of rocks crops out in a small, poorly exposed area in the northeastern Valdez quadrangle and is informally designated the Dadina River metamorphic assemblage (Winkler and others, 1981b; Plafker and others, 1989); the other group of rocks crops out in a much larger area in the northwestern Gulkana quadrangle and is is part of the informally designated metamorphic complex of Gulkana River (Nokleberg and others, 1986b). We correlate the metamorphic history of the two areas with one another and with the first metamorphic episode that we interpret for the Haley Creek metamorphic assemblage (unit GNS,AMP (lJ)+GNS (eTlK)) to the south and the Strelna Metamorphics of Plafker and others (1989) (unit GNS,AMP (lJ)+LPP (eTlK)) to the southeast.

Both areas of this unit are considered to be part of the Wrangellia terrane (Plafker and others, 1989) and are intruded by unfoliated to weakly to moderately foliated plutons of probable Late Jurassic age that are considered to be part of the Chitina Valley batholith (unit lJg, pl. 1) (Winkler and others, 1981b; Plafker and others, 1989). This batholithic belt is interpreted by Plafker and others (1989) to represent the vestiges of what they term the Chitina magmatic arc, which was formed by the left-oblique subduction of the Farallon plate beneath the southern margin of the southern Alaska composite terrane.

The Dadina River metamorphic assemblage is a diverse and thoroughly mixed group of strongly foliated and partly mylonitic greenschist- and amphibolite-facies rocks that include primarily chlorite schist and amphibolite and lesser amounts of pelitic and psammitic schist, metachert, and blastomylonitic gneiss that has a pronounced mortar structure. Greenschist-facies metavolcanic rocks typically contain chlorite+albite±actinolite, have a well-developed schistosity, and preserve a relict porphyritic texture. Amphibolite-facies mineral assemblages in metasedimentary rocks contain biotite+quartz+plagioclase± garnet±potassium feldspar±muscovite. Foliated rocks are tightly folded on all scales and are extensively faulted (Winkler and others, 1981b; J.S. Lull, written commun., 1989). U-Pb data on zircon fractions from blastomylonitic metagranodiorite indicate a Pennsylvanian (310±29-Ma) age for its protolith (Aleinikoff and others, 1988).

The part of this unit included in the metamorphic complex of Gulkana River is composed of greenschist-facies metavolcanic rocks (chlorite schist and greenstone), interlayered metasedimentary rocks, including sparce marble, and foliated metaplutonic rocks of intermediate composition. Greenstone (actinolite-chlorite-epidote-albite) and greenschist (chlorite-white mica-epidote-albite) occur within areas of metadiorite and metaandesite that contain relict igneous hornblende and calcic plagioclase (W.J. Nokleberg, unpub. data, 1985). Metavolcanic and metasedimentary rocks strike east-west and are steeply dipping. Locally, a well-developed, steeply dipping, mylonitic schistosity, defined by lower greenschist-facies minerals, parallels the regional strike of beds and of major faults that bound the complex (Nokleberg and others, 1986b). Amphibolite-facies minerals (hornblende-biotite-intermediate plagioclase) occur within and adjacent to metagranodiorte plutons (Nokleberg and others, 1986b) that we infer to be Late Jurassic in age.

An older metaigneous sequence of schistose hornblende diorite and lesser schistose gabbro occurs as dikes, sills, and small plutons within the metavolcanic and metasedimentary rocks of the metamorphic complex of the Gulkana River (from which they are not differentiated on pl. 1). Rocks from this metaigneous sequence yield K-Ar hornblende ages of 306, 295, 282, 233, 131, and 130 Ma (W.J. Nokleberg, T.E. Smith, and D.L Turner, unpub. data, 1986). The older ages of 306 to 282 Ma probably indicate a Late Pennsylvanian and Early Permian age of intrusion; we regard the younger ages of 131 and 130 Ma as a minimum age for regional metamorphism.

We interpret metamorphism in both areas of this unit to have slightly preceded and to have been associated with the intrusion of the presumed Late Jurassic synkinematic plutons for the following reasons: (1) sphene from the Pennsylvanian metagranodiorite dated in the Dadina River metamorphic assemblage gives a concordant U-Pb age of about 150 Ma (Aleinikoff and others, 1988); (2) amphibolite-facies minerals occur within and adjacent to the inferred Late Jurassic plutons that intrude the older rocks of the metamorphic complex of the Gulkana River; (3) schistose metagranodiorite and metaquartz diorite from a probable synkinematic Late Jurassic pluton at the southern margin of the metamorphic complex of Gulkana River yield K-Ar ages on biotite of 142 and 148 Ma and on white mica of 146 and 148 Ma (Nokleberg and others, 1986b), and metagabbro of the Dadina River metamorphic assemblage gives a K-Ar age on hornblende of 152±6 Ma (Winkler and others, 1981b); and (4) correlation of the protolith and metamorphic history of both areas of this unit with the first metamorphic episode of the Haley Creek metamorphic assemblage and the Strelna Metamorphics in which the Late Jurassic plutons are also thought to have been synkinematic with regional deformation and metamorphism.

GNS, AMP (lJ)+GNS (eTlK)

This unit comprises a klippe of a polydeformed and polymetamorphosed bedded sequence of greenschist, marble, calcareous quartz schist, quartzofeldspathic mica schist, micaceous quartz schist, and layers of metachert that is extensively intruded by a compositionally diverse suite of foliated to blastomylonitic metaplutonic rocks (Wallace, 1981; Winkler and others, 1981b; Plafker and others, 1985c; Nokleberg and others, 1989b; Plafker and others, 1989). These rocks are informally referred to as the Haley Creek metamorphic assemblage. The metaplutonic rocks consist of volumetrically minor amounts of Pennsylvanian metagranodiorite and metagranite (Aleinikoff and others, 1988; not differentiated from the bedded rocks of this unit) and more abundant synkinematic and synmetamorphic Late Jurassic gneissic metadiorite, metatonalite, metatrondhjemite, amphibolite, and rare ultramafic and gabbroic rocks (unit lJg, pl. 1) (Plafker and others, 1989). Protoliths of the bedded sequence are interpreted to be a marine sequence of dominantly quartzofeldspathic, pelitic, calcareous, and cherty rocks and subordinate volcanic rocks that were deposited in a shelf or upper slope basin (Plafker and others, 1989).

The bedded rocks of the Haley Creek metamorphic assemblage are very similar in age and composition to the Strelna Metamorphics (unit GNS,AMP (lJ)+LPP (eTlK)), and the synkinematic metaplutonic rocks are correlative with the synkinematic Late Jurassic plutons of the Chitina Valley batholith (Plafker and others, 1985c). On the basis of this correlation, protoliths of the bedded sequence of the Haley Creek metamorphic assemblage are considered to be Early Pennsylvanian in age or older. Geophysical and other geologic data indicate that the Haley Creek metamorphic assemblage is a relatively thin (1 km or less) structural flap of the Wrangellia terrane's southern margin, whose structural position resulted from at least 40 km of relative underthrusting by the Chugach terrane (Page and others, 1986; Plafker and others, 1989).

The first metamorphic episode (M_1) that affected this unit was synkinematic with the intrusion of the Late Jurassic metadiorite and compositionally related plutonic rocks. These plutonic rocks give a 153±4-Ma U-Pb age on zircon (Plafker and others, 1989). Evidence of the general synchroneity between Late Jurassic plutonism, deformation, and M_1 metamorphism consists of (1) a shared deformational fabric in plutons and wallrocks, and (2) the fact that metamorphic conditions during M_1 were highest (amphibolite facies) near the Late Jurassic plutons and were lower grade (greenschist facies) farther away from them. Metamorphic hornblende, biotite, garnet, diopside, and intermediate plagioclase occur in metasedimentary wallrocks adjacent to Late Jurassic plutons (Wallace, 1981; Nokleberg and others, 1989b). Away from the plutons, greenschist-facies assemblages, characterized by actinolite, chlorite, and epidote-clinozoisite, predominate.

Locally within this unit, a strongly mylonitic, near-vertical, east-west-striking fabric, which is characterized by a subhorizontal east-west stretching lineation, largely obscures M_1 structures within discrete shear zones (Pavlis and Crouse, 1989). Strain is variable, and in some areas rocks are L-tectonites, whereas elsewhere lineation is weakly developed (Pavlis and Crouse, 1989). The mylonitic fabric is interpreted by Pavlis and Crouse (1989) to indicate large-scale strike-slip displacement of unknown sense that was synchronous with or postdated intusion of the Late Jurassic plutons.

The synkinematic, synmetamorphic Late Jurassic plutons are part of the Tonsina-Chichagof plutonic belt that is inferred from geochemical, isotopic, and petrologic data to be the roots of a magmatic arc (Hudson, 1983; J. Arth, written commun., 1987) that was built along the southern margin of the Wrangellia terrane. This arc, like the Late Triassic to Middle Jurassic Talkeetna arc discussed previously (see units AMP,GNS (meJ), AMP,GNS (meJ)+GNS (eTeK), and GNS,AMP (eKJ)), probably developed as a result of continued left-oblique subduction of the Farallon plate beneath the southern Alaska composite terrane (Plafker and others, 1989).

The position of the Late Jurassic plutons within the Haley Creek metamorphic assemblage and related units GNS,AMP (lJ)+LPP (eTlK) (Strelna Metamorphics) and the southern exposure of unit GNS,AMP (lJ) (Dadina River metamorphic assemblage) at or very near the Border Ranges fault system indicates that a substantial part of the southern Wrangellia terrane margin was tectonically removed since Jurassic time (Plafker and others, 1989). Plafker and others (1989) suggest that the missing segment of the terrane margin has been offset by as much as 600 km of sinistral displacement along the terrane margin and that it now makes up the part of the Wrangellia terrane in British Columbia. The suggested displacement is interpreted by Plafker and others (1989) to have resulted in the near-vertical, east-west-striking mylonitic fabric developed in both the bedded sequence and the Late Jurassic plutons and, therefore, to have occurred sometime during or following intrusion of the Late Jurassic plutons but before north-directed accretion of the Chugach terrane mélange (McHugh Complex; unit LPP (eTJ)) to the truncated margin of the Wrangellia terrane.

The possibility that some or all of this unit may have been metamorphosed prior to Late Jurassic time cannot be ruled out and may be indicated by a U-Pb age of 220 to 200 Ma on sphene from the Pennsylvanian metagranodiorite (Aleinikoff and others, 1988), as well as a K-Ar age of 185 Ma on biotite from garnetiferous pelitic schist of the Strelna Metamorphics (unit GNS,AMP (lJ)+LPP (eTlK)) in the eastern Chitina River valley (George Plafker, unpub. data, 1988).

Greenschist-facies retrograde metamorphism (M_2) of this sequence was widespread and is, for the most part, attributed to latest Cretaceous to early Tertiary underthrusting of the Haley Creek metamorphic assemblage (and correlative Strelna Metamorphics) by the Chugach terrane, mainly by the adjacent part of the Valdez Group (unit GNL (eTlK)) and, perhaps, to a lesser extent by the McHugh Complex (unit LPP (eTJ)) and the schist of Liberty Creek (unit GNI/H (meJ)) (Wallace, 1981, 1984; Nokleberg others, 1989b; Plafker and others, 1989). Some M_2 metamorphism also may have occurred during either or both (1) a cryptic Cretaceous thermal event, suggested by Early to mid-Cretaceous K-Ar ages from the synkinematic Jurassic metaplutonic rocks that intrude this unit and from the nearby schist of Liberty Creek (Plafker and others, 1989) or (2) an early Tertiary (Eocene) postunderthrusting thermal event that affected both the Chugach and Wrangellia terranes and that is manifested within the Haley Creek metamorphic assemblage by the intrusion of dikes and a plug (Plafker and others, 1989).

Wallace (1981, 1984) proposed that M_2 metamorphism consisted of two phases. The early phase produced the upper greenschist-facies (biotite zone) assemblage albite+epidote+sericite+chlorite±actinolite±biotite±quartz. This phase was accompanied by deformation that evolved from ductile to brittle and resulted in the development of penetrative, commonly mylonitic axial planar foliation, complex imbrication, and underthrusting of this unit by Valdez Group rocks. The late phase produced lower greenschist-facies (chlorite zone) assemblages containing chlorite+quartz+calcite±stilpnomelane. Deformation accompanying this phase was brittle and produced spaced axial planar cleavage, variable rotation and transposition of earlier surfaces, and locally intense imbrication. M_2 metamorphism of the Haley Creek metamorphic assemblage also is considered to have resulted in greenschist-facies metamorphism of the Valdez Group to the south (Wallace, 1984). Metamorphic age constraints for M_2 are the Late Cretaceous depositional age of the Valdez Group and the early Tertiary (Eocene) age of postmetamorphic or, less likely, late-metamorphic intrusive rocks in the Haley Creek metamorphic assemblage and the Valdez Group (Plafker and others, 1985c).

GNS,AMP (lJ)+LPP (eTlK)

This unit comprises a sequence of undifferentiated lower to upper greenschist-facies and lower amphibolite-facies rocks including phyllite, semischist; pelitic, calcareous, and mafic schist; mafic to intermediate metavolcanic and metaplutonic rocks, amphibolite, marble, metachert, and a few small tectonically emplaced serpentinized ultramafic masses (MacKevett, 1978; Winkler and others, 1981b; Plafker and others, 1985a). These rocks crop out in the northeastern Chugach Mountains, where they primarily have been assigned to the Strelna Metamorphics (Plafker and others, 1989). Previously they were part of the now-abandoned Strelna Formation as used by Moffit (1938), or they were considered by MacKevett (1978) to be the metamorphosed equivalent of the Skolai Group (included in unit LPP,GNS (lKJ)). Possibly correlative rocks to the southeast in the St. Elias Mountains, also included in this unit, are described by Campbell and Dodds (1985) in Canada and by Hudson and others (1977b) in the Yakutat area. Late Jurassic tonalitic to granodioritic plutons of the Chitina Valley batholith and correlatives (shown as synmetamorphic and synkinematic unit lJg) intrude this sequence in both areas, and their intrusion probably overlapped with regional deformation and metamorphism. In the northeastern Chugach Mountains, prehnite-pumpellyite-facies assemblages (M_2) overprint both the greenschist- and amphibolite-facies mineral assemblages (M_1) of this sequence and the igneous mineral assemblages of the Late Jurassic plutons.

Protoliths are mainly a marine sequence of clastic, carbonate, and andesitic volcanic rocks. An Early Pennsylvanian protolith age for at least some of the sequence is indicated by conodont data (Plafker and others, 1985a). This sequence is intruded by a compositionally variable suite of metaplutonic rocks that includes a pyroxene-bearing metamorphosed monzonite that has a U-Pb zircon age of 307±2 Ma. This suite is essentially identical with the metagranodiorite of the Dadina River and the Haley Creek metamorphic assemblages (units GNS,AMP (lJ) and GNS,AMP (lJ)+GNS (eTlK), respectively) (Plafker and others, 1989, table 2). Hornblende from a weakly metamorphosed gabbroic pluton that intrudes the westernmost end of the sequence yields a K-Ar age of 246±12 Ma (Winkler and others, 1981b); we consider this age to indicate a minimum Late Permian protolith age for the weakly metamorphosed gabbroic plutons within this unit because the dated sample was clearly affected by greenschist-facies metamorphism. The gabbroic plutons within this unit are also probably part of the belt of compositionally variable metaplutonic rocks that locally intruded other areas of the Wrangellia terrane (units LPP,GNS (lKJ); GNS,AMP (lJ); and GNS,AMP (lJ)+GNS (eTlK)) and the Alexander terrane (unit GNS (eKlPz)) during Middle Pennsylvanian time (Aleinikoff and others, 1988; Plafker and others, 1989). Metacarbonate rocks and greenstone (Nikolai Greenstone) of Late Triassic age form a minor part of this unit in the eastern Valdez quadrangle (Winkler and others, 1981b) and in the Saint Elias Mountains of Canada (Campbell and Dodds, 1985).

The rocks of this unit are interpreted by Plafker and others (1985c) to be the basement of the Wrangellia terrane. Along its northern margin, the unit structurally overlies the slightly lower grade upper Paleozoic and lower Mesozoic rocks of the Wrangellia terrane (unit LPP,GNS (lKJ)) or the low-grade lower(?) Paleozoic to lower Mesozoic rocks of the Alexander terrane (unit GNS (eKlPz)) along the southwest-dipping Early Cretaceous Chitina fault in the northeastern Chugach Mountains (Gardner and others, 1986) and it is inferred to overlie the latter terrane along the Hubbard fault (Plafker and Campbell, 1979; formerly the Art Lewis fault of Hudson and others, 1977b) in the St. Elias Mountains. Along its southern margin, this unit is relatively underthrust along the Border Ranges fault system by the accreted flyschoid rocks of the Chugach terrane (units GNL (eTlK) and GNL (eTlK)+AML (eT)).

Within this unit, the degree of deformation decreases northeastward, away from the Border Ranges fault. Most rocks are strongly foliated and multiply deformed; locally they are sheared and mylonitized (Plafker and others, 1985a; C. Dusel-Bacon, unpub. data, 1985). In the St. Elias Mountains, rocks are more schistose toward the fault, where they commonly are tightly folded about steeply dipping axial planes (Plafker and Campbell, 1979). Characteristic (M_1) mineral assemblages in greenschist-facies rocks in both the Chugach and St. Elias Mountains include actinolite, chlorite, albite, epidote-group minerals, quartz, sphene, and less commonly white mica, biotite, and calcite (in mafic rocks); chlorite, biotite, white mica, quartz, plagioclase, epidote-group minerals, and chloritoid (in pelitic rocks); and calcite, tremolite, epidote-group minerals, white mica, and quartz (in marble). Amphibolite-facies rocks, generally only present in the northeastern Chugach Mountains, contain hornblende, calcic plagioclase, epidote-group minerals, sphene, biotite and (or) chlorite (in amphibolite); and quartz, biotite, calcic plagioclase, potassium feldspar, and possible garnet (in pelitic rocks).

CAI values were determined for fossiliferous Pennsylvanian and Triassic carbonate rocks from the southeastern Valdez quadrangle (Plafker and others, 1989). Similar minimum temperatures are indicated for both samples (Triassic CAI of 5 corresponds to about 300°C and Pennsyvanian CAI of 5.5 corresponds to about 350°C).

The Late Jurassic (about 147-157-Ma) tonalitic to granodioritic plutons (unit lJg, pl. 1) (Hudson, 1983; Dodds and Campbell, 1988; Plafker and others, 1989) that intrude this unit and related unit GNS,AMP (lJ)+GNS (eTlK) (Haley Creek metamorphic assemblage), described immediately above, are inferred to be the roots of a magmatic arc (Hudson, 1983) built along the southern margin of the Wrangellia terrane (Plafker and others, 1989). The plate tectonic setting of that arc is discussed above in the previous unit description. We interpret the intrusion of the Late Jurassic plutons to have been synkinematic to late kinematic with regional metamorphism and deformation because the plutons are generally foliate, elongate parallel to regional trends, and have sharp to migmatitic and gradational boundaries (Hudson, 1983). We also infer that the synplutonic or postplutonic deformational fabric associated with strike-slip faulting in the Haley Creek metamorphic assemblage (Pavlis and Crouse, 1989), described previously, is present in the rocks of this unit (GNS,AMP (lJ)+LPP (eTlK)) and the Late Jurassic plutons that intrude them.

Very limited evidence suggests that an earlier metamorphic episode may have occurred prior to the one that accompanied intrusion of the Late Jurassic magmatic arc. This evidence consists primarily of the recent discovery of a small area of undated sillimanite-grade schist that apparently underlies the weakly metamorphosed Pennsylvanian and Lower Permian Skolai Group of unit LPP,GNS (lKJ) at Hawkins Glacier in the eastern Wrangell Mountains and, hence, whose metamorphism is probably Pennsylvanian or older in age (Plafker and others, 1989). Plafker and others (1989) propose that the most likely correlatives of the sillimanite-grade schist are the rocks of the Strelna Metamorphics that make up this unit. As mentioned in the previous discussion of the Haley Creek metamorphic assemblage, a K-Ar age of 185 Ma on biotite from garnetiferous pelitic schist of this unit, as well as a U-Pb age on sphene from metagranodiorite of the Haley Creek metamorphic assemblage, also suggest a pre-Late Jurassic metamorphic episode.

Petrographic observations of rocks from the northeastern Chugach Mountains indicate that widespread, weakly to moderately well developed prehnite-pumpellyite-facies (M_2) assemblages overprint the M_1 greenschist and amphibolite-facies mineral assemblages of this unit as well as the igneous mineral assemblages of the Late Jurassic plutons in that area (C. Dusel-Bacon, unpub. data, 1986). Characteristic M_2 metamorphic minerals are prehnite (which occurs most commonly as lenses that bow apart the cleavage planes of metamorphic and igneous biotite and less commonly as veins), epidote-group minerals, chlorite, and rare pumpellyite or laumontite. We tentatively assume, on the basis of the continuity of the tectonic setting between the part of this unit in the Chugach Mountains and the part in the St. Elias Mountains, that the part of this unit that is in the St. Elias Mountains also experienced M_2 low-grade recrystallization.

We propose that M_2 took place during the underthrusting of this unit by Valdez Group rocks, including units GNL (eTlK), GNL (eTlK)+AML (eT), and AMP (lTK) that lie south of the Border Ranges fault, during latest Cretaceous to early Tertiary time (Plafker and others, 1985c). Calcium-rich fluids that formed veins of prehnite and probably played a part in crystallization of M_2 phases may have been derived from the underlying graywackes of the Valdez Group. Lower plate Valdez Group rocks may underlie the rocks of this unit at a fairly shallow level, as is the case with the correlative Haley Creek metamorphic assemblage (unit GNS,AMP (lJ)+GNS (eTlK)) where Valdez Group rocks occur at depths of no more than 1 km (Plafker and others, 1985c; Page and others, 1986; Nokleberg and others, 1989b). Although M_2 mineral assemblages are present in both deformed and undeformed rocks, mylonitization in most deformed rocks is accompanied by chlorite and prehnite-grade recrystallization (C. Dusel-Bacon, unpub. data, 1986). A possible analog to the proposed formation of prehnite in this unit is provided by the study by Ross (1976) of prehnite in plutonic and metamorphic rocks of the Salinian block of California. Ross proposed that hydrous solutions, possibly derived from a substratum of graywacke of the Franciscan Complex, migrated through fractured rocks of the tectonically thinned margin of the Salinian block near the Sur fault zone, causing widespread crystallization of calcium-aluminum silicates.

GNS (eKlPz)

This unit consists primarily of marble; subordinate phyllite, greenschist, mica schist, and metaplutonic rocks of intermediate composition; and minor amphibolite (MacKevett, 1978; Hudson and others, 1977b; Campbell and Dodds, 1978). The marble is, in part, Devonian in age and may be as old as Cambrian (Gardner and others, 1988). These rocks are included in the Craig subterrane of the Alexander terrane; they are bounded on the southwest by the Hubbard fault in Alaska and Canada (Plafker and Campbell, 1979; Gardner and others, 1988). Metamorphism took place under greenschist-facies and, locally, lower amphibolite-facies conditions. The metamorphic grade of these rocks generally does not exceed the biotite zone and decreases northeastward (Campbell and Dodds, 1978). Garnet occurs only rarely in the St. Elias Mountains (Hudson and others, 1977b). In that area, metavolcanic rocks contain actinolite+albite+epidote+calcite; mica schist contains muscovite+chlorite+quartz and biotite+plagioclase+muscovite+quartz±clinozoisite±chlorite±garnet (Hudson and others, 1977b). Rocks are multiply folded and most are strongly schistose; kink banding and slip cleavage are locally developed.

In the St. Elias Mountains, late Paleozoic plutons (shown by symbol for weakly metamorphosed plutons, pl. 1) are dioritic to tonalitic in composition and have been altered to greenschist-facies assemblages. Two samples from the northern pluton yield K-Ar hornblende ages of about 280 Ma (near the Pennsylvanian-Permian boundary) (Hudson and others, 1977a). The fact that the dated samples were altered, or, as herein interpreted, metamorphosed during regional metamorphism of this unit, suggests that their K-Ar ages may have been partly reset during metamorphism. Resetting during a Mesozoic metamorphic episode is further suggested by Triassic and Early Cretaceous ages that were obtained from the southern pluton in the area. In spite of some resetting of protolith ages, these plutons are considered to be part of a regional belt of Middle Pennsylvanian plutons that intrude both the Wrangellia and Alexander terranes (U-Pb ages on zircon are about 310 Ma; K-Ar hornblende ages are 270 to 312 Ma; Gardner and others, 1988; Aleinikoff and others, 1988; Plafker and others, 1989). In adjacent areas of Canada, the belt is named the "Icefield Ranges plutonic suite" (Campbell and Dodds, 1985; Dodds and Campbell, 1988). Relations between the metamorphic rocks and the late Paleozoic plutons in the St. Elias Mountains may indicate that metamorphism in that area was synkinematic with plutonism. These relations, reported by Hudson and others (1977a,b) consist of (1) limited data that suggest that slightly higher grade metamorphic mineral assemblages are developed adjacent to the late Paleozoic plutons, and (2) the facts that the plutons are dominately foliate and commonly altered and that contact relations between plutons and country rocks are locally complex, being sharp and crosscutting as well as gradational.

In the southeastern McCarthy quadrangle, a pluton of Middle Pennsylvanian age (shown as a weakly metamorphosed pluton of unit LPP,GNS (lKJ), discussed below) intrudes both the Alexander and Wrangellia terranes, thereby indicating that the two terranes have been sutured since late Paleozoic time (MacKevett and others, 1986; Gardner and others, 1986). Because of this late Paleozoic minimum age for the juxtaposition of the two terranes, low-grade metamorphism in much of the Alexander terrane (this unit), like the slightly higher grade M_1 metamorphism in the Strelna Metamorphics of the Wrangellia terrane (unit GNS,AMP (lJ)+LPP (eTlK)), may have been associated with the intrusion of Late Jurassic plutons. Although Late Jurassic plutons have not been mapped within the Alexander terrane in Alaska, Late Jurassic to Early Cretaceous (160- to 130-Ma) plutons compose a major intrusive suite within the continuation of these terranes in Canada (Campbell and Dodds, 1985; Dodds and Campbell, 1988). Geologic evidence from the continuation of this unit in Canada suggests regional metamorphism and deformation may have occurred during Late Jurassic to Early Cretaceous time (about 160 to 130 Ma) and was associated with plutonism of that age. According to R.B. Campbell and C.J. Dodds (written commun., 1986), "The younger of the 160-130 Ma plutons seems clearly to postdate the metamorphism and deformation in the northeast where they produce distinct contact metamorphic aureoles. The older plutons of this group to the southwest may have been intruded during the metamorphism and deformation; they are commonly elongate parallel with the regional structural grain, but they clearly have local cross-cutting contacts and probably in part postdate those events. Upper Triassic strata probably rest unconformably on Paleozoic rocks but nevertheless appear to be equally deformed and metamorphosed, thus, the widespread deformation and metamorphism seems to be post Late Triassic and pre-earliest Cretaceous".

