Distribution, Facies, Ages, and Proposed Tectonic Associations of Regionally Metamorphosed Rocks in Southwestern Alaska and the Alaska Peninsula

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By Cynthia Dusel-Bacon, Elizabeth O. Doyle, *and* Stephen E. Box

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By Cynthia Dusel-Bacon, Elizabeth O. Doyle, and Stephen E. Box

Abstract

Less than half of the exposed bedrock in southwestern Alaska has been regionally metamorphosed, and much of it under low-grade metamorphic conditions. The oldest known metamorphic episode in Alaska is inferred to have taken place in the Early Proterozoic (1.7-1.8 Ga) in two narrow, northeast-trending, fault-bounded complexes of continentally derived amphibolite-facies orthogneiss and subordinate metasedimentary rocks. Protoliths consist primarily of an Early Proterozoic (2.0-2.1 Ga) tonalitic suite of subduction-related magmatic rocks and minor granitic rocks, some of which were derived in part from Archean (2.5-2.6 Ga) sources. The southernmost complex, the (informal) Kanektok metamorphic complex, crops out in the Kilbuck and Ahklun Mountains; the northernmost one, the Idono Complex, crops out 250 km to the northeast in the southeastern borderlands of the Yukon-Koyukuk basin. These two Early Proterozoic metamorphic complexes were probably once continuous and have been offset by right-lateral strike-slip faulting in the late Mesozoic or Cenozoic.

Proterozoic or early Paleozoic metamorphism may have taken place in other areas of the continental basement of interior Alaska. Southeast of the Susulatna fault, Late Proterozoic felsic metavolcanic rocks and pre-Ordovician metasedimentary and mafic metavolcanic rocks of the Nixon Fork terrane were metamorphosed under greenschist-facies conditions prior to Ordovician time.

The major period of metamorphism in southwestern Alaska, however, like that in the rest of Alaska, occurred during the Mesozoic. Metamorphism during this period presumably resulted from subduction between the components of an oceanic arc complex and subsequent collision of the arc complex with the continental margin of North America. Both the overriding oceanic plate and the overridden continental plate were affected.

The earliest phase of this compressional episode, documented in the Kilbuck and Ahklun Mountains area, took place during the late Triassic to Middle Jurassic. Products of this phase include a nappe complex of high-pressure, blueschist-facies glaucophane- and lawsonite-bearing schistose metabasalt, and a strongly foliated package of intermediate-pressure, greenschist-facies metavolcanic and metasedimentary rocks. These oceanic rocks make up the Cape Peirce subterrane of the Goodnews terrane and are exposed near the northwest edge of Bristol Bay. Metamorphism of the Cape Peirce subterrane is presumed to have occurred during collision and partial subduction of an oceanic plateau (Platinum subterrane of the Goodnews terrane) beneath an overriding intraoceanic, subduction-related volcanic arc (Togiak terrane). Lithologic similarities between the protoliths of the schistose blueschist- and greenschist-facies rocks of the Cape Peirce subterrane and with those of the relatively undeformed and low-grade overlying Togiak terrane and underlying Platinum subterrane, suggest that the rocks of the Cape Peirce subterrane are the more tectonized equivalents of the adjacent two terranes. The original contractional-fault contact between the upper-plate Togiak terrane and the underlying Cape Peirce terrane has been modified by extensional faulting, which has resulted in lower temperature and pressure rocks being juxtaposed over higher temperature and pressure rocks.

The second phase of the compressional episode in southwestern Alaska took place during Jurassic and Early Cretaceous time and is interpreted to have involved continued subduction of oceanic material beneath the oceanic arc and the eventual collision of the arc complex with the continental margin. Greenschist- and, locally, blueschist-facies metamorphism occured within the northwest margin of the Goodnews terrane (Nukluk subterrane), presumably within the southeast-dipping subduction zone (present-day coordinates) that dipped beneath the oceanic arc complex. Widespread resetting of the Early Proterozoic mineral-isotopic systems of the continental Kanektok and Idono metamorphic complexes during Jurassic and Early Cretaceous time may have resulted from retrograde metamorphism during partial underthrusting of the continental margin (Kilbuck terrane) beneath the accretionary forearc (Goodnews terrane) of the intraoceanic volcanic arc (Togiak terrane).

The same relation between upper plate oceanic rocks (Angayucham and Tozitna terranes) and lower plate continental margin rocks (Ruby terrane) is present in the Ruby geanticline that makes up the southeastern borderlands of the Yukon-Koyukuk basin shown at the north edge of plate 1. In the Ruby geanticline, glaucophane, attesting to high-pressure metamorphism, is sporatically developed both within the continental rocks of the lower plate and, less commonly, near the base of the overlying oceanic thrust sheets. The direction from which the oceanic rocks were thrust and determination of which oceanic sheets were involved is unclear. Late extension is also suspected to have followed contractional faulting in the Ruby geanticline.

Metamorphism of greenschist- and amphibolite-facies volcaniclastic sedimentary rocks and mafic and intermediate volcanic rocks in the southern Alaska Range and the Alaska Peninsula was probably associated with intrusion of the Early to Middle Jurassic plutons of the Alaska-Aleutian Range batholith and accompanying intermittent tectonism. Both the Jurassic plutons of the batholith and the probable Lower(?) Jurassic and Upper Triassic volcanic protoliths of the associated metamorphic rocks are products of an Early Mesozoic magmatic arc that developed within the Peninsular terrane and the adjoining parts of a composite terrane, composed of the Peninsular, Wrangellia, and Alexander terranes, that stretched across southern Alaska.

Manuscript approved for publication, March 26, 1987.

INTRODUCTION

This report identifies, describes, and interprets the major regionally metamorphosed rocks of southwestern Alaska and the Alaska Peninsula. 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 1990) of the metamorphic grade, pressure and temperature conditions, age of protoliths and metamorphism, and speculated or known tectonic origin of regional metamorphism in southwestern Alaska and the Alaska Peninsula. 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. Units of the same metamorphic age or age range are generally discussed in order of increasing metamorphic grade. The description of nearly all metamorphic units includes a reference to the lithotectonic terrane(s) proposed by Jones and others (1987) (fig. 3) and, in a few cases, to the revised boundaries and subdivisions of these terranes proposed by Box (1985d) (figs. 3 and 6). Unless otherwise specified, all lithotectonic terranes are those of Jones and others (1987).

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

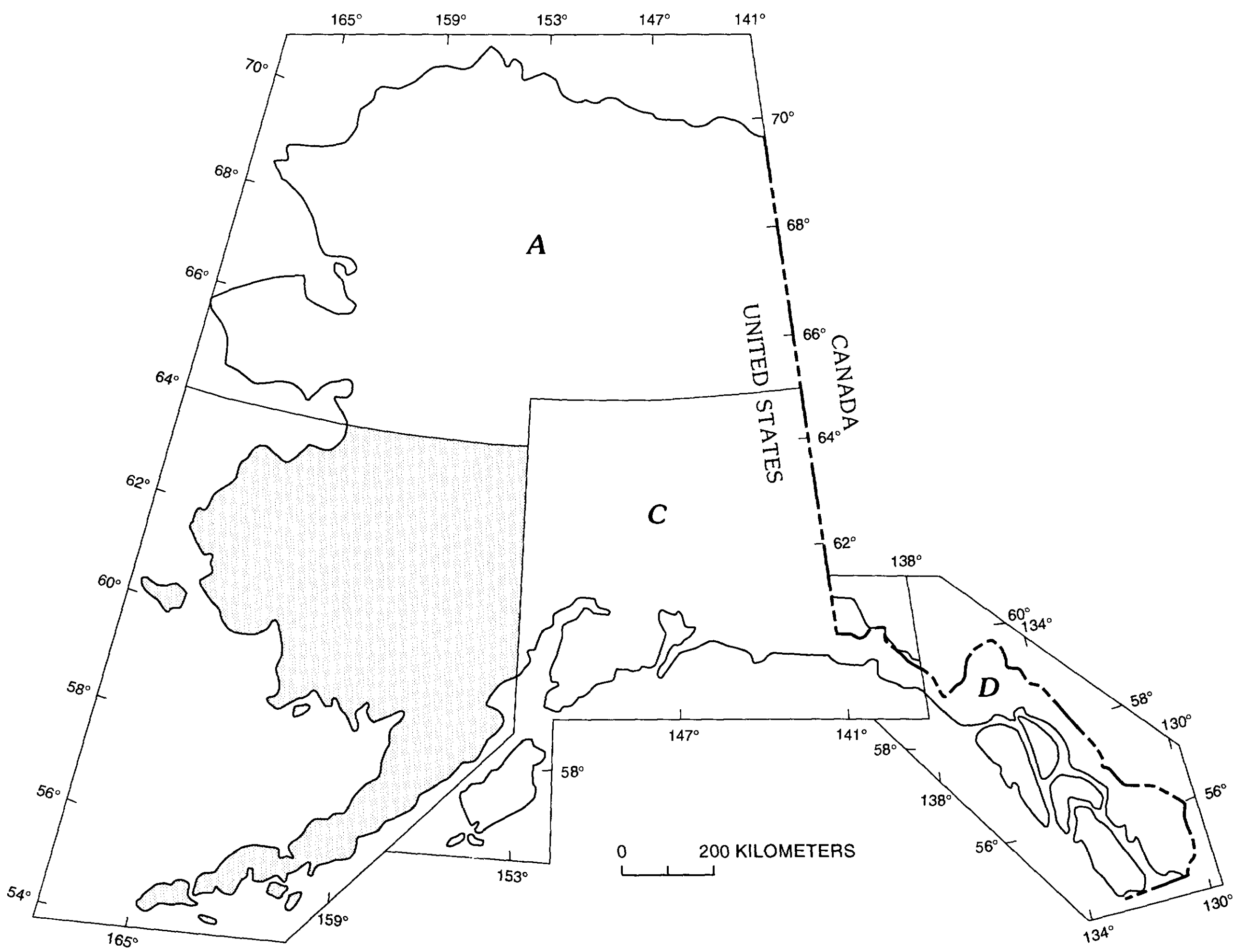

Figure 1.– Map showing area of this report and other reports in the series of metamorphic studies of Alaska. *A*, Dusel-Bacon and others (1989); *C*, Dusel-Bacon and others (1993); *D*, Dusel-Bacon and others (1996).

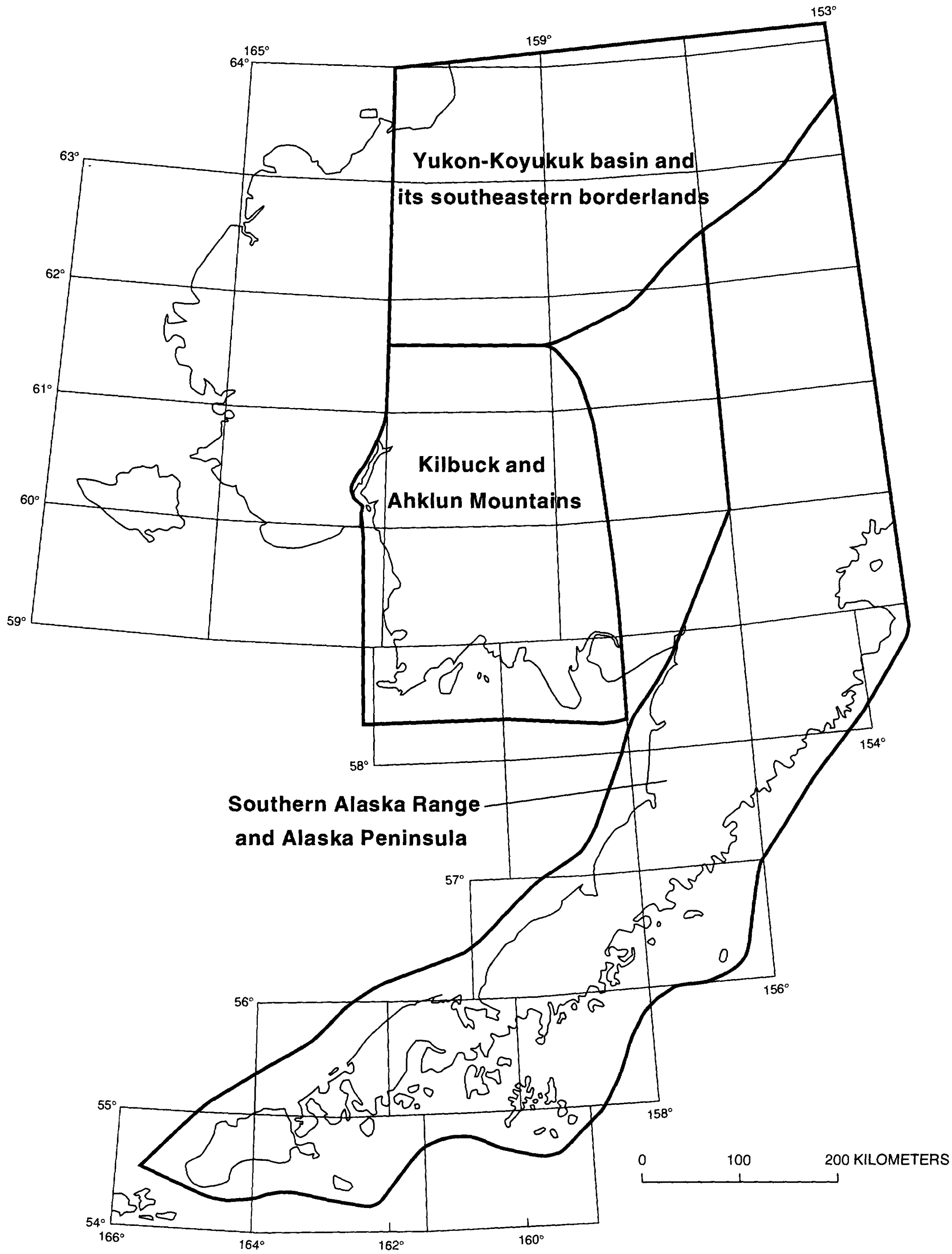

Figure 2.– Map showing regional geographic areas in southwestern Alaska and the Alaska Peninsula that are discussed in text. Boundaries of 1:250,000-scale quadrangles shown for reference.

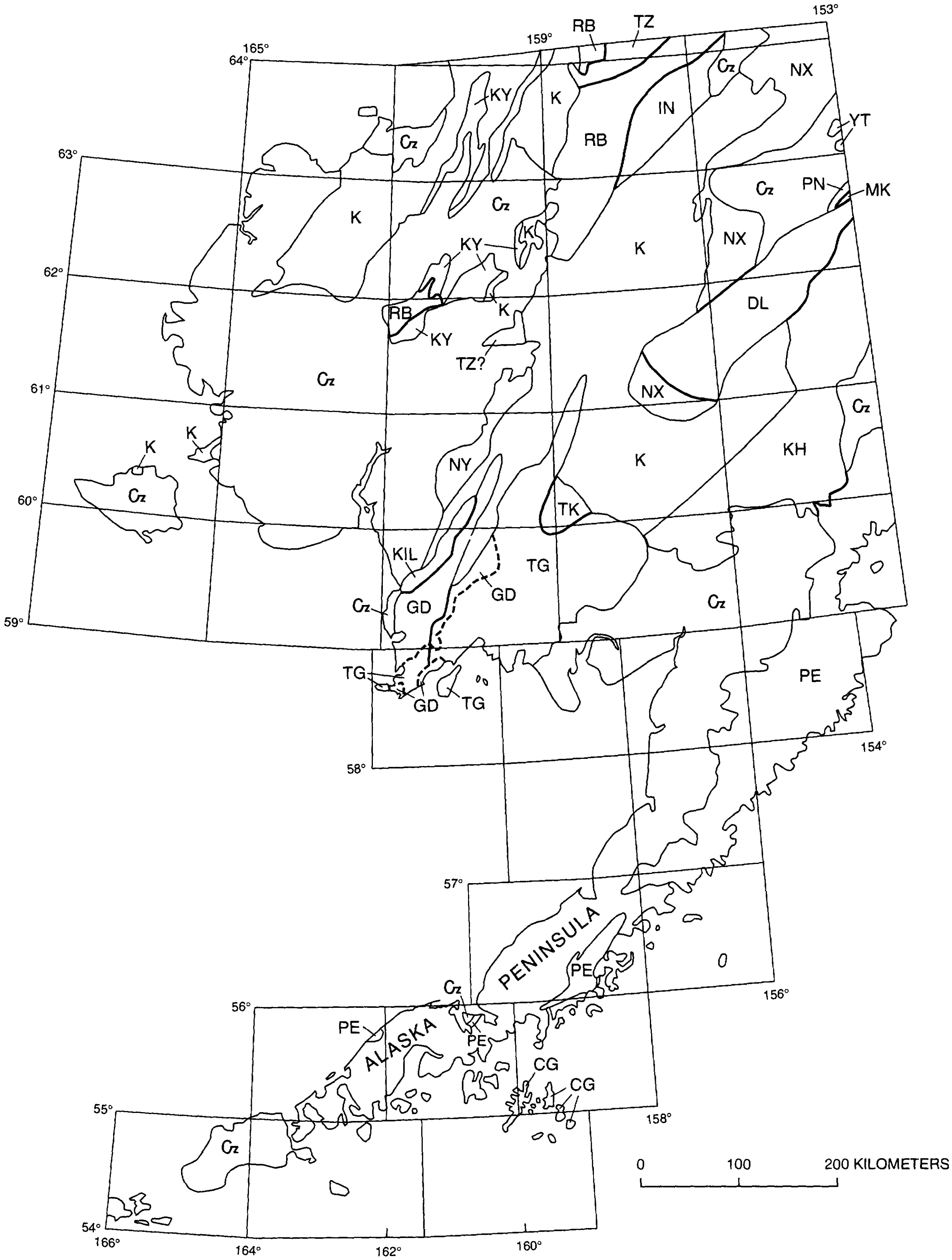

Figure 3.– Map showing lithotectonic terranes and the boundaries of 1:250,000-scale quadrangles in southwestern Alaska and the Alaska Peninsula. Terrane boundaries from Jones and others (1987) except just north of Bristol Bay where Box (1985d) revised two terrane boundaries (dashed lines). Most, but not all, terranes shown are referred to in the text. Abbreviated terrane names from Jones and others (1987). Incorrect spelling of Nyac terrane (previously given as Nyack terrane by Box (1985d) and Jones and others (1987)) is herein corrected.

are petrographically identifiable by most geologists. Regionally metamorphosed rocks are divided into three facies groups on the basis of 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 orange. Where possible, the greenschist-facies group is divided into two facies series on the basis of pressure. A high- or intermediate-pressure series is indicated by an H or I in place of the final letter in the symbol used for the greenschist-facies group.