The late Paleozoic to Early Cretaceous age constraints given for this unit reflect the possibility that one or both of the possible metamorphic episodes discussed above may have affected different parts of this unit.

AMP (lTPz)

This unit comprises a heterogeneous assemblage of banded granite and quartz diorite gneiss and biotite- and augite-bearing amphibolite that is gradational into biotite metagranodiorite and metagranite. This assemblage of metaplutonic rocks, referred to as the (informal) Cottonwood Creek complex (Richter and others, 1975; Richter, 1976), occurs within the Denali fault zone in the southeastern Nabesna quadrangle, where it is enclosed by schist and phyllite. Garnet porphyroblasts are locally abundant in the metaigneous rocks, particularly in the more silicic banded gneiss (Richter, 1976). Metagranitic rocks characteristically have a granoblastic texture.

K-Ar ages on metamorphic biotite and amphibole yield ages of 17 to 20 Ma (Richter and others, 1975). These ages provide a minimum metamorphic age. It remains to be determined whether these igneous or metamorphic crystalline rocks were: (1) metamorphosed during Early Miocene time as a result of a period of strong stress that immediately preceded and accompanied what may have been initial strike-slip movement along the fault, as suggested by Richter and others (1975); or (2) metamorphosed during an episode prior to and unrelated to faulting. In the case of the latter possibility, our preferred interpretation, the K-Ar ages are totally reset as a result of strike-slip faulting, and the (informal) Cottonwood Creek complex represents a fault slice of an older Paleozoic or Mesozoic igneous or metamorphic complex that is now widely separated from the rest of the complex. One possibility is that it was derived from the Ruby Range batholith and Kluane Schist in southern Yukon Territory (Muller, 1967), as proposed by Brewer (1982) and W.J. Nokleberg (this report).

Low-grade rocks of the Peninsular and Wrangellia terranes and low- to high-grade flyschoid rocks inboard of the Wrangellia terrane.

LPP (J)

The very weakly metamorphosed assemblage of laumontitic metagraywacke and metavolcanic rocks that make up this unit crops out on the Alaska Peninsula in the southwestern Kenai quadrangle and is part of the Peninsular terrane. Protoliths are Jurassic volcaniclastic sedimentary rocks and mafic and intermediate volcanic rocks (Detterman and Reed, 1980). Metagraywacke is characterized by the metamorphic mineral assemblage laumontite+chlorite+ quartz (R.L. Detterman, written commun., 1983). Metamorphism is thought to have been associated with and primarily to have preceded arc-related Jurassic plutonism of the Alaska-Aleutian batholith (Reed and Lanphere, 1973; Talkeetna magmatic arc of Plafker and others, 1989) of which the synmetamorphic plutons that intrude unit AMP,GNS (meJ) form a part.

LPP (eT/Ʀ)

The weakly metamorphosed pillowed greenstone and metavolcaniclastic turbidites of the Upper Triassic Shuyak Formation that compose this unit crop out on Kodiak and Afognak Islands and are included in the Peninsular terrane. Metamorphism of these rocks has not been studied in detail, but secondary prehnite and (or) pumpellyite are reported to occur in many samples (Connelly, 1978). The Shuyak Formation is interpreted as an early Mesozoic forearc basin deposit (Connelly, 1978). The metamorphic age is unknown and can only be bracketed between the Late Triassic protolith age and early Tertiary K-Ar cooling ages (Davies and Moore, 1984) from unmetamorphosed dikes that intrude the Jurassic plutons that in turn intrude this unit. Minor low-grade alteration locally has affected the Jurassic plutons. This alteration may have resulted from the regional prehnite-pumpellyite-facies metamorphism, but more likely was produced by hydrothermal alteration (S.M. Roeske, oral commun., 1984).

LPP,GNS (IKJ)

This unit comprises prehnite-pumpellyite- and lower greenschist-facies upper Paleozoic intermediate arc-related metavolcanic rocks, metalimestone, argillite, and metachert; Pennsylvanian intermediate to silicic metaplutonic rocks (diagonal dash pattern, pl. 1); Middle Triassic cherty and tuffaceous argillite, Upper Triassic subaerial and pillowed basalt (Nikolai Greenstone) and limestone; Upper Triassic and Lower Jurassic metasedimentary rocks of the McCarthy Formation; and small scattered outcrops of Mesozoic marine metasedimentary rocks that crop out in the northwestern part of this unit (Csejtey and others, 1982; Smith, 1981; Nokleberg and others, 1985a; Richter, 1976; MacKevett, 1978). All the rocks of this unit are included in the Wrangellia terrane.

Most rocks have not been penetratively deformed (except near major faults) and exhibit well-preserved volcanic, sedimentary, or plutonic textures (MacKevett, 1978; Richter, 1976; Beard and Barker, 1989; Nokleberg, unpub. data, 1984). Locally, however, in the general area that is proposed to be the leading edge along which the Wrangellia terrane was accreted (Csejtey and others, 1982), rocks are weakly phyllitic or schistose in the central Alaska Range (Smith, 1981; Nokleberg and others, 1985a) and intensely folded and sheared in the Talkeetna Mountains (Csejtey and others, 1978).

Very little detailed petrographic and petrologic study has been made of this metamorphic unit. Characteristic metamorphic minerals developed in Triassic greenstone and tuffaceous rocks include chlorite, prehnite, pumpellyite, quartz, albite, epidote-group minerals, calcite, sericite, and iron-oxides; recrystallized tuffs contain epidote, chlorite, and white mica (Richter, 1976; MacKevett, 1978; Csejtey and others, 1978; Smith, 1981; Nokleberg and others, 1985a). These assemblages indicate that metamorphic conditions were primarily those of the prehnite-pumpellyite facies. The metamorphic assemblage actinolite-chlorite-epidote-albite, characteristic of the lower greenschist facies, occurs pervasively in Triassic greenstone in the Mount Hayes quadrangle (Nokleberg and others, 1985a) and in the Talkeetna mountains (Csejtey and others, 1978). This assemblage indicates that metamorphic temperatures in those areas reached above about 330°C, based on the reaction pumpellyite+chlorite+quartz=clinozoisite+actinolite+water (Nitsch, 1971). CAI values of 5.5 to 6.0 from Upper Triassic conodonts collected in the McCarthy quadrangle from the Nizina and Chitistone Limestones and the lower part of the McCarthy Formation suggest metamorphic temperatures of about 350 to 450°C (M.W. Mullen, oral commun., 1989).

The intermediate metaplutonic rocks in the eastern Gulkana and western Nabesna quadrangles (Ahtell pluton and related rocks of the diorite complex of Richter and others (1975)) give Pennsylvanian U-Pb ages on zircon (Barker and Stern, 1986; J.N. Aleinikoff and W.J. Nokleberg, unpub. data, 1987); they are chemically similar to and are probably the plutonic equivalents of the upper Paleozoic metavolcanic rocks (Beard and Barker, 1989). The metamorphic grade of these late Paleozoic metavolcanic and metaplutonic rocks is generally comparable to that of the low-grade Mesozoic rocks. In the northeastern Gulkana quadrangle, the Ahtell pluton contains metamorphic white mica, chlorite, albite, and quartz (W.J. Nokleberg, unpub. data, 1984). Metamorphic minerals developed in the correlative diorite complex of Richter (1976) consist of actinolite, chlorite, zoisite, and white mica (Barker and Stern, 1986). Late Paleozoic metavolcanic rocks in the northwestern Nabesna quadrangle generally contain the low-grade assemblage chlorite-epidote-pumpellyite, except near the diorite complex where it has been recrystallized to massive, fine-grained assemblages of hornblende, epidote, chlorite, and feldspar (Richter, 1976). A variety of other medium- to high-grade rocks, including quartz-feldspar schist, gneissic metaplutonic rocks, and amphibolite, are intricately mixed with the weakly metamorphosed metaplutonic rocks of the diorite complex; contacts between the two groups of rocks are intrusive (W.J. Nokleberg and D.H. Richter, unpub. data, 1986). These higher grade rocks are not differentiated on plate 1 because of their limited aerial extent.

The (informal) Barnard Glacier pluton in the Wrangell Mountains is of monzonitic and syenitic composition and gives a Middle Pennsylvanian (309±5-Ma) U-Pb age on zircon (Gardner and others, 1988). The structural relations of the pluton show that it is intrusive into both the low-grade rocks of this unit to the west, included in the Wrangellia terrane, and the greenschist-facies rocks of unit GNS (eKIPz) to the east, included in the Alexander terrane, thereby indicating that the two terranes were sutured together by Middle Pennsylvanian time (MacKevett and others, 1986; Gardner and others, 1986). Generally the pluton is unfoliated, but, locally, it is cataclastically deformed (MacKevett, 1978). Although the data are inconclusive, the pluton is tentatively shown on plate 1 to have been weakly metamorphosed along with the Wrangellia terrane wallrocks on the west, although numerous other possible correlations of its metamorphic history are possible given the uncertainty of the timing of metamorphism in this region.

The age and cause of low-grade metamorphism of this unit are uncertain and may have differed in different parts of this unit. Because the metamorphic grade of these rocks is so low, it is difficult to determine with certainty whether some associated rocks have been metamorphosed. In the southern part of this unit, the CAI values from the Late Triassic conodonts indicate that metamorphism is post-Late Triassic in age. The minimum metamorphic age in that area is uncertain, but we also assume that it postdates the Lower Jurassic part of the McCarthy Formation. A tentative Middle or Late Jurassic minimum age of metamorphism for at least some areas of this unit is suggested by the apparent lack of metamorphism in the Upper Jurassic and Lower Cretaceous Nutzotin Mountains sequence in the Nabesna quadrangle (Richter, 1976) and in the Jurassic and Cretaceous sedimentary rocks that overlie the McCarthy Formation in the Valdez and McCarthy quadrangles (Winkler and others, 1981b; MacKevett, 1978).

Hornblende and biotite from the diorite complex in the northern part of this unit yield Early Jurassic K-Ar ages (Richter and others, 1975), but it is uncertain whether these ages (1) date the predominant period of metamorphism in that area, (2) provide a minimum age for a late Paleozoic or early Mesozoic episode, or (3) represent a partial resetting of the Pennsylvanian protolith age by a possible Cretaceous metamorphic episode, described below.

Metamorphism in some areas along the southern margin of unit LPP,GNS (lKJ) may have been associated with the intrusion of the Late Jurassic Chitina valley batholith (unit lJg) that we propose occurred during the greenschist- to amphibolite-facies metamorphism of the Strelna Metamorphics (shown as unit GNS,AMP (lJ)+LPP (eTlK)) to the south. Although the two units that may grade into one another are separated by a thrust fault of Cretaceous age, an overall proximity of the units during the Late Jurassic intrusive and metamorphic episode is suggested by the facts that (1) a Late Jurassic pluton also intrudes unit LPP,GNS (lKJ) in one area in the western McCarthy quadrangle, (2) higher grade unit GNS,AMP (lJ)+LPP (eTlK) includes a minor component of Upper Triassic rocks that are correlated with those of unit LPP,GNS (lKJ), and (3) metamorphic temperatures, as determined from Late Triassic conodonts, are comparable across the Chitina fault (that is, about 350 to 450°C to the north and about 350°C to the south; M.W. Mullen, written commun., 1989).

Limited data suggest an alternative Cretaceous metamorphic age for some areas of this unit. Field observations in the central Alaska Range and Talkeetna Mountains (Béla Csejtey, Jr., and W.J. Nokleberg, unpub. data, 1982) and petrographic data from the central Alaska Range (Nokleberg and others, 1985a) suggest that Jurassic and Cretaceous rocks that overlie the Nikolai Greenstone also have undergone low-grade metamorphism. Three K-Ar whole-rock ages from samples of the Nikolai Greenstone from the southern part of this unit in the central McCarthy quadrangle fall on a 112±11-Ma isochron (Silberman and others, 1981).

Silberman and his coworkers (1981) propose that the late Early Cretaceous K-Ar ages from the McCarthy quadrangle date an episode of low-grade metamorphism that was caused by frictional heating that accompanied the accretion of the Wrangellia terrane to the North American margin. Arguing against this hypothesis for at least the McCarthy quadrangle, however, is the fact that the Upper Triassic rocks show no sign of being deformed (although they have been heated to about 350 to 450°C since the Late Triassic). Assuming that the late Early Cretaceous K-Ar ages do in fact date the timing of low-grade metamorphism in the central McCarthy quadrangle, metamorphism may have been coeval with the northeast-directed, Early Cretaceous movement along the nearby Chitina fault (Gardner and others, 1986) that placed the medium-grade metamorphic rocks (unit GNS,AMP (lJ)+LPP (eTlK)) and synkinematic Jurassic plutonic rocks of the Wrangellia terrane on top of the low-grade rocks of this unit.

The localized development of a penetrative fabric and higher temperature, actinolite-bearing mineral assemblages in the central Alaska Range and the Talkeetna Mountains, areas that were near the leading edge along which this terrane is proposed to have been accreted in mid- to Late Cretaceous time (Jones and Silberling, 1982; Csejtey and others, 1982; Nokleberg and others, 1985a), supports the hypothesis that, at least in those areas, metamorphism occurred during the late Mesozoic accretionary event, either for the first time or following an earlier weak metamorphic episode. However, the general absence of a penetrative fabric in most of this unit, except for the more northerly part, may indicate that prehnite-pumpellyite-facies metamorphism in at least some areas developed as a result of burial metamorphism, perhaps in conjunction with dehydration reactions in the underlying rocks. Because it is not possible to determine the extent of the area where metamorphism may have accompanied accretion of the Wrangellia terrane during mid- to Late Cretaceous time and because widespread low-grade metamorphism of this unit in post-Late Jurassic time is still speculative in some areas, the metamorphic age for this low-grade episode is shown to have occurred sometime during Jurassic to Late Cretaceous time.

LPP (eTlK)

This unit consists of highly deformed prehnite-pumpellyite-facies flyschoid rocks of Late Jurassic to early Late Cretaceous (Cenomanian) age (Kahiltna terrane), primarily metagraywacke, semischist, and argillite, that occur northwest of the Talkeetna fault and rocks from several tectonic fragments included within the flysch basin. Tectonic fragments that are structurally interleaved with the weakly metamorphosed flysch include, from west to east and beginning in the southwest corner of the Healy quadrangle: (1) a sequence of folded and thrust-faulted ophiolite (shown as ultramafic body Du, pl. 1) of Late Devonian age and metachert, metaconglomerate, metalimestone, argillite, semischist, pillowed greenstone, and mafic metatuff of Late Devonian to Jurassic age (Chulitna terrane); (2) massive volcanic metapelite and intermediate or mafic metatuff of Triassic(?) and Early Jurassic age structurally or stratigraphically overlying disrupted argillite, metachert, and metasandstone of Late Jurassic age and fault-bounded slivers of metalimestone of Early Jurassic age (West

Fork terrane); (3) a structurally complex assemblage of metachert of Mississippian age, argillite, phyllite, metatuff, and metagraywacke of Late Devonian or younger Paleozoic age, and limestone blocks of Silurian(?) and Devonian age (Broad Pass terrane); and (4) pillowed greenstone and intercalated volcaniclastic metasedimentary rocks of Late Triassic (Norian) age (Susitna terrane) (Jones and others, 1980).

The dominant structural style of this metamorphic unit is contraction and attendant thrust faulting that has juxtaposed fragments of what were parts of extensive coherent terranes (Csejtey and others, 1978; Jones and others, 1980). Deformation and attendant recrystallization within the flysch terrane is most intense along zones of concentrated shear, and rocks in these zones are commonly phyllitic, semischistose, or protomylonitic. Mafic tuff in the Chulitna terrane is generally altered and sheared to a featureless chloritic rock (Jones and others, 1980).

The degree of metamorphism may vary within this unit, and this aspect of the terranes involved has not been studied in detail. Many protoliths, particularly sedimentary clastic rocks and limestones, yield metamorphic minerals that are stable over a range of low P-T conditions, making the establishment of metamorphic grade difficult. Such nondiagnostic metamorphic minerals in flyschoid rocks include fine-grained sericite or white mica, quartz, and chlorite in the matrix or, less commonly, as replacement minerals within clasts. Most of these rocks only show incipient flattening of grains, but semischistose or protomylonitic fabrics are present in some. Metamorphic minerals in Triassic greenstone in both the Chulitna and Susitna terranes consist of combinations of pumpellyite, chlorite, quartz, and calcite in amygdules and chlorite, iron-titanium oxides, granular sphene, and albite in the matrix. In the Susitna terrane, pumpellyite occurs within the matrix and in veinlets as well. Relict igneous (intersertal) textures generally are well preserved in these rocks. CAI values of 4.0 and 4.5 to 5.0 were determined for conodonts from two samples of Upper Devonian metalimestone from the Chulitna terrane (A.G. Harris, written commun., 1984), indicating metamorphic temperature conditions for those rocks were in the range of 200 to 300°C (Epstein and others, 1977; A.G. Harris, oral commun., 1984), temperatures that are characteristic of prehnite-pumpellyite-facies metamorphism.

Metamorphism of these low-grade rocks is bracketed between the early Late Cretaceous (Cenomanian) age of the youngest metamorphosed rocks and the latest Paleocene and Eocene ages of the overlying unmetamorphosed sedimentary and volcanic rocks and the early Tertiary age of postmetamorphic granitoids that intrude the flyschoid rocks (Csejtey and others, 1978, 1982, 1986). The tectonic juxtaposition of the disparate terranes included within this unit is considered to have occurred during mid-Cretaceous time (Csejtey and others, 1978, 1982; Jones and others, 1980) and perhaps extended into Late Cretaceous time (Jones and others, 1980). According to Csejtey and others (1982), the flyschoid sediments were deposited in a basin between the North American craton and the approaching Talkeetna superterrane to the south, and the small terranes within the flysch were transported in front of the superterrane by northward plate movement. If our present assumption that the disparate terranes of this unit were metamorphosed during the same episode is correct, it seems likely that metamorphism was related to the major accretionary event. This hypothesis is based on the regional similarity in metamorphic grade between various parts of the unit, the apparent increase in metamorphic grade toward zones of shearing, and the fact that the age brackets for accretion are approximately the same as those for low-grade metamorphism. However, prehnite-pumpellyite-facies metamorphism of the Triassic basalts may have occurred prior to juxtaposition and accretion of the terranes as well as, or instead of, during northward migration and accretion.

LPP $(eTIK)_1$

This unit comprises the lowest grade and southernmost part of the Maclaren metamorphic belt and consists of weakly metamorphosed argillite, graywacke, metaconglomerate, metagabbro, and volcaniclastic metasedimentary rocks (Alaska Division of Geological and Geophysical Surveys, 1974b; Smith, 1981, 1984). Csejtey and others (1982, 1986) consider this unit to be Jurassic and Cretaceous flysch. A pre-Late Jurassic protolith age and inferred accretionary age for at least part of the Maclaren metamorphic belt is indicated by a 146-Ma K-Ar age on hornblende from an undeformed alkali gabbro stock that crosscuts folded argillite (Turner and Smith, 1974; Smith, 1981). The unit crops out in the southeastern Healy quadrangle and is included in the Maclaren and Kahiltna terranes, east and west of the Susistna River, respectively.

Primary depositional features are generally preserved, except where penetrative deformation has developed near faults. A slaty cleavage is developed in the highest grade (northernmost) part of this unit.

Prehnite and pumpellyite commonly are developed in the graywacke groundmass, and chlorite and prehnite are present in the tuffaceous matrix of conglomerates; argillite contains metamorphic chlorite and white mica. Metamorphism of the alkali gabbro stock (shown as a metamorphosed pluton, pl. 1) has resulted in replacement of igneous plagioclase by white mica, epidote-group minerals, and quartz and replacement of clinopyroxene and hornblende by actinolite, sodic hornblende, or chlorite (Smith, 1981).

The Maclaren metamorphic belt comprises a dominantly fault-bounded, 140-km-long, roughly symmetrical, intermediate-pressure (Barrovian) sequence that developed during Late Cretaceous and early Tertiary time. Along the southern limb of the belt, lower grade rocks (including this unit) dip northward under higher grade units to form an inverted metamorphic sequence (Smith, 1981). The proposed age and tectonic origin of this metamorphic episode is based on isotopic data and structural relations observed in the amphibolite-facies part of the metamorphic belt described below.

GNI (eTIK)

The intermediate-pressure rocks of this unit form the greenschist-facies part of the Maclaren metamorphic belt described above that developed during Late Cretaceous and early Tertiary time (Alaska Division of Geological and Geophysical Surveys, 1974b; Smith, 1981, 1984). Greenschist-facies rocks just south of the McKinley fault and west of West Fork Glacier include carbonaceous marble, quartzite, and metapelite, and greenstone of Triassic age (Csejtey and others, 1982; Jones and others, 1984). The rest of this metamorphic unit consists of pelitic and calcareous phyllite and metagraywacke whose protoliths consist of flysch of mostly Jurassic and Cretaceous age (Jones and others, 1984; Csejtey and others, 1986). This unit is included in the Maclaren, Kahiltna, and Nenana terranes. Rocks are penetratively deformed and isoclinally folded.

Characteristic mineral assemblages contain quartz, albite, chlorite, white mica, graphite, and calcite; biotite has been reported to coexist with these minerals in metapelite at one locality west of West Fork Glacier (T.E. Smith, unpub. data, 1973). Conodonts from three samples of metamorphosed limestone, interlayered with greenstone, yield CAI values of 5 (two samples) and 5.5 (one sample) (Sherwood and Craddock, 1979; M.W. Mullen, unpub. data, 1983), indicating that they were metamorphosed under temperature conditions in the range of about 300 to 400°C (Epstein and others, 1977).

These greenschist-facies rocks flank a core of high-grade sillimanite-zone rocks, indicating symmetrical P-T conditions during prograde metamorphism of the northeast-trending, 140-km-long Maclaren metamorphic belt (Smith, 1984). Metamorphic contacts of this unit are generally gradational, and a gradual increase or decrease in metamorphic grade into the adjacent higher and lower grade metamorphic units of the complex takes place. Such a gradational contact occurs in the highest grade (northern) part of the southern limb of greenschist-facies rocks that crop out in the southeast corner of the Healy quadrangle; near the contact, biotite replaces chlorite and, locally, actinolite, epidote-group minerals, or garnet are present (Smith, 1981). Exceptions to this relation occur farther to the east in the Mount Hayes quadrangle, where an abrupt change in metamorphic grade between the greenschist-facies rocks and the higher and lower grade rocks is present as a result of tectonic shortening along steep north-dipping faults (Nokleberg and others, 1982). Greenschist-facies rocks of the southern limb of the symmetrical sequence form the middle part of a northward-dipping inverted metamorphic sequence in which lower grade units underlie higher grade units. The proposed age and tectonic origin of this metamorphic episode are based on isotopic data and structural relations observed in the amphibolite-facies part of the metamorphic belt described below.

AMI (eTIK)

This unit constitutes the core and highest grade part of the prograde, inverted, and tectonically shortened metamorphic sequence of the Maclaren metamorphic belt (Alaska Division of Geological and Geophysical Surveys, 1974b; Smith, 1981, 1984; Nokleberg and others, 1982, 1985a). It comprises intermediate-pressure amphibolite-facies pelitic schist, gneiss, and amphibolite and is intruded by foliated intermediate metaplutonic rocks of the East Susitna batholith (Nokleberg and others, 1982) and the quartz diorite sill (Smith, 1981) (shown as the synmetamorphic and synkinematic intrusive rocks of unit TKg, pl. 1). Protoliths are Jurassic and Cretaceous flysch and carbonaceous shale and sandstone of Triassic age (Csejtey and others, 1982, 1986). This unit is included in the Kahiltna, Nenana, and Maclaren terranes.

Typical metamorphic mineral assemblages in pelitic schist and gneiss include quartz, plagioclase, biotite, muscovite, garnet, staurolite, and graphite; sillimanite is common in the highest grade core of the complex (shown by the sillimanite isograd). Kyanite is abundant in pelitic schist east of the Susitna

River in the southeastern Healy quadrangle, where it coexists with sillimanite, garnet, and staurolite (Smith, 1981), and sillimanite pseudomorphs after kyanite are also present in the same general area (L.S. Hollister, written commun., 1985). Cordierite has been reported to occur in quartz mica schist at one locality near West Fork Glacier just south of the McKinley fault (Brewer, 1982). Andalusite has been identified in pelitic schist at two localities: (1) in the far western part of this unit, west of the Susitna River (T.E. Smith, written commun., 1980), and (2) near the eastern boundary of this unit, just west of the Delta River (J.H. Stout, written commun., 1972). These reported occurrences of andalusite warrant further investigation, but they may simply indicate that higher structural levels are exposed on the flanks of the metamorphic complex relative to deeper levels exposed in its central part. Chemical and petrographic evidence indicate that the schist unit is derived from prograde metamorphism of the lower grade phyllite, argillite, and metagraywacke units previously described (Smith, 1981).

Characteristic assemblages in amphibolites are quartz+calcic plagioclase+hornblende±garnet±clinozoisite±calcite and hornblende+diopside+calcic plagioclase. Kyanite is also reported to occur in amphibolite in the southeastern Healy quadrangle (Smith, 1981), further evidence of intermediate- or even high-pressure conditions.

Typical metamorphic minerals in the foliated plutons are quartz+calcic plagioclase+potassium feldspar+hornblende+biotite±white mica±sphene. Staurolite was observed in one sample of granodiorite (Nokleberg and others, 1985a). A sharp change in metamorphic grade occurs on either side of a north-dipping thrust that forms the southern margin of the foliated quartz diorite sill in the southeastern Healy quadrangle (Smith, 1981) and the East Susitna batholith in the western Mount Hayes quadrangle (Nokleberg and others, 1982). Deeper level rocks are exposed north of the thrust. The first appearance of kyanite and sillimanite in the southeastern Healy quadrangle occurs in the upper plate adjacent to the thrust (Smith, 1981).

Metamorphic recrystallization occurred during and after two dynamic phases of a prolonged metamorphic episode (Smith, 1981). Disoriented crystals of hornblende and garnet preserve helicitic remnants of an older foliation and are interpreted to have grown during a dynamically quiescent period and to have been subsequently rotated by shearing. Many garnets have cores that crystallized dynamothermally and rims that crystallized during a final prolonged thermal phase of the episode. Kyanite and staurolite are generally idioblastic, having been formed postkinematically (Smith, 1981). Retrogressive replacement of garnet, hornblende, and biotite by greenschist-facies minerals occurred to varying degrees throughout the unit during the waning stages of the thermal phase (Smith, 1981), and it also occurred locally as a result of subsequent intense shearing (Nokleberg and others, 1982).

The concordancy between intrusive contacts and metamorphic foliations in the granitoids and in the metamorphosed wallrocks and the fact that metamorphic grade increases toward the East Susitna batholith (Nokleberg and others, 1985a) indicate that the granitoids were intruded during the early part of the dynamothermal metamorphic episode (Smith, 1981; Nokleberg and others, 1982, 1985a). Smith (1981) proposes that the concordant, foliated granitoids were intruded toward the end of an early shearing phase or interkinematically before a final phase of shearing. U-Pb data on zircon indicate an intrusive age of 70±7 Ma for schistose quartz diorite of the East Susitna batholith (Aleinikoff and others, 1982). K-Ar ages on hornblende from metaigneous rocks are as old as 87.4 Ma, indicating synkinematic intrusion over a long period of time. U-Pb data on sphene and K-Ar data on biotite from the East Susitna batholith indicate a metamorphic age of 56 Ma (Aleinikoff and others, 1982), which probably marks the end of the prolonged Late Cretaceous and early Tertiary metamorphic episode. Biotite from pelitic schist gives a similar K-Ar age of 57 Ma (Smith and Lanphere, 1971). Rapid uplift and cooling during metamorphism is indicated by the fact that approximately the same age is given by sphene, whose closure temperature is greater than 600°C (Mattinson, 1978), and biotite, whose closure temperature is about 280°C (Harrison and others, 1985).

Metamorphism and tectonic shortening of the Maclaren metamorphic belt apparently resulted from the accretion of the previously amalgamated Peninsular and Wrangellia terrane onto the Yukon-Tanana and Nixon Fork terranes of the ancient North American continent (Csejtey and others, 1982) and the synkinematic intrusion of the East Susitna batholith (Nokleberg and others, 1985a). The flyschoid protoliths of the Maclaren metamorphic belt, as well as those of unit LPP (eTIK), were deposited mostly in the narrowing and subsequently collapsed ocean basin between the converging terranes (Csejtey and others, 1982; Nokleberg and others, 1985a).

The location in which the convergence, deformation, plutonism, and metamorphism took place is disputed, however. Several lines of evidence suggest that the Maclaren metamorphic belt and East Susitna batholith are the offset equivalents of the Kluane

Schist and Ruby Range batholith in the Yukon Territory, displaced from each other by about 400 km of right-lateral movement along the McKinley and Denali faults (for example, Forbes and others, 1973; Alaska Division of Geological and Geophysical Surveys, 1974a,b; Smith, 1981; Nokleberg and others, 1985a; Aleinikoff and others, 1987). Nokleberg and coworkers (1985a) postulate that intense deformation and prograde metamorphism of the belt began during mid- to Late Cretaceous time as a result of the accretion of the Wrangellia terrane onto the North American margin farther to the south and continued during early Tertiary time as a result of the northward migration of the flyschoid (Maclaren) terrane and the Wrangellia terrane along the North American margin.

Csejtey and others (1982, 1986) dispute the correlation between the Maclaren metamorphic belt and the Kluane Schist and propose instead that regional metamorphism of the Maclaren metamorphic belt occurred in place, extends across the McKinley fault, and is only slightly offset by it. Although there is an apparent similarity in metamorphic grade and a similar eastward increase in metamorphic grade on either side of the McKinley fault in the east-central part of the Healy quadrangle, metamorphic data are insufficient to document continuity of metamorphic history across the fault. Arguing against continuity of metamorphic history on either side of the McKinley fault is the fact that the fault-bounded block of unit GNS (lKD) (Windy terrane) occurs between the areas of amphibolite-facies rocks that crop out on either side of the fault in the central Mount Hayes quadrangle. This relation shows that, at least in that area, substantial movement took place along the McKinley fault after metamorphism.

AREA SOUTH OF THE BORDER RANGES FAULT SYSTEM

CHUGACH TERRANE

GNl/H (meJ)

The belt of transitional, intermediate-pressure greenschist-facies to high-pressure greenschist- (blueschist-) facies metabasalt, metachert, mica schist, marble, and fine-grained clastic rocks that makes up this unit is derived from oceanic protoliths, and it crops out immediately south of the Border Ranges fault system (pl. 1) near the northern margin of the Chugach terrane (fig. 4). The belt extends discontinuously for about 750 km from Kodiak Island on the west to the Copper River on the east. This unit consists of fault-bounded and commonly internally imbricated blocks, and it includes from southwest to northeast, the Raspberry Schist of Roeske (1986) on Kodiak and Afognak Islands (Carden and Forbes, 1976; Roeske, 1986), the schist of Seldovia on the Kenai Peninsula (Forbes and Lanphere, 1973; Carden and others, 1977), the schist of Iceberg Lake near Tazlina Glacier (Winkler and others, 1981a,b; Sisson and Onstott, 1986), and the schist of Liberty Creek just west of the Copper River (Metz, 1976; Winkler and others, 1981b; Plafker and others, 1989). Protolith ages are unknown. Because this unit forms the innermost part of the Chugach terrane accretionary complex, its protoliths are probably older than the Late Triassic to mid-Cretaceous protoliths of the prehnite-pumpellyite-facies McHugh Complex (unit LPP (eTJ) of the Chugach terrane that borders it on the south (Plafker and others, 1989).

In most areas, discussed individually below, greenschists that contain chlorite+actinolite commonly are finely intercalated with blue-amphibole-bearing schists that contain crossite+epidote (Forbes and Lanphere, 1973; Carden and others, 1977; Carden, 1978; Winkler and others, 1981a,b). Glaucophane (+epidote) has been identified only in the Raspberry Schist on Afognak Island (pl. 1; Roeske, 1986), and the assemblage garnet+crossite+epidote is present in the schist of Iceberg Lake near Tazlina Glacier (Winkler and others, 1981a,b). Lawsonite coexists with blue amphibole at scattered localities along the belt (pl. 1).

The coexistence of blue amphibole with epidote and, in one area, with garnet is indicative of the high-temperature subdivision of the blueschist facies (Taylor and Coleman, 1968; Evans and Brown, 1987). However, the sporatic occurrence of lawsonite, which is diagnostic of the low-temperature subdivision of the blueschist-facies, indicates that temperatures during metamorphism were probably near the boundary between the two subdivisions. Phase equilibria that involve the breakdown of pumpellyite to form epidote (Nitsch, 1971) and the breakdown of lawsonite to form zoisite (Franz and Althaus, 1977) suggest temperatures between about 350 and 400°C. Phase equilibria and crossite composition indicate crystallization at about 6±2 kb for the schists of Iceberg Lake and Liberty Creek (Sisson and Onstott, 1986). This P-T range is consistent with the hypothesis of Carden and others (1977) and Forbes and others (1979) that the finely developed intercalation of actinolite-chlorite-bearing layers and crossite-bearing layers in the Raspberry Schist (Kodiak schist unit of Carden and others, 1977) and the schist of Seldovia are probably due to minor variations in the original chemistry of layers that were metamorphosed under conditions close to the boundary between the greenschist and blueschist facies (Turner, 1981).

Detailed mapping on Kodiak, Raspberry, and Afognak Islands indicates that postmetamorphic faults separate blocks, which range from meters to hundreds of meters wide, that are composed primarily of metabasite and metachert that were derived from oceanic protoliths and lesser amounts of quartz-mica schist (Roeske, 1984a,b, 1986). The metamorphic grade of the fault-bounded blocks increases from southeast to northwest, but all blocks appear to have undergone intermediate- to high-pressure metamorphism. The following metamorphic zones, in order of increasing grade, occur in these blocks: pumpellyite; pumpellyite-actinolite; lawsonite-albite; and actinolite-epidote in rocks that contain pillow structures and relict igneous fabric and actinolite and (or) epidote-crossite, glaucophane-epidote, and epidote-barroisitic amphibole assemblages in rocks characterized by a strong fabric and complex deformation (Roeske, 1986). Zoned amphiboles typically contain actinolite cores and crossite or glaucophane rims, which indicates that the most recent metamorphism occurred under high-pressure conditions. Homogeneous glaucophane also occurs in some rocks, where it coexists with epidote, quartz, albite, chlorite, phengite, calcite, and sphene.

The equivalent schist near Seldovia also is composed primarily of metabasalt and metachert, but it differs from the schist on the islands to the south in that it contains a greater proportion of quartz-mica schist and, also, a large block of marble (Forbes and Lanphere, 1973; Carden, 1978; S.M. Roeske, oral commun., 1984). Blue-amphibole-bearing rocks include chlorite-crossite-albite schist, chlorite-white mica-epidote-crossite schist, and epidote-chlorite-albite-crossite schist (Carden, 1978). Seldovia schists also occur as fault-bounded blocks of varying metamorphic grade (S.M. Roeske, oral commun., 1984).

The schist of Iceberg Lake forms an elongate, fault-bounded belt, approximately 40 by 4 km in size. The belt is enclosed by the low-grade McHugh Complex (unit LPP (eTJ) near the Tazlina Glacier and consists primarily of greenschist intercalated with lesser amounts of crossite-epidote schist and minor amounts of lawsonite schist, muscovite schist, actinolite schist, carbonaceous schist, stilpnomelane-bearing siliceous rocks, and foliated calcareous rocks (Winkler and others, 1981b). Several small elongate blocks of this unit (too small to be shown on pl. 1) also occur in mélange along the Border Ranges fault to the north (Winkler and others, 1981a).

The schist of Liberty Creek is composed of polydeformed mafic metavolcanic rocks and minor pelitic rocks (Metz, 1976; Winkler and others, 1981b; Plafker and others, 1989). Most rocks are schistose and are characterized by millimeter-scale crenulated lamination. Locally, sedimentary and volcaniclastic features remain and pillowed metabasalt is present. Highly deformed carbonaceous phyllite occurs within some of the metavolcanic rocks as pods and anastomosing layers as much as a few meters in thickness (Plafker and others, 1989).

Similar metamorphic mineral assemblages are developed in the schist of Liberty Creek and the schist of Iceberg Lake, but rocks are noticeably finer grained (generally less than 3 mm) in the former unit than they are in the latter unit (Plafker and others, 1989). Characteristic greenschist-facies assemblages include chlorite, white mica, epidote, albite, sphene, actinolite, and stilpnomelane. Blue amphibole-bearing assemblages are sporatically developed in both these units and are characterized by crossite+epidote+albite+chlorite±calcite±quartz±white mica±sphene±magnetite. Crossite-bearing rocks in the schist of Iceberg Lake locally contain garnet, and those in the schist of Liberty Creek locally contain hematite. Within the schist of Liberty Creek, crossite is incipiently developed in the southern part of the unit, and its modal percent increases northward (Metz, 1976). Lawsonite coexists with crossite, together with combinations of chlorite, calcite, quartz, white mica, and sphene, in isolated occurrences in the schist of Iceberg Lake and at one locality in the schist of Liberty Creek.

Data for several isotopic systems suggest an Early to Middle Jurassic age for the intermediate- to high-pressure greenschist-facies episode. Crossite-bearing rocks from the Raspberry Schist at the western end of the belt give an Early Jurassic age of 196 Ma for a Rb-Sr whole rock-phengite isochron and a 204±8-Ma age for a U-Pb isochron for sphene, white mica, albite, and amphibole (Roeske and Mattinson, 1986). Near the eastern end of the belt, crossite and phengite from unsheared pillowed metabasalt of the schist of Iceberg Lake yield $^{40}Ar/^{39}Ar$ plateau ages of about 185 Ma (Sisson and Onstott, 1986). K-Ar ages on white mica and crossite (as well as on actinolite from the Seldovia schist unit) from unsheared rocks in all units except the schist of Liberty Creek range from about 190 to about 152 Ma but are primarily Early and Middle Jurassic in age (Forbes and Lanphere, 1973; Carden and others, 1977; Winkler and others, 1981b).

Strongly sheared rocks from the schist of Iceberg Lake yield Early Cretaceous (138 to 113 Ma) K-Ar mineral ages (Winkler and others, 1981b), which indicate partial resetting subsequent to the well-dated

Jurassic metamorphic episode. Resetting of the isotopic ages may have taken place during the emplacement of the schistose rocks of the McHugh Complex, the adjacent seaward subduction complex (unit LPP (eTJ) that was accreted in pre-latest Cretaceous time (Winkler and others, 1981b; Plafker and others, 1989).

Early Cretaceous (123-107 Ma) K-Ar whole-rock ages have been determined for three samples of sheared rock from the schist of Liberty Creek (Plafker and others, 1989), but interpretation of these ages is uncertain. Due to the very fine grain size of the unit, no minerals suitable for isotopic dating have been successfully separated. If the schist of Liberty Creek, like the rest of the belt, was originally metamorphosed during a Jurassic subduction-related transitional greenschist- to blueschist-facies episode, then its Early Cretaceous ages probably represent the same resetting event that was proposed for the nearby schist of Iceberg Lake. Alternatively, the Early Cretaceous whole-rock ages may in fact date the timing of subduction-related metamorphism of the schist of Liberty Creek. In this case, a better analog for its metamorphic history would be that of the sparse blue-amphibole-bearing schist within prehnite-pumpellyite- to greenschist-facies mélange (Kelp Bay Group) of the Chugach terrane on Chichagof Island, over 600 km to the southeast (lithologically correlated by Plafker and others (1977) with the McHugh Complex that makes up most of unit LPP (eTJ)). These rocks on Chichagof Island give K-Ar ages of 106 to 91 Ma on actinolite and sericite and are interpreted to represent the more deeply subducted parts of the mélange (Decker and others, 1980). Arguing against the analogy with the rocks on Chichagof Island is the fact that blue amphibole has only been found at one locality on Chichagof Island, whereas it occurs across a much larger area and in more abundance in the schist of Liberty Creek.

Similarities in lithology, mineralogy, and isotopic ages suggest that all parts of this unit, with the possible exception of the schist of Liberty Creek, are segments of a formerly continuous belt of accreted, subduction-related rocks. Metamorphism of the Raspberry Schist and schist of Seldovia apparently occurred as a result of north-directed subduction beneath the composite Peninsular-Wrangellia terrane that was coeval with Early and Middle Jurassic arc magmatism that produced the synkinematic plutons of the Alaska-Aleutian Range and the Talkeetna Mountains (unit meJg), the deep-level mafic-ultramafic assemblage (unit Jmu), and the volcanic rocks of the Talkeetna Formation (shown as unmetamorphosed sedimentary and volcanic rocks, pl. 1) (Carden and others, 1977; Connelly, 1978; Plafker and others, 1989). Plafker and his coworkers (1989) point out that the juxtaposition (across the Border Ranges fault system) of the low-temperature, high-pressure rocks of unit GNI/H (meJ) with the approximately coeval high-temperature plutonic and volcanic rocks, implies structural disruption of the seaward margin of the arc. On the basis of the separation between the inner margins of accretionary prisms and magmatic belts in modern arcs, Plafker and others (1989) propose that the observed juxtaposition suggests relative underthrusting, on the order of 50 km, of the high-pressure rocks beneath the plutonic rocks after the plutonic rocks had cooled to below about 300°C.

LPP (eTJ)

This unit is made up of a weakly metamorphosed tectonic mélange of flysch (argillite and metagraywacke), greenstone, metatuff, metachert, and minor amounts of metalimestone, mafic metaplutonic rocks, serpentinite, and slices of exotic metamorphic rocks that locally contain blueschist-facies mineral assemblages. Blocks of competent rocks, ranging from tens of meters to several kilometers in the longest dimension, are aligned in a sheared matrix of argillite, tuffaceous argillite, or metachert. These rocks compose the McHugh Complex in the Chugach Mountains (Clark, 1973; Tysdal and Case, 1979; Winkler and others, 1981b), the correlative Seldovia Bay Complex (Cowan and Boss, 1978; Clark, 1981) on the Kenai Peninsula, and the Uyak Complex of Kodiak and Afognak Islands (Connelly, 1978). All of these rocks, as well as the correlative Kelp Bay Group (revised) of Decker (1980) on Chichagof Island in southeastern Alaska (not shown on pl. 1), are included in the mélange facies of the Chugach terrane (Plafker and others, 1977). Along its northern margin, this unit is bounded by either the Border Ranges fault system or by faults that separate this unit from the greenschist- and blueschist-facies rocks of the Chugach terrane described immediately above. Along its southern margin, this unit is bounded by north-dipping thrust faults that separate it from the low-grade flysch facies of the Chugach terrane, described later in this paper.

The mélange complex is considered to be a subduction complex consisting of oceanic sedimentary and igneous rocks and offscraped fragments of continental margin or older subduction assemblages (Clark, 1973; Moore and Connelly, 1979; Plafker and others, 1977; Cowan and Boss, 1978; Winkler and others, 1981b; Nelson and others, 1986). The volcanogenic strata and olistostromal blocks of this unit are similar in age and lithology to the arc-related rocks and basement in the adjacent composite Peninsular-Wrangellia terrane to the north. Citing these similarities, Plafker and others (1989) propose that much of this unit was derived from the composite terrane and that no more than several hundred kilometers of strike-slip displacement has separated this part of the Chugach terrane from the composite Peninsular-Wrangellia terrane.

A protolith age for the mélange matrix can be inferred from the age of radiolarians that were presumably deposited as pelagic ooze on the sea floor. In the western Valdez quadrangle, the McHugh Complex contains Late Triassic, Early Jurassic, Late(?) Jurassic, Late Jurassic to Early Cretaceous, and mid-Cretaceous (Albian to Cenomanian) radiolarian assemblages (Winkler and others, 1981b) that generally decrease in age from north to south. Paleontologic ages of radiolarian from the mélange matrix of the correlative geologic units around the Gulf of Alaska, mentioned previously, fall in this same Late Triassic to mid-Cretaceous range, and the bulk of the ages are Late Jurassic to Early Cretaceous (Plafker and others, 1977; Connelly, 1978; Decker, 1980; Karl and others, 1982; Nelson and others, 1987).

Metasedimentary and metavolcanic rocks commonly contain combinations of the metamorphic minerals prehnite, pumpellyite, calcite, quartz, albite, fine-grained phyllosilicates (mostly chlorite), epidote, and sphene. Laumontite and other zeolites occur in veinlets near the front of the western Chugach Mountains near Anchorage (Clark, 1973). Sedimentary and igneous textures are generally well preserved in unsheared domains; rocks in shear zones are semischistose or mylonitic. Prehnite, the most ubiquitous metamorphic mineral, is most commonly postkinematic, occurring in veinlets that cut foliation or as undeformed crystals within a sheared matrix. The local occurrence of deformed prehnite in shear zones indicates that metamorphism was synkinematic as well (Connelly, 1978). Some postmetamorphic deformation also took place, as evidenced by the fact that some prehnite veinlets that cut foliation are truncated by later brittle fractures (Connelly, 1978).

The relation of crystallization to deformation observed by Connelly on Kodiak and Afognak Islands led him to propose that metamorphism of the Uyak Complex may have occurred during active underthrusting, continued after accretion of the subduction complex onto the overthrust plate, and was followed by late fracturing and cataclasis during uplift of the complex (Connelly, 1978). As pointed out by Connelly, a similar progression of deformation has been proposed for the subduction complex that makes up the Franciscan Complex (Glassley and Cowan, 1975). We agree with the deformational and metamorphic history proposed by Connelly for the Uyak Complex and assert that this history also applies to the rest of this unit.

Accretion of this mélange complex postdates the Late Triassic age of the oldest matrix in the complex and may have taken place over a long time span that extended throughout the Jurassic and Cretaceous. This prolonged period of accretion is suggested by Plafker and others (1989) on the basis of the apparent southward decrease in age from Late Triassic to mid-Cretaceous noted in the western part of the Valdez quadrangle and on the basis of the probable convergent plate motion that is indicated along the southern margin of the composite Peninsula-Wrangellia terrane during much or all of the Jurassic and Cretaceous (Engebretsen and others, 1985). As suggested by Plafker and others (1989), the earliest accretion of Chugach terrane rocks is probably represented by the mostly Early to Middle Jurassic intermediate- to high-pressure greenschist-facies metamorphism of the rocks shown on plate 1 as unit GNI/H (meJ).

We assign a Jurassic maximum metamorphic age limit to this unit on the basis of the maximum accretionary age possible for the innermost and oldest part of the mélange complex. An early Tertiary minimum metamorphic age is proposed because emplacement and metamorphism of the mélange complex predates the Late Cretaceous to early Tertiary accretion and metamorphism of the greenschist- and prehnite-pumpellyite-facies Chugach terrane flysch outboard (south) of the complex. Two lines of evidence suggest that accretion and metamorphism of part of this unit occurred during Early to mid-Cretaceous time: (1) low-grade metamorphic minerals that were interpreted to have formed during subduction and accretion of the correlative mélange-facies (Kelp Bay Group) on Chichagof Island in southeastern Alaska give mid-Cretaceous K-Ar ages of 106-91 Ma (Decker and others, 1980), and (2) Early Cretaceous trondhjemite plutons that intrude the McHugh Complex and the adjacent part of the Peninsular terrane (unit GNS,AMP (eKJ) in the Anchorage quadrangle are interpreted by Pavlis (1982) to be the result of near-trench plutonism that occurred during accretion of the mélange complex.

LPP $(eTIK)_2$

This unit comprises slate, phyllite, argillite, metasandstone, and metaconglomerate of the Kodiak Formation that underlies much of Kodiak Island (Moore, 1973; Sample and Moore, 1987). Protoliths consist of medium- to thick-bedded arkosic wacke and shale and occasional beds of pebbly conglomerate that compose a Late Cretaceous (Maastrichtian) turbidite sequence (Nilsen and Moore, 1979). The Kodiak Formation is part of the accretionary prism (Chugach terrane flysch facies) that extends for at least 1,700 km around the Gulf of Alaska (Plafker and others, 1977). Low-grade metamorphism through out the accretionary prism probably accompanied north-vergent underthrusting within the prism during latest Cretaceous to early Tertiary time, as has been proposed for the Kodiak Formation (Moore and others, 1983; Sample and Moore, 1987). Metamorphic mineral assemblages developed during this episode suggest an overall northeastward increase in metamorphic grade around the Gulf of Alaska; lower greenschist-facies assemblages are typical of metamorphosed flysch in the Kenai and Chugach Mountains (unit GNL (eTIK)).

Approximately 80 percent of the Kodiak Formation consists of coherent thrust packages; the remainder is made up of zones of disrupted metasandstone that are associated with a scaly argillite matrix (Sample and Moore, 1987). The dominant structures of the coherent packages are a landward-dipping (northwest-dipping) slaty cleavage (S_1) and northwest-dipping, southeast-verging thrust faults. Outcrop-scale folds (F_1) that have axial planes parallel to slaty cleavage commonly exhibit southeast-vergence. Within a central belt of this unit, interpreted as a low-angle detachment zone by Sample and Fisher (1986) and Sample and Moore (1987), structures are more shallow, cleavage surfaces are locally phyllitic rather that slaty, and cleavage formation has locally transposed bedding (Sample and Moore, 1987). S_1 cleavage, F_1 folds, and thrust faults probably developed synchronously and accomodate most of the shortening in the Kodiak Formation. These structures are interpreted to have developed during underplating that also resulted in the formation of duplexes at the base of the accretionary prism (Sample and Fisher, 1986; Sample and Moore, 1987). Sample and Moore (1987) propose that about half of the disrupted sandstone zones are related to preaccretion deformation and the other half developed along postmetamorphic, late-stage right-lateral strike-slip faults.

Regional, low-grade metamorphism of this unit accompanied accretion and resulted in the development of sheet silicates along cleavage planes and as beards at the ends of grains and in sericitization and albitization of feldspars (Sample and Moore, 1987). Metamorphic mineral assemblages include quartz, albite, white mica, and, less commonly, pyrite, carbonate, prehnite, and pumpellyite. P-T conditions indicated by metamorphic mineral assemblages, illite crystallinity, vitrinite reflectance, deformation mechanisms in quartz, and methane-water fluid inclusions from syndeformational quartz veins are internally consistent and indicate pressures of about 2.65 to 2.8 kb (fluid inclusion data of Myers and Vrolijk, 1986) and temperatures of about 200 to 250°C (Sample and Moore, 1987). These conditions indicate that metamorphism during underplating occurred under prehnite-pumpellyite-facies conditions at a depth of about 10 km.

Low-grade metamorphism of this unit is closely bracketed between the Maastrichtian age of the protoliths and the approximately 62 Ma K-Ar mica ages of crosscutting granodiorite plutons, dikes, and sills (Davies, 1985). Contact-metamorphic assemblages that developed adjacent to the intrusions appear to overprint the more widespread regional low-grade fabric (Sample and Moore, 1987). Within the central belt of this unit, a second generation of structures that consist of southeast-dipping crenulations and crenulation cleavage postdates regional low-grade metamorphism and postmetamorphic intrusion. These second generation structures and late-stage thrust faults are attributed to postaccretion, intrawedge shortening (Sample and Moore, 1987).

GNL (eTIK)

This unit consists of low-pressure greenschist-facies flyschoid metasedimentary rocks and oceanic metabasaltic rocks of the Valdez Group, including primarily metagraywacke, carbonaceous slate and phyllite, semischist and quartzofeldspathic schist, and locally intercalated metaconglomerate, metatuff, greenstone, metagabbro, and greenschist (Tysdal and Case, 1979; Winkler and others, 1981b; Plafker and others, 1989). It forms part of the continuous belt of flysch that extends around the Gulf of Alaska for more than 1,700 km in length and 60 to 100 km in width that makes up the flysch facies of the Chugach terrane (Plafker and others, 1977). Sparse and widely separated fossils indicate a latest Cretaceous (Maastrichtian and Campanian?) protolith age (Jones and Clark, 1973; Tysdal and Plafker, 1978). Sedimentary protoliths were deposited in a trench or deep-sea fan setting (Nilsen and Zuffa, 1982); oceanic protoliths are probably the upper levels of oceanic crust upon which the clastic materials were deposited (Plafker and others, 1989).

To the north, this unit is bounded by north-dipping faults that separate it from the more weakly metamorphosed mélange of the Chugach terrane (unit LPP (eTJ)) in the west and the medium-grade rocks of the combined Peninsular-Wrangellia terrane in the east (units GNS,AMP (lJ)+GNS (eTlK) and GNS,AMP (lJ)+LPP (eTlK)). To the south, it is bounded by the vertical to north-dipping Contact fault that separates it from the low-grade rocks of the Prince William terrane (unit LPP (eT)).

Relict sedimentary textures, indicative of deposition by turbidity currents, are generally preserved in all but the highest grade part of this unit. Primary volcanic textures are common in the Seward quadrangle except for an elongate (5 by 70 km) belt of schistose, slightly higher grade (biotite-zone) metasedimentary and metavolcanic rocks that crop out as upper plate rocks just west of a thrust fault in the western part of the quadrangle (Tysdal and Case, 1979). Farther to the northeast in the Valdez quadrangle, metavolcanic rocks characteristically are schistose, although relict pillow structures are discernible only rarely in the more massive units; locally these rocks are mylonitic (Winkler and others, 1981b; Plafker and others, 1989).