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. Where the metamorphic grade of a unit is transitional between two facies groups, the lower-grade designation is given first, and the two designations are separated by a slash. Where two facies groups or facies series are found 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 metamorphic 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 one instance, the numerical subscript "1" is used to differentiate between map units that have the same metamorphic grade and metamorphic age

EXPLANATION

—— Terrane-bounding fault

—— Postaccretion or postamalgamation contact

TERRANES

CG	Chugach	NY	Nyac
DL	Dillinger	PE	Peninsular
GD	Goodnews	PN	Pingston
IN	Innoko	RB	Ruby
KH	Kahiltna	TG	Togiak
KIL	Kilbuck	TK	Tikchik
KY	Koyukuk	TZ	Tozitna
MK	McKinley	YT	Yukon-Tanana
NX	Nixon Fork		

OTHER SYMBOLS

Cz	Cenozoic sediments	K	Cretaceous sediments

Figure 3.—Continued

but 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.

ACKNOWLEDGMENTS

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SUMMARY OF THE MAJOR METAMORPHIC EPISODES THAT AFFECTED SOUTHWESTERN ALASKA AND THE ALASKA PENINSULA

The oldest dated metamorphic episode in Alaska took place in the Early Proterozoic and is recorded in two narrow, northeast-trending, fault-bounded complexes of continentally derived amphibolite-facies orthogneiss and subordinate metasedimentary rocks. The southernmost complex comprises the (informal) Kanektok metamorphic complex of Hoare and Coonrad (1979) and crops out in the Kilbuck and Ahklun Mountains; the northernmost one comprises the Idono Complex of Miller and others (1991) and crops out 250 km to the northeast in the southeastern borderlands of the Yukon-Koyukuk basin (pl. 1). The Kanektok metamorphic complex and the Idono Complex have been assigned by Jones and others (1987) to the Kilbuck and Ruby lithotectonic terranes, respectively (fig. 3) (Box and others, 1990; Miller and others, 1991).

The Kanektok metamorphic complex includes layered biotite-hornblende gneiss intercalated with pyroxene gneiss, garnet-mica schist, orthogneiss, garnet amphibolite, and rare marble (Hoare and Coonrad, 1979; Turner and others, 1983). Kyanite, indicative of intermediate- to high-pressure conditions, is found in garnet-mica schist at one locality in the Kanektok metamorphic complex (pl. 2; table 2). The Idono Complex is made up of granitic, dioritic, and tonalitic orthogneiss, amphibolite, and subordinate pelitic schist and quartzite (Miller and Bundtzen, 1985; Miller and others, 1991).

U-Pb zircon upper-intercept ages and Sm-Nd isotopic data from both complexes indicate that igneous protoliths consist primarily of an Early Proterozoic (2.0-2.1 Ga) tonalitic suite of subduction-related magmatic rocks and minor granitic rocks derived in part from Archean (2.5-2.6 Ga) sources (Box and others, 1990; Miller and others, 1991).

Isotopic data from both complexes also suggest that protoliths may have been metamorphosed under amphibolite-facies conditions during the Early Proterozoic (1.7-1.8 Ga). A 1.77-Ga metamorphic age for the Kanektok metamorphic complex is suggested by a U-Pb age on sphene from one sample of orthogneiss (Turner and others, 1983). Additional support for the 1.77 Ga metamorphic age is provided by the oldest of five Proterozoic K-Ar hornblende ages from amphibolite, and possibly also by a whole-rock Rb-Sr scatter chron (Turner and others, 1983).

Rocks in both complexes were subsequently affected by a Jurassic to Early Cretaceous thermal disturbance indicated by local resetting of Proterozoic mineral-isotopic systems (Turner and others, 1983; Miller and others, 1991). Nearly all of the rocks collected from the Kanektok metamorphic complex show a total or partial resetting of K-Ar hornblende and biotite ages and fall in the range of 150 to 120 Ma (D.L. Turner, written commun., 1982; Turner and others, 1983). Similarly, most K-Ar ages on white mica, biotite, and hornblende from the Idono Complex cluster in the range of 190 to 120 Ma (Miller and others, 1991). A 182±8-Ma U-Pb lower-intercept age on zircon from three samples of orthogneiss from the Idono

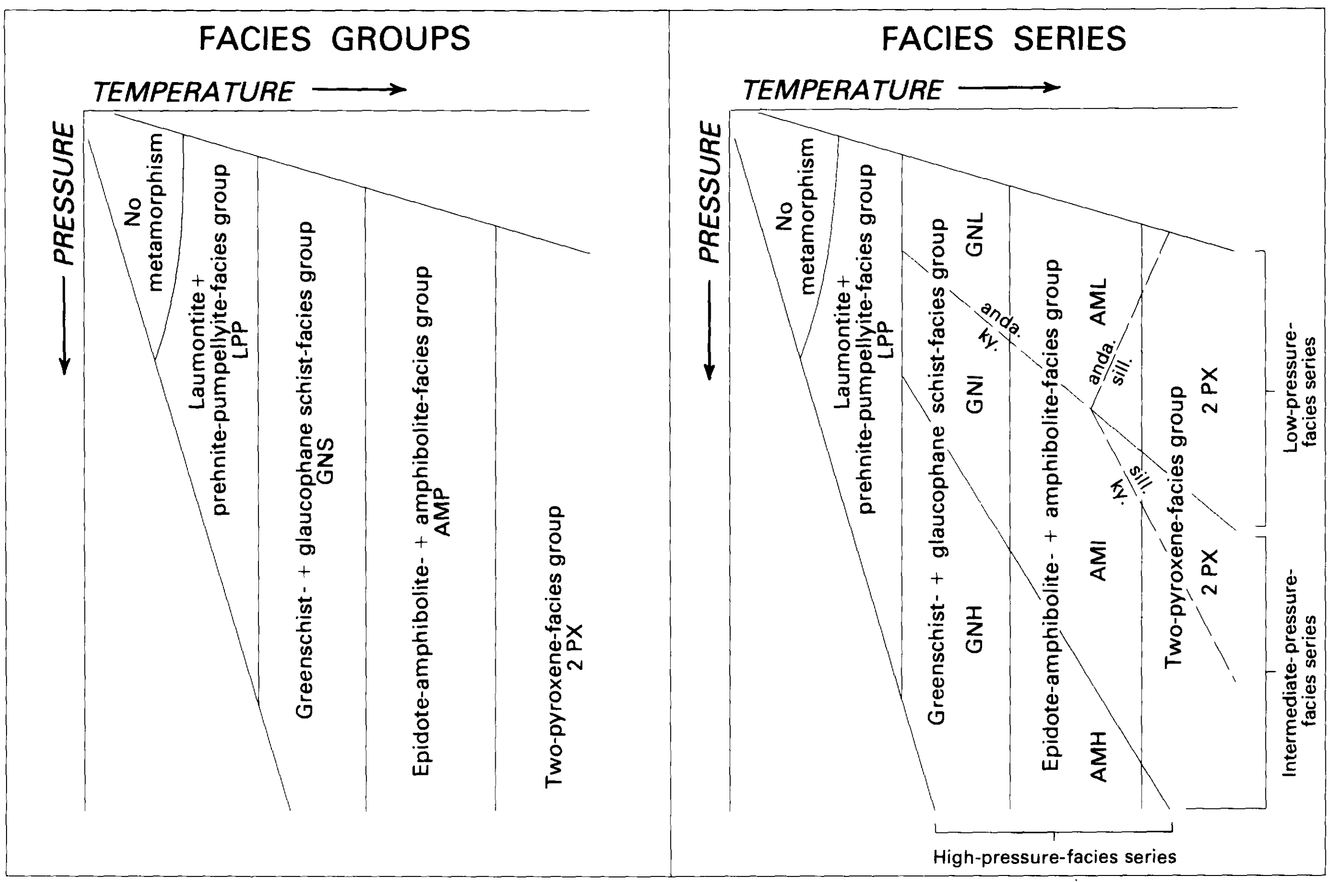

Figure 4.– Diagram showing schematic representation of metamorphic-facies groups and series in pressure-temperature space and their letter symbols used in this report (modified from Zwart and others, 1967). Stability fields of Al_2SiO_5 polymorphs andalusite (anda.), kyanite (ky.), and sillimante (sill.) 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		
	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

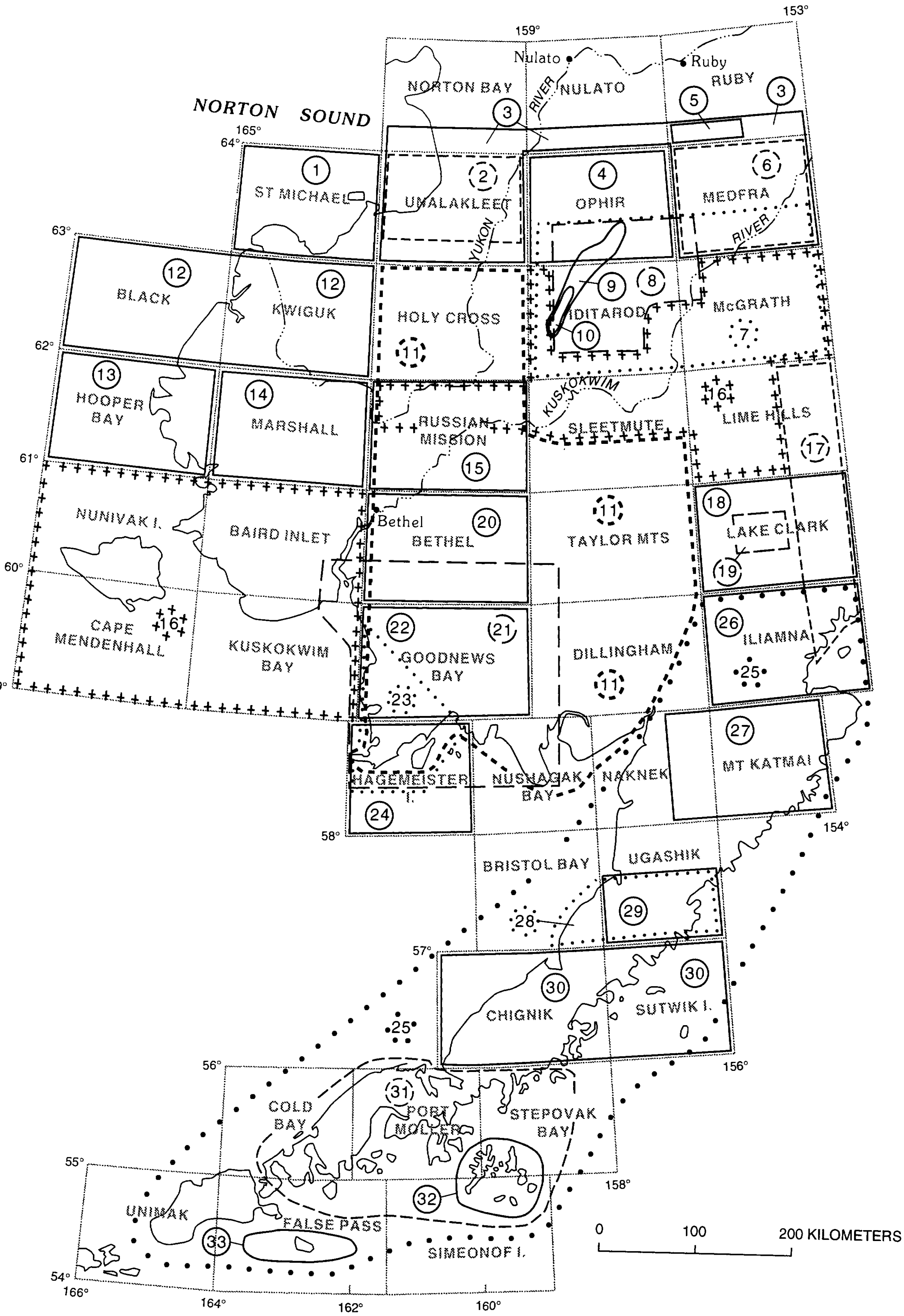

Figure 5.– Map showing general sources of metamorphic data for the metamorphic facies map of southwestern Alaska and the Alaska Peninsula (pl. 1). Numbers refer to sources of data listed in explanation. Boundaries of 1:250,000-scale quadrangles shown for reference. Ring patterns around numbers correspond to boundary patterns used to delineate that area.

Complex is interpreted as the approximate time of major episodic Pb loss and falls in the upper end of the range of the partly to totally reset K-Ar ages (Miller and others, 1991). The probable tectonic origin of this thermal disturbance is discussed near the end of this section.

Proterozoic or early Paleozoic metamorphism may have taken place in other areas of the continental basement of interior Alaska. Southeast of the Susulatna fault (pl. 1), Late Proterozoic felsic metavolcanic rocks (Dillon and others, 1985) and pre-Ordovician schist, quartzite, phyllite, argillite, marble, and mafic metavolcanic rocks (Silberman and others, 1979; Patton and others, 1980) of the Nixon Fork terrane (fig. 3) were metamorphosed under greenschist-facies conditions prior to Ordovician time. The pre-Ordovician metamorphic as well as protolith age for these rocks is indicated by the fact that overlying, virtually unmetamorphosed, Ordovician through Devonian strata yield conodont-alteration indices that correspond with very low temperatures, generally less than 200°C (W.W. Patton, Jr., oral commun., 1984; A.G. Harris, unpub. data, 1984). A minimum metamorphic age of 514 Ma is provided by the oldest of three K-Ar mineral ages on mica from quartz-muscovite-chlorite schist (Silberman and others, 1979). Northwest of the Susulatna and Nixon Fork-Iditarod faults, metamorphism of greenschist-facies rocks of Proterozoic(?) and probable early to middle Paleozoic age that form part of the Ruby terrane is thought to be primarily Mesozoic.

The predominant metamorphic episode in southwestern and interior Alaska occurred under low-grade conditions during Mesozoic time. Metamorphism during this period presumably resulted from subduction between the components of an active oceanic arc system and the subsequent collision of the oceanic arc with the continent lithosphere of North America. Both the overriding oceanic plate and the overridden continental plate were affected.

In the southeastern borderlands of the Yukon-Koyukuk basin, within the northern area shown on pl. 1, the continental plate consists of sedimentary and volcanic rocks of the Ruby terrane (fig. 3). These lower-plate rocks, including phyllite, greenschist, pelitic schist, quartzite, calcareous schist, greenstone, metachert, and marble of Proterozoic(?) and probable early to middle Paleozoic protolith age, were primarily metamorphosed under greenschist-facies conditions. In the Kaiyuh Mountains, however, glaucophane is present in correlative continental rocks shown on the adjacent northern metamorphic facies map (Dusel-Bacon and others, 1989), indicating that, at least locally, high-pressure (blueschist-facies) metamorphic conditions prevailed.

Upper-plate oceanic rocks in this area consist of locally schistose greenstone, metachert, metagraywacke, metalimestone, argillite, metadiabase, metatuff, volcaniclastic rocks, and mafic intrusive rocks. Protoliths range in age from Late Devonian to Late Triassic and are considered to be part of the Innoko and Tozitna terranes (fig. 3). These rocks were metamorphosed under prehnite-pumpellyite-facies conditions. North of the study area (pl. 1), glaucophane is present sporadically near the structural base of lithologically similar oceanic rocks of the Tozitna and Angayucham terranes (Dusel-Bacon and others, 1989).