Characteristic metamorphic minerals in metasedimentary rocks are quartz, white mica, and locally chlorite, carbonate, and epidote-clinozoisite; chloritoid occurs locally in the Bering Glacier quadrangle, and biotite occurs locally in the western Seward quadrangle and in the southern part of this unit near the Copper River. Metaigneous rocks are partly recrystallized (in the Anchorage-Seward area) to totally recrystallized (northeast and east of Prince William Sound) to metamorphic assemblages that include quartz, chlorite, epidote, actinolite, albite, and locally stilpnomelane. The metamorphic mineral assemblages suggest temperatures of 300 to 400°C (Turner, 1981). Fluid-inclusion data suggest a metamorphic pressure of about 3 kb in greenschist-facies rocks near the (informal) Chugach metamorphic complex of Hudson and Plafker (1982) (shown as unit GNL (eTlK)+AML (eT)) (Sisson and Hollister, 1988) and a minimum pressure of about 1.5 kb near the city of Valdez (Goldfarb and others, 1986).

Metamorphic grade increases along strike to the east, where it culminates in the polymetamorphic rocks of the Chugach metamorphic complex (discussed below) in the eastern Chugach Mountains and St. Elias Mountains. These rocks experienced subsequent amphibolite-facies metamorphism that was associated with widespread intrusion during early Eocene time. In areas of this unit near the Chugach metamorphic complex, this increase in grade is indicated by a gradual increase in grain size, biotite content, and amount of quartz veining and quartzofeldspathic segregation (Hudson and Plafker, 1982).

Greenschist-facies metamorphism closely followed or overlapped folding and imbrication of the Valdez Group flysch sequence as it was accreted to and deformed against the continental margin in Late Cretaceous and early Tertiary time (Hudson and Plafker, 1982). In the eastern Chugach Mountains, south-vergent structures were developed during underthrusting of the Chugach terrane beneath the composite Peninsular-Wrangellia terrane to the north. These structures were overprinted by north-vergent structures in the early Tertiary (Nokleberg and others, 1985b, 1989b). Farther to the west on Kodiak Island, south-vergent structures are also present in the lower grade flysch of the Chugach terrane (unit LPP $(eTlK)_2$), and they are interpreted to be related to underplating and duplex formation (Sample and Fisher, 1986; Sample and Moore, 1987). Although comparable structural data are unavailable outside of Kodiak Island, the south-vergent structures in the eastern Chugach Mountains also may have formed in a similar structural setting, as speculated by Sisson and Hollister (1988) and Sisson and others (1989).

The development of temperatures required for greenschist-facies metamorphism is attributed by Sisson and Hollister (1988) and Sisson and others (1989) to a combination of (1) advection of hot fluids that were generated by dehydration of sediment within the accretionary prism and (2) conduction during either subduction of hot, young (less than 0.5 Ma), and buoyant oceanic crust or, as proposed by Marshak and Karig (1977) to explain early Tertiary near-trench plutonism around the Gulf of Alaska, subduction of the Kula-Farallon spreading ridge. This greenschist-facies metamorphic episode postdates the Maastrichtian age of the youngest protoliths and predates the 60- to 55-Ma age of anatectic plutonism and associated low-pressure amphibolite-facies metamorphism in the Chugach metamorphic complex of the eastern Chugach Mountains (Hudson and Plafker, 1982; Sisson and others, 1989).

GNL (eTlK)+AML (eT)

This unit consists of polymetamorphosed quartz-mica schist and gneiss of the (informal) Chugach metamorphic complex of Hudson and Plafker (1982) that crops out as an elongate 200-km-long and less than 50-km-wide east-west-trending belt in the eastern Chugach Mountains and the Saint Elias Mountains. These rocks represent the deepest part of the accretionary prism that composes the Chugach terrane. They were initially metamorphosed and deformed during the low-pressure greenschist-facies episode that accompanied north-directed underthrusting of the Chugach terrane beneath the combined Peninsular-Wrangellia terrane and the development of south-vergent folds (described for unit GNL (eTIK)). Subsequently, the rocks of this unit were metamorphosed during low-pressure amphibolite-facies metamorphism that accompanied widespread intrusion during early Eocene time. Metamorphic protoliths are the same sequence of flysch and related rocks that compose the Maastrichtian and Campanian(?) Valdez Group described previously for unit GNL (eTIK).

The boundaries of this unit are defined by the disappearance of chlorite and the appearance of biotite, cordierite, and (or) garnet (Hudson and Plafker, 1982). Metamorphic grade generally increases from the edges toward the elongate core of the complex. This overall increase is independent of the exposed distribution of major plutons, and, as Sisson and others (1989) point out, this progression is not solely a product of the effects of contact metamorphism. In addition to the overall distribution of metamorphic grade, local contact metamorphism has produced high-grade rocks near the contacts of large felsic intrusions (Sisson and Hollister, 1988). Amphibolite-facies metamorphism and partial melting in the core of the complex overlapped in time with the development of second generation north-vergent folds, steeply dipping cleavage and schistosity, and near horizontal east-west-trending fold axes and lineations (Sisson and Hollister, 1988).

The outer part of the complex is made up of schist composed of biotite+quartz+plagioclase+muscovite± fibrolitic sillimanite±staurolite±garnet±andalusite± cordierite±tourmaline. Hornblende+quartz+biotite+ plagioclase is present in some schistose layers. Schists commonly contain veins, lenses, boudins, and discontinuous layers of quartz or quartz and feldspar a few millimeters to centimeters thick (Hudson and Plafker, 1982).

As metamorphic grade increases toward the core of the complex, the more regularly banded schist becomes irregularly layered, inhomogeneous, and contorted schist and gneiss. These rocks consist primarily of biotite, plagioclase, and quartz. Muscovite, garnet, fibrolite, rare staurolite, and pseudomorphs of sillimanite after andalusite are present in minor amounts locally (Hudson and Plafker, 1982; Sisson and Hollister, 1988). Discontinuous quartose layers and lenses alternate with finer grained, streaky biotitic layers. The most highly metamorphosed rocks are migmatitic gneiss in which blocks, lenses, or hazy disrupted remnants of banded schist are enveloped by swirly granoblastic pods and stringers of leucocratic material (Hudson and others, 1979; Hudson and Plafker, 1982). Large- and small-scale tonalite intrusions, present throughout the metamorphic complex, are most abundant in the core. Anatexis occurred locally within the core and produced granitic melts that are compositionally distinct from the tonalite intrusions (Sisson and Hollister, 1988).

In the western part of the metamorphic complex, cordierite appears before garnet in the south, and the opposite relation occurs in the north (Sisson and Hollister, 1988; Sisson and others, 1989). Because garnet-bearing rocks generally form at a deeper pressure than cordierite-bearing rocks under moderate temperatures of metamorphism (Hess, 1969), Sisson and her coworkers suggest that the distribution of garnet and cordierite in the western area implies higher pressures to the north. Garnet-zoning profiles that were calculated according to the method of Spear and others (1984) indicate that in some regions garnets grew during decompression, while in other areas they grew during compression (Sisson and Hollister, 1988). The distribution of garnet and cordierite, together with the garnet-zoning profiles, were reasonably interpreted by Sisson and her coworkers to have resulted from synmetamorphic thrusting.

Metamorphic pressures throughout the complex were between 2 and 3 kb (about 10 km) on the basis of mineralogy (andalusite-sillimanite-bearing mineral assemlages), geobarometry (garnet-plagioclase-aluminosilicate-quartz and garnet-plagioclase-biotite-muscovite), and isochores of associated CO_2-rich fluid inclusions. Metamorphic temperatures estimated from garnet-biotite equilibria range upward from about 500°C near the edge of the complex to about 650°C in its migmatitic core (Sisson and others, 1989). These P-T estimates together with those from the adjacent greenschist-facies unit GNL (eTIK) suggest a nearly isobaric P-T-time path in which the rocks of this unit, already heated to greenschist-faces conditions and at a depth of about 10 km during the Late Cretaceous to early Tertiary episode recorded in the adjacent unit, were further heated to amphibolite-facies conditions in the early Tertiary. The increased heat required to produce the regional distribution of andalusite and cordierite and the core zone of sillimanite-bearing migmatite is inferred to have resulted from the intrusion of synmetamorphic, concordant tonalite sills along shallow north-dipping shear zones (Sisson and others, 1989).

K-Ar mineral ages (Winkler and Plafker, 1981; George Plafker, unpub. data, 1984) and $^{40}Ar/^{39}Ar$

incremental-heating data (Sisson and others, 1989) for the synmetamorphic tonalite bodies indicate the time of intrusion to be about 53±2 Ma. K-Ar ages on metamorphic minerals from the complex (53±2 Ma on hornblende from amphibolite and 48±2 Ma on biotite from quartz-mica schist; Hudson and Plafker, 1982) fall within or close to this age range. Cooling of the plutons and metamorphic complex was initially rapid (~ 65°C/Ma) to about 300°C on the basis of $^{40}Ar/^{39}Ar$ ages of 53 Ma for hornblende and 50 Ma for biotite from synmetamorphic tonalite bodies (Sisson and others, 1989).

Intrusion and metamorphism postdated the accretion of the upper Paleocene to middle Eocene Orca Group of the Prince William terrane against the southern margin of the Chugach terrane (south of the Contact fault system). This relation is indicated by the fact that an elongate tonalite pluton that yields K-Ar hornblende and biotite ages of about 51 Ma (Winkler and Plafker, 1981) and metamorphic affects associated with the pluton (biotite-cordierite mineral assemblages) crosscut the Chugach-Prince William terrane boundary near Miles Glacier (Miller and others, 1984; Sisson and others, 1989). Intrusions of similar age are also younger than the displacements on the Border Ranges fault system that separates the northern margin of the Chugach terrane from the Wrangellia terrane because they intrude rocks on both sides of the fault, and a dike at one locality crosscuts the fault (Plafker and others, 1989).

The problematic origin of the heat that produced both the amphibolite-facies Chugach metamorphic complex and the widespread belt of early Tertiary plutons within the Chugach and Prince William terranes is discussed at the end of this paper in the overview section on conditions, timing, and origin of metamorphism.

GNS/AMP (lTK)

Transitional greenschist- to amphibolite-facies biotite schist, semischist, and amphibolite (George Plafker, unpub. data, 1978) crop out in the southeast corner of the Yakutat quadrangle and in adjacent parts of the Skagway quadrangle that is outside of the area shown on plate 1 (see Dusel-Bacon, Brew, and Douglass, in press, for adjoining geology). Protoliths are interpreted to be sandstone and mudstone turbidites and oceanic tholeiite on the basis of lithologic similarity with the Valdez Group elsewhere in the Chugach terrane (Plafker and others, 1977; Plafker and Campbell, 1979; Barker and others, 1985). Although the protolith age is unknown, a late Mesozoic, probably Late Cretaceous, age is inferred by continuity northwestward along strike with the Upper Cretaceous Valdez Group in the Chugach Mountains (Plafker and Campbell, 1979).

Biotite schist is fine grained, variably banded, granoblastic to strongly schistose, and composed of quartz+biotite±garnet±plagioclase±muscovite (Hudson and others, 1977b). Mafic metavolcanic rocks are fine to medium grained, variably segregated, and contain the following assemblages: chlorite+white mica+albite+epidote±quartz±sphene; plagioclase+biotite+chlorite+quartz+actinolite+calcite; and hornblende+epidote+plagioclase+sphene.

The timing and number of metamorphic episodes that affected this unit are unknown. A Cretaceous maximum age of metamorphism is proposed on the basis of the age of the protoliths. At least some of the metamorphism is known to have occurred prior to the intrusion of crosscutting plutons of intermediate composition that have K-Ar ages on hornblende of 61±2 Ma in the southeastern Yakutat quadrangle (Hudson and others, 1977a) and K-Ar ages of about 52 Ma in the southwestern Skagway quadrangle (George Plafker, unpub. data, 1978). A K-Ar age on hornblende of 67 Ma from amphibolite in the Nunatak Fiord area, 55 km northeast of Yakutat, suggests a latest Cretaceous metamorphic age (Barker and others, 1985). In the same area, however, K-Ar ages on hornblende and biotite from metamorphic rocks between Nunatak Fiord and the southwestern Skagway quadrangle range from about 23 to 19 Ma, which suggests an additional, or alternative, Miocene metamorphic age; these K-Ar ages fall close to or within the 37- to 21-Ma range of K-Ar ages from widespread felsic intrusive rocks (Hudson and others, 1977b; George Plafker, unpub. data, 1978).

The origin of the metamorphic episode(s) that resulted in the greenschist- to amphibolite-facies metamorphism of this unit (GNS/AMP (lTK)) and the related amphibolite-facies metamorphism of the adjacent unit (AMP (lTK)), described below, is unknown, although the spatial relation of the higher grade metamorphic rocks and Tertiary plutons suggests a genetic relation. Unlike the Chugach metamorphic complex (unit GNL (eTlK)+AML (eT), described above), the thermal history of these two units appears to be complicated by the occurrence of multiple periods of plutonism (and perhaps metamorphism) in the Tertiary and also probably by a much younger uplift history, as indicated by the exposure of the Miocene plutonic rocks and discordant biotite-hornblende pairs. Another difference between unit (AMP (lTK) and the Chugach metamorphic complex is the fact that kyanite occurs at one locality in the former (described immediately below), whereas its lower pressure polymorph, andalusite, is present in the Chugach metamorphic complex.

AMP (lTK)

Amphibolite-facies biotite gneiss and hornblende schist and amphibolite (Hudson and others, 1977b; Hudson and Plafker, 1982; Barker and others, 1985) crop out as a narrow, elongated fault-bounded block near Novatak Glacier in the Yakutat quadrangle and as a large fault-bounded block that straddles the United States-Canadian border near Mount St. Elias (Saint Elias terrane of Jones and others, 1987). Protoliths are interpreted to be sandstone and mudstone turbidites and oceanic tholeiite of inferred Cretaceous age on the basis of lithologic similarity with the Valdez Group of the Chugach terrane (Plafker and others, 1977; George Plafker, unpub. data, 1978). Rocks are well foliated, and, locally, amphibolite is also well lineated. Biotite gneiss is composed primarily of biotite, quartz, plagioclase, and locally garnet. Kyanite coexists with fibrolite at one locality near Mount St. Elias. Amphibolites contain hornblende+plagioclase±garnet±biotite±chlorite (Brew, 1978; George Plafker, unpub. data, 1969, 1978).

Constraints on the age of metamorphism and questions about its origin are the same as described for the unit immediately above. A pluton of intermediate composition on Mount St. Elias yields K-Ar hornblende ages of about 55 Ma and discordant biotite ages of 38-35 Ma (Dodds and Campbell, 1988). A pluton on Mount Newton in the same structural block has a K-Ar age of 27 Ma on hornblende (Dodds and Campbell, 1988), and nearby metamorphic rocks have K-Ar ages on amphibole of 23 to 17 Ma (Hudson and others, 1977b). The Saint Elias fault block is inferred to have shared the same metamorphic and plutonic history as the Novatak Glacier fault block to the southeast and to have subsequently been separated by fault movement. Structural and lithologic data suggest that the Saint Elias block may have been separated from the block to the southeast by about 100 km of right-lateral displacement along the Fairweather fault (George Plafker, unpub. data, 1969). Along its southern margin, the Saint Elias block is underthrust by prehnite-pumpellyite- and greenschist-facies rocks of the Yakutat terrane (Hudson and others, 1977b).

YAKUTAT TERRANE

LPP (eTlK)$_3$

The laumontite- and prehnite-pumpellyite-facies upper Mesozoic flysch and mélange that make up this unit (Hudson and others, 1977b) constitute the lowest grade part of a low-pressure-facies series that developed within the Yakutat Group of the Yakutat terrane. Mélange within the Yakutat terrane has not been delineated because generally it is tectonically intermixed with flyschoid rocks on a scale that is too small to show on plate 1. The latest Cretaceous flysch and the Late Jurassic(?) and Early Cretaceous mélange of the Yakutat Group are correlative with the flysch and mélange units of the Chugach terrane (Plafker and others, 1977, 1989). The Yakutat Group, like the components of the Chugach terrane in south-central and southeastern Alaska, is extensively intruded by Eocene granitoid plutons.

The predominant lithologies of this unit include thick sequences of Upper Cretaceous feldspathic metasandstone, argillite, and metaconglomerate and structurally disrupted interleaved lenses of disrupted Upper Jurassic and (or) Lower Cretaceous metachert, argillite, metaconglomerate, and mafic metavolcanic rocks and abundant exotic olistostromal blocks of older rocks (Jones and others, 1984; Plafker, 1987). The exotic upper Paleozoic, Upper Triassic, and Jurassic olistostromal blocks are mainly characteristic of the Wrangellia terrane in the Queen Charlotte Islands and Vancouver Island off the coast of British Columbia (Plafker, 1987).

Metamorphic minerals developed in metasandstones include interstitial and vein-filling laumontite, prehnite, and quartz and interstitial chlorite, sphene, and white mica. Pumpellyite also occurs interstitially but is dominantly restricted to lithic grains of mafic composition. A very steep thermal gradient is indicated by a rapid progressive increase in metamorphic grade (over a horizontal distance commonly less than 1.5 km) between the rocks of this unit and an area of amphibolite-facies rocks near Dry Bay, and only a narrow interval of greenschist-facies rocks (too small to show at the scale of plate 1) between the two units (Hudson and others, 1977b).

A latest Cretaceous and (or) early Tertiary age for major metamorphism is provisionally assigned on the basis of (1) the latest Cretaceous protolith age of the youngest rocks in this unit, (2) K-Ar ages on hornblende of about 65 Ma, determined for amphibolites from higher grade rocks (unit AML (eTlK)) of the Yakutat terrane that occur in the adjacent fault block to the east (Hudson and others, 1977b), and (3) the interpretation that this unit shared a common metamorphic history with that of the adjacent Chugach terrane (Plafker and others, 1977; George Plafker, unpub. data, 1984) (discussed under the descriptions for the nearby units GNL (eTlK) and

GNL (eTIK)+AML (eT)). The low-pressure-facies series developed within the Yakutat terrane probably developed in response to a steep geothermal gradient over a thermal high. Metamorphism of the oldest parts of the Yakutat Group may have occurred earlier, because, at one locality, deformed mélange is crosscut by a tonalite pluton (unit Kg, pl. 1) that gives discordant K-Ar ages of 96 Ma on hornblende and 84 Ma on biotite (George Plafker, unpub. data, 1978). It is also likely that blueschist-facies metamorphism has affected some of these rocks because glacial erratics of crossite-bearing metabasalt occur locally along Russell Fiord and Yakutat Bay (George Plafker, unpub. data, 1987). The lithology and occurrence of these erratics are most compatible with a source in the ice-covered parts of the Yakutat terrane.

Metamorphism of the Yakutat terrane took place when the terrane was located much farther to the south, most probably along the continental margin south of Chatham Strait (Plafker, 1987; Plafker and others, 1989). Geologic and paleontologic data suggest that the Yakutat terrane was transported to its present position during the late Cenozoic by dextral strike-slip along the Fairweather-Queen Charlotte transform fault system from a site along the continental margin at least 600 km to the southeast (Plafker, 1987).

GNL $(eTIK)_1$

The greenschist-facies slate, phyllite, and semischist that comprise this unit (Hudson and others, 1977b) are interpreted to form the intermediate-grade part of the low-pressure-facies series developed within the Yakutat terrane. Many original sedimentary features, such as bedding and detrital textures can be recognized in this unit. Characteristic metamorphic mineral assemblages include white mica, chlorite, calcite, epidote, and, locally, biotite. An apparent westward transition to lower grade rocks is suggested in the area near Seward Glacier, but metamorphic relations are confused by structural complexities in mélange and by large intrusive bodies (Hudson and others, 1977b). In general, this unit is fault bounded; the greenschist- and amphibolite-facies rocks of the Chugach terrane lie to the north and the lower grade rocks of the Yakutat terrane lie to the south.

The protoliths and the metamorphic and tectonic history of this unit are the same as those described above for the lowest grade part of the facies series (unit LPP $(eTIK)_3$).

AML (eTIK)

This unit comprises amphibolite- and epidote-amphibolite-facies mafic metavolcanic rocks, quartzofeldspathic schist, pelitic schist, and minor amounts of interlayered metaconglomerate and marble of the Yakutat terrane (Hudson and others, 1977b), and it forms the highest grade part of the low-pressure-facies series that also includes the above two units. Amphibolite-facies rocks in the Dry Bay area form a broad northwest-plunging antiform of interbedded quartzofeldspathic and pelitic schist. Pelitic rocks are rich in biotite and also contain quartz, garnet, and, locally, andalusite porphyroblasts. These rocks are characteristized by semigranoblastic textures and unstrained biotite and quartz, evidence that metamorphism of these rocks was dominantly thermal in nature. K-Ar ages on biotite from these rocks yield an anomalously young age of 4 Ma (Hudson and others, 1977b). This age is probably best interpreted as the time at which the metamorphic sequence was uplifted and passed through the critical biotite isotherm for argon retention (Hudson and others, 1977b).

The rest of this amphibolite-facies unit occurs as an elongate fault-bounded sliver that is separated from the low-pressure amphibolite-facies rocks of the Valdez Group by the Fairweather fault to the northeast and from the very low grade correlative rocks of the Yakutat terrane by another major fault to the southwest. Tectonic shortening, by thrust faulting or strike-slip faulting with a significant dip-slip component, is suggested by the juxtaposition of high- and low-grade rocks along the southwest boundary and by the absence of intervening greenschist-facies rocks. The northern metamorphic contact of the elongate sliver with correlative greenschist-facies rocks may be gradational, but interpretation of metamorphic-facies relations are obscured by thermal upgrading in the vicinity of the pluton that crops out near this contact. Amphibolite and mafic metavolcaniclastic rocks from within the fault sliver typically contain hornblende, epidote group minerals, calcic plagioclase, calcite, and quartz. Characteristic metamorphic assemblages in lower grade schist consist of quartz, plagioclase, biotite, epidote group minerals, and garnet; higher grade schist contains quartz, calcic plagioclase, biotite, muscovite, garnet, and, locally, staurolite. Schistosity is variable, and many of the more foliated rocks are locally cataclastic. Contrasts in the degree of diversity of metamorphic fabrics and perhaps also minor changes in metamorphic grade between some areas (Hudson and others, 1977b) suggest late-metamorphic or postmetamorphic faulting within the metamorphic unit.

A latest Cretaceous and (or) early Tertiary age of major metamorphism is provisionally assigned on the basis of hornblende K-Ar ages of about 65 Ma determined for amphibolites from the elongate sliver of this unit (Hudson and others, 1977b) and on the geologic reasoning discussed above in the description of the lowest grade part (LPP $(eTIK)_3$) of this low-pressure-facies series. Additional information about the tectonic and metamorphic history of this unit is given in the description of the lowest grade unit.

GHOST ROCKS AND PRINCE WILLIAM TERRANES

LPP (eT)

This unit is composed of a strongly deformed and weakly metamorphosed accretionary complex consisting of isoclinally folded flysch (metagraywacke, argillite, and minor metaconglomerate), metalimestone, pillowed greenstone, and greenschist derived from mafic to intermediate tuffs, sills, and dikes. It occurs seaward of the Chugach terrane from which it is separated by the vertical to landward-dipping Contact fault system. Ourcrop areas of this unit on Kodiak Island are assigned to the Ghost Rocks terrane. The rest of the unit crops out in the Copper River and Prince William Sound region and is assigned to the Prince William terrane.

On Kodiak Island, the rocks of this metamorphic unit are included in the Ghost Rocks Formation of Moore and others (1983), and protoliths are an accretionary complex made up of both coherent terranes composed of deep-sea sedimentary rocks and mafic and intermediate volcanic rocks and sandstone-shale mélange terranes (Byrne, 1982, 1984). Sparce paleontological data suggest that the Ghost Rocks Formation was deposited during earliest Paleocene time; mélange units, however, contain Late Cretaceous fossils (Moore and others, 1983). The Ghost Rocks Formation was accreted against the Chugach terrane prior to, or during, intrusion of a 62-Ma pluton (Moore and others, 1983). Intrusive rocks of comparable age and lithology occur within the Chugach and Peninsular terranes in the Kodiak area (Davies and Moore, 1984).

Within the Prince William terrane, the rocks are included in the Orca Group, and protoliths are an accreted deep-sea-fan complex interbedded with oceanic volcanic rocks and minor pelagic sediment (Winkler, 1976; Tysdal and Case, 1979; Winkler and Plafker, 1981; Helwig and Emmet, 1981). Also included within the Orca Group are numerous shear zones, one of which (on Knight, Evans, and Bainbridge Islands) has been described by Helwig and Emmet (1981) as a narrow (approximately 10-km-wide) northeast-trending mélange belt that consists of originally interbedded basalt and turbidites deposited on an ophiolite basement. The depositional age of the Orca Group is late Paleocene through early middle Eocene (Plafker and others, 1985b). It was accreted to the Chugach terrane prior to, or during, intrusion of a 51±3-Ma pluton that stitches across the terrane boundary east of the Copper River (Winkler and Plafker, 1981; Plafker, 1987).

Although the Orca Group was previously correlated with the Ghost Rocks Formation by Plafker (1971), the subequently determined differing ages of deposition and accretion, as well as differing displacement histories implied for the two geologic entities (discussed below), led Plafker and others (1985b) to retract this correlation. Because the overall metamorphic grade and tectonic setting in which metamorphism took place are similar within the two parts of this unit, and because aspects of the metamorphic and tectonic evolution(s) of both geologic entities are still uncertain, we have shown them as one metamorphic unit.

Determination of the metamorphic grade of this unit is difficult because the majority of the rocks are graywacke, and their composition does not generally favor the development of metamorphic minerals that are diagnostic of a particular facies of low-pressure, low-temperature metamorphism. Characteristic metamorphic minerals in basaltic rocks include prehnite, pumpellyite, chlorite, epidote, and sphene. These same minerals plus clay minerals or white mica also are developed in graywacke matrix. Minor variation in metamorphic grade occurs within this unit.

Basaltic rocks west of the fault through Montague Strait in the southeastern Seward quadrangle commonly contain actinolite-epidote-chlorite assemblages (Tysdal and Case, 1979). The fact that several prehnite- and one pumpellyite-bearing assemblages occur in the same area suggests that metamorphic conditions west of the fault were slightly higher in that area and were probably close to those of the lower limit of the pumpellyite-actinolite facies, as defined by the prehnite-out isograd (Liou, 1971; Bishop, 1972). Vitrinite reflectance values determined for the Orca Group range from 0.8 to 1.1 percent in Prince William Sound (Helwig and Emmet, 1981) and 1.0 to 2.0 percent near Katalla, east of the mouth of the Copper River (Mull and Nelson, 1986); these values indicate a lower degree of metamorphism than that indicated by the mineral assemblages. In general, the Orca Group shows a gradual increase in metamorphic grade from south to north (Goldfarb and others, 1986). In some areas, especially within the Seward quadrangle, the metamorphic grade and lithology of the Orca Group at the northern boundary of this metamorphic unit are virtually indistinguishable from those of the Valdez Group (unit GNL (eTIK)), and our placement of the metamorphic boundary may be questioned.

On Kodiak Island, metamorphism of the Ghost Rocks Formation resulted in the development of prehnite veins that locally cut sedimentary rocks and the development of pumpellyite in veins and the groundmass of volcanic and tuffaceous rocks. Vitrinite reflectance values for shales from within this formation are about 3.0 percent and suggest maximum metamorphic temperatures of 225 to 250°C (Moore and others, 1983).

Both the Ghost Rocks Formation and the Orca Group are structurally complex. Where their deformational histories have been studied in detail (by Byrne (1982, 1984, 1986) on Kodiak Island and by Helwig and Emmet (1981) in the area of southern Prince William Sound that extends from Montague Island northwestward to the mainland), both geologic entities have been subdivided into several belts, many of which have several generations of structures. However, the origin of the various structures, the timing of their juxtaposition, and the relation between deformation and low-grade metamorphism are unclear in many instances.

Low-grade metamorphism and deformation within both terranes occurred during underthrusting of these terranes beneath the Chugach terrane during the early Tertiary. Metamorphism predated, perhaps by very little, the intrusion of the early Tertiary plutons that stitch them to the Chugach terrane landward of them. On Kodiak Island, these plutons, which are dated at 62 Ma, contact metamorphosed the Upper Cretaceous to Paleocene Ghost Rocks Formation and cut its structural fabric (Moore and others, 1983). Eocene and younger rocks in the Kodiak Islands are only slightly altered, further supporting a Paleocene metamorphic age for that area (Moore and others, 1983). Intrusion and metamorphism of the upper Paleocene to middle Eocene Orca Group occurred slightly later than did metamorphism of the Ghost Rocks Formation. From Prince William Sound to the east, 53- to 48-Ma plutons crosscut and contact metamorphosed already deformed and weakly metamorphosed Orca Group rocks (Winkler and Plafker, 1981; Miller and others, 1984).

Deposition, deformation, metamorphism, and intrusion of the Ghost Rocks Formation and the Orca Group all took place within brief time intervals. Byrne (1986) proposed that the development of conjugate folds and spaced cleavage within the Ghost Rocks Formation occurred as a result of subhorizontal shortening of the accretionary complex during underthrusting. Some of the metamorphism and deformation of the Orca Group may have had a similar origin.

The preaccretionary history of this unit is unresolved and controversial. Geologic data have been used to suggest that Orca Group sediments were derived from the coastal mountains of southeastern Alaska and British Columbia (Hollister, 1979; Winkler and Plafker, 1981; Helwig and Emmet, 1981). Paleomagnetic data from the Orca Group give contradictory results: data from the Knight Island area in western Prince William Sound suggest little or no northward displacement (Hillhouse and Grommé, 1977), whereas preliminary analysis of data from the northeastern part of Prince William Sound suggests as much as 40° northward displacement (Plumley and Plafker, 1985). Paleomagnetic data for volcanic rocks of the Ghost Rocks Formation indicate a northward translation of as much as 25° (Plumley and others, 1983), and data for a possibly correlative sequence on the Resurrection Peninsula (included in unit GNL (eTIK) on pl. 1) indicate a translation of about 16° (Bol and Coe, 1987).

LPP (eT)+AML (eT)

This unit comprises an area just east of the Copper River in which the low-grade metasedimentary rocks of the upper Paleocene to middle Eocene Orca Group, which were initially metamorphosed during the early Tertiary prehnite-pumpellyite-facies episode and are described immediately above, were subsequently remetamorphosed during the low-pressure amphibolite-facies episode associated with the intrusion of Eocene plutons, in particular the elongate pluton exposed along the eastern margin of this unit. Amphibolite-facies metamorphism produced biotite- and biotite+cordierite-bearing assemblages that overprint the earlier low-grade fabric (Miller and others, 1984; Sisson and others, 1989).

Plutons dated at about 51 Ma (K-Ar ages on biotite and hornblende; Winkler and Plafker, 1981) crosscut the Contact fault system and stitch the Prince William terrane to the Chugach terrane to the north. Metamorphic effects of the low-pressure amphibolite-facies episode recorded in this unit also extend across the fault and characterize the second and dominant metamorphism of the Chugach metamorphic complex of Hudson and Plafker (1982) (unit GNL (eT)+AML (eT)).

The probable tectonic setting and origin of the first metamorphic episode that affected this unit is the same as that described above for unit LPP (eT), and the setting and origin of the second episode is the same as that described above for the second metamorphic episode that affected unit GNS (eTlK)+AML (eT).

OVERVIEW AND DISCUSSION OF THE CONDITIONS, TIMING, AND TECTONIC ORIGIN OF REGIONAL METAMORPHISM IN EAST- AND SOUTH-CENTRAL ALASKA

AREA NORTH OF THE McKINLEY AND DENALI FAULTS

The metamorphic and structural history of the northernmost area is the most poorly constrained of the three areas as a result of poor exposure and paucity of paleonotologic age control and detailed structural studies. In the Kantishna River area, shown in the northwestern corner of plate 1, greenschist-facies metamorphism of continental rocks (unit GNS (eKmPz)) of the Nixon Fork terrane is bracketed between the middle(?) Paleozoic age of the youngest protoliths and the Cretaceous or Tertiary age of crosscutting granitoids; it may have been related to tectonic overthrusting of oceanic rocks rooted in the Yukon-Koyukuk basin northwest of the area shown in plate 1. The origin of the prehnite-pumpellyite-facies metamorphism of the continental rocks (unit LPP (lKD)) of the Nixon Fork, White Mountains, and Minchumina terranes in the same general region is unknown, and the age of metamorphism is known only to postdate the Devonian age of the youngest protoliths and to predate the Late Cretaceous age of the oldest pluton that is thought to intrude the unit.

The age and origin of metamorphism of many of the units in the Yukon-Tanana upland and northern Alaska Range are also poorly known. Metamorphism throughout the Yukon-Tanana upland predates the widespread intrusion of undeformed mid-Cretaceous granitoids. Mylonitic and blastomylonitic textures are common in most rocks, reflecting a history of dynamic metamorphism followed by varying degrees of more static recrystallization. Many metamorphic-unit boundaries are also terrane or subterrane boundaries that are defined by low-angle faults. Metamorphic grade changes abruptly across many of the faults, which indicates that major metamorphism predated final emplacement of the fault-bounded units. With the exception of one area near the United States-Canadian border in which thrusting has been shown to have occurred in Early Jurassic time, the age of thrusting in the rest of the Yukon-Tanana upland can only be constrained to predate the intrusion of early Tertiary plutons and probably mid-Cretaceous plutons as well.

Examination of plate 1 shows that some of the low-angle faults place higher grade over lower grade rocks (the relation expected of contractional faulting), whereas other faults place lower grade over higher grade rocks (the relation expected of extensional faulting); this suggests a complex synmetamorphic or postmetamorphic structural evolution. In their regional synthesis, Foster and her coworkers (1987a) tentatively interpret the low-angle faults as south-dipping thrusts. In one area, however, near the Salcha River in the Big Delta quadrangle, kinematic indicators in mylonitic greenschist-facies rocks (unit GNS (eKPz)) that form the hanging wall to a window of sillimanite gneiss indicate hanging-wall transport to the east-southeast (Pavlis and others, 1988b, in press). The kinematic data and the fact that lower grade rocks structurally overlie higher grade rocks indicate that latest movement along this fault was extensional rather than contractional (Pavlis and others, 1988b, 1993). Kinematic and age data also suggest an extensional contact between unit AMP (eK) and overlying unit AMH,l (eJlŦ) (Hansen and others, 1991).

The oldest documented metamorphic episode in the Yukon-Tanana upland occurred during latest Triassic and earliest Jurassic time as a result of (1) subduction beneath a northeast-facing arc developed on a continental fragment, Stikinia, rifted off of western North America, (2) closure of the intervening ocean basin that separated the arc from the western margin of North America, (3) and accretion of the arc and pieces of the ocean basin onto the North American margin (Tempelman-Kluit, 1979; Monger and others, 1982; Foster and others, 1985; Hansen, 1990). Metamorphic unit AMH,l (eJlŦ), together with the latest Triassic to Early Jurassic plutons (JŦg) that intrude it, and unit GNS (eJlŦ) are part of the arc and accretionary prism; unit LPP/GNS (eJlŦ) and associated ultramafic rocks (unit MzPzu) are remnants of the telescoped ocean basin (Seventymile terrane). Foster and others (1987a) assign the rocks of unit AMH,l (eJlŦ) to a subterrane (Y4) of the Yukon-Tanana terrane and propose that, although they could be a part of the Stikinia terrane of Jones and others (1987), more likely they are a comparable but different part of the composite Terrane I of Monger and others (1982) that was accreted to the margin of North America. Hansen (1990) includes them in the Teslin-Taylor Mountain terrane and interprets them as a deeply subducted part of the accretionary prism of the southwest-dipping (present-day coordinates) early Mesozoic subduction system.

High-pressure metamorphic conditions of 8 to 12 kb for amphibolite-facies rocks of unit AMH,I (eJI₮) in Alaska (Dusel-Bacon and Douglass, 1990; Dusel-Bacon and Hansen, 1992) and 12±4 kb for correlative albite-epidote-amphibolite-facies rocks in southern Yukon, Canada (Hansen, 1990) support the subduction setting for metamorphism of this unit. Glaucophane is found in greenstone at one locality within unit LPP/GNS (eJI₮) and probably developed within part of a fault sliver that was dragged to a greater depth in the subduction zone. Hansen (1990), Hansen and others (1991), and Dusel-Bacon and Hansen (1992) interpret unit AMP (eK) as part of the lower plate continental margin that was overridden by the accretionary prism and arc, and propose that high-pressure metamorphism in the eastern part of unit AMP (eK) occurred as a result of imbrication of the continental margin and overthrusting by the accreted rocks of the ocean basin, arc, and accretionary prism. The tectonic affinity of unit GNS (eKPz) is uncertain. Hansen (1990) and Hansen and others (1991) interpret unit GNS (eKPz) as upper plate, accreted rocks, metamorphosed at shallower levels in the subduction zone than were the rocks of unit AMH,I (eJI₮), whereas Foster and others (1985) and Nokleberg and others (1989) interpret unit GNS (eKPz) as lower plate continental margin.

Amphibolite-facies metamorphism reached its peak about 213±2 Ma ($^{40}Ar/^{39}Ar$ integrated plateau age on amphibole) and was followed by synmetamorphic intrusion of the Taylor Mountain batholith (shown as unit J₮g) at about 209±3 Ma (Cushing and others, 1984). Northward accretion of the amphibolite-facies unit followed or was synchronous with the low-grade metamorphism of unit LPP/GNS (eJI₮) ($^{40}Ar/^{39}Ar$ integrated plateau age of 201±5 Ma on actinolite from greenstone; G.W. Cushing, unpub. data, 1984). Biotite in a thrust zone within the central part of unit AMH,I (eJI₮) y ields a $^{40}Ar/^{39}Ar$ integrated plateau age of 187±2 Ma, interpreted as the age of regional thrusting during accretion of the outboard terranes (Cushing and others, 1984; Foster and others, 1985). Rapid uplift and cooling during accretion is indicated by two $^{40}Ar/^{39}Ar$ mineral pairs from garnet-biotite amphibolite gneiss from the central area of unit AMH,I (eJI₮), which gives ages of 188 Ma (hornblende) and 186 Ma (biotite), and of 187 Ma (hornblende) and 185 Ma (biotite) (Hansen and others, 1991).

The original western extent of this latest Triassic to Early Jurassic metamorphic episode is unknown, and it is possible that metamorphism of other units in the Yukon-Tanana upland whose metamorphic age is either given as Early Cretaceous or is shown as having occurred sometime during Paleozoic to Early Cretaceous time may have been associated with the latest Triassic to Early Jurassic episode described above. An argument in favor of this possibility is the occurrence of oceanic rocks in the western part of the Yukon-Tanana upland that are similar to those in the eastern part of the upland and several Middle to Early Jurassic metamorphic cooling ages (hornblende K-Ar and $^{40}Ar/^{39}Ar$; Wilson and others, 1985; C. Dusel-Bacon and M.A. Lanphere, unpub. data, 1991). However, arguing against it are the facts that latest Triassic to earliest Jurassic plutonic rocks do not occur outside the area described above and that isotopic ages from upper greenschist- and amphibolite-facies metamorphic rocks in the rest of the Yukon-Tanana upland and adjacent parts of the Alaska Range are, with few exceptions, late Early Cretaceous.

The largest number of isotopic ages have been determined for unit AMP (eK), which is an extensive subterrane of the Yukon-Tanana terrane and is characterized by concordant bodies of Mississippian augen gneiss. Within this unit, most conventional K-Ar mineral ages fall in the range of about 125 to 110 Ma; a Rb-Sr mineral isochron age for augen gneiss is 119 Ma; sphene from augen gneiss gives a concordant U-Pb age of 134 Ma; U-rich zircon fractions from sillimanite gneiss and quartzite show Early Cretaceous lead loss (Aleinikoff and others, 1986); and hornblende from amphibolite associated with augen gneiss gives a $^{40}Ar/^{39}Ar$ incremental-heating plateau age of 119 Ma (T.M. Harrison, written commun., 1987). The few K-Ar ages determined for nearby units whose metamorphic ages are shown to be bracketed between Paleozoic and Early Cretaceous time are generally also Early Cretaceous. We tentatively interpret these cooling ages to indicate an Early Cretaceous age for regional metamorphism. However, we recognize the possibility that the ages may instead date uplift and cooling, perhaps related to extension within the Yukon Tanana terrane (Pavlis and others, 1988b, 1993; Pavlis, 1989; Duke and others, 1988; Hansen, 1989, 1990; Hansen and others, 1991), that followed an earlier (Late Triassic? to Early Jurassic?) contractional episode.

Support for the existence of both major extensional and contractional events in the Mesozoic tectonic evolution of the Yukon-Tanana upland is provided by deep crustal studies along the Trans-Alaska Crustal Transect (TACT) corridor in east-central Alaska. Seismic reflection and wide-angle refraction studies indicate that a relatively thin (about 30 km), seismically reflective, and low-velocity crust underlies the main part of the Yukon-Tanana upland (Berge and others, 1987; Fuis and others, 1987; Beaudoin and others, 1991). Magnetotelluric and seismic reflection surveys from along the corridor indicate that the rocks of the Yukon-Tanana terrane extend from the surface to depths of as little as 10 km, where they are underlain by a shallowly north-dipping band, approximately 20 km in thickness, of highly conductive rocks, interpreted as Late Jurassic and Early Cretaceous flysch from a regionally extensive basin that separated the Yukon-Tanana terrane from the outboard Peninsular and Wrangellia segments of the southern Alaska composite terrane (Stanley and others, 1990; Beaudoin and others, 1991; Nokleberg and others, 1991).

The anomalously thin and reflective crust of the Yukon-Tanana is best explained by extensive crustal attenuation, whereas the interpretation of the highly conductive lower two-thirds of the crustal section as underplated Mesozoic flysch requires major north-directed convergence. Uncertainties in the timing, number, relation, and relative importance of extensional and contractional events allow for numerous differing interpretations of the metamorphic history of the Yukon-Tanana upland.

South of the Tanana River, the metamorphic and deformational history of Yukon-Tanana-terrane units within the Alaska Range apparently differed somewhat from that of lithologically correlative units in the Yukon-Tanana upland. A polymetamorphic and polydeformational history has been proposed for two of these units. In most areas, the metamorphic rocks yield Early Cretaceous K-Ar, U-Pb (sphene), and Rb-Sr (mineral isochron) isotopic ages, similar to those determined for rocks to the north. In the western part of the Alaska Range near the McKinley River, M_1 occurred under greenschist- to amphibolite-facies conditions and was associated with the development of northwest-trending folds. M_2 in that area occurred under lower greenschist-facies conditions and was synchronous with the development of northeast-trending folds and with low-grade metamorphism in adjacent unit LPP/GNL (eK). An eastward-increasing metamorphic sequence developed during Early(?) to Late Cretaceous time within rocks of the relatively small Pingston, McKinley, Dillinger, and Windy terranes that crop out just north of the McKinley fault. The tectonic origin of the assumed Early Cretaceous metamorphism is unknown. The Late Cretaceous metamorphism in the area just north of the McKinley fault may have been related to accretion of the Peninsular and Wrangellia segments of the southern Alaska composite terrane in mid- to Late Cretaceous time (Csejtey and others, 1982; Nokleberg and others, 1985a).

AREA BETWEEN THE McKINLEY AND DENALI FAULTS AND THE BORDER RANGES FAULT SYSTEM

Greenschist- to amphibolite-facies metamorphism across much of the Peninsular terrane and the southern margin of the Wrangellia terrane was apparently early to synkinematic with the intrusion of tonalitic to granodioritic plutons throughout much of Jurassic time. Lithologic assemblages in the various units are similar and include intermediate to mafic metaplutonic rocks that are variably altered, sheared, and foliated; amphibolite and other amphibolite-facies rocks, including mafic, calcareous, and pelitic schist and gneiss, marble, and quartzite or metachert; and greenschist-facies mafic schist, greenstone, metavolcaniclastic rocks, phyllite, argillite, and slate. The association of protoliths (mafic to intermediate intrusive and extrusive rocks, siliciclastic rocks, calcareous rocks, and chert) suggests an oceanic affinity for most rocks; protoliths range in age from late Paleozoic to Late Triassic.

Following the model of Plafker and others (1989), we propose that metamorphism and synkinematic plutonism took place within a magmatic arc(s) that probably developed as a result of left-oblique subduction of the Farallon plate beneath the southern Alaska composite terrane. Units near the southern margin of the Peninsular and Wrangellia segments of the composite terrane subsequently were remetamorphosed during at least one retrograde metamorphic episode that occurred sometime during mid-Cretaceous to Eocene time. Retrograde metamorphism was probably related to one or more of the following: (1) an enigmatic late Early Cretaceous thermal episode evidenced by near-trench tonalitic plutonism and possible associated metamorphism within the southern Peninsular terrane northeast of Anchorage (Pavlis and others, 1988a) and by K-Ar metamorphic mineral ages in the southern Wrangellia and northern Chugach terranes in the eastern Chugach Mountains (Winkler and others, 1981b; Silberman and others, 1981; Plafker and others, 1989); (2) north-directed underthrusting of the Chugach terrane, primarily (or at least most recently) the Late Cretaceous to Eocene underthrusting of the flyschoid rocks (Valdez Group) beneath the Peninsular and Wrangellia terranes; and (3) an Eocene thermal episode that produced widespread but volumetrically minor dikes and K-Ar mineral ages in metamorphic rocks within the Wrangellia terrane in the eastern Chugach Mountains (Winkler and others, 1981b; Plafker and others, 1989).

With the exception of the Jurassic metamorphic belt along its southern margin, the rest of the Wrangellia terrane experienced either low-grade or no metamorphism. Most low-grade rocks (shown as unit LPP,GNS (IKJ)) have not been penetratively deformed (except near major faults) and exhibit well-preserved volcanic, sedimentary, or plutonic textures. Locally, however, in the general area that is proposed to be the leading edge along which the Wrangellia terrane was accreted (Csejtey and others, 1982), the rocks of this unit are weakly phyllitic or schistose in the central Alaska Range (Smith, 1981; Nokleberg and others, 1985a) and intensely folded and sheared in the Talkeetna Mountains (Csejtey and others, 1978).

The age and cause of low-grade metamorphism of this unit are uncertain, and they may have differed in different parts of this unit. A tentative pre-Middle or pre-Late Jurassic age of metamorphism for at least some areas of this unit in the Valdez, McCarthy, and Nabesna quadrangles is suggested by the apparent lack of metamorphism in overlying Middle Jurassic to Late Cretaceous sedimentary rocks. Metamorphism in some areas along the southern margin of this unit near the Chitina River may have been associated with the intrusion of Jurassic plutons. Finally, limited data suggest that an alternative or additional low-grade metamorphic episode, which was associated with accretion of the Wrangellia terrane, may have affected at least the northern part of this unit in mid- to Late Cretaceous time.

Northward migration and accretion of the Wrangellia terrane segment of the southern Alaska composite terrane resulted in low- to high-grade metamorphism and deformation within a flysch basin that separated the Wrangellia terrane from North America. In east-central Alaska, most of this flysch basin forms a northeastward-tapering wedge between the Talkeetna and McKinley faults. The western part of the wedge consists of highly deformed but weakly metamorphosed flysch of Late Jurassic to early Late Cretaceous (Cenomanian) age and low-grade rocks from several small, lithologically disparate tectonic fragments that are interleaved with the flysch. Protolith ages within the tectonic fragments range from Devonian to Jurassic. The tectonic juxtapositioning of the disparate fragments (possibly individual terranes) is bracketed between the Cenomanian protolith age of the youngest flysch and the Paleocene age of unconformably overlying unmetamorphosed rocks and postmetamorphic granitoids.

The eastern part of the flysch wedge composes the 140-km-long, roughly symmetrical Maclaren metamorphic belt. The Maclaren metamorphic belt is an intermediate-pressure (Barrovian) sequence of prehnite-pumpellyite-facies metasedimentary rocks and metagabbro; greenschist-facies phyllite, metagraywacke, marble, quartzite, metapelite, and greenstone; and amphibolite-facies schist, gneiss, and amphibolite that are intruded by foliated, synkinematic plutons of intermediate composition (Smith, 1981, 1984; Csejtey and others 1982, 1986; Nokleberg and others, 1982, 1985a). Protoliths are Triassic to Cretaceous in age. Where not affected by tectonic shortening, metamorphic grade increases gradually from the flanks of the sequence toward its core. Along the southern limb of the belt, lower grade rocks dip northward under higher grade rocks to form an inverted metamorphic sequence (Smith, 1981). Within the eastern part of the metamorphic belt, greenschist- and amphibolite-facies rocks are juxtaposed along steep, north-dipping thrust faults (Nokleberg and others, 1982, 1985a). A similarly sharp change in metamorphic grade occurs on either side of a north-dipping thrust that forms the southern margin of the foliated plutonic body named the "East Susitna batholith" by Nokleberg and others (1982) (Smith, 1981; Nokleberg and others, 1982; 1985a). Intrusive contacts and metamorphic foliations in the granitoids and in the metamorphosed wallrocks are all concordant, and the metamorphic grade increases toward the East Susitna batholith, which suggests that the granitoids intruded during the early part of the dynamothermal metamorphic episode (Smith, 1981; Nokleberg and others, 1982; 1985a). U-Pb ages on zircon fractions from schistose quartz diorite indicate an intrusive age of 70±7 Ma for part of the East Susitna batholith (Aleinikoff and others, 1982). K-Ar ages on hornblende from the batholith are as old as 87.4 Ma (Turner and Smith, 1974), which indicates synkinematic intrusion over a long period of time (Nokleberg and others, 1985a). A U-Pb age on sphene and a K-Ar age on biotite from the same rock indicate a metamorphic age of 56 Ma (Aleinikoff and others, 1982), which probably marks the end of the prolonged Late Cretaceous to early Tertiary metamorphic episode. Rapid uplift and cooling during metamorphism is indicated by the fact that approximately the same age is given by sphene and biotite, which have closure temperatures greater than 600°C (Mattinson, 1978) and about 280°C (Harrison and others, 1985), respectively.

AREA SOUTH OF THE BORDER RANGES FAULT SYSTEM

South of the Border Ranges fault system lie the oceanic rocks of the successively accreted Chugach, Yakutat, Ghost Rocks, and Prince William terranes. The Chugach terrane, between the steeply dipping to north-dipping Border Ranges and Contact fault systems, comprises three successively accreted sequences that are separated by vertical- to north-dipping faults. The innermost sequence (unit GNI/H (meJ)) is a discontinuous belt of transitional intermediate-pressure greenschist-facies to high-pressure greenschist- (blueschist-) facies metabasalt, metachert, and metasedimentary rocks of unknown protolith age. In most areas, greenschists that contain chlorite+actinolite commonly are finely intercalated with blue-amphibole-bearing schists that contain crossite+epidote. Lawsonite coexists with blue amphibole at scattered localities along the belt. Data for several isotopic systems suggest an Early to Middle Jurassic age for the intermediate- to high-pressure greenschist-facies episode. Strongly sheared rocks within the parts of this unit near the Tazlina glacier (schist of Iceberg Lake) and adjacent to the Copper River (schist of Liberty Creek) yield late Early Cretaceous K-Ar mineral ages (Winkler and others, 1981b; Plafker and others, 1989). These ages probably indicate partial resetting of the isotopic ages during emplacement of the adjacent seaward subduction complex (unit LPP (eTJ) that was accreted between Middle Jurassic and Late Cretaceous time (Plafker and others, 1989). Metamorphism of unit GNI/H (meJ) apparently occurred as a result of north-directed subduction that was coeval with Early to Middle Jurassic magmatism in the nearby Alaska-Aleutian Range (Carden and others, 1977; Connelly, 1978) and the southern Peninsula terrane. Plafker and others (1989) propose that northward to eastward subduction beneath the Peninsular and parts of the Wrangellia terrane began in Late Triassic time and continued to Middle(?) Jurassic time as a result of left-oblique subduction of the Farallon plate.

The middle sequence (unit LPP (eTJ)) is a prehnite-pumpellyite-facies mélange that consists of oceanic sedimentary and igneous rocks and offscraped fragments of continental margin or older subduction assemblages. Radiolarians from the mélange matrix range in age from Late Triassic to mid-Cretaceous and show an apparent southward decrease in age (Plafker and others, 1989, and references given therein). Initial metamorphism and deformation of this unit probably occurred during active underthrusting within an accretionary prism and was followed by late fracturing and cataclasis during uplift of the complex, as proposed by Connelly (1978) for the part of this unit in the area of Kodiak Island. Accretion of this mélange complex postdates the Late Triassic age of the oldest matrix in the mélange complex and may have taken place over a long time span that extended throughout the Jurassic and into the Late Cretaceous.

The outermost and most extensive part of the Chugach terrane is an accretionary prism made of uppermost Cretaceous flyschoid metasedimentary rocks and oceanic metabasaltic rocks. These rocks underwent prehnite-pumpellyite- to lower greenschist-facies low-pressure metamorphism that probably accompanied north-directed underthrusting beneath the older and inner parts of the Chugach accretionary prism and the combined Peninsular and Wrangellia terranes during latest Cretaceous to early Tertiary time; metamorphism and underthrusting also apparently accompanied the development of south-vergent folds (Moore and others, 1983; Sample and Moore, 1987; Nokleberg and others, 1989b). Metamorphic grade within the accretionary prism is lowest in its western end on Kodiak Island, and it is highest in the polymetamorphic (informal) Chugach metamorphic complex of Hudson and Plafker (1982) that crops out as an elongate 200-km-long and less than 50-km-wide east-west-trending belt in the eastern Chugach Mountains and the Saint Elias Mountains. The metamorphic complex is made up of andalusite- and cordierite-bearing schist and gneiss and a core zone of sillimanite-bearing migmatite; these rocks are the deepest parts of the accretionary prism that makes up the southern part of the Chugach terrane. P-T estimates from the Chugach metamorphic complex and from the adjacent greenschist-facies rocks suggest a nearly isobaric P-T-time path in which the rocks of the complex were initially heated to greenschist-faces conditions at a depth of about 10 km during Late Cretaceous to early Tertiary underthrusting, and they were further heated during low-pressure amphibolite-facies metamorphism that accompanied widespread intrusion during early Eocene time (Sisson and Hollister, 1988). Amphibolite-facies metamorphism and partial melting in the core of the metamorphic complex overlapped in time with the development of second generation north-vergent folds, steeply dipping cleavage and schistosity, and near horizontal east-west-trending fold axes and lineations (Sisson and Hollister, 1988).