EXPLANATION

1 Hoare and Condon (1971b)
2 Patton and Moll (1985)
3 E.J. Moll and W.W. Patton, Jr., unpublished metamorphic facies compilation (1983)
4 R.M. Chapman and S.L. Douglass, unpublished metamorphic facies compilation (1983)
5 Chapman and Patton (1979)
6 Patton and others (1980)
7 Gemuts and others (1983)
8 T.K. Bundtzen, unpublished mapping (1984)
9 Angeloni and Miller (1985)
10 Miller and Bundtzen (1985); Miller and others (1991)
11 T.P. Miller, unpublished metamorphic facies compilation (1974); S.E. Box, unpublished data (1985)
12 Hoare and Condon (1966)
13 Hoare and Condon (1968)
14 Hoare and Condon (1971a)
15 Hoare and Coonrad (1959b); Box and others (1993)
16 Beikman (1974)
17 Reed and others (1983)
18 Nelson and others (1983)
19 Bundtzen and others (1979)
20 Hoare and Coonrad (1959a); Box and others (1993)
21 Hoare and Coonrad (1978a)
22 Hoare and Coonrad (1961a)
23 Hoare and Coonrad (1961b)
24 Box (1985c)
25 R.L. Detterman, unpublished geologic compilation (1982)
26 Detterman and Reed (1980)
27 J.R. Riehle and R.L. Detterman, unpublished geologic compilation (1986)
28 Detterman and others (1983)
29 Wilson (1982)
30 Detterman and others (1981)
31 Burk (1965)
32 Moore (1973, 1974a)
33 Moore (1974b)

Figure 5.– Continued

The intermediate- to locally high-pressure metamorphism of the lower-plate rocks is believed to have occurred as a result of tectonic loading accompanying the obduction of a disrupted mafic-ultramafic oceanic complex onto the Proterozoic and lower Paleozoic continental margin during Middle Jurassic to Early Cretaceous time (Patton and others, 1977; Patton and Moll, 1982; Patton, 1984; Dusel-Bacon and others, 1989). The direction from which these rocks were thrust is unclear. According to one hypothesis, on the basis of large-scale geologic similarities between the Ruby geanticline and the southern Brooks Range (shown and discussed in Dusel-Bacon and others, 1989), the thrust sheets of a (composite) Angayucham-Tozitna terrane were rooted in the Yukon-Koyukuk basin and thrust southeastward over the continentally derived rocks of the Ruby terrane (Patton and others, 1977, 1989; Patton and Moll, 1982). According to an alternative hypothesis, on the basis of structural analysis of S-C fabrics (non-coaxial schistosity and shear surfaces) and the sense of rotation of large-scale nappe-like folds (Miyaoka and Dover, 1985; Smith and Puchner, 1985; G.M. Smith, written commun., 1986), the Tozitna terrane was thrust in the opposite direction—from the southeast toward the northwest. However, subsequent fabric analysis (Miyaoka and Dover, 1990) indicates much more complex motions of the Tozitna terrane over the Ruby terrane.

A continuation of this same metamorphic and tectonic history has been proposed for the rocks farther to the southwest, in the Kilbuck and Ahklun Mountains area (Box, 1985a, d). Similarities that suggest this correlation are (1) the same relation between upper-plate oceanic rocks (Goodnews and Togiak terranes) and lower-plate continental rocks (Kilbuck terrane) in southwestern Alaska as is present in the Ruby geanticline and southern Brooks Range; (2) evidence of low-grade, locally high-pressure, metamorphism in the oceanic rocks; and (3) the widespread occurrence of Late Jurassic to Early Cretaceous isotopic cooling ages. These similarities between the southeastern borderlands of the Yukon-Koyukuk basin, the southern Brooks Range, and southwestern Alaska are best explained by a tectonic model in which a continuous, sinuous suture between a volcanic arc and the Mesozoic margin of continental North America (that extended across northern, central, and southwestern Alaska) was subsequently offset by major right-lateral strike-slip faults (Box, 1985a; Wallace, 1984).

Mesozoic metamorphism and presumed concomitant underthrusting in the Kilbuck and Ahklun Mountains area of southwestern Alaska took place during two related episodes. The first episode, produced a nappe complex of high-pressure greenschist-(blueschist-) facies, glaucophane- and lawsonite-bearing schistose metabasalt, strongly foliated volcaniclastic rocks, black phyllite, tuffaceous phyllite and marble, and calcareous schist (Box, 1985c). These rocks are complexly deformed and locally possess a mélange-like fabric. They make up the Cape Peirce subterrane of the Goodnews terrane (figs. 3 and 6). Protoliths are interpreted as oceanic crustal fragments (accretionary forearc) of Permian and Late Triassic age that were thrust beneath the northwestern margin of an oceanic volcanic arc (Togiak terrane) (fig. 6). Metamorphism during this first episode is bracketed between the Late Triassic age of the youngest protolith and the Middle Jurassic age of postmetamorphic mafic and ultramafic plutons that intrude the Togiak and Goodnews terranes. A 231.2±6.9-Ma K-Ar age on amphibole from schist of the Cape Peirce subterrane (Box, 1985c) suggests that metamorphism may have begun during Late Triassic time.

Structural data suggest that the overriding arc of the Togiak terrane was originally thrust to the north-northeast over the Goodnews terrane (Box, 1985b). However, the low-angle, southeast-dipping fault mapped between the upper plate Togiak terrane and the underlying Cape Peirce terrane (fig. 6) juxtaposes lower temperature and pressure rocks over higher temperature and pressure rocks, suggesting that the fault is a low-angle normal fault rather than a thrust fault, and that contractional faulting was followed by extensional (detachment) faulting (Box, 1985b). This same structural juxtapositioning of shallow level over deeper level rocks is found in the southern Brooks Range and Ruby geanticline and has been interpreted as evidence of late extensional faulting along that part of the convergent margin as well (Miller, 1987; Gottschalk and Oldow, 1988; Dusel-Bacon and others, 1989, among others).

Greenschist-facies and locally developed blueschist-facies mafic schist, quartzose schist, calcareous schist, marble, phyllite, and minor amounts of graphite schist (Hoare and Coonrad, 1959a, 1961a) were probably metamorphosed during the second episode of underthrusting. These rocks, of Ordovician to latest Jurassic (Tithonian) age (Box, 1985c), crop out along the northwest margin of the Nukluk subterrane of the Goodnews terrane (Box, 1985d) (fig. 6). Greenschist-facies mafic schist is characterized by chlorite, epidote, and actinolite, and blueschist-facies mafic schist by these same minerals plus glaucophane and magnesioriebeckite, a sodic amphibole (S.M. Roeske, written commun., 1988). A latest Jurassic to earliest Cretaceous minimum metamorphic age for this episode is suggested by a 146±15-Ma K-Ar age on actinolite from the northern exposure of this unit (Box and Murphy, 1987).

The Jurassic to Early Cretaceous metamorphism of these greenschist- and blueschist-facies rocks, as well as the postulated retrograde metamorphism of the Early Proterozoic Kanektok metamorphic complex of the Kilbuck terrane (and by correlation, the Idono Complex), probably took place as the continental Kilbuck terrane was partly thrust beneath the accretionary forearc (Goodnews terrane) of the intraoceanic volcanic arc (Togiak terrane) (Box, 1985d) (fig. 6). The minimum age of this episode of thrusting and metamorphism is constrained by the Cen-

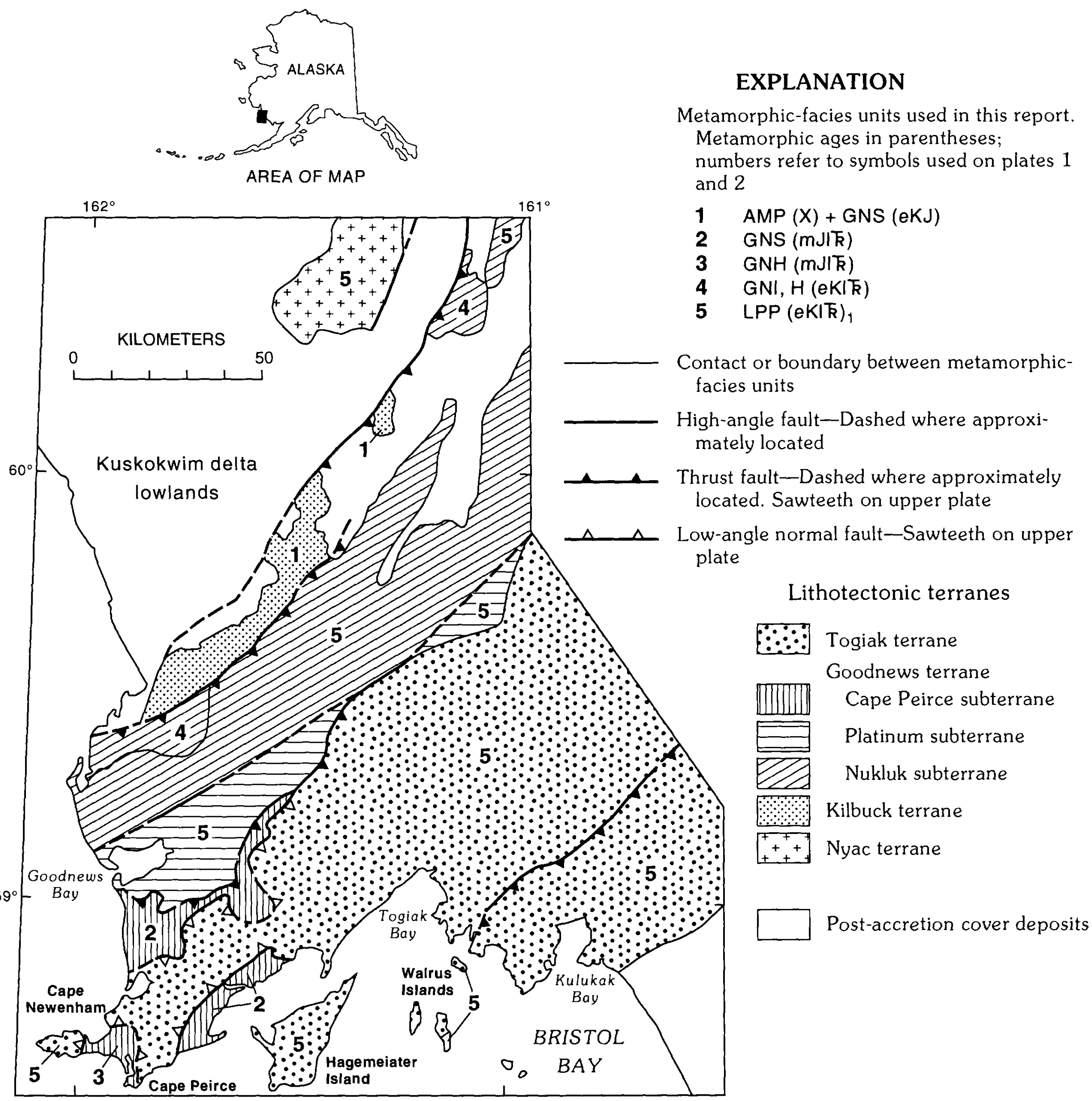

Figure 6.– Generalized map showing lithotectonic terranes and metamorphic facies units in the Kilbuck and Ahklun Mountains area. Incorrect spelling of Nyac terrane (previously given as Nyack terrane by Box (1985d) and Jones and others (1987)) is herein corrected.

omanian and Turonian (early Late Cretaceous) age of clastic rocks (Box and Elder, 1992) that overlap the Togiak, Goodnews, and Kilbuck terranes.

Metamorphism of greenschist- and amphibolite-facies rocks in the southern Alaska Range and the Alaska Peninsula was probably associated with intrusion of the Early to Middle Jurassic plutons of the Alaska-Aleutian Range batholith and accompanying intermittent tectonism (Detterman and Reed, 1980). The primary evidence for this assumption is a spatial association of the metamorphic rocks with the plutons, an overall increase in metamorphic grade toward them, and parallelism between structures in the metamorphic rocks, pluton contacts, and foliation within the margins of the plutons. Protoliths include Lower(?) Jurassic volcaniclastic sedimentary rocks and mafic and intermediate volcanic rocks and Upper Triassic calcareous sedimentary rocks and mafic volcanic rocks (Detterman and Reed, 1980) of the Peninsular terrane. Jurassic plutons of the batholith and the volcanic protoliths of the associated metamorphic rocks are products of an Early Mesozoic magmatic arc that developed within the Peninsular terrane and adjoining parts of a composite terrane, composed of the Peninsular, Wrangellia, and Alexander terranes (Plafker and others, 1989; Wallace and others, 1989), that stretched across southern Alaska. Common rock types include mafic schist, metavolcaniclastic rocks, marble, massive to layered metagabbro, metachert, and gneiss. Rock fabrics range from massive to imperfectly schistose to those in which segregation banding is well developed. Dynamothermal amphibolite-facies metamorphism is characterized by hornblende+garnet in mafic rocks and biotite + muscovite + garnet ± potassium-feldspar ± andalusite ± staurolite in pelitic rocks. Locally, thermal metamorphism has produced rocks with granoblastic textures and amphibolite-facies and pyroxene hornfels-facies mineral assemblages (Detterman and Reed, 1980).

A similar, but more internally faulted, heterogeneous sequence of rocks is exposed along the west margin of the Alaska-Aleutian Range batholith near Lake Clark (Tlikakila complex of Wallace and others (1989)). Metamorphism of these greenschist- and amphibolite-facies rocks may have occurred, in part, during the episode of metamorphism and tectonism that was associated with Middle to Late Jurassic plutonism. However, these rocks are more spatially associated with the Late Cretaceous and Tertiary plutons of the batholith than they are with the Jurassic part of it, suggesting that metmorphism may have been related to either one or both of the younger plutonic episodes instead of, or as well as, the older one.

DETAILED DESCRIPTION OF METAMORPHIC MAP UNITS

YUKON-KOYUKUK BASIN AND ITS SOUTHEASTERN BORDERLANDS

GNS (pO)

This unit comprises Late Proterozoic felsic metavolcanic rocks (Dillon and others, 1985) and pre-Ordovician pelitic schist, calc schist, semischist, quartzite, phyllite, argillite, marble, and mafic metavolcanic rocks (Silberman and others, 1979; Patton and others, 1980). It crops out southeast of the Susulatna fault in the southeast corner of the Ruby and the north half of the Medfra quadrangles and is included in the Nixon Fork terrane (fig. 3). Characteristic metamorphic mineral assemblages in pelitic rocks are quartz + muscovite ± chlorite ± biotite ± garnet and chloritoid + chlorite + muscovite + quartz; metabasite contains the metamorphic assemblage chlorite + epidote + actinolite + albite ± calcite ± sphene ± biotite. A pre-Ordovician metamorphic as well as protolith age for this unit is indicated by the fact that overlying Ordovician through Devonian strata yield conodont-alteration indices that correspond with very low temperatures, generally less than 200°C (W.W. Patton, Jr., oral commun., 1984; A.G. Harris, unpub. data, 1984), and, therefore, are considered to be unmetamorphosed. A minimum metamorphic age of 514 Ma is provided by the oldest of three K-Ar mineral ages on mica from quartz-muscovite-chlorite schist in the Medfra quadrangle (Silberman and others, 1979). U-Pb zircon and K-Ar data suggest that the rocks in this unit were not affected by the Late Jurassic to Early Cretaceous metamorphic episode that occurred northwest of the Susulatna fault in the southeastern borderlands of the Yukon-Koyukuk basin (Dillon and others, 1985).

GNS (eKmPz)

The continentally derived phyllite, greenschist, pelitic schist, quartzite, calcareous schist, greenstone, metachert, and marble of Proterozoic(?) and probable early to middle Paleozoic protolith age that compose this unit are part of the Ruby terrane (fig. 3). These rocks crop out in the Iditarod (Angeloni and Miller, 1985), Ophir (Chapman and others, 1985), and Nulato (W.W. Patton, Jr., unpub. mapping, 1986) quadrangles (pl. 1) and continue into the Ruby and

Kantishna River quadrangles to the northeast (Dusel-Bacon and others, 1989; Dusel-Bacon and others, 1993). Pelitic schist is characterized by the assemblagequartz + muscovite ± chlorite ± carbonaceous material ± stilpnomelane ± sphene, and metabasite is characterized by the assemblage green amphibole + quartz + epidote + albite + chlorite + sphene ± stilpnomelane ± biotite ± plagiocase ± muscovite (Angeloni and Miller, 1985). Age of metamorphism is constrained only by the probable early to middle Paleozoic protolith age of the youngest rocks and by the Cretaceous or Tertiary K-Ar ages (Silberman and others, 1979) of unmetamorphosed granitoids that crosscut this unit. On the basis of geologic similarities and geographic position, the age and origin of metamorphism of this unit is most likely the same as that proposed for unit GNI,H (eKmJ) described below, namely tectonic overthrusting of a mafic-ultramafic oceanic complex onto the Proterozoic and lower Paleozoic continental margin during Middle Jurassic to Early Cretaceous time (Patton, 1984).

LPP (eKlŦ)

The assemblage of weakly metamorphosed oceanic rocks that make up this unit consists of locally schistose greenstone, metachert, metagraywacke, metalimestone, argillite, metadiabase, metatuff, volcaniclastic rocks, and mafic intrusive rocks. This unit crops out in the following quadrangles: Russian Mission (Hoare and Coonrad, 1959b), Iditarod (Miller and Bundtzen, 1985), Ophir (Chapman and others, 1985), Nulato (E.J. Moll and W.W. Patton, Jr., unpub. compilation, 1983), Ruby (Chapman and Patton, 1979; E.J. Moll and W.W. Patton, Jr., unpub. compilation, 1983), and Medfra (Patton and others, 1980). It continues into the southeastern borderlands of the Yukon-Koyukuk basin north of our study area (pl. 1) (Dusel-Bacon and others, 1989). Protoliths range in age from Late Devonian to Late Triassic and are considered to be part of the Innoko and Tozitna terranes (fig. 3).