The heat source that produced both the amphibolite-facies Chugach metamorphic complex and the widespread Sanak-Baranof belt of early Tertiary plutons that crops out within the Chugach terrane and the outboard Prince William terrane (Hudson and others, 1979; Hudson, 1983) is problematic. Marshak and Karig (1977) point out that in a normal subduction setting, the temperatures within an accretionary prism, such as the Chugach and Prince William terranes, are much too low to cause partial melting. They propose that the anomalous near-trench plutonism was a result of eastward migration of a ridge-trench-trench triple junction along the continental margin and subduction of the Kula-Farallon spreading ridge. Sisson and Hollister (1988) and Sisson and others (1989) postulate that the metamorphism resulted from a combination of heat introduced by extensive horizotal, as well as vertical, transport of fluids (beginning during initial greenschist-facies metamorphism) that were followed by felsic melts, both of which were generated from downdip in the subduction zone and involved either subduction of young, hot oceanic crust at a high rate and a low angle of subduction, or subduction of a spreading ridge. An alternate but related hypothesis, proposed by Plafker and others (1989) to account for the anomalous heating during the early Tertiary metamorphic and plutonic episode, is that it resulted from the opening of an oceanic-slab-free mantle window beneath the continental margin as the subducting Kula plate pulled away from the Farallon-Pacific plate, in a manner analogous to that described along the San Andreas transform fault system by Dickinson and Snyder (1979).

A low-pressure-facies series also developed within upper Mesozoic flysch and mélange of the Yakutat terrane that are thought to be correlative with the flysch and mélange of the Chugach terrane (Plafker and others, 1989). Both lithologic associations are in the Yakutat terrane and are extensively intruded by Eocene granitoid plutons similar to those in the Sanak-Baranof belt. The metamorphic evolution of the flysch and mélange of the Yakutat terrane probably resembled that of the flysch and mélange of the Chugach terrane, discussed above.

Seaward of the metamorphic rocks of the Chugach terrane and separated from them by the Contact fault system lie the strongly deformed but weakly metamorphosed Ghost Rocks Formation and Orca Group of the Ghost Rocks and Prince William terranes, respectively. Although the protolith age range and timing of accretion of these two terranes differ slightly, we include them in the same metamorphic unit because we interpret their overall metamorphic history to have been similar. The Ghost Rocks Formation crops out mainly on and in the vicinity of Kodiak Island, where it is a Late Cretaceous to Paleocene accretionary complex made up of coherent packages composed of deep-sea sedimentary rocks and mafic and intermediate volcanic rocks and packages composed of sandstone-shale mélange (Byrne, 1982, 1984). Possibly correlative rocks on the Resurrection Peninsula (included in unit GNL (eTIK)) are dominantly pillow basalt and an ultramafic-mafic complex (Plafker, 1987). The Orca Group crops out around Prince William Sound and comprises a late Paleocene through early middle Eocene accreted deep-sea-fan complex that contains interbedded oceanic volcanic rocks, minor pelagic sediment, and local mélange (Winkler, 1976; Tysdal and Case, 1979; Winkler and Plafker, 1981; Helwig and Emmet, 1981; Plafker and others, 1985b). Byrne (1986) proposed that the development of conjugate folds and spaced cleavage within the Ghost Rocks Formation occurred as a result of subhorizontal shortening of the accretionary complex during underthrusting. Some of the metamorphism and deformation of the Orca Group may have had a similar origin.

Low-grade metamorphism and deformation within both terranes took place during early Tertiary time, not long after the youngest strata were deposited, and it predated, perhaps by very little, the intrusion of the early Tertiary plutons that stitch the Ghost Rocks and Prince William terranes to the Chugach terrane landward of them. On Kodiak Island, these plutons, which are dated at about 62 Ma, are structurally discordant, and they contact metamorphosed the Ghost Rocks Formation and the adjacent Chugach and Peninsular terranes (Moore and others, 1983; Davies, 1985). Intrusion and metamorphism of the Orca Group postdated that of the Ghost Rocks Formation by about 10 m.y. From Prince William Sound to the east, 53- to 48-Ma plutons crosscut and contact metamorphosed the already deformed and weakly metamorphosed Orca Group (Winkler and Plafker, 1981; Miller and others, 1984) and the adjacent Chugach, Peninsular, and Wrangellia terranes (Plafker and others, 1989). In one area, just east of the Copper River, the low-pressure thermal metamorphism associated with the intrusion of Eocene plutons was particularly widespread, and the plutons extend across the Contact fault system. K-Ar ages of 51 Ma on biotite and hornblende (Winkler and Plafker, 1981) from one of the largest plutons that stitches the fault establish a minimum age for the juxtaposition of the Chugach and Prince William terranes.

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TABLE 2

TABLE 2.—*Metamorphic mineral-assemblage data*

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
Kantishna River								
57	1	R.M. Chapman	PE	AS	QZ+CL+WM	LPP ?	LPP (lKD)	
57	2	F.R. Weber	PE	OC	WM	LPP	-------do-------	
57	3	R.M. Chapman	BA	AS	CL+EP+QZ+WM+AC(?)	GNS	GNS (eKmPz)	
57	4	-------do-------	BA	AS	QZ+CL+WM+CA	GNS	-------do-------	
57	5	-------do-------	PE	AS	QZ+CL+WM+ZO	LPP	LPP (lKD)	
57	6	-------do-------	PE	AS	QZ+CL+WM	LPP	-------do-------	
57	7	-------do-------	PE	AS	QZ+CL	LPP	-------do-------	
57	8	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	9	-------do-------	PE	AS	QZ+CL	LPP	-------do-------	
57	10	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	11	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	12	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	13	-------do-------	PE	AS	QZ+CL+WM	LPP	-------do-------	
57	14	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	15	-------do-------	PE	AS	QZ+WM	LPP	-------do-------	
57	16	F.R. Weber	PE	AS	QZ+WM+CA±PP±MU	LPP	-------do-------	
57	17	-------do-------	PE	OC	WM+QZ	LPP	-------do-------	
Fairbanks								
58	1	-------do-------	OT	OC	WM	LPP	-------do-------	
58	2	R.B. Forbes	CA	AS	CA+QZ+WM	GNS	GNI (eKPz)	
58	2	-------do-------	PE	AS	QZ+CL+WM+AB	GNS	-------do-------	
58	3	-------do-------	PE	AS	QZ+WM+CL+AB	GNS	-------do-------	
58	4	-------do-------	PE	AS	QZ+WM+CL+AB	GNS	-------do-------	
58	5	-------do-------	BA	AS	HO+CP+GA+BI	AMP	AMI (eKPz)	
58	6	-------do-------	BA	AS	HO+PL+QZ+GA	AMP	-------do-------	
58	7	-------do-------	BA	AS	QZ+CL+WM+AB	LPP / GNS	GNS (eKPz)	
58	7	-------do-------	CA	AS	QZ+CA+PP+AB	LPP / GNS	-------do-------	
58	8	-------do-------	BA	AS	HO+PL+GA+BI+QZ	AMP	AMI (eKPz)	
58	9	F.R. Weber	CA	AS	CA+MU+QZ	GNS	GNS (eKPz)	
58	10	-------do-------	PE	AS	QZ+WM±CL	LPP / GNS	-------do-------	
58	11	-------do-------	OT	OC	QZ+MU	GNS	-------do-------	
58	12	-------do-------	PE	OC	QZ+WM±MU±GA	GNS	-------do-------	
58	13	-------do-------	OT	AS	QZ+PL+KF+MU	GNS	LPP/GNL (eK)	
58	14	T.K. Bundtzen	BA	AS	PU+CL+ZO	LPP	-------do-------	75AST2084
58	15	-------do-------	PE	AS	WM+BI+QZ+AB	GNS	-------do-------	75AST2072
Big Delta								
59	1	F.R. Weber	PE	AS	QZ+MU+GA+BI±CL	AMP	AMI (eKPz)	
59	2	-------do-------	CA	AS	CA+QZ+WM	LPP / GNS	LPP,GNS (eKPz)	
59	3	-------do-------	PE	AS	QZ+BI+MU+GA	AMP	AMI (eKPz)	
59	4	Cynthia Dusel-Bacon	PE	AS	MU+QZ+ST+KY+SI (?)+AN	AML/ I	-------do-------	75AFr4074A
59	4	-------do-------	PE	AS	QZ+MU+PL+BI+CL+ST+KY+TO	AMI	-------do-------	75AFr4074D
59	5	H.L. Foster	PE	AS	QZ+PL+BI+WM±ST±GA±SI±CL	AMP	-------do-------	
59	6	Cynthia Dusel-Bacon	BA	AS	AC+FS+QZ+WM+BI	GNS	GNS (eKPz)	72AWr39
59	7	F.R. Weber	PE	AS	QZ+MU+BI	GNS	-------do-------	
59	8	Cynthia Dusel-Bacon	BA	AS	AC+EP+SH+AB+CL	GNS	-------do-------	72AWr88E
59	9	-------do-------	PE	AS	MU+BI+QZ+PL+ST+GA+KF	AMP	AMP (eK)	77AFr4179
59	10	-------do-------	PE	AS	MU+BI+QZ+AN+PL+SI+GA+ST+KY	AML/ I	-------do-------	76AFr272A
59	11	-------do-------	PE	AS	MU+AN+BI+QZ+KF+PL+SI+KY+ST	AML/ I	-------do-------	77AFr43A
59	11	-------do-------	PE	AS	QZ+BI+MU+PL+GA	AML/ I	-------do-------	77AFr43F
59	12	-------do-------	OT	AS	QZ+WM+BI+KF+TO+EP	AML/ I	-------do-------	75AFr33B
59	13	F.R. Weber	PE	OC	WM	LPP	LPP,GNS (eKPz)	
59	14	-------do-------	PE	AS	CB+WM+QZ	LPP / GNS	GNS (eKPz)	
59	15	-------do-------	PE	AS	QZ+FS+CL+PP±CA	GNS	LPP,GNS (eKPz)	
59	16	-------do-------	CA	AS	CA+QZ+WM	LPP / GNS	-------do-------	
59	17	-------do-------	OT	AS	CB+QZ+WM	LPP / GNS	-------do-------	
59	18	Cynthia Dusel-Bacon	OT	AS	QZ+KF+PL+WM+BI+CL	GNS	GNS (eKPz)	64AWr190
59	19	F.R. Weber	PE	AS	QZ+MU+BI±CB	AMP	AMP (eK)	
59	20	-------do-------	BA	AS	HO+PL±WM±CL	AMP	-------do-------	
59	21	-------do-------	PE	AS	QZ+FS+MU+BI+SI±CL	AMP	-------do-------	
59	22	-------do-------	PE	AS	QZ+FS+SI+MU+BI±CL	AMP	-------do-------	
59	23	Cynthia Dusel-Bacon	PE	AS	BI+KF+SI+QZ+PL	AMP	-------do-------	77AFr3020
59	24	F.R. Weber	PE	AS	MU+BI+FS+SI±CL	AMP	-------do-------	
59	25	-------do-------	PE	AS	QZ+MU+BI±GA	AMP	-------do-------	
59	26	-------do-------	PE	AS	QZ+FS+BI+SI±GA±MU	AMP	-------do-------	
59	27	Cynthia Dusel-Bacon	PE	AS	BI+KF+CO+SI+QZ+PL	AMP	-------do-------	77AFr4103
59	28	-------do-------	PE	AS	KF+CO+QZ+BI+SI+MU+PL	AMP	------do-------	72AWr49B
59	29	F.R. Weber	PE	AS	QZ+FS+BI+SI±GA	AMP	------do-------	
59	30	-------do-------	OT	OC	QZ+FS+MU+WM	GNS	GNS (eKPz)	
59	31	-------do-------	PE	AS	QZ+FS+BI+ST±AN±CL	AML	AMP (eK)	
59	32	-------do-------	OT	OC	QZ+MU±BI	GNS	GNS (eKPz)	
59	33	-------do-------	OT	AS	QZ+KF+PL+BI±HO±CL	AMP	AMP (e K)	
59	34	-------do-------	PE	AS	QZ+MU+CL+GA±BI	GNS	GNS (e KPz)	
59	35	Cynthia Dusel-Bacon	OT	AS	QZ+KF+PL+BI+MU+GA	AMP	AMP (e K)	78AG3B
59	36	-------do-------	PE	AS	WM+BI+QZ+PL+GA+ST+KY+AN	AMP	------do-------	74AWr125
59	37	-------do-------	BA	AS	HO+CP+SH+CL+EP+CZ	AMP	------do-------	79AFr4017B
59	38	F.R. Weber	PE	AS	BI+KF+QZ+PL±CL±CZ±GA	AMP	------do-------	
59	39	Cynthia Dusel-Bacon	BA	AS	HO+CP+EP+SH	AMP	------do-------	79AFr4024J
59	40	F.R. Weber	PE	AS	QZ+BI+MU	AMP	------do-------	

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
59	41	Cynthia Dusel-Bacon	OT	AS	KF+PL+QZ+BI+MU	AMP	AMP (eK)	
59	42	F.R. Weber	OT	AS	QZ+KF+PL+BI+CZ+MU±GA	AMP	------do-------	
59	43	-------do-------	BA	AS	HO+BI+FS±CZ±QZ	AMP	------do-------	
59	43	-------do-------	OT	AS	QZ+FS±WM	AMP	------do-------	
59	44	-------do-------	PE	AS	QZ+MU+PP±CL	AMP	------do-------	
Eagle								
60	1	H.L. Foster	PE	AS	QZ+PL+BI+WM±KF±GA±SI±CL	AMP	AMI (eKPz)	
60	2	-------do-------	PE	AS	QZ+PL+KF+BI+WM±KY±EP±SI±CL	AMI	------do-------	
60	3	-------do-------	PE	AS	BI+QZ+PL+WM±KF±CL	AMP	------do-------	
60	4	-------do-------	PE	AS	QZ+BI+PL+WM+EP+CL±KF±GA±SI	AMP	AMP (eK)	
60	5	-------do-------	OT	AS	QZ+BI+FS+CL±GA	AMP	------do-------	
60	6	-------do-------	PE	AS	QZ+WM±BI±CB	GNS	GNS (eKPz)	
60	7	-------do-------	PE	AS	WM+QZ+CL	GNS	------do-------	
60	8	-------do-------	OT	AS	WM+CL+QZ±AB±CA±SH	GNS	------do-------	
60	9	-------do-------	OT	AS	QZ+WM+CL	GNS	------do-------	
60	10	-------do-------	OT	AS	PL+PH+PU±WM±QZ±EP±CL	LPP	LPP/GNS (eJTR)	
60	11	-------do-------	OT	AS	QZ+WM+CL±AB±BI	GNS	GNS (eKPz)	
60	12	-------do-------	PE	AS	QZ+WM+CL±CB	GNS	------do-------	
60	13	-------do-------	PE	AS	QZ+WM+BI±ST±CA±KY±CL	AMI	AMP (eK)	
60	14	-------do-------	BA	AS	PL+HO+DI+BI+SH+CL	AMI	------do-------	
60	15	-------do-------	BA	AS	EP+CL+FS±GL±CA±SH±GA	GNH	LPP/GNS (eJTR)	
60	16	------do-------	OT	AS	QZ+WM+CL±CB	GNS	------do-------	
60	17	------do-------	OT	AS	QZ+EP+CL±BI±PL±WM±CA	GNS	GNS (eKPz)	
60	18	------do-------	OT	AS	WM+QZ+CL±CA±KF	GNS	------do-------	
60	19	------do-------	OT	AS	QZ+WM+CL±BI±FS	GNS	------do-------	
60	20	------do-------	OT	AS	QZ+PL+WM+CL	GNS	------do-------	
60	21	------do-------	BA	AS	PL+CL+CA+EP+PX+SH	GNS	------do-------	
60	22	------do-------	OT	AS	QZ+EP+CL±CA±WM±FS	GNS	LPP/GNS (eJTR)	
60	23	------do-------	OT	AS	QZ+PL+BI+EP+CL+SH±AM±GA	GNS	AMH,I (eJTR)	
60	24	------do-------	OT	AS	QZ+AM+BI+PL+EP+CL±GA	AMP	------do-------	
60	25	------do-------	OT	AS	QZ+WM+CL±CB	GNS	GNS (eJTR)	
60	26	------do-------	OT	AS	QZ+PL+BI+CL±KF±GA	AMP	AMH,I (eJTR)	
60	27	------do-------	OT	AS	QZ+PL+EP±KF±WM	AMP	------do-------	
60	28	------do-------	BA	AS	HO+PL+EP+SH+CL±QZ±GA±BI	AMP	------do-------	
60	29	------do-------	OT	AS	QZ+PL+AM+BI+EP±GA	AMP	------do-------	
60	30	------do-------	BA	AS	HO+PL+EP+QZ±GA	AMP	------do-------	
60	31	------do-------	OT	AS	QZ+PL+BI+EP±AM±GA	AMP	------do-------	
60	32	------do-------	BA	AS	HO+PL+SH±BI±CL±QZ	AMP	------do-------	
60	33	------do-------	OT	AS	QZ+PL+BI+EP±GA±AM±WM	AMP	------do-------	
60	34	------do-------	PE	AS	QZ+WM+BI+PL±GA±ST±KY	AMI	------do-------	
60	35	------do-------	PE	AS	QZ+WM+BI+CL±ST±GA	AMP	------do-------	
60	36	------do-------	BA	AS	AM+BI+PL+QZ+SH±GA±WM	AMP	------do-------	
60	37	------do-------	OT	AS	QZ±BI±CL±EP±FS	GNS	LPP/GNS (eJTR)	
60	38	------do-------	BA	AS	CL+PL+EP+CA±AC	GNS	------do-------	
60	39	------do-------	OT	AS	QZ+CL+EP±CA±WM±PL	GNS	------do-------	
60	40	------do-------	BA	AS	AM+PL+EP	GNS	------do-------	
60	41	------do-------	OT	AS	QZ+WM+CL±FS±PL±CA	GNS	------do-------	
60	42	------do-------	OT	AS	QZ+PL+WM+CL±BI±EP	GNS	GNS (eKPz)	
60	43	------do-------	OT	AS	QZ+WM+CL	GNS	------do-------	
60	44	------do-------	OT	AS	QZ+WM+CL±AB±SH±EP	GNS	------do-------	
60	45	------do-------	PE	AS	QZ+BI+PL+WM+EP+CL±GA±SI±SH	AMP	AMP (eK)	
60	46	------do-------	PE	AS	QZ+BI+PL±ST±SI±GA±SH	AMP	AMH,I (eJTR)	
60	47	------do-------	PE	AS	QZ+PL+BI+KF+WM+GA+SH+CL	AMP	AMP (eK)	
60	48	------do-------	PE	AS	QZ+PL+BI+WM±GA±CL	AMP	------do-------	
60	49	------do-------	OT	AS	QZ+PL+BI±KF±WM±SH±GA	AMP	------do-------	
60	50	------do-------	PE	AS	QZ+PL+KF+BI+WM±EP±GA±CL	AMP	------do-------	
60	51	------do-------	PE	AS	QZ+PL+BI+GA+KF+CL	AMP	------do-------	
60	52	------do-------	BA	AS	HO+PL+EP±SH	AMP	------do-------	
Mt. McKinley								
66	1	F.R. Weber	OT	AS	QZ+WM	LPP	LPP (IKD)	
66	2	T.K. Bundtzen	BA	AS	AC+CL+EP+AB+TO	GNS	LPP/GNS (eK)	75AST2761
66	2	------do-------	BA	AS	CZ/ZO+CA+CL+AB	GNS	------do-------	75AST2638
66	3	------do-------	BA	AS	PH+CL+AB+ZO	LPP	------do-------	75AST1648
66	3	------do-------	OT	AS	WM+AB+FS+CL+TO	GNS	------do-------	75AST1654
66	3	------do-------	OT	AS	WM+FS+QZ	GNS	------do-------	75AST1623
66	3	------do-------	OT	AS	EP+CL+AB+CA	GNS	------do-------	75AST1703
66	4	------do-------	OT	AS	PU+AB+CL+QZ	LPP	------do-------	75AST1890a
66	5	------do-------	BA	AS	(1) HO+CP+BI+WM (2) AC+AB+BI+WM	AMP GNS	AMP (eKD) + GNS (eK)	75AST2905
66	6	------do-------	BA	AS	(1) HO+CP+BI+EP+GA+SH (2) CL+ZO+AB+CA	AMP GNS	------do-------	75AST1687
66	6	------do-------	BA	AS	(1) HO+CP+BI+EP (2) AC+CL+ZO+AB+BI	AMP GNS	------do-------	75AST1581
66	7	------do-------	PE	AS	(1) BI+WM+GA+CP+EP (2) CL+WM+ZO+AB+CA	AMP GNS	------do-------	75AST2621
66	8	------do-------	BA	AS	(1) HO+CP+GA+BI (2) AC+AB+CL+ZO	AMP GNS	------do-------	75AST1993

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
66	8	T.K. Bundtzen	PE	AS	(1) BI+HO+CP+GA+WM	AMP	AMP (eKD) + GNS (eK)	75AST1882
					(2) AB+ZO+CL+WM+BI	GNS		
66	8	------do-------	PE	AS	(1) GA+CP+WM+BI	AMP	------do-------	75AST3054
					(2) EP+CL+AB+WM+BI	GNS		
66	9	------do-------	PE	AS	(1) DU(?)+BI+WM+GA+ZO	AMP	------do-------	75AST2955
					(2) CL+WM	GNS		
66	10	------do-------	BA	AS	CL+ZO+AB+QZ	GNS	LPP/GNL (eK)	75AST2000
66	11	------do-------	BA	AS	AB+ZO+CA+CL+TR	GNS	------do-------	75AST3021
66	11	------do-------	CA	AS	WM+CA+CL	GNS	------do-------	75AST3024
66	12	------do-------	BA	AS	BI+WM+CL+CA+AB+SH+TO	GNS	------do-------	75AST2030
66	12	------do-------	BA	AS	AC+ZO+CL+AB	GNS	------do-------	75AST2033
66	12	------do-------	OT	AS	AB+ZO+CL+WM+FS+QZ	GNS	------do-------	75AST2027
66	13	------do-------	PE	AS	(1) WM+PL+BI+TO	GNS	GNS (eKD) + GNS (eK)	75AST1689
					(2) KF+AB+CL	GNS		
66	14	------do-------	BA	AS	(1) PL+BI+EP+AC	GNS	------do-------	75AST2992
					(2) AB+CA+ZO+FS+CL	GNS		
66	15	------do-------	BA	AS	(1) AC+PL+BI+EP+GA+SH	GNS	------do-------	75AST1943
					(2) AB+CL+ZO+FS+CA	GNS		
66	15	------do-------	BA	AS	(1) PL+BI+EP+AC	GNS	------do-------	75AST1822
					(2) AB+CA+ZO+FS+CL	GNS		
66	16	------do-------	BA	AS	(1) PL+BI+EP+AC	GNS	------do-------	75AST2954
					(2) AB+CA+ZO+FS+CL	GNS		
66	16	------do-------	BA	AS	(1) AC+PL+BI+EP+GA+SH	GNS	------do-------	75AST2952
					(2) AB+CL+ZO+FS+CA	GNS		
Healy								
67	1	------do-------	PE	AS	WM+QZ+CL+FS	GNS	LPP/GNL (eK)	76BT227
67	2	------do-------	PE	AS	WM+QZ+AB+EP	GNS	------do-------	76BT233
67	3	R.G. Hickman	PE	AS	QZ+WM±CL±CB±CA±AB	GNS	GNS (eKD) + GNS (eK)	
67	3	------do-------	OT	AS	QZ+ZO+AB+CL±TR	GNS	------do-------	
67	4	------do-------	PE	AS	QZ+WM±CL±CB±CA	GNS	------do-------	
67	4	------do-------	BA	AS	CL+ZO+AB±AC±QZ±CA	GNS	------do-------	
67	5	------do-------	BA	AS	AB+ZO+CL±SP±AC	GNS	------do-------	
67	5	------do-------	OT	AS	EP+QZ+CL	GNS	------do-------	
67	5	------do-------	OT	AS	QZ+CL+WM+AB±CA±CZ	GNS	------do-------	
67	6	T.K. Bundtzen	BA	AS	(1) WM+BI+AB+GA+EP	GNS	------do-------	76BT245
					(2) CL+CA+ZO	GNS		
67	7	------do-------	BA	AS	(1) AC+AB+GA+BI+WM	GNS	------do-------	76BT248
					(2) WM+CL+CA+ZO	GNS		
67	8	R.G. Hickman	BA	AS	TR+CL+CZ+CA+AB	GNS	LPP/GNL (eK)	
67	9	T.K. Bundtzen	BA	AS	CL+QZ+CA+BI+ZO	GNS	------do-------	76BT242
67	9	------do-------	BA	AS	PH+ZO+CL+FS	LPP	------do-------	76BT241
67	10	R.G. Hickman	PE	AS	TR+QZ+CA+EP	GNS	GNS (eKD) + GNS (eK)	
67	10	------do-------	PE	AS	QZ+CL+WM	GNS	------do-------	
67	11	K.W. Sherwood	BA	AS	AC+SP+SH+CA+CL+CZ+AB+QZ+WM	GNS	------do-------	
67	11	------do-------	OT	AS	CL+QZ+AB+EP+AC+WM+SP	GNS	------do-------	
67	12	Béla Csejtey, Jr.	PE	AS	QZ+MU+CA	GNS	------do-------	81ACy74
67	13	------do-------	BA	AS	CL+PU+SH+CA+AB+QZ+EP	GNS (?)	------do-------	75ACy133
67	13	W.M. Brewer	OT	AS	(1) QZ+MU±CL±AB±CA	GNS	------do-------	
67	13	------do-------	BA	AS	(2) PU+AC+CL+AB+QZ+SH±SP±CA ±EP	GNS	------do-------	
67	13	------do-------	BA	AS	(2) AC+CZ+AB+QZ+SH±CL±SP±CA ±EP	GNS	------do-------	
67	14	K.W. Sherwood	BA	AS	(2) PU+AC+SP+SH+CA+CL+EP+AB +QZ+WM	GNS	------do-------	
67	15	R.G. Hickman	PE	AS	QZ+CL+MU±CZ	GNS	LPP/GNS (K)	
67	16	Béla Csejtey, Jr.	BA	OC	CL+AC	GNS	GNL/I (K)	78ACy208
67	17	K.W. Sherwood	PE	AS	QZ+AB+CA+CL+WM+SP+TR/AC+EP	GNS	------do-------	
67	18	Béla Csejtey, Jr.	CA	AS	QZ+MU+CA	GNS	------do-------	80ACy18
67	19	W.M. Brewer	PE	AS	BI+MU+QZ±CL±PL±CB±TO	GNS	------do-------	
67	19	------do-------	PE	AS	GA+CL+MU+BI+QZ+TO	GNS	------do-------	
67	19	------do-------	CA	AS	CA+TR+QZ+GA	GNS	------do-------	
67	19	------do-------	PE	AS	BI+CL+MU	GNS	------do-------	
67	20	------do-------	OT	AS	PL+CZ+GA+AN	AML	AML/I (K)	
67	20	------do-------	PE	AS	SI+MU+BI	AMP	------do-------	
67	21	------do-------	PE	AS	MU+BI+GA	AMP	------do-------	
67	21	------do-------	PE	AS	MU+BI+SI	AMP	------do-------	
67	21	------do-------	PE	AS	MU+BI+GA+ST	AMP	------do-------	
67	21	------do-------	PE	AS	BI+GA+ST+SI	AMP	------do-------	
67	21	------do-------	PE	AS	BI+GA+SI+MU	AMP	------do-------	
67	21	------do-------	BA	AS	HO+PL+CZ+BI+QZ±GA±CU±SH±CA	AMP	------do-------	
67	21	------do-------	BA	AS	HO+PL+GA+BI±QZ±SH±CA	AMP	------do-------	
67	22	Béla Csejtey, Jr.	PE	AS	QZ+BI+CP+GA	AMP	------do-------	80ACy78
67	23	------do-------	BA	AS	AC+CP+BI±QZ±GA±CA	AMP	AMI (eTIK)	80ACy107
67	24	W.M. Brewer	BA	AS	HO+PL+QZ+BI	AMP	------do-------	
67	24	------do-------	CA	AS	QZ+DI+CA+GA+SC+SH	AMP	------do-------	
67	24	------do-------	PE	AS	QZ+BI+MU+SI	AMP	------do-------	

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
67	25	T.E. Smith	PE	AS	GA+BI+QZ+CP+MU	AMP	AMI (eTlK)	72ASt325
67	26	------do------	PE	AS	CA+CB+BI+QZ+CP	AMP	------do------	72ASt330
67	27	W.M. Brewer	BA	AS	AC+CZ+CL+AB+QZ+BI+SH+CA	GNS	------do------	
67	27	------do------	CA	AS	QZ+CA+TR	GNS	------do------	
67	27	------do------	CA	AS	QZ+CA+DI+ID	AMP	------do------	
67	27	------do------	PE	AS	QZ+MU+BI+CO+CA+CZ	AMP	------do------	
67	28	T.E. Smith	CA	AS	CA+QZ+MU+AB+CB	GNS	GNI (eTlK)	72ASt347
67	29	------do------	PE	AS	BI+CL+QZ+MU+PL+CB	GNS	------do------	72ASt350
67	30	Béla Csejtey, Jr.	CA	AS	QZ+CA+MU	GNS	------do------	80ACy100
67	31	------do------	BA	AS	PU+CL+QZ+SH	LPP	LPP (eTlK)	76ACy112
67	31	------do------	BA	AS	CL+PU+CA+QZ+AB	LPP	------do------	76ACy115
67	32	------do------	BA	AS	CL+AC	GNS	------do------	78ACy8
67	33	------do------	PE	AS	QZ+WM	LPP / GNS	------do------	80AMw27
67	34	T.E. Smith	PE	AS	BI+CB+QZ+GA+AN+CP	AML	AMI (eTlK)	72ASt195
67	35	Béla Csejtey, Jr.	OT	OC	BI+HO	AMP	------do------	81ACy117
67	36	T.E. Smith	PE	AS	SI+GA+BI+QZ+CP+CB	AMP	------do------	72ASt123
67	37	------do------	PE	AS	SI+QZ+MU+GA+CB+CP	AMP	------do------	72ASt1600
67	38	------do------	PE	AS	EP+CL+MU+QZ+AB	GNS	LPP (eTlK)$_1$	72ASt1551
67	39	------do------	BA	AS	PH+AB+CL+CZ+EP	LPP	LPP,GNS (lKlTr)	72ASt1770
67	40	Béla Csejtey, Jr.	BA	OC	CL	LPP	------do------	78ACy180
67	41	T.E. Smith	BA	AS	PH+CL+AB+QZ+CA±PU	LPP	------do------	72ASt159
67	42	------do------	BA	AS	PH+PU+CA+CL+EP	LPP	------do------	72ASt1533
67	43	------do------	PE	AS	QZ+AB+MU+CL+CA+PH+PU+CB	LPP	LPP (eTlK)$_1$	68ASt31
67	44	------do------	PE	AS	QZ+MU+CL+BI+CB	GNS	------do------	68ASt10
67	45	------do------	PE	AS	CL+MU+AB+QZ+CB+CA	GNS	GNI (eTlK)	72ASt1520
67	46	Béla Csejtey, Jr.	PE	AS	CL+MU	GNS	------do------	79ACy47
67	47	T.E. Smith	PE	AS	QZ+CP+BI+CB+GA+KY+SI	AMI	AMI (eTlK)	69ASt195
67	48	------do------	PE	AS	MU+BI+CL+AB+QZ	GNS	------do------	68ASt398
67	49	------do------	PE	AS	QZ+CP+BI+MU+CB+GA+KY+SI	AMI	------do------	
67	50	------do------	PE	AS	QZ+BI+CA+MU+AC+CB	GNS	------do------	
67	51	------do------	PE	AS	MU+BI+CL+AB+QZ	GNS	LPP (eTlK)$_1$	
Mt. Hayes								
68	1	W.J. Nokleberg	PE	AS	MU+QZ+KF+BI+SI±GA	AMP	AMP (eK)	81AIL059D 81ANK108A
68	2	H.L. Foster	OT	AS	PL+QZ+BI±HO	AMI	------do------	
68	3	------do------	OT	AS	QZ+PL+BI±WM±EP±GA	AMI	------do------	
68	4	------do------	OT	AS	PL+QZ+WM+CL±KF±GA±EP±BI	AMI	GNS (eKD) + GNS (eK)	
68	5	------do------	PE	AS	PL+QZ+WM±KF±GA	AMI	------do------	
68	6	------do------	PE	AS	QZ+PL+BI±GA±EP	AMI	------do------	
68	7	W.J. Nokleberg	PE	AS	QZ+KF+PL+BI+MU+AN+CO	AML	------do------	80AAF053A 80AAF020B
68	8	------do------	CA	AS	CA+QZ+BI+AC	GNS	------do------	81AIL149A
68	9	------do------	BA	AS	PL+QZ+WM(?)+CL±BI±EP	GNS	------do------	80AAF013A
68	10	------do------	PE	AS	QZ+PL+BI+AN+MU±CL	GNL	------do------	80ANK021B
68	11	------do------	CA	AS	QZ+CX+PL+KF+CA±BI±ZO	AMP	AML/I (K)	80ANK069A
68	11	------do------	BA	AS	PL+HO+BI+CX±CA±MU	AMP	------do------	80ANK069B
68	12	------do------	BA	AS	HO+BI+PL+GA±EP	AML	AMI (eTlK)	79ANK142A
68	12	------do------	BA	AS	PL+QZ+SI+GA+BI±CL	AML	------do------	79ANK073A
68	13	T.E. Smith	PE	AS	BI+SI+CP+CB+QZ+MU	AMP	------do------	72ASt310
68	14	------do------	PE	AS	GA+MU+QZ+CB+CP	AMP	------do------	72ASt219
68	15	W.J. Nokleberg	BA	AS	PL+KF+CL+EP	GNS	GNS (lKD)	79ACH095A
68	15	------do------	PE	AS	QZ+AC+CA	GNS	------do------	79ANK229A
68	15	------do------	PE	AS	QZ+CA+MU+EP	GNS	------do------	79ACH097B
68	16	J.H. Stout	PE	AS	SI+GA+AB+QZ+CB+BI±ST	AMP	AMI (eTlK)	
68	16	------do------	BA	AS	HO+DI+CP	AMP	------do------	
68	17	------do------	PE	AS	AN+GA+ST+BI+QZ+AB+CB	AML	------do------	
68	18	------do------	PE	AS	GA+BI+CB+QZ+AB+CL+SP	GNS (?)	------do------	
68	18	------do------	PE	AS	CL+SP+QZ+AB+MU	GNS	------do------	
68	19	W.J. Nokleberg	BA	AS	PL+AC+CL+EP±ZO	GNS	LPP,GNS (lKJ)	79ANK033A
68	19	------do------	BA	AS	PL+CL+EP+MU+CA	GNS	------do------	79ANK010A
68	20	T.E. Smith	PE	AS	CL+CB+MU+QZ	GNS (?)	------do------	72ASt242
68	21	------do------	PE	AS	MU+QZ+CL+CA+BI+EP+AB	GNS (?)	------do------	72ASt172
68	22		PE	AS	GA+BI+QZ+AB+MU+CA	GNS (?)	AMI (eTlK)	72ASt228
68	23	W.J. Nokleberg	PE	AS	GA+PL+HO+CA+QZ±CL	AMP	------do------	79ANK088A
68	24	------do------	PE	AS	QZ+PL+MU+CZ+CA+BI±GA±CL	GNS	GNI (eTlK)	79AZN040A,B
68	25	------do------	PE	AS	QZ+CB+CZ+PL+MU+CL±CA	GNS	LPP,GNS (lKJ)	79AZN044A,B
68	26	T.E. Smith	BA	AS	PH+CA+CL+AB+QZ+PU	LPP	------do------	71ASt259
68	27	------do------	BA	AS	PU+PH+CL+AB+QZ	LPP	------do------	72ASt267
68	28	W.J. Nokleberg	BA	AS	CL+EP+AC+PL	GNS	------do------	79AHZ059B
68	28	------do------	PE	AS	QZ+KF+MU+CL	GNS	------do------	79AHZ057C
68	29	------do------	BA	AS	PL+CL+EP+AC±ZO±CA±PH±PU	GNS	------do------	79ANW065A
68	29	------do------	BA	AS	PL+AC+CL+GA+EP	GNS	------do------	79ANK084A
68	30	T.E. Smith	BA	AS	PH+CL+AB+QZ+EP	LPP	------do------	71ASt200
68	31	------do------	BA	AS	PH+PU+CL+AB+AC+EP	LPP	------do------	71ASt42
68	32	W.J. Nokleberg	BA	AS	PL+AC+CL+MU+EP±CA	GNS	------do------	79ANW115A
68	32	------do------	BA	AS	PL+CL+EP+AC±PH±PU	LPP	------do------	79ANK002A,B
68	33	------do------	PE	AS	QZ+MU+BI+AN+PL±SI	AML	GNS (eKD) + GNS (eK)	81ASB048A

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
68	33	W.J. Nokleberg	PE	AS	MU+BI+QZ+AN+PL	AML	GNS (eKD) + GNS (eK)	81ANK080B 81AIL071A 81ARM028A
68	33	------do-------	CA	AS	AC+CA+CZ+QZ	GNS	------do-------	81ANK081D
68	34	------do-------	CA	AS	MU+BI+CA+GA+QZ	GNS	------do-------	81ANK138C
68	34	------do-------	PE	AS	MU+AB+CL+BI+CA+EP	GNS	------do-------	81ANK138B
68	34	------do-------	PE	AS	QZ+KF+PL+BI+MU+AN+CO	AML	------do-------	80AAF053A
68	35	------do-------	PE	AS	BI+AN+QZ+MU+KF±PL±CL	GNL	------do-------	81ANK207A
68	36	------do-------	BA	AS	PL+CL+MU+CA	GNS	LPP,GNS (IKJ)	79AZN062E
68	36	------do-------	PE	AS	BI+CL+MU+CB+QZ+PL+CA	GNS	------do-------	79AZN061C
Tanacross								
69	1	H.L. Foster	OT	AS	QZ+KF+PL+BI±WM	AMP	AMP (eK)	
69	2	------do-------	OT	AS	QZ+FS+BI+EP±WM±CL	AMP	------do-------	
69	3	------do-------	OT	AS	QZ+KF+PL+BI±WM±GA	AMP	------do-------	
69	4	------do-------	BA	AS	HO+PL+QZ+EP+SH	AMP	------do-------	
69	5	------do-------	BA	AS	HO+PL+SH±PP±CL	AMP	------do-------	
69	6	------do-------	OT	AS	QZ+PL+BI±KF±WM±GA	AMP	------do-------	
69	7	------do-------	OT	AS	QZ+BI+PL+FS+CL±WM±EP	AMP	AMH,I (eJlTR)	
69	8	------do-------	PE	AS	QZ+PL+KF+BI+WM±GA±CL	AMP	AMP (eK)	
69	9	------do-------	OT	AS	QZ+PL+BI±WM±CO±SI	AMP	------do-------	
69	10	------do-------	OT	AS	HO+FS+SH±GA	AMP	------do-------	
69	11	------do-------	OT	AS	QZ+FS+BI±WM±EP±CL±GA±SH	AMP	------do-------	
69	12	------do-------	OT	AS	QZ+BI+WM+FS±CL±GA	AMP	------do-------	
69	13	------do-------	PE	AS	QZ+WM+FS	GNS	GNS (eJlTR)	
69	14	------do-------	OT	AS	CL+QZ±EP	GNS	------do-------	
69	15	------do-------	OT	AS	QZ+CL+WM±CB	GNS	------do-------	
69	16	------do-------	PE	AS	QZ+FS+PL+BI±WM±SI	AMP	AMP (eK)	
69	17	------do-------	OT	AS	QZ+PL+BI+KF±WM	AMP	------do-------	
69	18	------do-------	BA	AS	WM+CL±AC±EP±FS±BI	GNS	GNS (eKD) + GNS (eK)	
69	19	------do-------	OT	AS	QZ+BI+FS+WM±GA	AMP	AMP (eK)	
69	20	------do-------	OT	AS	QZ+PL+KF+BI+WM±GA	AMP	------do-------	
69	21	------do-------	OT	AS	QZ+BI+FS±WM±GA	AMP	------do-------	
69	22	------do-------	OT	AS	QZ+FS+BI+PL+EP±GA±WM±CL±CA	AMP	------do-------	
69	23	------do-------	OT	AS	QZ+KF+PL+BI±WM±EP±CL±SH	AMP	------do-------	
69	24	------do-------	OT	AS	QZ+WM+FS	GNS	GNS (eKD) + GNS (eK)	
69	25	------do-------	PE	AS	QZ+WM+CL±CB	GNS	------do-------	
Talkeetna								
75	1	S.W. Nelson	OT	AS	MU+QZ	GNS	GNS (KM)	
75	1	------do-------	BA	AS	CL+EP	GNS	------do-------	
75	2	------do-------	OT	OC	PH+CL+WM	LPP	LPP (eTlK)	
Talkeetna Mtns.								
76	1	Béla Csejtey, Jr.	OT	AS	QZ+WM+CL	LPP / GNS	------do-------	75ANw81
76	2	------do-------	OT	AS	WM+QZ	LPP / GNS	------do-------	75ANw123
76	3	T.E. Smith	BA	AS	DI+CP+QZ+GA+BI	AMP	AMI (eTlK)	TT572
76	4	------do-------	BA	AS	CL+AB+PH+EP	LPP	LPP,GNS (IKJ)	72ASt1699
76	5	------do-------	BA	AS	CL+EP+AB+CA	GNS	------do-------	72ASt1785
76	6	------do-------	BA	AS	CP+MU+BI+ZO+HO	AMP	AMP,GNS (meJ)	72ASt298
76	7	------do-------	BA	AS	CL+EP+BI+MU+GA	GNS	------do-------	72ASt176
76	8	------do-------	BA	AS	BI+HO+CP	AMP	------do-------	72ASt215
76	9	Béla Csejtey, Jr.	BA	AS	AM+CP	AMP	------do-------	74ACy4
76	10	------do-------	OT	AS	AC+CL+QZ+AB+CA+WM	GNS	LPP,GNS (IKJ)	72ACy3
76	11	T.E. Smith	BA	AS	PH+AB+CL	LPP	------do-------	72ASt301
76	12	Béla Csejtey, Jr.	BA	AS	CL+AB+QZ+PU	LPP	------do-------	77ACy31
76	13	------do-------	PE	AS	CL+CA+WM+QZ	LPP / GNS	------do-------	74ACy12
76	14	------do-------	PE	AS	CL+EP±AC±AB±QZ±CA±WM	GNS	------do-------	
76	15	------do-------	BA	AS	AC+EP+AB	GNS	------do-------	75ACy76
76	16	------do-------	OT	AS	WM+QZ+CL	GNS (?)	LPP (eTlK)	75ACy55
76	17	------do-------	BA	AS	CL+AB±EP±AC	GNS	LPP,GNS (IKJ)	
76	17	------do-------	BA	AS	AB+AC+CL+EP	GNS	------do-------	
76	18	------do-------	BA	AS	AM+CP+GA	AMP	AMP,GNS (meJ)	74ACy90
Gulkana								
77	1	T.E. Smith	BA	AS	EP+QZ+BI+CL+AB+CA+CZ	GNS	LPP,GNS (IKJ)	72ASt342
77	2	W.J. Nokleberg	BA	AS	AC+CL+EP+AB	GNS	GNS,AMP (IJ)	83NK232A
77	3	T.E. Smith	BA	AS	EP+CL+CA+QZ+AB+MU+CZ	GNS	------do-------	72ASt345
77	4	W.J. Nokleberg	BA	AS	CL+MU+EP+AB	GNS	------do-------	83NK221B
77	5	------do-------	BA	AS	HO+CP+BI+QZ	AMP	------do-------	83NK216A
77	6	------do-------	OT	AS	EP+CP+MU+QZ	GNS	------do-------	83SB103A
77	7	------do-------	BA	AS	CL+EP+AC+AB(?)	GNS	------do-------	83BR045A
77	8	------do-------	BA	AS	CL+EP+AB+QZ	GNS	------do-------	83NK100C
77	9	------do-------	BA	AS	AC+CL+EP+AB	GNS	------do-------	83NK103A
77	10	------do-------	BA	AS	HO+EP+CP	AMP	------do-------	83NK206A
77	11	------do-------	BA	AS	AC+CZ+AB+CL	GNS	------do-------	83NK215A
77	12	------do-------	BA	AS	HO+EP+MU	AMP	------do-------	83SB051A
77	13	T.E. Smith	BA	AS	EP+CL+AB+AC	GNS	------do-------	TT182
77	14	------do-------	BA	AS	AC+EP+AB+QZ	GNS	------do-------	TT156.5

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
77	15	W.J. Nokleberg	OT	AS	EP+MU+BI	AMP(?)	GNS,AMP (lJ)	83NK183A
77	16	------do------	BA	AS	HO+EP+QZ	AMP	------do------	83SB078A
77	17	------do------	BA	AS	HO+CP+BI+QZ	AMP	------do------	83NK188A
77	18	------do------	OT	AS	BI+MU+CP+QZ	AMP(?)	------do------	83NK186A
77	19	------do------	BA	AS	HO+CP+EP	AMP	------do------	83NK185C
77	20	------do------	BA	AS	CL+EP+AB+AC	GNS	------do------	83SB92A
77	21	------do------	BA	AS	CL+AB+EP	GNS(?)	LPP,GNS (IKJ)	83NK150A
77	22	------do------	BA	AS	SE+CL+AB	GNS	------do------	83NK071A
77	23	------do------	BA	AS	WM+CL+AB+QZ	GNS	------do------	83NK106A
77	24	------do------	OT	AS	WM+CL+AB+QZ	GNS	------do------	
Nabesna								
78	1	D.H. Richter	PE	AS	QZ±MU±BI±CL±AB±AC±CA	GNS	GNS (IKD)	
78	2	------do------	PE	AS	QZ+MU±BI±CL±AB±AC±CA	GNS	GNS (eKD) + GNS (eK)	
78	3	------do------	BA	AS	CL+QZ+EP+CA±PU±PH	LPP	LPP,GNS (IKJ)	
78	4	------do------	BA	OC	AC±AB±CL±EP±QZ	GNS	GNS (IKD)	
78	5	------do------	OT	AS	BI+CP+GA+QZ±CL±MU	AMP	AMP (IT Pz)	
Anchorage								
85	1	Béla Csejtey, Jr.	BA	AS	AM+GA+CP	AMP	AMP,GNS (meJ)	76ACy14
85	2	------do------	PE	AS	MU+QZ+AB+CL+CA+CB+GA	GNS	AMP (meJ) + GNS (eTmK)	73ACy71
85	3	S.H. Clark	OT	AS	AM+PL±BI±QZ	GNS/AMP	GNS,AMP (eKJ)	
85	4	------do------	PE	AS	QZ+CL+WM	LPP/GNS	LPP (eTJ)	
85	5	T.L. Pavlis	BA	AS	PU+CL+WM+QZ	LPP	------do------	
85	5	------do------	OT	AS	PH+QZ+CL	LPP	------do------	
85	6	------do------	BA	AS	CP+BI+HO+GA+QZ	AMP	GNS,AMP (eKJ)	
85	6	------do------	CA	AS	ZO+CP+CA+QZ+GA	AMP	------do------	
85	6	------do------	CA	AS	WO+CA+QZ+DI+GA	AMP	------do------	
85	6	------do------	PE	AS	BI+MU+GA+CP+QZ	AMP	------do------	
85	7	------do------	OT	AS	WM+PU+QZ	LPP/GNS	GNL (eTlK)	
85	8	M.L. Miller	OT	OC	CM	LPP(?)	------do------	81AMH66A
85	9	S.H. Clark	PE	AS	WM+CL+QZ+PL	GNS	------do------	
85	10	------do------	BA	AS	AC+EP+QZ+CL	GNS	GNS,AMP (eKJ)	
85	11	------do------	PE	AS	QZ+CL+WM+PU	GNS(?)	GNL (eTlK)	
85	12	------do------	PE	AS	AB+QZ+CA+CL+EP±PH	LPP	LPP (eTJ)	
85	13	------do------	PE	AS	PH+PU+LU	LPP	------do------	
85	14	------do------	PE	AS	LU+PU+WM	LPP	------do------	
85	15	------do------	BA	AS	AB+EP+QZ±PU	LPP	------do------	
85	16	M.L. Miller	OT	OC	CM	LPP(?)	GNL (eTlK)	82ANS95A
85	17	------do------	OT	AS	EP+CL+CM+SH(?)	LPP/GNS	------do------	81ANS57A
85	18	------do------	OT	AS	CL+CM+EP	LPP/GNS	------do------	81ANS58B
85	19	------do------	OT	AS	CL+EP+CM	LPP/GNS	------do------	82ANS96A
85	20	------do------	OT	AS	CM+CL	LPP(?)	LPP (eT)	82ANS80A
85	21	------do------	OT	OC	CM	LPP(?)	------do------	81ADU76B
85	22	------do------	OT	AS	WM+CL+EP	LPP/GNS	GNL (eTlK)	82ANS88B
85	23	------do------	OT	AS	PH+EP+CM	LPP/GNS	------do------	81AMH81A
Valdez								
86	1	G.R. Winkler	BA	AS	PU+CA+QZ+PH+CL	LPP	LPP (eTJ)	
86	2	------do------	BA	AS	EP+AB+CA+HO+CL+BI+SH	GNI	GNI/H (meJ)	
86	3	------do------	PE	AS	LW+EP+CS+MU+QZ+AB+CA+CL+SH	GNH	------do------	
86	4	------do------	PE	AS	LW+CS+MU+EP+QZ+AB+CA+CL+SH	GNH	------do------	
86	5	------do------	BA	AS	AM+GA+AB+MU+EP+SH+CL	GNH	------do------	
86	6	------do------	BA	AS	CL+CA+PU+QZ	LPP	LPP (eTJ)	
86	6	------do------	OT	AS	QZ+CA+SP	LPP/GNS	------do------	
86	7	------do------	BA	AS	QZ+CL+CA+PU	LPP	GNL (eTlK)	
86	8	------do------	BA	AS	CL+CA+SP	LPP/GNS	LPP (eTJ)	
86	9	------do------	BA	AS	(2) AB+AC±SP±CL	GNS	GNS,AMP (lJ) + GNS (eTlK)	
86	10	------do------	BA	AS	EP+CL+MU+AB±SP±CA±PU	LPP/GNS	LPP (eTJ)	
86	11	------do------	BA	AS	EP+CL+MU+AB±AC±SP	GNS	GNI/H (meJ)	
86	12	------do------	OT	AS	LW+QZ+CA±CS	GNH	------do------	
86	13	------do------	BA	AS	EP+CL+MU+AB±AC±CA±PU	GNS	LPP (eTJ)	
86	14	------do------	BA	AS	(1) EP+HO+PL±MU±BI±GA	AMP	GNS,AMP (lJ) + LPP (eTlK)	
86	15	M.L. Miller	OT	AS	BI+MU+QZ+CA	GNS	GNL (eTlK)	82AMH126A
86	16	------do------	PE	AS	BI+CL+WM+QZ	GNS	------do------	82ANS142A
86	17	G.R. Winkler	BA	AS	AC+EP+AB	GNS	------do------	
86	18	------do------	PE	AS	MU+EP+AC+AB	GNS	------do------	
86	19	M.L. Miller	OT	AS	CM+CL+EP	LPP(?)	------do------	82ANS57B
86	20	------do------	OT	AS	CL+WM+EP	LPP(?)	LPP (eT)	82AMH65A
86	21	------do------	OT	AS	PH+CL+WM	LPP	------do------	82AMH64A
86	22	------do------	OT	AS	WM+EP+CL	LPP(?)	------do------	82ADU118A
86	23	------do------	OT	AS	BI+CL+WM	GNS	------do------	82ANS60B
McCarthy								
87	1	E.M. MacKevett	OT	AS	PL+QZ+EP+MU+CL	GNS	LPP,GNS (IKJ)	