Low-grade metamorphism is documented in rocks from the northern extension of this unit that contain prehnite- and pumpellyite-bearing assemblages (Dusel-Bacon and others, 1989). Metamorphism postdates the Late Triassic age of the youngest protoliths and predates the Early Cretaceous (111-Ma) age of the oldest pluton that intrudes lithologically similar rocks in the Melozitna quadrangle (Patton and others, 1978) northeast of our study area (pl. 1) (see Dusel-Bacon and others, 1989). Although rocks of this unit have not been studied in detail, by analogy with the northern extension of this unit, this segment may also comprise a tectonically emplaced thrust sheet of oceanic rocks. The direction from which these rocks were thrust, however, is controversial and is described below in the discussion of unit GNI,H (eKmJ).

GNI,H (eKmJ)

This unit comprises quartz-mica schist, quartzite, phyllite, slate, and mafic metavolcanic rocks of Proterozoic(?) and Paleozoic age and recrystallized limestone, dolomite, and metachert of Paleozoic age; protoliths are continental sedimentary and volcanic rocks (Patton and Moll, 1982; Patton and others, 1984, 1989; A.G. Harris, unpub. data, 1985). These rocks crop out in the Kaiyuh Mountains in the Nulato quadrangle and are part of the Ruby terrane (fig. 3).

Glaucophane is found in correlative rocks shown on the adjacent northern metamorphic facies map (Dusel-Bacon and others, 1989), indicating that, at least locally, high-pressure metamorphic conditions prevailed. Metamorphic mineral assemblages present in the northern extension of this unit include quartz + white mica + chlorite ± chloritoid ± clinozoisite ± plagioclase and, locally, glaucophane + white mica + garnet + chlorite + chloritoid + quartz in pelitic schist and albite + chlorite+actinolite + epidote group minerals ± calcite ± sphene and chlorite + epidote + sphene + plagioclase ± white mica ± glaucophane in metabasalt.

The intermediate-pressure to locally high-pressure metamorphism of these rocks is believed to have occurred as a result of the obduction of a disrupted mafic-ultramafic oceanic complex (shown as the adjacent prehnite-pumpellyite facies unit LPP (eKlŦ) and, north of the map area, as unit LPP (eKmJ) (Dusel-Bacon and others, 1989)) onto the Proterozoic and lower Paleozoic continental margin, including the rocks of this unit, during Middle Jurassic to Early Cretaceous time (Patton and others, 1977, 1989; Patton and Moll, 1982; Patton, 1984). The direction from which these rocks were thrust is unclear. According to Patton and others (1977), the oceanic complex appears to have been rooted along the margin of the Yukon-Koyukuk basin and to consist of two separate thrust sheets: (1) a lower sheet of structurally shuffled pillow basalt, diabase, massive gabbro, and chert and (2) an upper sheet of ultramafic rocks and layered gabbro. Blueschist-facies mineral assemblages (primarily defined by the presence of glaucophane) are found in the base of the lower thrust sheet, as well as in the underlying metasedimentary rocks of this unit (Patton and Moll, 1982). Garnet amphibolite is found locally at the base of the upper sheet of ultramafic rocks and is proposed to have formed when the two thrust sheets were tectonically juxtaposed prior to their final southeastward emplacement onto the continental margin (Patton and others, 1977; Patton, 1984). Recent structural data collected from two units northeast of the map area (unit LPP (eKlTR) and unit GNI,H (eKmJ); see the adjacent map of Dusel-Bacon and others, 1989) suggest a complex history of north-northwest- and southeast-directed upper plate motion (Miyaoka and Dover, 1990), which Miyaoka and Dover interpret to indicate outward thrusting of an essentially in situ oceanic crustal complex.

The age of metamorphism is bracketed between Middle Jurassic and late Early Cretaceous time. The lower constraint is based on 172 to155-Ma K-Ar ages on hornblende from garnet amphibolite and associated layered gabbro that formed during tectonic shuffling of the oceanic package, prior to its obduction onto the continental margin. The upper constraint is based on (1) the Albian age of conglomerates deposited along the margins of the Yukon-Koyukuk basin that contain clasts of both the metamorphosed continental and oceanic rocks and on (2) the late Early Cretaceous (111-Ma) age of a granitoid pluton that intrudes both the continental and overthrust oceanic rocks in the Kokrines Hills north of the map area (Patton and others, 1977, 1978; Patton, 1984). K-Ar ages of 134 and 136 Ma on metamorphic muscovite from glaucophane-bearing schist of this unit in the Kaiyuh Mountains north of the map area (Patton and others, 1984) indicate that the lower, continental plate had cooled to about 350°C (approximate blocking temperature of white mica) by Early Cretaceous time.

The present structural and metamorphic relation, in which the higher grade continental rocks of this unit are overlain by much lower grade oceanic rocks, suggests that late metamorphic or postmetamorphic low-angle extensional faulting has dismembered the upper plate and removed much of the section that originally buried the continental rocks. This late extensional phase, following collision and obduction of the oceanic complex, has been proposed for the entire belt of high-pressure continental rocks and overlying oceanic rocks that stretches across the southern Brooks Range, Ruby geanticline, and southwesternmost Alaska (Miller, 1987; Gottschalk and Oldow, 1988; Dusel-Bacon and others, 1989; among others).

LPP (peK)

Very weakly metamorphosed metabasalt (possibly pillow basalt), fine-grained metadiabase, and intercalated cherty metatuff in the Unalakleet quadrangle (Patton and Moll, 1984, 1985), and locally schistose greenstone and altered mafic intrusive rocks in the Russian Mission and Holy Cross quadrangles (Hoare and Coonrad, 1959b), make up this unit. Protoliths in the Unalakleet quadrangle predate the Middle to Late Jurassic age (based on 173-154-Ma K-Ar ages) of a trondhjemite and tonalite pluton (unit Jg) that intrudes the northern sliver of this unit (Patton and Moll, 1985).

Metabasalt and metadiabase are composed almost entirely of sausseritized, weakly twinned plagioclase and fine-grained, pale-green metamorphic amphibole. Prehnite and pumpellyite(?) have been identified in one sample, suggesting metamorphic conditions of the prehnite-pumpellyite facies. Relict igneous textures are preserved, and locally rocks are highly sheared and granulated (Patton and Moll, 1984).

The age and origin of this low-grade metamorphic episode are unknown. Metamorphism predates the Early Cretaceous (Neocomian) age of the unmetamorphosed andesitic volcanic rocks that unconformably overlie this unit and probably also predates the intrusion of the Middle to Late Jurassic trondhjemite and tonalite pluton (Patton and Moll, 1984). Although the pluton has been potassium metasomatized, it does not appear to have been metamorphosed.

KILBUCK AND AHKLUN MOUNTAINS

AMP (X) + GNS (eKJ)

This unit comprises elongate, fault-bounded, crustal slivers or flakes of amphibolite-facies orthogneiss and subordinate metasedimentary rocks in two separate areas of southwestern Alaska. Rocks of the southernmost area comprise the (informal) Kanektok metamorphic complex of Hoare and Coonrad (1979) and crop out in the Kilbuck and Ahklun Mountains. Those of the northernmost area comprise the Idono Complex of Miller and others (1991) and crop out 250 km to the northeast in the southeastern borderlands of the Yukon-Koyukuk basin. A shared origin and thermal history of the Kanektok metamorphic complex and the Idono Complex is inferred on the basis of available U-Pb, Sm-Nd, Rb-Sr, K-Ar, and $^{40}Ar/^{39}Ar$ isotopic data (Turner and others, 1983; Box and others, 1990; Miller and others, 1991). These data indicate that (1) protoliths consist primarily of an Early Proterozoic (2.0-2.1 Ga) tonalitic suite of subduction-related magmatic rocks and minor granitic rocks that give Archean (2.5-2.6 Ga) Nd model ages; (2) igneous and sedimentary protoliths were probably metamorphosed under amphibolite-facies conditions during Early Proterozoic (1.7-1.8 Ga) time; and (3) most rocks were affected by a Jurassic to Early Cretaceous thermal disturbance indicated by local resetting of Proterozoic mineral-isotopic systems (Turner and others, 1983; Box and others, 1990; Miller and others, 1991).

The Kanektok metamorphic complex (discussed separately in the following paragraphs) is composed of amphibolite-facies layered biotite-hornblende gneiss intercalated with pyroxene gneiss, garnet-mica schist, orthogneiss, garnet amphibolite, and rare marble (Hoare and Coonrad, 1979; Turner and others, 1983). The Kanektok metamorphic complex is exposed along a northeast-trending belt (15 by 150 km) extending from the northwestern part of Goodnews Bay quadrangle into the south-central part of Bethel quadrangle (Hoare and Coonrad, 1959a, 1961a) and comprises the Kilbuck terrane (figs. 3 and 6). Aeromagnetic and gravity data and field evidence indicate the complex to be a rootless subhorizontal klippe or crustal flake between two southeast-dipping thrust faults (Hoare and Coonrad, 1979; Box and others, 1990).

Amphibolite-facies mineral assemblages, presumably produced during the Early Proterozoic episode, are: hornblende + garnet + plagioclase + biotite + quartz ± clinopyroxene and garnet + augite + biotite + anti-perthitic plagioclase ± potassium feldspar + plagioclase + quartz + biotite ± muscovite ± epidote ± garnet in schist. Intercalated, thin, and discontinuous marble layers contain minor amounts of white mica, phlogopite, quartz, plagioclase, and epidote. A kyanite-bearing garnet-mica schist was collected near Thumb Mountain, and an impure marble with incipient diopside was recovered from a nearby outcrop (D.L. Turner, written commun., 1982; J.Y. Bradshaw, oral commun., 1990).

Metamorphic mineral grains generally define a strong lineation and a foliation that is parallel to compositional layering. All of these structural features strike consistently to the northeast, roughly parallel to the trend of the complex (Hoare and Coonrad, 1979; D.L. Turner, written commun., 1982). Granitic gneisses appear to be deformed into subisoclinal upright folds with limbs which descend toward the margins of the complex (D.L. Turner, written commun., 1982).

A 1.77-Ga (Early Proterozoic) metamorphic age for the first, and presumably dominant, metamorphism is suggested by the U-Pb age on sphene from orthogneiss and by the oldest of five Proterozoic K-Ar hornblende ages from amphibolite (Turner and others, 1983). A Rb-Sr scatter chron for 6 of 13 whole-rock samples gives the same age and also is interpreted by Turner and others (1983) to be a metamorphic age. Turner and others (1983) further suggest that a minimum age for this metamorphic episode is provided by a 1.2-Ga age from $^{40}Ar/^{39}Ar$ incremental heating studies on hornblende from garnet amphibolite. Rb-Sr isotopic data collected from metagranitic rocks of the Kanektok metamorphic complex by Moll-Stalcup and others (1990) suggest model ages of about 1.7 Ga, which they interpret to indicate either the age of metamorphism or, alternatively, the age of igneous crystallization of the protolith.

The occurrence of a subsequent Mesozoic thermal episode within the Kanektok metamorphic complex is indicated by total or partial resetting of K-Ar hornblende and biotite ages from nearly all of the 58 dated rocks collected throughout the metamorphic complex. A Late Jurassic to Early Cretaceous age for this thermal episode is suggested by the fact that most of these ages fall in the range of 150 to 120 Ma (Turner and others, 1983; D.L. Turner, written commun., 1982). An Early Cretaceous minimum age for this second metamorphic episode is supported by the observations of Murphy (1987) that (1) unmetamorphosed Cenomanian conglomerates that depositionally overlie the complex contain Kanektok components and (2) unmetamorphosed Valanginian sedimentary rocks to the south of the complex contain metamorphic garnet and epidote thought to be derived from the complex.

Turner and others (1983) propose that the Mesozoic thermal episode that affected the Kanektok metamorphic complex was accompanied by granitic plutonism and greenschist-facies metamorphism of overlying sedimentary and probable volcanic rocks within a narrow zone (approximately 1-2 km wide and too small to show at the scale of this map) that flanks the amphibolite-facies rocks of the Kanektok metamorphic complex. These greenschist-facies rocks include greenschist, epidote-quartz-biotite schist, micaceous quartzite, calc-phyllite, marble, and metaconglomerate. K-Ar ages on minerals from the greenschist-facies rocks fall within the same range as those from the amphibolite-facies complex (D.L. Turner, unpub. data, 1982). However, the relation of the narrow zone of flanking greenschist-facies rocks to the amphibolite-facies Kanektok metamorphic complex is unclear. The flanking lower grade rocks appear to grade into the higher grade rocks of the complex, but it is equally possible that the flanking rocks are in fault contact with the higher grade rocks and that the former were metamorphosed during a separate metamorphic episode (D.L. Turner, oral commun., 1985).

Box (1985c) suggests that the greenschist-facies rocks that are found in the narrow zone marginal to the amphibolite-facies rocks of the Kanektok metamorphic complex were metamorphosed in a zone of high shear-strain that developed when amphibolite-facies rocks (Kilbuck terrane) were overthrust by rocks to the southeast (unit LPP (eKlTr)$_1$) during latest Jurassic to Early Cretaceous time. This thrusting event is interpreted to record partial subduction of the older continental block (Kilbuck terrane) beneath an intraoceanic volcanic-arc complex (Goodnews and Togiak terranes) (figs. 3 and 6) during arc-continent collision (Box, 1985c), discussed in the last section of this geographic area.

The Idono Complex comprises an elongate, northeast-trending belt (8 by 34 km) of granitic, dioritic, and tonalitic orthogneiss, amphibolite, and subordinate semipelitic schist and quartzite (Miller and Bundtzen, 1985; Miller and others, 1991). These rocks, originally informally designated as the Idono sequence by Gemuts and others (1983), crop out in the Iditarod quadrangle and are included by Jones and others (1987) in the Ruby terrane (fig. 3). Rocks typically exhibit a well-developed foliation that strikes northeast to east-northeast, parallel to the trend of the complex, and dips 10° to 80° northwest (Miller and others, 1991). The Idono Complex is faulted on the east-southeast against the Paleozoic and Mesozoic oceanic rocks of the Innoko terrane (unit LPP (eKlTr)) and is overlain by postaccretionary, unmetamorphosed volcanic and sedimentary rocks of Late Cretaceous to early Tertiary age.

Amphibolite-facies metamorphic grade is indicated by the assemblages: hornblende + garnet + biotite + intermediate plagioclase ± epidote and garnet + epidote + muscovite + biotite + feldspar + quartz, potassium feldspar + biotite + plagioclase + quartz, and sodic oligoclase + biotite + muscovite + quartz in semipelitic metasedimentary rocks (Miller and others, 1991). Metamorphic grain boundaries in many samples have 120° terminations, consistent with textural equilibrium during metamorphism (Miller and others, 1991). Locally, an intense late, or subsequent, phase of deformation has resulted in the development of blastomylonitic augen gneiss in granitic ortho-gneiss, and granulation of grain boundaries in semischist and other rock types (Miller and others, 1991).

Nine zircon fractions from three samples of orthogneiss from the Idono Complex define a U-Pb discordia with upper and lower intercepts with concordia of 2,062 ± 7 Ma and 182 ± 8 Ma (Miller and others, 1991). The upper intercept is interpreted as the crystallization age of the granitoid protolith. The lower intercept is interpreted as the approximate time of major episodic Pb loss. Zircons from the Idono Complex are significantly more discordant (generally about 50 percent loss of radiogenic lead) than are those from the Kanektok metamorphic complex (generally much less than about 25 percent loss of radiogenic lead; D.L. Turner, unpub. data, 1982; Box and others, 1990), suggesting that the Mesozoic thermal perturbation was of greater intensity in the Idono Complex, than in the Kanektok metamorphic complex (Miller and others, 1991). The U-Pb lower intercept falls in the range of the partly to totally reset K-Ar ages of white mica, biotite, and hornblende (Miller and others, 1991). Most K-Ar mineral ages (17 out of 21 ages) from the Idono Complex cluster in the range 190 to 120 Ma. Three out of eight samples yield hornblende ages greater than 190 Ma. The oldest sample gives an average amphibole age of 1,226±37 Ma and a biotite age of 324±10 Ma.

As mentioned above, a second metamorphic episode during the Jurassic to Early Cretaceous is tentatively proposed for this unit on the basis of the 182±8-Ma U-Pb lower-intercept age of zircons from the Idono Complex and variably reset K-Ar mineral ages from both metamorphic complexes. The fact that nearly all of the K-Ar ages on hornblende from 58 samples from the Kanektok metamorphic complex and five out of eight samples from the Idono Complex were reset during the Jurassic or Early Cretaceous suggests that temperatures at that time were near the blocking temperature of hornblende (approximately 500°C) throughout much of this unit. If the thermal disturbance was, in fact, a subsequent metamorphic episode, temperatures may have been as high as those of the upper greenschist facies. Enigmatic to this interpretation, however, is the absence in both complexes of textural evidence of an overprinting crystallization event that could correlate with the isotopic disturbance (Miller and others, 1991; J.Y. Bradshaw, unpub. data, 1990). An alternative interpretation of the Jurassic and Early Cretaceous isotopic data, particularly the K-Ar mineral ages, is that they are cooling ages resulting from uplift and unroofing.

The two Early Proterozoic metamorphic complexes that make up this unit were probably once continuous and have been offset right-laterally in the late Mesozoic or Cenozoic (Box and others, 1990; Miller and others, 1991). Several linear northeast-trending faults (Iditarod-Nixon Fork, Susulatna, Golden Gate faults) separate the Kanektok and Idono complexes.

The Iditarod-Nixon Fork fault shows evidence of about 90 km of Cenozoic right-lateral offset (Miller and Bundtzen, 1988). Similar senses of displacement on the other faults would explain the present distribution of the metamorphic complexes. The Jurassic to Early Cretaceous thermal disturbance within the Idono Complex is therefore interpreted to be related to the same tectonic events proposed by Box (1985c) to explain the Mesozoic partial subduction of the Proterozoic continental block beneath an intraoceanic volcanic-arc complex during arc-continent collision, referred to above and discussed in the last section of this geographic area.

The Kanektok and Idono complexes are similar in their structural relation to adjacent oceanic complexes and their predominance of Jurassic and Early Cretaceous K-Ar ages to the metamorphic belt of continental affinity that surrounds the Yukon-Koyukuk basin to the north (blueschist- and greenschist-facies rocks of the southern Brooks Range and greenschist- and amphibolite-facies rocks of the Ruby terrane; Dusel-Bacon and others, 1989). Metamorphic units of the south end of the Ruby terrane (units GNI,H (eKmJ) and GNS (eKm₽)) are shown on plate 1 and discussed in the preceding section of this report (and more completely in Dusel-Bacon and others, 1989). The general similarity of the Jurassic and Early Cretaceous histories of the southern Brooks Range, the Ruby terrane, and the metamorphic complexes of this unit suggests a coherent tectonic process, namely obduction of an oceanic arc onto the Proterozoic and Early Paleozoic continental margin of North America (Box, 1983, 1985a).

GNH (mJ₹)

This unit is made up of a nappe complex of high-pressure greenschist-facies, glaucophane- and lawsonite-bearing schistose metabasalt, strongly foliated volcaniclastic rocks, black phyllite, tuffaceous phyllite and marble, and calcareous schist (Box, 1985c). Isolated occurrences of ultramafic rocks crop out within this unit north of Cape Peirce in the Hagemeister Island quadrangle. Lithologies are divisible into three nappes, or thrust sheets: an upper metabasaltic sheet, a middle metapsammitic sheet, and a lower mixed calcareous metasedimentary and metabasaltic sheet. Serpentinite is found locally between thrust sheets. Recrystallization of these rocks is generally incomplete, and primary textures and mineralogies are partly preserved. Rocks are complexly deformed and locally possess a mélange-like fabric. This unit makes up the Cape Peirce subterrane of the Goodnews terrane (figs. 3 and 6). Lithologic similarities with overlying (Togiak terrane) and underlying (Platinum subterrane of the Goodnews terrane) thrust sheets of prehnite-pumpellyite-facies rocks suggest that protoliths are of Permian and Late Triassic age. Metamorphic protoliths include basalt, diabase, gabbro, volcanic breccia, tuff, volcanic sandstone and conglomerate, limestone, and limestone conglomerate (Box, 1985c).

High-pressure greenschist- (blueschist-) facies metamorphism is characterized in meta-basalt by the assemblage quartz + chlorite ± calcite ± lawsonite ± sphene ± white mica ± pumpellyite ± glaucophane ± actinolite ± epidote and in metavolcaniclastic rocks by the assemblage quartz + chlorite + calcite + epidote + plagioclase + glaucophane + actinolite (Hoare and Coonrad, 1978b; Box, 1985c). Glaucophane both rims and is rimmed by actinolite (S.E. Box, unpub. data, 1984). Effects of greenschist-facies replacement of blueschist-facies mineral assemblages are seen in the widespread overgrowth and replacement of mafic minerals by chlorite. The diagnostic high-pressure minerals glaucophane and lawsonite are sparse and poorly developed, suggesting either that: (1) they are controlled by subtle compositional variations; (2) these rocks record transitional greenschist-to blueschist-facies metamorphism; or (3) blueschist-facies metamorphism was subsequently overprinted by metamorphism that evolved into conditions of the intermediate-pressure greenschist facies. The highly tectonized and ophiolitic character of these rocks and the presence of high-pressure minerals suggest that this unit developed within a subduction complex (Hoare and Coonrad, 1978b; Box, 1985b, c).

Metamorphism is bracketed between the postulated Late Triassic age of the youngest protolith and the Middle Jurassic age of postmetamorphic plutons that intrude this unit. A 231.2±6.9-Ma K-Ar age on amphibole from schist of this unit (W.K. Wallace, oral commun., 1984; data in Box, 1985c) suggests that metamorphism may have begun during Late Triassic time.

GNS (mJ₹)

This unit is composed of schistose metavolcanic and metasedimentary rocks that are correlative with the schistose nappes of unit GNH (mJ₹) described above, but which lack glaucophane or lawsonite, and an unfoliated package of uralitized metagabbro, serpentinized peridotite, and metadiabase (Box, 1985c). The schistose rocks are part of the Cape

Peirce subterrane of the Goodnews terrane and are exposed in structural windows through unit LPP $(eKlTR)_1$ (Togiak terrane of Box, 1985c) (figs. 3 and 6). The protoliths of the unfoliated package are interpreted by Box (1985c) to make up the stratigraphically lower part of the structurally overlying Togiak terrane and to be Late Triassic in age. Protoliths of the schistose package are thought to include Permian and Late Triassic basalt, diabase, gabbro, volcanic breccia, tuff, and volcanic sandstone and conglomerate (Box, 1985c).

Mafic rocks in the schistose package contain the metamorphic mineral assemblages chlorite + epidote + albite + actinolite + calcite ± sphene ± white mica ± quartz ± pumpellyite, and hornblende + plagioclase + clinozoisite + epidote + sphene + quartz + chlorite. Unfoliated metagabbro contains approximately 50 percent secondary actinolite and is characterized by the metamorphic mineral assemblage actinolite ± albite ± tremolite ± sphene ± chlorite ± calcite. Unfoliated metadiabase contains the metamorphic minerals epidote, actinolite, plagioclase, and chlorite (Box, 1985c).

A Middle Jurassic minimum metamorphic age is indicated by the age of unfoliated postmetamorphic plutons that intrude this unit (Hoare and Coonrad, 1978a). A Late Triassic maximum metamorphic-age constraint is indicated by the probable age of the youngest protolith. A single 231.9±6.9-Ma K-Ar age on amphibole from higher pressure rocks of unit GNH (mJlTR) (Goodnews terrane) (W.K. Wallace, oral commun., 1984; data in Box, 1985c), interpreted as being a more deeply subducted equivalent of the same package of rocks, suggests that metamorphism may have begun during Late Triassic time.

GNI,H (eKlTR)

Undifferentiated intermediate-pressure greenschist-facies and high-pressure greenschist- (blueschist-) facies mafic schist, quartzose schist, calcareous schist, marble, phyllite, and a minor amount of graphite schist (Hoare and Coonrad, 1959a, 1961a) make up this unit. These rocks are part of the Nukluk subterrane of the Goodnews terrane and are found along the boundary between the Kilbuck and Goodnews terranes (figs. 3 and 6). Latest Devonian marbles are present within this unit (A.G. Harris, written commun., 1989) but, on the basis of lithologic correlation with fossiliferous rocks in the adjacent prehnite-pumpellyite-facies unit LPP $(eKlTR)_1$ to the south, cherts may range from Early Mississippian to as young as latest Jurassic (Tithonian) in age (Box, 1985c).

Intermediate-pressure greenschist-facies metamorphism is characterized by the presence of chlorite, epidote, and actinolite within the mafic schist (J.M. Hoare, written commun., 1973). Within the southern exposure of this unit, in the Goodnews Bay quadrangle, mafic schist contains the mineral asssemblage chlorite + actinolite + epidote ± sphene ± calcite ± glaucophane ± plagioclase (M.M. Donato., unpub. data, 1984). The sporadic occurrence of glaucophane (pl. 1) in that area indicates the localized development of high-pressure conditions (Hoare and Coonrad, 1978b). Within the northern exposure of this unit, in the Bethel quadrangle, high-pressure conditions are also indicated locally by (1) cores of lavender-blue magnesio-riebeckite (a sodic amphibole) within pale-green amphiboles, and (2) by calcic to sodic-compositions of the pale-green rims of these amphiboles (sample 87SR1b, table 2, loc. 2, Bethel quadrangle) and of pale-green amphiboles from a different sample nearby (sample 87SR5, table 2, loc. 2, Bethel quadrangle) (S.M. Roeske, written commun., 1988). The pale-green amphiboles are actinolite to winchite in composition and have a high sodium content for a given Tschermak component and plot more closely along the glaucophane-substitution line compared to actinolite from low-pressure environments (S.M. Roeske, written commun., 1991; Laird and Albee, 1981).

Given the uncertainty in the age of the protoliths, the maximum age of metamorphism is poorly constrained. Because the oldest documented Phanerozoic metamorphism in the area occurred between Late Triassic and Middle Jurassic time (units GNS (mJlTR) and GNH (mJlTR)), the maximum age of metamorphism tentatively is considered to apply to this unit also. A latest Jurassic to earliest Cretaceous minimum metamorphic age is suggested by a 146±15-Ma K-Ar age on actinolite from the northern exposure of this unit (Box and Murphy, 1987).

LPP $(eKlTR)_1$

The very weakly to weakly metamorphosed metabasalt, metagabbro, metavolcaniclastic rocks, metatuff, metagraywacke, argillite, metaconglomerate, metachert, and metalimestone that compose this extensive unit are included in the Togiak, Goodnews, Nyac, and Tikchik terranes (figs. 3 and 6). Rocks range in age from Ordovician to latest Jurassic (Tithonian) in the Hagemeister Island, Goodnews Bay, and Bethel quadrangles (Goodnews terrane); from early Paleozoic to Late Triassic in the Taylor Mountains, Bethel, Goodnews Bay, and Dillingham quadrangles (Tikchik terrane); from Late Triassic to Early Cretaceous in the Sleetmute, Bethel, Taylor Mountains, Goodnews Bay, Dillingham, Hagemeister Island, and Nushagak Bay quadrangles (Togiak terrane); and from Middle to Late Jurassic in the Russian Mission and Bethel quadrangles (Nyac terrane) (Hoare and Coonrad, 1959a, b; 1961a, b; J.M. Hoare and W.L. Coonrad, unpub. data, 1976; Hoare and Coonrad, 1978a; J.W. Miller, written commun., 1982; Box, 1983, 1985c).

Rocks of this unit generally have well-preserved primary igneous or depositional fabrics. Penetrative structural fabrics (slaty cleavage) are sporadically developed. Typical metamorphic mineral assemblages may include quartz, chlorite, epidote, calcite, albite, sphene, prehnite, pumpellyite, clinozoisite, and white mica. Laumontite veins are found sporadically throughout the area (S.E. Box and M.M. Donato, unpub. data, 1984).

The age of metamorphism is poorly constrained. The lack of structural fabric, the disrupted character, and the very low grade of this unit make it difficult both to determine which rocks have been metamorphosed and to assess the relation between metamorphism and the intrusion of crosscutting igneous bodies. Such information is essential for placing constraints on the metamorphic age. The varied geologic histories and tectonic settings of rock packages that compose this metamorphic unit (Box, 1985c, d) suggest that this seemingly uniform low-grade metamorphism actually may be the result of several unrelated metamorphic episodes that occurred prior to, during, and subsequent to the juxtaposition of the regional lithotectonic terranes, discussed in the following section. However, at present, metamorphic data are insufficient to permit clearly distinguishable subdivisions of this unit into areas of differing metamorphic history.

Metamorphism of this unit is considered to have occurred prior to Early Cretaceous time. This minimum metamorphic age is based on the fact that an unmetamorphosed Valanginian sequence in the northern part of Goodnews Bay and the southern part of Bethel quadrangles contains prehnite-pumpellyite-bearing metavolcanic clasts (Murphy, 1987). This constraint is tentatively applied to the entire unit.

Determination of the maximum metamorphic age is more difficult because the youngest protolith age (Cretaceous) of the tectonically juxtaposed terranes included in this unit cannot be assumed to indicate a maximum metamorphic age for this entire unit. Because the oldest documented Phanerozoic metamorphism in the area occurred no earlier than Late Triassic time (units GNS (mJIT̄R) and GNH (mJIT̄R)), this maximum age of metamorphism tentatively is considered to apply to this unit also. The fact that a granodioritic pluton on Hagemeister Island, dated as early Middle Jurassic in age on the basis of a 183±7-Ma K-Ar age on biotite (William Connelly, written commun., 1980; data in Box, 1985c), contains secondary sericite, chlorite, and epidote (Box, 1985c) and that prehnite-pumpellyite-bearing rocks northeast of Kulukak Bay are dated as Late Jurassic (Oxfordian) in age indicate that at least some of the low-grade metamorphism is Middle Jurassic or younger in age.

PROPOSED TECTONIC ORIGIN OF MESOZOIC LOW-GRADE METAMORPHISM IN THE KILBUCK AND AHKLUN MOUNTAINS AREA

Low-grade Mesozoic metamorphism in the Kilbuck and Ahklun Mountains area is attributed to progressive underthrusting of oceanic crustal fragments (accretionary forearc) of the Goodnews terrane beneath the northwest margin of an intraoceanic arc (Togiak terrane), followed by underthrusting of the Early Proterozoic continental metamorphic complex (Kilbuck terrane) beneath the northwest margin of Goodnews terrane (fig. 6) (Box, 1985b, d). The above mentioned terranes are considered to be major components in the tectonic consolidation of southwestern Alaska whereby the Togiak arc complex (Goodnews, Togiak, and Tikchik terranes) overrode the Alaskan continental margin (Kilbuck, Ruby, and Nixon Fork terranes) (fig. 3) (Wallace, 1984; Box, 1985a).

According to this tectonic model, metamorphism of blueschist- and greenschist-facies units GNH (mJIT̄R) and GNS (mJIT̄R), respectively, occurred during the first episode of underthrusting. These two units make up the Cape Peirce subterrane of the Goodnews terrane of Box (1985b, d) (fig. 6). Box believes that this subterrane structurally underlies the prehnite-pumpellyite-facies rocks of the Togiak terrane and overlies the prehnite-pumpellyite-facies rocks of the Platinum subterrane of the Goodnews terrane (terranes and subterranes are those of Box, 1985d) along low-angle southeast-dipping faults (fig. 6). Both of these areas of prehnite-pumpellyite-facies rocks are included in unit LPP (eKIT̄R)$_1$. Metamorphism of the Cape Peirce subterrane is presumed to have occurred during collision and partial subduction of an oceanic plateau (Platinum subterrane of the Goodnews terrane) beneath an overriding intraoceanic volcanic arc (Togiak terrane). Lithologic similarities between the protoliths of the schistose blueschist- and greenschist-facies rocks of the Cape Peirce subterrane and those of the relatively undeformed and low-grade overlying Togiak terrane and underlying Platinum subterrane suggest that the rocks of the Cape Peirce subterrane are the more tectonized equivalents of the adjacent two terranes (Box, 1985b). Mafic and ultramafic plutons that intrude the Cape Peirce subterrane, the overlying Togiak terrane, and the underlying Platinum subterrane, provide a Middle Jurassic minimum age for amalgamation of the three subterranes.

Structural data suggest that the overriding arc of the Togiak terrane was originally thrust to the north-northeast over the Goodnews terrane (Box, 1985b). However, the low-angle fault mapped between the upper plate Togiak terrane and the underlying Cape Peirce terrane (fig. 6) juxtaposes lower temperature and pressure rocks over higher temperature and pressure rocks, suggesting that the fault is a low-angle normal fault rather than a thrust fault (Box, 1985b). As suggested by Box, a good explanation for the present relation between the plates is that early north-northeastward contractional faulting was followed by extensional (detachment) faulting. This same fault relation (lower grade rocks above higher grade rocks) is found in the southern Brooks Range and Ruby geanticline (Dusel-Bacon and others, 1989, and references therein); faulting in all of these areas may have the same origin (extensional reactivation of earlier contractional structures).

The greenschist- and blueschist-facies rocks of unit GNl,H (eKlTR) were probably metamorphosed during the second episode of underthrusting. These rocks crop out along the northwest margin of the Nukluk subterrane of the Goodnews terrane of Box (1985d) (fig. 6). Late Jurassic to Early Cretaceous metamorphism of unit GNl,H (eKlTR), and retrograde metamorphism of unit AMP (X) + GNS (eKJ), probably took place as the latter (continental Kilbuck terrane) was partially thrust beneath the accretionary forearc (Goodnews terrane) of the intraoceanic volcanic arc (Togiak terrane) (Box, 1985d). The following evidence supports this interpretation of the metamorphic history: (1) unit GNl,H (eKlTR) is found along the tectonic boundary between the Kilbuck and Goodnews terranes, and (2) the K-Ar age (146±14 Ma) on actinolite from unit GNl,H (eKlTR) falls in the same range as the Jurassic and Early Cretaceous K-Ar ages (120-150 Ma) from the Kilbuck terrane.