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
87	2	E.M. MacKevett	OT	AS	AB±PU±PH±BI±CL±CA	LPP	LPP,GNS (IKJ)	
87	3	------do-------	OT	AS	AB+PU±CA±CL±SH	LPP	------do-------	
87	4	------do-------	BA	AS	HO+PL+EP±CL±WM±SH	AMP	GNS,AMP (IJ) + LPP (eTIK)	72AMK26C
87	5	------do-------	BA	AS	QZ+CL+MU+PL	GNS	------do-------	72AMK27A
87	6	------do-------	BA	AS	HO+PL+CL	AMP	------do-------	74AMK21
87	7	------do-------	BA	AS	QZ+BI+CP+KF+GA(?)	AMP	------do-------	74AMK30B
87	8	------do-------	CA	AS	CA+TR+WM+QZ	GNS	------do-------	74AMK29A
87	9	------do-------	BA	AS	PL+HO+EP+BI+QZ+CL+SH	AMP	------do-------	74AMK24A
Seward								
95	1	S.H. Clark	PE	AS	QZ+PL+WM+CL±EP	GNS	GNL (eTIK)	
95	2	M.L. Miller	OT	AS	CM+EP	LPP / GNS	------do-------	75ACe226
95	3	S.H. Clark	PE	AS	QZ+WM+CL+PL±EP	GNS	------do-------	
95	4	M.L. Miller	OT	AS	CL+WM+EP	LPP / GNS	------do-------	81ADU51C
95	5	------do-------	OT	AS	WM+CL	LPP / GNS	------do-------	81ANS51A
95	6	------do-------	PE	AS	BI+CL	GNS	------do-------	82ASK258A
95	7	------do-------	OT	OC	CM	LPP (?)	LPP (eT)	81ADU65D
95	8	------do-------	OT	OC	CM	LPP (?)	------do-------	82ANS65A
95	9	------do-------	OT	OC	CM+EP	LPP	------do-------	80AMH142A
95	10	------do-------	BA	AS	CL+EP	LPP / GNS	------do-------	80AMH148A
95	11	------do-------	OT	AS	CM+EP+PH	LPP	------do-------	81AMH64A
95	12	------do-------	OT	AS	WM+CL	LPP	------do-------	81ANS65A
95	13	------do-------	BA	AS	CL+ZE(?)	LPP	------do-------	81ANS64B
95	14	------do-------	OT	OC	CM	LPP (?)	GNL (eTIK)	75ACe68
95	15	S.H. Clark	PE	AS	QZ+PL+WM+CL±EP	GNS	------do-------	
95	16	M.L. Miller	OT	AS	WM+CL	LPP	------do-------	75ACe123
95	17	------do-------	PE	AS	BI+WM	GNS	------do-------	75ACe210
95	18	------do-------	BA	AS	CL+EP+WM+AC	GNS	------do-------	75ACe186
95	19	------do-------	OT	OC	CL	LPP (?)	------do-------	75ACe168
95	20	------do-------	OT	AS	CL+CM	LPP (?)	------do-------	75ACe169
95	21	------do-------	BA	AS	AC+CL+EP+AB	GNS	------do-------	75ACe190A
95	22	------do-------	PE	AS	BI+MU+CL+EP	GNS	------do-------	75ACe38
95	23	------do-------	PE	AS	BI+CL+WM	GNS	------do-------	76ACe53
95	24	------do-------	OT	AS	CL+EP	LPP	------do-------	76ACe51
95	25	S.W. Nelson	BA	OC	AC+EP+CL	GNS	------do-------	
95	25	------do-------	OT	OC	BI+QZ	GNS	------do-------	
95	26	M.L. Miller	BA	AS	AC+CL+EP+AB	GNS	------do-------	75ACe218
95	27	------do-------	OT	AS	CM+CL	LPP (?)	------do-------	75ACe217
95	28	------do-------	OT	OC	WM	LPP	------do-------	75ACe378
95	29	------do-------	OT	AS	CL+CM	LPP (?)	------do-------	75ACe422
95	30	------do-------	OT	OC	CM	LPP (?)	------do-------	75ACe410
95	31	------do-------	PE	AS	BI+WM+EP+CL	GNS	------do-------	75ACe246
95	32	------do-------	PE	AS	WM+EP	LPP	------do-------	75ACe259A
95	33	------do-------	OT	AS	CL+WM+EP	LPP	------do-------	75ACe250
95	34	------do-------	OT	AS	CL+CM	LPP	------do-------	80ANS74A
95	35	------do-------	OT	AS	CM+EP+PH	LPP	LPP (eT)	80ANS80A
95	36	------do-------	OT	AS	PH+EP+CM	LPP	------do-------	80ANS67A
95	37	------do-------	BA	AS	EP+CA+CL	LPP / GNS	------do-------	80AMH28A
95	38	------do-------	BA	AS	ZE+PU+CL	LPP	------do-------	80AWK51
95	39	------do-------	OT	AS	CM+CL+EP	LPP	------do-------	82AMH77A
95	40	------do-------	BA	AS	AC+CL+BI	GNS	------do-------	80AMH38A
95	41	------do-------	OT	AS	WM+EP+CL	LPP	------do-------	82ADU126B
95	42	------do-------	OT	AS	CL+CM	LPP (?)	------do-------	82AMH20A
95	43	------do-------	OT	OC	CM	LPP (?)	------do-------	81AMH39A
95	44	------do-------	OT	AS	EP+CL+CM	LPP	------do-------	80ANS93A
95	45	------do-------	OT	AS	CL+WM+EP	LPP	------do-------	80AMH6A
95	46	------do-------	OT	AS	CL+CA	LPP	------do-------	80AMH35A
95	47	------do-------	OT	AS	WM+CL+EP+CA	LPP	------do-------	81AMH25A
95	48	------do-------	OT	AS	CM+PH	LPP	------do-------	80ANS43B
95	49	------do-------	OT	AS	CL+EP+WM	LPP	------do-------	81ANS33A
95	50	------do-------	BA	AS	AC+CL	GNS	GNL (eTIK)	81ANS24A
95	51	------do-------	BA	OC	CL	LPP / GNS	------do-------	81ANS21A
95	52	------do-------	OT	AS	WM+CL+BI	GNS	------do-------	76ACe41b
95	53	------do-------	OT	AS	CL+WM+EP	LPP	------do-------	75ACe322
95	54	------do-------	OT	AS	PH+CL+CM	LPP	------do-------	75ACe450
95	55	------do-------	PE	OC	BI+WM	GNS	------do-------	75ACe321
95	56	------do-------	OT	AS	WM+EP+PH+CA	LPP	------do-------	75ACe398
Cordova								
96	1	------do-------	OT	AS	PH+WM+EP+CL	LPP	------do-------	82ANS43A
96	2	------do-------	OT	OC	BI+WM	GNS	------do-------	82ADU97A
96	3	------do-------	PE	OC	WM	LPP	------do-------	81AMH93A
96	4	------do-------	PE	AS	MU+EP+CL+QZ	GNS	------do-------	82ANS160A
96	5	------do-------	OT	AS	BI+CL+WM	GNS	------do-------	82ANS36A
96	6	------do-------	OT	AS	BI+QZ+FS±MU±GA	GNS / AMP	------do-------	80ANS141A
96	7	------do-------	BA	AS	AC+CL+EP	GNS	------do-------	82ADU83C
96	8	------do-------	OT	AS	BI+MU+CL+EP	GNS	------do-------	82AMH132A
96	9	George Plafker	BA	AS	EP+CL+AC+QZ+AB+CA	GNS	------do-------	71APr13C
96	10	M.L. Miller	PE	AS	BI+WM+CL+QZ+FS	GNS	------do-------	82AMH115B
96	11	------do-------	PE	AS	BI+CL+WM	AMP/GNS	LPP (eT) + AML (eT)	80AMH172A

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
96	12	George Plafker	OT	AS	BI+CZ+EP+CL±CA	GNS	LPP (eT) + AML (eT)	71APr24A
96	13	M.L. Miller	OT	AS	PH+CA	LPP	LPP (eT)	82AMH120A
96	14	------do------	OT	OC	WM	LPP	------do------	82ANS163A
96	15	------do------	OT	AS	CL+CM+PH	LPP	------do------	82AMH4A
96	16	------do------	OT	AS	PH+CL+EP+CM	LPP	------do------	80AMH183A
96	17	------do------	BA	AS	PU+PH+CL	LPP	------do------	81ADU84A
96	18	------do------	OT	AS	PH+WM+EP+CL	LPP	------do------	80AMH187B
96	19	------do------	BA	AS	AC+CL+EP+SH	LPP / GNS	------do------	80AMH115A
96	20	------do------	OT	AS	EP+CL+CM+PH(?)	LPP	------do------	82ADU91A
96	21	------do------	BA	AS	CL+PH+SH	LPP	------do------	71AWK60A
96	22	------do------	OT	AS	EP+CL+CM	LPP	------do------	71AWK21C
96	23	------do------	OT	AS	CM+EP+CL	LPP	------do------	72AWK50A
96	24	------do------	OT	AS	CM+CL	LPP	------do------	72AWK109A
96	25	G.R. Winkler	OT	AS	CL+PH+LU+PU	LPP	------do------	71AWK184A
96	26	M.L. Miller	BA	AS	CL+PU+CA	LPP	------do------	71AWK104B
96	27	G.R. Winkler	OT	AS	CL+LU+PH±PU	LPP	------do------	71AWK48A
								71AWK111A
96	28	M.L. Miller	BA	AS	PH+PU+EP+CL+SH(?)	LPP	------do------	71AWK63A
96	29	------do------	OT	AS	CL+WM+EP	LPP	------do------	72AWK6A
96	30	------do------	BA	AS	PH+EP+CA+CL	LPP	------do------	71AWK107A
96	31	------do------	OT	AS	EP+CM+PH+CL	LPP	------do------	71AWK137A
96	32	------do------	OT	AS	CL+CM	LPP	------do------	81ANS103A
96	33	------do------	BA	AS	PU+PH+CL+EP	LPP	------do------	81AMH110A
96	34	------do------	OT	AS	PH+CL+PU	LPP	------do------	81ANS111E
96	35	------do------	OT	AS	CM+CL+EP	LPP	------do------	81AMH106A
96	36	George Plafker	BA	AS	PU+WM+CL+QZ+PH	LPP	------do------	72APr35A2
Bering Glacier								
97	1	------do------	OT	AS	QZ+BI+PL+GA+SH	AMP(?)	GNL (eTIK)	74AH179
97	2	------do------	OT	AS	QZ+BI+CL+SH+MU+EP+GA	AMP(?)	GNL (eTIK) + AML (eT)	73APr317A
97	3	------do------	BA	AS	HO+WM/TA+PL+SH+EP/CZ+CL	AMP	GNS,AMP (lJ) + LPP (eTIK)	73APr372A
97	4	------do------	BA	AS	HO+PL+WM+EP+SH+CL+BI	AMP	------do------	73APr373A
97	5	------do------	BA	AS	PL+EP+WM+CL+SH	GNS	GNS (eKIPz)	73APr395A
97	5	------do------	BA	AS	ZE+EP+CB+CL+QZ+PL	GNS/LPP	------do------	73APr395B
97	6	------do------	BA	AS	PL+AC+EP/CZ+CL+QZ	GNS	------do------	73APr394C
97	7	------do------	BA	AS	PL+HO+QZ+CL+EP	AMP	GNL (eTIK) + AML (eT)	73APr326A
97	8	------do------	OT	AS	QZ+PL+BI+GA+SI+CL(?)	AMP	------do------	74AH156B
97	9	------do------	PE	AS	QZ+FS+BI+CL+EP+MU	AMP	------do------	73APr327A
97	10	------do------	PE	AS	BI+FS+QZ+MU+CL+GA+EP	AMP	------do------	74AT378
97	11	------do------	PE	AS	QZ+PL+MU+BI+SI+SH+AN	AML	------do------	74AT379
97	12	------do------	PE	AS	QZ+FS+BI+MU+GA+SH+CL	AMP	------do------	74AH158A
97	13	------do------	PE	AS	PL+QZ+BI+CB+WM+CL+EP	GNS	GNS,AMP (lJ) + LPP (eTIK)	73APr323A
97	14	------do------	PE	AS	QZ+BI+GA+AN+ST+MU	AML	GNL (eTIK) + AML (eT)	73AH274A
97	14	L.S. Hollister	PE	OC	AN+CO+GA+ST	AML	------do------	
97	15	George Plafker	BA	AS	AC+CL+QZ+AB+SH+HE	GNS	GNS (eTIK)	73APr322A
97	16	------do------	PE	AS	QZ+PL+KF+MU+BI+GA	AMP	GNL (eTIK) + AML (eT)	73AT3241A
97	17	------do------	PE	AS	BI+QZ+PL	AMP	------do------	
97	18	------do------	OT	AS	QZ+PL+BI+CL+EP	AMP	------do------	73AH239A
97	19	------do------	PE	AS	PL+QZ+BI+MU+CL+GA(?)	AMP	------do------	73APr296A
97	20	------do------	BA	AS	QZ+HO+PL+BI+KF	AMP	------do------	73APr297
97	21	------do------	PE	AS	QZ+BI+MU+GA+ST+SI+CL(?)	AMP	------do------	73AH236A2
97	22	------do------	PE	AS	PL+QZ+BI+CL+MU+SI+GA	AMP	------do------	73APr298
97	23	------do------	PE	AS	BI+QZ+MU+ST+GA+SI+CL+WM	AMP	------do------	73AH237A
97	24	------do------	PE	AS	QZ+CP+BI+MU	AMP	------do------	74APr152
97	25	------do------	PE	AS	QZ+PL+BI+CD+GA+SH+ZO	GNS	------do------	74APr153
97	26	------do------	PE	AS	QZ+MU+CZ/ZO+SH+CL(?)	GNS	GNL (eTIK)	73APr348A
97	27	------do------	PE	AS	PL+QZ+MU+EP+BI	GNS	------do------	71APr27B
97	28	------do------	BA	AS	EP+PH+PU+WM+SH	LPP	LPP (eT)	71APr20D
97	29	------do------	PE	AS	QZ+PL+EP+CL+WM	LPP	------do------	73APr281
97	30	------do------	BA	AS	PU+PH+SH+QZ	LPP	------do------	
97	31	------do------	BA	AS	PL+CL+QZ	LPP	------do------	73APr305
97	32	------do------	BA	AS	AB+CL+PU+WM+QZ	LPP	------do------	73APr328C
97	33	------do------	OT	AS	QZ+AB+BI+GA+CL	GNS	GNL (eTIK) + AML (eT)	
97	33	------do------	BA	AS	HO+PL	AMP	------do------	
Mt. St. Elias								
98	1	------do------	BA	AS	WM+PH+PU(?)+CL	LPP	LPP $(eTIK)_3$	69APr52D3
98	2	------do------	PE	AS	ST+MU+BI+GA+QZ+PL+KY	AMI	AMP (ITK)	69APr47C1
98	3	------do------	PE	AS	CA+WM+CM+CL	LPP	LPP $(eTIK)_3$	69APr35B2
98	4	------do------	CA	AS	CA+EP+ZO+TR(?)	GNS	GNS,AMP (lJ) + LPP (eTIK)	69APr43B1
98	4	------do------	BA	AS	AC+AB+BI	GNS	------do------	69APr43B2
98	4	------do------	PE	AS	QZ+AB+BI+CD+WM	GNS	------do------	69APr43B3
98	5	------do------	BA	AS	CL+AC+QZ+WM+ZO	GNS	GNL (eTIK)	69APr33B

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
98	6	George Plafker	BA	AS	CL+AC+AB+TR+SH	GNS	GNL (eTlK)	69APr44B
98	7	------do-------	BA	AS	AC+CL+AB+EP+QZ	GNS	GNS,AMP (lJ) + LPP (eTlK)	69APr37D
98	8	------do-------	BA	AS	AC+CL+EP+ZO+QZ	GNS	------do-------	69APr37C
98	9	------do-------	BA	AS	EP+CL±WM±CA±QZ±AC	GNS	------do-------	67APr75B
98	10	------do-------	PE	AS	WM+BI+CL+EP	GNS	GNL (eTlK) + AML (eT)	67APr74C
98	11	------do-------	OT	AS	BI+QZ+AB+CD+ZO	GNS	GNS,AMP (lJ) + LPP (eTlK)	67APr63A1
98	12	------do-------	BA	AS	AC+QZ+AB+BI	GNS	------do-------	67APr82B
98	13	------do-------	PE	AS	QZ+PL+GA+MU+CL	GNS	GNL (eTlK)	67APr63B2
98	14	------do-------	PE	AS	WM+CL+CA	GNS	------do-------	67APr81D
98	15	------do-------	PE	AS	WM+CL	GNS	------do-------	67APr74A
98	16	------do-------	OT	AS	WM+CA+CL+EP+SH	GNS	GNL $(eTlK)_1$	69APr41D1
98	17	------do-------	CA	AS	CA+CD+ZO	GNS	------do-------	67APr77A1
98	17	------do-------	BA	AS	CL+EP+WM+CA	GNS	------do-------	67APr77A2
Seldovia								
104	1	R.B. Forbes	BA	AS	AC+EP+WM+AB+CA+QZ	GNS	GNI/H (meJ)	
104	1	------do-------	BA	AS	GL+EP+AB+QZ	GNH	------do-------	
104	1	------do-------	CA	AS	WM+CL+CA+AB+QZ	GNS	------do-------	
Blying Sound								
105	1	M.L. Miller	BA	AS	AC+AB	GNS	GNL (eTlK)	81AMH4A
105	2	------do-------	BA	AS	AC+CL+AB	GNS	------do-------	81AMH15A
105	3	------do-------	OT	AS	CM+CL+EP	LPP (?)	LPP (eT)	81ADU14A
105	4	------do-------	OT	AS	EP+CL+WM+CA	LPP	------do-------	75ACe382
105	5	------do-------	OT	AS	WM+EP+CL	LPP	------do-------	75ACe383
105	6	------do-------	OT	AS	CM+EP	LPP	------do-------	80ADU19A
105	7	------do-------	OT	AS	CL+WM	LPP	------do-------	80AWK5
105	8	------do-------	OT	OC	CM	LPP	------do-------	80AWK21A
105	9	------do-------	OT	AS	CM+CL	LPP	------do-------	80AMH64A
105	10	------do-------	OT	AS	CL+LU	LPP	------do-------	81AMH31A
105	11	------do-------	OT	AS	CL+CM	LPP	------do-------	80ADU2A
105	12	------do-------	OT	AS	ZE+CL	LPP	------do-------	81ANS43A
Middleton Island								
106	1	------do-------	BA	AS	PH+CL	LPP	------do-------	82ANS126E
Yakutat								
108	1	George Plafker	OT	AS	WM+PH+CL+EP	LPP	LPP $(eTlK)_3$	68APs27D
108	2	------do-------	PE	AS	CM+WM+CL+EP	LPP	GNL $(eTlK)_1$	68APr57A3
108	3	------do-------	PE	AS	QZ+PL+BI+GA±ST±MU	AMP/GNS	AMP (lTK)	67APr58B
108	4	------do-------	OT	AS	BI+QZ+PL+GA±CZ±HO	AMP/GNS	GNS,AMP (lJ) + LPP (eTlK)	67APr58A
108	5	------do-------	BA	AS	AC+EP+AB+BI+SH	GNS	------do-------	69APr29E
108	6	------do-------	OT	AS	CL+EP±WM±SH	GNS	------do-------	67APr59A
108	7	------do-------	BA	AS	AC+PL+QZ+EP+CL+MU	GNS	------do-------	67APr58C
108	8	------do-------	OT	AS	BI+PL+GA+MU+CL	GNS	GNS (eKlPz)	67APr69B3
108	9	------do-------	PE	AS	QZ+PL+BI+MU±CZ	GNS	------do-------	67APr45B
108	10	------do-------	PE	AS	QZ+BI+PL+GA±MU±ZO	AMP	AMP (lTK)	67APr44C1
108	11	------do-------	OT	AS	HO+PL+QZ+EP+CL+WM+CZ	AMP	------do-------	68APr70C
108	12	------do-------	BA	AS	HO+PL+EP+SH	AMP	------do-------	67APr44B
108	13	------do-------	OT	AS	QZ+PL+BI+HO+CZ+CL+WM	AMP	------do-------	67APr62C2
108	14	------do-------	BA	AS	HO+PL+GA+CL	AMP	AML (eTlK)	63APr219
108	15	------do-------	PE	AS	ST+BI+QZ+PL+MU	AMP	------do-------	67APr89C
108	16	------do-------	PE	AS	ST+QZ+PL+BI+MU	AMP	------do-------	63APr233
108	17	------do-------	OT	AS	PL+QZ+KF+BI+GA±ZO±SH	AMP	------do-------	67APr87D
108	18	------do-------	BA	AS	HO+QZ+PL+CL±CA±SH	AMP	------do-------	69APr25D
108	19	------do-------	PE	AS	WM+CM+SH+PH+PU(?)	LPP	LPP $(eTlK)_3$	68APr30A
108	20	------do-------	BA	AS	CL+CM+WM+PU(?)	LPP	------do-------	68APs72C
108	21	------do-------	BA	AS	CL+CM+CA+PU(?)	LPP	------do-------	68APs47A
108	22	------do-------	PE	AS	QZ+PL+BI+MU+EP+ZO	GNS/AMP	AML (eTlK)	67APr66D
108	23	------do-------	OT	AS	BI+GA+QZ+PL	GNS/AMP	------do-------	67APr90C
108	24	------do-------	BA	AS	HO+EP+PL	AMP	AMP (lTK)	67APr46C
108	25	------do-------	PE	AS	BI+QZ+PL+MU+TO(?)	GNS/AMP	GNS,AMP (lJ) + LPP (eTlK)	68APr105C
108	26	------do-------	OT	AS	QZ+BI+AC+CA	GNS	------do-------	78APr95
108	27	------do-------	OT	AS	QZ+PL+AM+BI+CA+SH	GNS	------do-------	68APr103C
108	28	------do-------	OT	AS	CL+EP+SH	GNS	------do-------	68APr82A
108	29	------do-------	BA	AS	AC+PL+EP+CZ+SH+QZ	GNS	------do-------	78APr11C
108	30	------do-------	BA	AS	AC+AB+QZ+CZ+CL±SH	GNS	------do-------	78APr49
108	31	------do-------	BA	AS	AC+CL+CZ	GNS	------do-------	68APr82C
108	32	------do-------	BA	AS	AC+PL+BI+EP±CZ	GNS	------do-------	78APr48A
108	33	------do-------	BA	AS	HO+QZ+PL+BI	AMP	AMP (lTK)	68APr81B
108	34	------do-------	OT	AS	QZ+PL+BI+ZO+SH	GNS/AMP	------do-------	68APr85A
108	35	------do-------	OT	AS	QZ+PL+BI+HO+CZ+SH	AMP	------do-------	68APr84A
108	36	------do-------	PE	AS	MU+BI+QZ+GA+CL	AMP	------do-------	68APr88E
108	37	------do-------	PE	AS	QZ+BI+GA+PL+MU	AMP	------do-------	68APr88D
108	38	------do-------	PE	AS	QZ+PL+BI+GA+MU	AMP	------do-------	68APr91A
108	39	------do-------	BA	AS	HO+EP+PL+SH+CA+MU	AMP	------do-------	68APr91E

TABLE 2.—*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate2)[1]	Contributors	Rock type[2]	Assemblage (AS) or occurrence (OC)	Metamorphic mineral assemblage[3]	Metamorphic facies indicated by given assemblage[4]	Metamorphic-facies unit in which assemblage occurs[4,5]	Sample No., if available
108	40	George Plafker	BA	AS	HO+PL+SH	AMP	AMP (ITK)	78APr12A
108	41	------do-------	BA	AS	HO+QZ+PL+BI+CU±CZ	AMP	------do-------	67APr44D2
108	42	------do-------	BA	AS	HO+PL+QZ+EP+SH+CZ	AMP	------do-------	63APr103A
108	43	------do-------	PE	AS	QZ+PL+GA+BI+MU	AMP	------do-------	67APr46E
108	44	------do-------	BA	AS	HO+PL+SH	AMP	AML (eTIK)	68APr106B
108	45	------do-------	BA	AS	HO+PL+QZ+SH+EP	AMP	------do-------	67APr92A
108	46	------do-------	BA	AS	HO+PL+QZ±SH	AMP	------do-------	67APr93C
108	47	------do-------	BA	AS	CL+CA+WM+SH+PU(?)	LPP	LPP $(eTIK)_3$	68APr98C1
108	48	------do-------	OT	AS	CL+CM+WM	LPP	------do-------	68APs81E
108	49	------do-------	OT	AS	QZ+BI+GA+PL	AMP	------do-------	68APr96C
108	50	------do-------	BA	AS	HO+PL+BI+QZ	AMP	AML (eTIK)	68APs65B
108	51	------do-------	BA	AS	HO+PL+QZ	AMP	------do-------	68APs58D
108	52	------do-------	OT	AS	QZ+PL+KF+BI+GA	AMP	------do-------	68APs57F
108	53	------do-------	BA	AS	AC+CL+AB+EP	GNS	GNS/AMP (eTK)	68APr89B
108	54	------do-------	BA	AS	AC/HO(?)+CL+EP+BI+AB	GNS/AMP	------do-------	68APr80B
108	55	------do-------	BA	AS	AC+EP+AB+SH	GNS	------do-------	68APr78D1
Afognak								
115	1	S.M. Roeske	BA	AS	CA+PH+PU+QZ+AB	LPP	LPP (eTIK)	
115	2	------do-------	OT	AS	CS+WM+EP+QZ	GNH	GNI/H (meJ)	
115	3	------do-------	BA	AS	CL+EP+CS+CA+AB	GNH	------do-------	
Karluk								
122	1	------do-------	OT	AS	CS+LW+CL+SH	GNH	------do-------	
Kodiak								
123	1	------do-------	BA	AS	CL+PU±EP±CA	LPP	LPP (eTJ)	
123	1	Cynthia Dusel-Bacon	OT	AS	QZ+AB+CL+PH+PU+SH±CA±WM	LPP	------do-------	
123	1	------do-------	BA	AS	AB+PU+CL+SH±CA±PH±QZ±EP	LPP	------do-------	

[1]Localities numbered consecutively within each 1:250,000-scale quadrangle
[2]Rock types: BA, basic; CA, calcic; OT, other; PE, pelitic
[3]Metamorphic minerals:

AB,	albite (An 0-10)	CS,	crossite	KY,	kyanite	SI,	sillimanite
AC,	actinolite	CU,	cummingtonite	LU,	laumontite	SP,	stilpnomelane
AM,	amphibole	CX,	clinopyroxene	LW,	lawsonite	ST,	staurolite
AN,	andalusite	CZ,	clinozoisite	MU,	muscovite	TA,	talc
BI,	biotite	DI,	diopside	PH,	prehnite	TO,	tourmaline
CA,	carbonate	DU,	dumortierite	PL	plagioclase (An 0-100)	TR,	tremolite
CB,	carbonaceous and(or) graphitic material	EP,	epidote			WM,	white mica
		FS,	feldspar	PP,	phlogopite	WO,	wollastonite
CD,	chloritoid	GA,	garnet	PU,	pumpellyite	ZE,	zeolite
CH,	clinohumite	GL,	glaucophane	PX,	pyroxene	ZO,	zoisite
CL,	chlorite	HE,	hematite	QZ,	quartz		
CM,	clay minerals	HO,	hornblende	SE,	serpentine		
CO,	cordierite	HY,	hypersthene	SH,	sphene		
CP,	calcic plagioclase (An 11-100)	ID,	idocrase				
		KF,	potash feldspar				

Minerals arranged in order of decreasing abundance. (1), (2), first and second phases of a polymetamorphic episode.
[4]Refer to text for explanation of symbols.
[5]In a few cases, the area of the metamorphic-facies unit in which the assemblage occurs is too small to show on the map.