The minimum age of thrusting and metamorphism is constrained by the Cenomanian (early Late Cretaceous) age of unmetamorphosed clastic rocks (Box and Elder, 1992) that overlap the Togiak, Goodnews, and Kilbuck terranes.

CENTRAL AND SOUTHERN ALASKA RANGE AND ALASKA PENINSULA

GNS (KM)

This unit comprises sheared and foliated quartz and quartz-feldspar grit and quartzite intercalated with quartz-muscovite-chlorite and quartz-muscovite-biotite schist, and subordinate phyllite, limestone, and metachert (Patton and others, 1980). It crops out in the central Alaska Range in the southeast corner of the Medfra quadrangle and probably includes both the Proterozoic and (or) Paleozoic basement rocks and the overlying middle Paleozoic rocks of the Yukon-Tanana terrane (fig. 3).

The metamorphic history of these rocks has not been studied. Northeast of this area in the Kantishna Hills of the Mount McKinley quadrangle, correlative basement rocks are interpreted to be polymetamorphic, and correlative middle Paleozoic rocks are interpreted to be monometamorphic (Bundtzen, 1981; Dusel-Bacon and others, 1993). Because reconnaissance mapping in the southeastern part of the Medfra quadrangle has not been adequate to delineate the two groups of rocks or to determine their metamorphic histories, the metamorphic age of this unit is tentatively bracketed between the Mississippian maximum metamorphic age of the basement rocks and the Cretaceous minimum metamorphic age of the episode that presumably metamorphosed both basement and overlying middle Paleozoic rocks in the eastern continuation of this metamorphic unit (Dusel-Bacon and others, 1993).

LPP/GNS (K)

This weakly metamorphosed sequence of prehnite-pumpellyite- and (or) greenschist-facies rocks is composed of phyllite and minor metalimestone and metachert of Pennsylvanian and Permian protolith age; metalimestone, carbonaceous slate and metasiltstone, and minor quartzite of Late Triassic protolith age; and greenstone (metagabbro and metadiabase) of unknown protolith age (Jones and others, 1983). These rocks are exposed on the east border of the McGrath quadrangle in the central Alaska Range and are included in the Pingston terrane (fig. 3). Very little study has been made of the metamorphism of these rocks.

In the eastern continuation of this unit in the northwest corner of the adjacent Talkeetna quadrangle (see Dusel-Bacon and others, 1993), fine-grained clastic rocks generally lack a semischistose fabric and cleavage, and greenstones contain well-developed secondary chlorite, biotite, and amphibole (Reed and Nelson, 1980).

A Cretaceous metamorphic age is suggested on the basis of the age relations of unit GNL,I (K), which is tentatively considered to be the higher grade equivalent of the eastern continuation of this unit and is shown on the adjacent metamorphic facies map (Dusel-Bacon and others, 1993). In unit GNL,I (K), metamorphism is thought to postdate the mid-Cretaceous age of the youngest protolith and to predate the Paleocene age of the overlying unmetamorphosed Cantwell Formation (Wolfe and Wahrhaftig, 1970; Gilbert and Redman, 1977).

LPP (lJl₸)

The weakly metamorphosed metabasalt, meta-andesite, metachert, metalimestone, and tuffaceous metasedimentary rocks that make up this unit crop out in the Lake Clark quadrangle of the southern Alaska Range. These rocks comprise the Chilikadrotna Greenstone (Bundtzen and others, 1979) and are interpreted to be part of the Peninsular terrane exposed as windows within the Kahiltna terrane (fig. 3) (Chris Carlson, oral commun., 1985; Wallace and others, 1989). Protoliths include sedimentary rocks and mafic and intermediate volcanic rocks from which conodonts of Late Triassic age (Wallace and others, 1989) and brachiopods and a pelecypod originally interpreted to be Silurian in age (Bundtzen and others, 1979) have been recovered. The minimum Late Triassic protolith age is well established, but the Silurian fossils cannot be located, and, therefore, this age cannot be confirmed. Bundtzen and others (1979) note that Na_2O, K_2O, and TiO_2 values from whole-rock chemical analyses of the metavolcanic rocks are similar to those of spilitic tholeiites found in mid-ocean-ridge environments and that the association of mafic volcanic rocks, fine-grained clastic rocks, and chert suggests an ocean-floor assemblage.

Low-grade metamorphism has resulted in replacement of almost all of the original minerals in most rocks. In metabasalt and metatuff, metamorphism is characterized by the following: plagioclase that has been albitized or altered to calcite, pumpellyite, and prehnite(?); phenocrysts of clinopyroxene altered to chlorite and opaque minerals; minor hornblende rimmed with chlorite; rare olivine crystals altered largely to antigorite(?); zeolite-epidote masses; and a groundmass of secondary clinozoisite, magnetite, and chlorite, in part cored with zeolite(?). Veinlets of epidote and calcite or quartz and of pumpellyite and calcite cut metabasalt and metatuff. Metachert contains possible recrystallized radiolarians, shown as faint outlines of rounded organic features in plain light. Metalimestone that is coarse grained in texture contains partly to completely recrystallized calcite and minor epidote minerals (Bundtzen and others, 1979).

The age and tectonic origin of the metamorphic episode that affected these rocks is unknown. Metamorphism is known to postdate the Late Triassic age of the youngest protolith and to predate the deposition of the Late Jurassic and Early Cretaceous (Kimmeridgian to Valanginian) flysch that is interpreted to overlie this unit (Wallace and others, 1989). Speculations about the tectonic setting of these rocks that in turn bear on their metamorphic history include the possibilities that they represent: (1) part of the basement to the Jurassic and Cretaceous flysch basin (Christine Carlson, oral commun., 1985) and (or) (2) a low-grade part of the pre-Jurassic mafic metavolcanic schist and greenstones of the Tlikakila complex (GNS,AMP (Tl₸)) and the Kakhonak Complex (GNS,AMP (J)) to the south (Bundtzen and others, 1979), which may be a part of the pre-Jurassic basement to the Peninsular terrane (Wallace and others, 1989) (fig. 3). This second correlation would require an abrupt increase in metamorphic grade to the southeast.

GNS (J)

The mafic and intermediate composition metavolcanic rocks, metavolcaniclastic rocks, metalimestone, greenstone-limestone breccia, metatuff, metasedimentary rocks, and metachert that compose this unit crop out in the Iliamna and Mount Katmai quadrangles adjacent to the Alaska-Aleutian Range batholith. They are part of the Peninsular terrane (fig. 3). Protoliths include Upper Triassic calcareous sedimentary rocks and mafic volcanic rocks and Lower Jurassic volcaniclastic sedimentary rocks and mafic and intermediate volcanic rocks (Detterman and Reed, 1980). Metavolcanic rocks are generally massive, but locally more schistose variants are found. Low- to intermediate-pressure greenschist-facies metamorphism is characterized in mafic rocks by the minerals chlorite, actinolite, epidote, muscovite, albite, calcite and quartz (Detterman and Reed, 1980).

On the basis of an overall increase in metamorphic grade toward the Jurassic plutons of the Alaska-Aleutian Range batholith (Detterman and Reed, 1980) by the two metamorphic units on this map (GNS (J) and

GNS,AMP (J)), which lie within or adjacent to them, metamorphism is thought to have been associated with this plutonic episode.

GNS,AMP (J)

This unit comprises a heterogeneous assemblage of penetratively deformed, undifferentiated greenschist- and amphibolite-facies metasedimentary and mafic meta-igneous rocks of the Kakhonak Complex in the Iliamna (Detterman and Reed, 1980) and Mount Katmai quadrangles (J.R. Riehle and R.L. Detterman, unpub. data, 1985). Rocks are preserved as roof pendants in a north east-trending belt within Jurassic plutons of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973). Common rock types include mafic schist, calcareous schist, pelitic schist, phyllite, argillite, slate, quartzite, metavolcanic rocks, metavolcaniclastic rocks, marble, massive to layered metagabbro, metachert, and gneiss.

Protoliths are a wide variety of siliciclastic rocks, calcareous rocks, mafic to intermediate intrusive and extrusive rocks, and chert. Lithologic correlation with rocks to the east that are considered to be lower grade equivalents of the Kakhonak Complex has been used to suggest Late Triassic and Early Jurassic ages. These presumed lower grade equivalents are the Cottonwood Bay Greenstone, the Kamishak Formation, and the Talkeetna Formation, all of which compose unit GNS (J) described previously and which belong to the stratified part of the Peninsular terrane (fig. 3) (Detterman and Reed, 1980; W.K. Wallace, written commun., 1986). Both the Jurassic plutons of the Alaska-Aleutian Range batholith and the probable Lower(?) Jurassic and Upper Triassic volcanic protoliths of the associated metamorphic rocks are products of an Early Mesozoic magmatic arc that developed within the Peninsular terrane and adjoining parts of a composite terrane, composed of the Peninsular, Wrangellia, and Alexander terranes, that stretched across southern Alaska (Plafker and others, 1989; Wallace and others, 1989).

Rock fabrics range from those that are imperfectly schistose to those in which segregation banding is well developed. Dynamothermal metamorphism resulted in greenschist-facies rocks and, to a lesser extent, in amphibolite-facies rocks with a penetrative fabric. Locally, thermal metamorphism has produced rocks with granoblastic textures and amphibolite-facies and pyroxene hornfels-facies mineral assemblages (Detterman and Reed, 1980).

Greenschist-facies metamorphism is characterized by the following metamorphic-mineral assemblages: muscovite + albite + quartz ± chlorite ± epidote ± actinolite ± garnet ± calcite in pelitic rocks, actinolite + chlorite + epidote ± muscovite ± albite in mafic rocks, and calcite + quartz ± tremolite and actinolite + albite + calcite + chlorite ± epidote ± sphene in calcareous schist.

Amphibolite-facies metamorphism is characterized by hornblende + plagioclase + biotite + garnet ± potassium-feldspar ± sphene in mafic rocks and biotite + muscovite + quartz + plagioclase + garnet ± potassium feldspar ± andalusite ± staurolite ± spinel in pelitic rocks. A small outcrop at the edge of Nonvianuk Lake contains abundant garnet and sillimanite in addition to biotite, muscovite, quartz, orthoclase, and, in a few specimens, andalusite. Pelitic rocks in which Al_2SiO_5 polymorphs, indicative of pressure conditions during metamorphism, could develop are extremely rare, but the occurrence of andalusite at two localities suggests that, at least locally, metamorphism took place under low-pressure conditions. Although plutonic rocks have not been mapped near the andalusite localities, the development of andalusite may have resulted from thermal metamorphism associated with Jurassic plutons of the Alaska-Aleutian Range batholith and not necessarily from dynamothermal metamorphism that produced the penetrative fabric in some of the rocks of this unit. Any thermal metamorphism associated with intrusion of the batholith would be expected to have been of a low pressure-facies series, given the fact that the batholith was shallow enough to intrude its own ejecta (the Talkeetna Formation) (Detterman and Reed, 1980).

The metamorphic and tectonic history of the Kakhonak Complex is uncertain. The relation of this metamorphic complex to older rocks is obscured by intrusive contacts. Mapping of the Kakhonak Complex has not been detailed enough to determine if these rocks consist of fault-bounded packages of differing metamorphic grade, as is the case with metamorphic unit GNS,AMP (TIƦ), described below, that occurs adjacent to and within Late Cretaceous and Tertiary plutons of the Alaska-Aleutian Range batholith to the west-northwest.

Metamorphism of the Kakhonak Complex is presumed to postdate the probable Early Jurassic youngest protolith age and, on the basis of field observations, is interpreted to have been associated with the forceable emplacement of the Jurassic (176-155-Ma) plutons of the Alaska-Aleutian Range batholith and accompanying intermittent tectonism (Reed and Lanphere, 1973). Although the possibility of a preplutonic dynamothermal origin of metamorphism cannot be ruled out, no prebatholithic structural features have been recognized in the country rocks. Folds and foliation of country rocks trend northeast and generally conform to the contacts of the plutonic rocks. Foliation is well developed near the contacts of the plutons and may extend into the pluton for as much as 2 km. These features indicate that, at the present level of exposure, many of the Jurassic plutonic rocks may have been syntectonic and forcefully intruded (Reed and Lanphere, 1973). Additional evidence for metamorphism being associated with Jurassic plutonism is an overall increase in metamorphic grade toward these plutons by the two metamorphic units (pl. 1, units GNS (J) and GNS,AMP (J)) that lie within or adjacent to them (Detterman and Reed, 1980).

GNS,AMP (TIR̄)

This unit makes up a heterogeneous assemblage of penetratively deformed, undifferentiated greenschist- and amphibolite-facies metasedimentary and mafic meta-igneous rocks of the Tlikakila complex of Wallace and others (1989) in the Lake Clark quadrangle (Carlson and Wallace, 1983; Nelson and others, 1983) and of the westernmost part of the Kakhonak Complex in the southern part of the Iliamna quadrangle (Detterman and Reed, 1980) and the northern part of the Mount Katmai quadrangle (J.R. Riehle and R.L. Detterman, unpub. data, 1985). It crops out in a northeast-trending belt within and adjacent to the Late Cretaceous and Tertiary plutons of the Alaska-Aleutian Range batholith. Common rock types in the Tlikakila complex include calcareous schist, pelitic schist, phyllite, schistose quartzite, metabasalt, metachert, marble, cummingtonite schist, metavolcanic breccia, massive to layered metagabbro and pyroxenite that locally intrude the supracrustal elements of the Tlikakila complex, and metaserpentinite (Carlson and Wallace, 1983; Christine Carlson, oral commun., 1985). Similar rock types are present in the areas of this unit originally mapped as part of the Kakhonak Complex (Detterman and Reed, 1980; W.K. Wallace, oral commun., 1986).

Protoliths are a wide variety of siliciclastic rocks, calcareous rocks, mafic to intermediate intrusive and extrusive rocks, chert, and, in the Tlikakila complex, also ultramafic rocks. Protolith ages are poorly known. Lithologic correlation with Late Triassic and Early Jurassic lower grade equivalents on the west side of Cook Inlet (GNS (J)) have been used to suggest Late Triassic and Early Jurassic ages for the rocks of this unit in the Iliamna and Mount Katmai quadrangles (Detterman and Reed, 1980; R.L. Detterman and J.R. Riehle, unpub. data, 1985). On the basis of conodont identification, protoliths of the Tlikakila complex include at least some Upper Triassic rocks (Wallace and others, 1989). However, on the basis of the age span of conodonts from several marble samples for which the specific age could not be determined, a broader protolith age ranging from Ordovician to Late Triassic is tentatively assigned (A.G. Harris, unpub. data, 1984).

The Tlikakila complex has undergone heterogeneous polyphase deformation and is characterized by steeply dipping, isoclinally folded, and generally schistose rock assemblages. Schistose rocks have been affected by a later period of deformation that produced closely spaced fractures and that, locally, tightly folded the earlier foliation. Most contacts are faults and little lateral continuity of rock assemblages is present as a result of complex tectonic mixing (Carlson and Wallace, 1983). Although most rocks have been penetratively deformed, the degree of metamorphism varies from fault block to fault block, indicating juxtaposition of rocks that may have had different metamorphic histories or that were derived from different parts of a single tectonic regime. The majority of these rocks were metamorphosed under greenschist-facies conditions; however, some rocks have undergone lower to upper amphibolite-facies metamorphism, and a small percentage appear to be virtually unmetamorphosed (Christine Carlson, oral commun., 1985). Pelitic schist, phyllite, metasiltstone, and quartzite commonly contain quartz, muscovite, biotite, and locally garnet; some contain plagioclase and cummingtonite. Schistose calc-silicate rocks contain calcite and various combinations of talc, fibrous amphibole, clinozoisite, quartz, diopside, chlorite, and garnet. Garnet in schistose rocks is broken, and the fragments are drawn out parallel to the foliation, indicating garnet formed early in, or prior to, the development of the foliation. Garnet and biotite in schistose rocks is commonly replaced by chlorite. Mafic metavolcanic rocks primarily consist of chlorite, epidote, and fibrous amphibole. Metamorphism of some mafic rocks has produced a nearly homogeneous cummingtonite schist that also contains minor talc and carbonate. Metaserpentinite commonly contains talc and magnetite, and metagabbro is composed of either (1) hornblende (in places partly altered to saussurite, uralite, and actinolite) and calcic plagioclase or (2) actinolite, relict clinopyroxene, clinozoisite (originally calcic-plagioclase), chlorite, and serpentine (Nelson and others, 1983; Christine Carlson, oral commun., 1985).

The metamorphic and tectonic history of this unit is uncertain. The relation of this unit to older rocks is obscured by intrusive contacts. Within the Tlikakila complex, internal relations also are obscured by fault contacts. Metamorphism of this unit is known to postdate the Late Triassic minimum protolith age of rocks from the Tlikakila complex. The spatial association between the metamorphic rocks of this unit and adjacent Late Cretaceous and Tertiary plutons suggests that metmorphism may have been related to either one or both of the Late Cretaceous to Paleocene or the late Eocene to Oligocene plutonic episodes. However, the possibility of a preplutonic dynamothermal origin of metamorphism cannot be ruled out. At one locality within this unit, a clinopyroxene-hornblende andesite dike that crosscuts the metamorphic rocks of the Tlikakila complex has yielded a K-Ar age on hornblende of 79.6±2.4 Ma (Wallace and others, 1989).

Stratigraphic affinities of the Tlikakila complex of the Lake Clark quadrangle are uncertain, but on the basis of lithologic similarities and spatial relations several correlations are possible. The Chilikadrotna Greenstone (LPP (lJlTr)), described above, is the nearest pre-Late Jurassic unit to the west and may be correlative with the metavolcanic part of the Tlikakila complex (Nelson and others, 1983). Wallace and his coworkers (1989) have found that the Chilikadrotna Greenstone includes Late Triassic elements and suggest that it is probably depositional basement for Jurassic and Cretaceous flyschoid rocks of the Kahiltna terrane (fig. 3). Correlatives of the metasedimentary and possibly the metavolcanic rocks may occur to the southeast in the Kakhonak Complex that is included in unit GNS,AMP (J) (Nelson and others, 1983; Christine Carlson, oral commun., 1985). The Tlikakila complex may also correlate with unit GNS (J), which consists of Triassic to Lower Jurassic rocks (Wallace and others, 1989). According to this correlation, metasedimentary elements would correspond to the Upper Triassic Kamishak Formation, and metavolcanic elements would correspond to the Cottonwood Bay Greenstone and the Talkeetna Formation. These units are an integral part of the Peninsular terrane (fig. 3), suggesting that the Kakhonak Complex, the Tlikakila complex, and the Chilikadrotna Greenstone are parts of a northwestward continuation of the Peninsular terrane displaying some variation in facies (Wallace and others, 1989).

LPP (eTlK)

The weakly metamorphosed sequence of laumontite-facies interbedded sandstone and mudstone (Moore, 1973) that makes up this unit crop out on the Sanak and Shumagin Islands off the southeast coast of the Alaska Peninsula. Protoliths have tentatively been assigned a latest Cretaceous (Maastrichtian) age on the basis of sparse macrofossil (*Inoceramus*) collections from Shumagin Island and lithologic correlation with the Kodiak Formation (Moore, 1973; Nilsen and Moore, 1979).

Rocks have a pervasive slaty cleavage whose development is ascribed to the mechanical rotation of platy minerals during dewatering of the sediments (Moore, 1973). Petrographic evidence of burial metamorphism consists of rare alteration of plagioclase to prehnite, laumontite, and possibly albite. These minerals are only present in specimens without calcareous cement and (or) calcareous products, which Moore (1973) points out is consistent with patterns of burial metamorphism in the Great Valley sequence of California (Dickinson and others, 1969). Whole-rock X-ray studies confirm the optical identification of prehnite and laumontite and indicate that well-crystallizedillite (muscovite) and chlorite are the dominant clay minerals in the upper parts of graded beds (Moore, 1973). Distribution of this zeolite-(laumonite-) facies burial metamorphism appears to be nonstratigraphic (Moore, 1973).

The timing of burial metamorphism of these rocks is bracketed between the Late Cretaceous protolith age and the early Tertiary (Paleocene) age (Wilson, 1981) of crosscutting intrusive rocks.

REFERENCES CITED

Angeloni, L.M., and Miller, M.L., 1985, Greenschist-facies metamorphic rocks of north-central Iditarod quadrangle, west-central Alaska, *in* Bartsch-Winkler, Susan, ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 19-21.

Beikman, H.M., 1974, Geologic map of the southwest quadrant of Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-611, scale 1:250,000, 2 sheets.

Box, S.E., 1983, Tectonic synthesis of Mesozoic histories of the Togiak and Goodnews terranes, southwest Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 406.

———1985a, Early Cretaceous orogenic belt in northwestern Alaska: Internal organization, lateral extent, and tectonic interpretation, *in* Howell, D.G., ed., Tectonostratigraphic terranes of the Circum-Pacific region: Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, no. 1 (American Association of Petroleum Geologists bookstore, Tulsa, Oklahoma), p.137-145.

———1985b, Geologic setting of high-pressure metamorphic rocks, Cape Newenham area, southwestern Alaska, in Bartsch-Winkler Susan, ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 37-42.

———1985c, Mesozoic tectonic evolution of the northern Bristol Bay region, southwestern Alaska: Santa Cruz, Calif., University of California, Ph.D. dissertation, 125 p.

———1985d, Terrane analysis, northern Bristol Bay region, southwestern Alaska, *in* Bartsch-Winkler, Susan, ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 32-37.

Box, S.E., and Elder, W.P., 1992, Depositional and biostratigraphic framework of the Upper Cretaceous Kuskokwim Group, southwestern Alaska, *in* Bradley, D.C., and Ford, A.B., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 8-16.

Box, S.E., Moll-Stalcup, E.J., Frost, T.P., and Murphy, J.M., 1993, Preliminary geologic map of the Bethel and southern Russian Mission quadrangles, southwest Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-2226-A, scale 1:250,000.

Box, S.E., Moll-Stalcup, E.J., Wooden, J.L., and Bradshaw, J.Y., 1990, Kilbuck terrane: Oldest known rocks in Alaska: Geology, v.18, p. 1219-1222.

Box, S.E., and Murphy, J.M., 1987, Late Mesozoic structural and stratigraphic framework, eastern Bethel quadrangle, southwestern Alaska, *in* Hamilton, T.D., and Galloway, J.P., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p. 78-82.

Bundtzen, T.K., 1981, Geology and mineral deposits of the Kantishna Hills, Mt. McKinley quadrangle, Alaska: Fairbanks, Alaska, University of Alaska, M.S. thesis, 237 p.

Bundtzen, T.K., Gilbert, W.G., and Blodgett, R.B., 1979, The Chilikadrotna greenstone, an Upper Silurian metavolcanic sequence in the central Lake Clark quadrangle, Alaska; short notes on Alaskan geology—1978: Alaska Division of Geological and Geophysical Surveys, Geologic Report 61, p. 31-35.

Burk, C.A., 1965, Geology of the Alaska Peninsula—Island arc and continental margin (parts 1, 2, and 3): Geological Society of America Memoir 99, scale 1:1,000,000 and 1:250,000, 2 sheets, 250 p.

Carlson, Christine, and Wallace, W.K., 1983, The Tlikakila complex, a disrupted terrane in the southwestern Alaska Range [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 406.

Chapman, R.M., and Patton, W.W., Jr., 1979, Two upper Paleozoic sedimentary rock units identified in southwestern part of the Ruby quadrangle, *in* Johnson, K.M., and Williams, J.R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B59-B61.

Chapman, R.M., Patton, W.W., Jr., and Moll, E.J., 1985, Reconnaissance geologic map of the Ophir quadrangle, Alaska: U.S. Geological Survey Open-File Report 85-203, scale 1:250,000.

Detterman, R.L., Case, J.E., Wilson, F.H., Yount, M.E., and Alloway, W.H., 1983, Geologic map of the Ugashik, Bristol Bay, and part of the Karluk quadrangles, Alaska: U.S. Geological Survey Miscellaneous Studies Map MF-1539-A, scale 1:250,000.

Detterman, R.L., Miller, T.P., Yount, M.E., and Wilson, F.H., 1981, Geologic map of the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1229, scale 1:250,000.

Detterman, R.L., and Reed, L.R., 1980, Stratigraphy, structure, and economic geology of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-B, scale 1:250,000, 86 p.

Dickinson, W.R., Ojakangus, R.W., and Stewart, R.J., 1969, Burial metamorphism of the late Mesozoic Great Valley Sequence, Cache Creek, California: Geological Society of America Bulletin, v. 80, no. 3, p. 519-526.

Dillon, J.T., Patton, W.W., Jr., Mukasa, S.B., Tilton, G.R., Blum, Joel, and Moll, E.J., 1985, New radiometric evidence for the age and thermal history of the metamorphic rocks of the Ruby and Nixon Fork terranes, *in* Bartsch-Winkler, Susan, and Reed, K.M., eds., The United States Geological Survey in Alaska: Accomplishments during 1983: U.S. Geological Survey Circular 945, p.13-18.

Dusel-Bacon, Cynthia, Brew, D.A., and Douglass, S.L., 1996, Metamorphic facies map of southeastern Alaska—Distribution, facies, and ages of regionally metamorphosed rocks: U.S. Geological Survey Professional Paper 1497-D, 42 p., 2 pls.

Dusel-Bacon, Cynthia, Brosgé, W.P., Till, A.B., Doyle, E.O., Mayfield, C.F., Reiser, H.N., and Miller, T.P., 1989, Distribution, facies, ages, and proposed tectonic associations of regionally metamorphosed rocks of northern Alaska: U.S. Geological Survey Professional Paper 1497-A, 44 p., 2 pls.

Dusel-Bacon, Cynthia, Csejtey, Béla, Foster, H.L., Doyle, E.O., Nokleberg, W.J., and Plafker, George, 1993, Distribution, facies, ages, and proposed tectonic associations of regionally metamorphosed rocks of east- and south-central Alaska: U.S. Geological Survey Professional Paper 1497-C, 73 p., 2 pls.

Gemuts, I., Puchner, C.C., and Steffel, C.I., 1983, Regional geology and tectonic history of western Alaska: Journal of the Alaska Geological Society, v. 3, p. 67-86.

Gilbert, W.G., and Redman, Earl, 1977, Metamorphic rocks of Toklat-Teklanika Rivers area, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 50, 13 p.

Gottschalk, R.R., and Oldow, J.S., 1988, Low-angle normal faults in the south-central Brooks Range fold and thrust belt, Alaska: Geology, v. 16, no. 5, p. 395-399.

Hoare, J.M., and Condon, W.H., 1966, Geologic map of the Kwiguk and Black quadrangles, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-469, scale 1:250,000.

———1968, Geologic map of the Hooper Bay quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-523, scale 1:250,000.

———1971a, Geologic map of the Marshall quadrangle, western Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-668, scale 1:250,000.

———1971b, Geologic map of the St. Michael quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-682, scale 1:250,000.

Hoare, J.M., and Coonrad, W.L., 1959a, Geology of the Bethel quadrangle, Alaska: U.S. Geological Survey Miscellaneous

Geologic Investigations Series Map I-285, scale 1:250,000.

———1959b, Geology of the Russian Mission quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-292, scale 1:250,000.

———1961a, Geologic map of the Goodnews quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-339, scale 1:250,000.

———1961b, Geologic map of the Hagemeister Island quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-321, scale 1:250,000.

———1978a, Geologic map of the Goodnews and Hagemeister Island quadrangles region, southwestern Alaska: U.S. Geological Survey Open-File Report 78-9-B, scale 1:250,000.

———1978b, Lawsonite in southwestern Alaska, *in* Johnson, K.M., ed., The United States Geological Survey in Alaska: Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B55-B57.

———1979, The Kanektok metamorphic complex, a rootless belt of Precambrian rocks in southwestern Alaska, *in* Johnson, K.M., and Williams, J.R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B72-B74.

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

Jones, D.L., Silberling, N.J., Gilbert, W.G., and Coney, P.J., 1983, Interpretive bedrock geologic map of the Mount McKinley region: U.S. Geological Survey Open-File Report 83-11, scale 1:250,000, 2 sheets.

Laird, Jo, and Albee, A.L., 1981, Pressure, temperature, and time indicators in mafic schist: Their application to reconstructing the polymetamorphic history of Vermont: American Journal of Science, v. 281, p. 127-175.

Miller, E.L., 1987, Dismemberment of the Brooks Range orogenic belt during middle Cretaceous extension: Geological Society of America Abstracts with Programs, v. 19, no. 6, p. 432.

Miller, M.L., Bradshaw, J.Y., Kimbrough, D.L., Stern, T.W., and Bundtzen, T.K., 1991, Isotopic evidence for Early Proterozoic age of the Idono Complex, west-central Alaska: Journal of Geology, v. 99, no. 2, p. 209-223.

Miller, M.L., and Bundtzen, T.K., 1985, Metamorphic rocks in the western Iditarod quadrangle, west-central Alaska, *in* Bartsch-Winkler, Susan, and Reed, K.M., eds., The United States Geological Survey in Alaska: Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 24-28.

———1988, Right-lateral offset solution for the Iditarod-Nixon Fork fault, western Alaska, *in* Galloway, J.P., and Hamilton, T.D., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 99-103.

Miyaoka, R.T., and Dover, J.H., 1985, Preliminary study of shear sense in mylonites, eastern Ray Mountains, Tanana quadrangle, *in* Bartsch-Winkler, Susan, ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 29-32.

———1990, Shear sense in mylonites, and implications for transport of the Rampart assemblage (Tozitna terrane), Tanana quadrangle, east-central Alaska, *in* Dover, J.H., and Galloway, J. P., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological Survey Bulletin 1946, p. 51-64.

Moll-Stalcup, E.J., Wooden, J.L., Bradshaw, J.Y., and Box, S.E., 1990, A Sr, Nd, and Pb isotopic study of 2.07 Ga metaigneous rocks from the Kilbuck terrane, southwestern Alaska [abs.]: Geological Association of Canada, Mineralogical Association of Canada Program with Abstracts, v. 15, p. A89.

Moore, J.C., 1973, Cretaceous continental margin sedimentation, southwestern Alaska: Geological Society of America Bulletin, v. 84, no. 2, p. 595-614.

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

———1974b, Geologic and structural map of the Sanak Islands, southwestern Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-817, 1:63,360.

Murphy, J.M., 1987, Early Cretaceous cessation of terrane accretion, northern Eek Mountains, southwestern Alaska, *in* Hamilton, T.D., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p. 83-85.

Nelson, W.H., Carlson, Christine, and Case, J.E., 1983, Geologic map of the Lake Clark quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1114-A, scale 1:250,000.

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

Palmer, A.R., 1983, The decade of North American geology geologic time scale: Geology, v. 11, no. 9, p. 503-504.

Patton, W.W., Jr., 1984, Timing of arc collision and emplacement of oceanic crustal rocks on the margins of the Yukon-Koyukuk basin, western Alaska, [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 5, p. 328.

Patton, W.W., Jr., Box, S.E., Moll-Stalcup, E.J., and Miller, T.P., 1989, Geology of west-central Alaska: U.S. Geological Survey Open-File Report 89-554, 41 p.

Patton, W.W., Jr., Miller, T.P., Chapman, R.M., and Yeend, Warren, 1978, Geologic map of the Melozitna quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1071, scale 1:250,000.

Patton, W.W., Jr., and Moll, E.J., 1982, Structural and stratigraphic sections along a transect between the Alaska Range and Norton Sound, *in* Coonrad, W.L., ed., The United States Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 76-78.

———1984, Reconnaissance geology of the northern part of the Unalakleet quadrangle, *in* Coonrad, W.L., and Elliot, R.L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 24-27.

———1985, Geologic map of the northern and central parts of the Unalakleet quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1749, scale 1:250,000.

Patton, W.W., Jr., Moll, E.J., Dutro, J.T., Jr., Silberman, M.L., and Chapman, R.M., 1980, Preliminary map of the Medfra quadrangle, Alaska: U.S. Geological Survey Open-File Report 80-811-A, scale 1:250,000.

Patton, W.W., Jr., Moll, E.J., Lanphere, M.A., and Jones, D.L., 1984, New age data for the Kaiyuh Mountains, *in* Coonrad, W.L., and Elliot, R.L., eds., The United States Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 30-32.

Patton, W.W., Jr., Tailleur, I.L., Brosgé, W.P., and Lanphere, M.A., 1977, Preliminary report on the ophiolites of northern and western Alaska, *in* Coleman, R.G., and Irwin, W.P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 51-58.

Plafker, George, Nokleberg, W.J., and Lull, J.S., 1989, Bedrock geology and tectonic evolution of the Wrangellia, Peninsular, and Chugach terranes along the Trans-Alaskan crustal transect in the Chugach Mountains and southern Copper River basin, Alaska: Journal of Geophysical Research, v. 94, no. B4, p. 4255-4295.

Reed, B.L., and Lanphere, M.A., 1973, Alaska-Aleutian Range batholith: Geochronology, chemistry, and relation to circum-Pacific plutonism: Geological Society of America Bulletin, v. 84, no. 8, p. 2583-2610.

Reed, B.L., Miesch, A.T., and Lanphere, M.A., 1983, Plutonic rocks of Jurassic age in the Alaska-Aleutian Range batholith: Chemical variations and polarity: Geological Society of America Bulletin, v. 94, no. 10, p. 1232-1240.

Reed, B.L., and Nelson, S.W., 1980, Geologic map of the Talkeetna quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1174, 15 p., scale 1:250,000.

Silberman, M.L., Moll, E.J., Patton, W.W., Jr., Chapman, R.M., and Connor, C.L., 1979, Precambrian age of metamorphic rocks from the Ruby province, Medfra and Ruby quadrangles — preliminary evidence from radiometric age data, *in* Johnson, K.M., and Williams, J.R., eds., The United States Geological Survey in Alaska: Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B66-B68.

Smith, G.M., and Puchner, C.C., 1985, Geology of the Ruby geanticline between Ruby and Poorman, Alaska and the tectonic emplacement of the Ramparts Group [Abs.]: EOS, Transactions, American Geophysical Union, v. 66, no. 46, p. 1102.

Steiger, R.H., and Jäger, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, no. 3, p. 359-362.

Turner, D.L., Forbes, R.B., Aleinikoff, J.N., Hedge, C.E., and McDougall, Ian, 1983, Geochronology of the Kilbuck terrane of southwestern Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 407.

Wallace, W.K., 1984, Mesozoic and Paleogene tectonic evolution of the southwestern Alaska Range—Southern Kuskokwim Mountains region [abs.]: Geological Society of America Abstracts with Programs, v.16, no. 5, p. 339.

Wallace, W.K., Hanks, C.L., and Rogers, J.F., 1989, The southern Kahiltna terrane: Implications for the tectonic evolution of southwestern Alaska: Geological Society of America Bulletin, v. 101, no. 11, p.1389-1407.

Wilson, F.H., 1981, Map and table showing radiometric ages of rocks in the Aleutian Islands and Alaska Peninsula: U.S. Geological Survey Open-File Report 81-471, scale 1:1,000,000.

———1982, Map and tables showing preliminary results of K-Ar age studies in the Ugashik quadrangle, Alaska Peninsula: U.S. Geological Survey Open-File Report 82-140, scale 1:250,000.

Wolfe, J.A., and Wahrhaftig, Clyde, 1970, The Cantwell Formation of the central Alaska Range: U.S. Geological Survey Bulletin 1294A, p. A41-A46.

Zwart, H.J., Corvalan, J., James, H.L., Miyashiro, A., Saggerson, E.P., Sobolev, V.S., Subramaniam, A.P., and Vallance, T.G., 1967, A scheme of metamorphic facies for the cartographic representation of regional metamorphic belts: International Union of Geological Sciences Geological Newsletter, v. 1967, p. 57-72.

Table 2.–*Metamorphic mineral-assemblage data*

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate 2)[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
Nulato								
55	1	E.J. Moll and W.W. Patton, Jr.	BA	AS	CL+PU+QZ	LPP	LPP (eKlTr)	74APa234
Ruby								
56	1	R.M. Chapman	CA	AS	CA+CL+SH+QZ+EP+AB	GNS	GNS (pO)	
56	2	-----do.-----	BA	AS	CL+EP+SH	GNS	-------do.-------	
Ophir								
64	1	-----do.-----	BA	AS	CL+PU+QZ+ZO+AC+SP+TA(?)	LPP	LPP (eKlTr)	
64	2	-----do.-----	PE	AS	QZ+MU+CB	GNS	GNS (eKmPz)	
64	3	-----do.-----	PE	AS	QZ+WM	GNS	-------do.-------	
64	3	-----do.-----	PE	AS	QZ+CL+MU	GNS	-------do.-------	
64	4	-----do.-----	PE	AS	QZ+MU+CB	GNS	-------do.-------	
64	5	-----do.-----	PE	AS	QZ+MU+HE	GNS	-------do.-------	
64	6	-----do.-----	PE	AS	QZ+AB+ZO+WM	LPP	LPP (eKlTr)	
64	7	-----do.-----	OT	AS	QZ+AB+PH	LPP	-------do.-------	
64	8	-----do.-----	CA	AS	CA+QZ+WM	LPP	-------do.-------	
64	9	-----do.-----	PE	AS	QZ+MU+CL+SP+SH+HE	GNS	GNS (eKmPz)	
64	10	-----do.-----	BA	AS	AC+QZ+EP+AB+CL+HE+SP+SH	GNS	-------do.-------	
64	11	-----do.-----	PE	AS	QZ+WM+CL+PU	LPP	LPP (eKlTr)	
64	12	-----do.-----	PE	AS	WM+AB+PU(?)+CL+QZ	LPP	-------do.-------	
64	13	-----do.-----	OT	AS	CA+CL+QZ	LPP	-------do.-------	
64	14	-----do.-----	BA	AS	AM+CA+QZ+CL+EP(?)	LPP	-------do.-------	
64	15	-----do.-----	PE	AS	QZ+WM	LPP	-------do.-------	
64	16	-----do.-----	PE	AS	QZ+WM+CL+CA	GNS	GNS (eKmPz)	
64	16	-----do.-----	CA	AS	CA+QZ+CB	GNS	-------do.-------	
64	17	-----do.-----	BA	AS	EP+CL+QZ+SH+AB+AC	GNS	-------do.-------	
Medfra								
65	1	E.J. Moll	PE	AS	QZ+CL+MU	GNS	GNS(pO)	75APa77
65	2	-----do.-----	PE	AS	MU+CL+QZ	GNS	-------do.-------	78APa34b
65	3	-----do.-----	OT	AS	MU+CL+QZ	GNS	-------do.-------	78APa28d
65	4	-----do.-----	BA	AS	BI+CL+AC+SH+PL	GNS	-------do.-------	75APa104A
65	4	-----do.-----	BA	AS	EP+AC+CA+SH+PL	GNS	-------do.-------	75APa104I
65	4	-----do.-----	OT	AS	MU+CL+PL	GNS	-------do.-------	75APa104B
65	4	-----do.-----	OT	AS	GA+BI+MU	GNS	-------do.-------	75APa104J
65	5	-----do.-----	OT	AS	CA+HE+CL+QZ+EP	GNS	-------do.-------	77APa 27
65	6	-----do.-----	PE	AS	GA+MU+BI+CL+QZ+PL	GNS	-------do.-------	77APa31
65	7	-----do.-----	OT	AS	CL+EP+QZ+HE(?)	GNS	-------do.-------	77APa28
65	8	-----do.-----	PE	AS	CD+CL+MU+QZ+HE(?)	GNS	-------do.-------	77APa29
65	8	-----do.-----	BA	AS	CL+MU+EP+PL+HE(?)	GNS	-------do.-------	
65	9	-----do.-----	CA	AS	CA+QZ+MU	GNS	-------do.-------	75APa103
65	10	-----do.-----	OT	AS	CL+BI+QZ	GNS	-------do.-------	75APa106
65	11	-----do.-----	PE	AS	CL+MU+QZ+PL	GNS	-------do.-------	75APa105
65	12	-----do.-----	CA	AS	CA+QZ+BI	GNS	-------do.-------	75APa102B
65	13	-----do.-----	OT	AS	QZ+MU+BI+CL	GNS	GNS (KM)	77APa35A
65	14	-----do.-----	OT	AS	MU+BI	GNS	GNS (pO)	77APa60b
65	15	-----do.-----	OT	AS	MU+QZ	GNS	-------do.-------	77APa59a
65	16	-----do.-----	OT	AS	MU+CL+BI+HE	GNS	-------do.-------	78APa42b
65	17	-----do.-----	OT	AS	CL+MU+BI+SH+QZ+PL	GNS	-------do.-------	75APa107
65	18	-----do.-----	OT	AS	MU+QZ+KF+HE(?)	GNS	-------do.-------	79APa16A
65	18	-----do.-----	PE	AS	CL+MU+BI+CA+PL+QZ	GNS	-------do.-------	79APa16B
65	19	-----do.-----	BA	AS	CL+EP+AC+AB+CA	GNS	-------do.-------	79APa17
65	19	-----do.-----	PE	AS	CL+MU+CA+FS	GNS	-------do.-------	79APa7
65	20	-----do.-----	OT	AS	CL+QZ+CA+PL	GNS	-------do.-------	79APa19
65	21	-----do.-----	OT	AS	QZ+PL+MU	GNS	GNS (KM)	79APa13A
65	22	-----do.-----	OT	AS	QZ+MU+CA+BI	GNS	-------do.-------	78APa50C
65	23	-----do.-----	OT	AS	QZ+CA+MU+CL	GNS	-------do.-------	79APa14
65	24	-----do.-----	OT	AS	QZ+CA	GNS	-------do.-------	78APa52B
Iditarod								
73	1	M.L. Miller	BA	AS	AC+QZ+AB+EP+CL+SH	GNS	GNS (eKmPz)	84AM272A
73	2	-----do.-----	BA	AS	CL+EP+CA+QZ+PU	LPP	LPP (eKlTr)	85AM135A
73	3	-----do.-----	BA	AS	AC+QZ+AB+EP+CL+SH	GNS	GNS (eKmPz)	84AM282A
73	4	-----do.-----	BA	AS	AC+BI+AB+QZ+CL+SH+EP	GNS	-------do.-------	85AAi672A
73	5	-----do.-----	BA	AS	HO+PL+BI+QZ+GA	AMP	AMP (X) + GNS (eKJ)	85AM93A
73	6	-----do.-----	BA	AS	HO+CP+QZ+EP+SH	AMP	-------do.-------	83AM134A
73	6	-----do.-----	PE	AS	QZ+MU+BI+FS	AMP	-------do.-------	83AM134B
73	7	-----do.-----	BA	AS	HO+CP+QZ+GA+EP+CA	AMP	-------do.-------	84BT213B

Table 2.–*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate 2)[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
73	8	M.L. Miller	PE	AS	QZ+PL+KF+BI+CL+GA+	AMP	AMP (X) + GNS (eKJ)	84AM181A
73	9	-----do.-----	BA	AS	CL+CA+PU+PH	LPP	LPP (eKIT̄R)	85AM37A
73	10	-----do.-----	BA	AS	CL+EP+PU+PH	LPP	-------do.-------	84AM238A
73	10	-----do.-----	BA	AS	CL+PH	LPP	-------do.-------	84AM238B
Sleetmute								
82	1	J.M. Hoare	OT	AS	LU+CL+CA+QZ+PL	LPP	LPP (eKIT̄R)$_1$	
Bethel								
91	1	S.M. Roeske	BA	AS	HO+CP+EP+QZ	AMP	AMP (X) + GNS (eKJ)	87ACz88
91	2	-----do.-----	BA	AS	CL+EP+MR+AB	GNI,H	GNI,H (eKIT̄R)	87SR1b
91	2	-----do.-----	BA	AS	EP+CL+AC+QZ	GNI,H	-------do.-------	87SR5
91	3	-----do.-----	BA	AS	HO+CP+QZ	AMP	-------do.-------	87APa21
91	4	-----do.-----	BA	AS	AC+AB+CL+EP	GNS	-------do.-------	87SR9
91	5	J.M. Hoare	BA	AS	EP+CL	LPP	LPP (eKIT̄R)	
91	6	-----do.-----	OT	AS	LU+CL+CA+QZ+PL	LPP	-------do.-------	
Taylor Mountains								
92	1	-----do.-----	OT	AS	CL+CA+BI+AC+EP	GNS	-------do.-------	
Lake Clark								
93	1	T.K. Bundtzen and W.G. Gilbert	BA	AS	CL+CA+ZO	LPP	-------do.-------	77BT200
93	2	-----do.-----	BA	AS	CL+CA+PU+ZO+PL	LPP	LPP (eJIT̄R)	77BT141
93	3	-----do.-----	BA	AS	PH+CL+QZ	LPP	-------do.-------	78BT1
93	4	-----do.-----	BA	AS	CL+CA+ZO+PU	LPP	-------do.-------	78BT9
93	5	-----do.-----	BA	AS	CL+PU+ZO+CA	LPP	-------do.-------	78BT3
93	6	-----do.-----	BA	AS	ZO+CL+QZ+AB(?)	LPP	-------do.-------	77WG162
93	6	-----do.-----	BA	AS	PU+CL+QZ	LPP	-------do.-------	78WG5a
93	7	-----do.-----	BA	AS	AC+AB+CL+QZ	GNS	GNS,AMP (TIT̄R)	77BT-HB22
93	8	-----do.-----	BA	AS	CL+AC+AB+SH+FS	GNS	-------do.-------	77BT-HB17
Goodnews Bay								
101	1	J.M. Hoare	PE	AS	CL+ZO+CA	LPP	LPP (eKIT̄R)$_1$	
101	2	-----do.-----	OT	AS	LU+CL+CA+QZ+PL	LPP	-------do.-------	
101	3	-----do.-----	BA	AS	HO+GA+CX+PL+BI+QZ	AMP	AMP (X) + GNS (eKJ)	
101	4	J.Y. Bradshaw	PE	AS	MU+QZ+GT+KY+RU	AMI	-------do.-------	
101	5	-----do.-----	OT	AS	KF+PL+QZ+GA+BI+EP	AMP	-------do.-------	
101	6	-----do.-----	OT	AS	KF+BI+QZ+PL+MU	AMP	-------do.-------	
101	7	-----do.-----	BA	AS	HO+GA+BI+PL+QZ	AMP	GNI, H (eKIT̄R)	
101	8	M.M. Donato	BA	AS	CA+CL+AC+EP+GL	GNH	-------do.-------	51AHr42
101	9	J.M. Hoare	OT	AS	LU+CL+CA+QZ+PL	LPP	LPP (eKIT̄R)$_1$	
101	10	M.M. Donato	BA	AS	CL+AC+SH+EP+PL	GNH	GNI, H (eKIT̄R)	75AHr1501
101	11	-----do.-----	BA	AS	CL+CA+EP+PH+PU+AC	LPP	LPP (eKIT̄R)$_1$	71ACk310
101	12	-----do.-----	BA	AS	CL+EP+WM+AB+PU	LPP	-------do.-------	71AGk131
101	13	-----do.-----	BA	AS	PU+PH+EP+CA+CL+SH	LPP	-------do.-------	75AHr1016
Iliamna								
103	1	R.L. Detterman	PE	AS	MU+AB+AC+QZ+CL±EP	GNS	GNS,AMP (J)	61ADt117
103	1	-----do.-----	BA	AS	AC+CL+EP±MU±AB	GNS	-------do.-------	67ADt1475 6ADt18
103	1	-----do.-----	CA	AS	CA+QZ±TR	GNS	-------do.-------	61AHe30
103	2	-----do.-----	BA	AS	CL+EP+AC+AB±MU±ZE	GNS	GNS (J)	62AR11 62AR77 65ADt1057
103	3	-----do.-----	BA	AS	HO+PL+BI+GA±KF±SH	AMP	-------do.-------	61ADt84 61ADt72 64ADt791
103	4	-----do.-----	PE	AS	MU+AB+AC+QZ±CA±GA	GNS	-------do.-------	62AR274b 62AR285
103	4	-----do.-----	PE	AS	AB+AC+QZ±MU±GA	GNS	-------do.-------	
103	5	-----do.-----	BA	AS	EP+AB+CL+AC	GNS	-------do.-------	62AR403b
103	5	-----do.-----	CA	AS	AC+AB+CA+CL±EP±SH	GNS	-------do.-------	63AR12
103	5	-----do.-----	PE	AS	BI+MU+PL+QZ+KF+GA+AN±ST	AML	GNS,AMP (J)	62AR405
103	6	-----do.-----	PE	AS	BI+MU+QZ+GA±KF±PL±SL	AMP	-------do.-------	67ADt1553 63AR3
103	6	-----do.-----	PE	AS	BI+MU+QZ±PL±GA	AMP	-------do.-------	

Table 2.–*Metamorphic mineral-assemblage data*—Continued

Quadrangle name and reference No. (plates 1,2)	Locality No. (plate 2)[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
103	7	R.L. Detterman	PE	AS	BI+MU+QZ+KF+SI+GA±AN	AML	GNS,AMP (J)	
Hagemeister Island								
111	1	M.M. Donato	BA	AS	QZ+EP+CL+WM+GA	GNS	GNS (mJTR)	71AGK50
111	2	-----do.-----	BA	AS	CL+EP+CA+AC+WM+AB	GNS	-------do.-------	71AGK78
111	3	-----do.-----	BA	AS	PU+EP+CL+CA+ZO+SH	LPP	LPP (eKITR)	52AHr147
111	4	J.M. Hoare	BA	AS	EP+CA+AB	GNS	GNS (mJTR)	
111	5	S.E. Box	BA	AS	QZ+AB+CL+AC+EP+PU+CA+SH	GNS	-------do.-------	81SB105B
111	6	-----do.-----	BA	AS	AC+EP+CL+CA+AB+WM	GNS	-------do.-------	81SB120
111	7	-----do.-----	OT	AS	QZ+PH+CA+WM±PU	LPP	LPP (eKITR)	81SB544
111	8	-----do.-----	BA	AS	AC+CZ+CL+AB+PH+CA+QZ	GNS	-------do.-------	81SB21
111	9	J.M. Hoare	BA	AS	LU+CL+CA+QZ+PL	LPP	-------do.-------	
111	10	S.E. Box	BA	AS	CL+CA+CZ+AB+PH+QZ	GNS	-------do.-------	81SB85A
111	11	-----do.-----	BA	AS	CL+EP+CZ+CA+AB	GNS	-------do.-------	81SB81B
111	12	M.M. Donato	BA	AS	HO+PL+CZ+EP+SH+QZ+CL	GNS	GNS (mJTR)	52AHr67
111	13	J.M. Hoare	BA	AS	CL+EP+CA	GNS	-------do.-------	
111	14	M.M. Donato	BA	AS	SH+CL+QZ+PU+EP+PH	LPP	LPP (eKITR)	71AGK216
111	15	S.E. Box	BA	AS	QZ+CL+EP+PU	LPP	-------do.-------	81SB220
111	16	M.M. Donato	BA	AS	QZ+CL+CA+LW+SH	GNH	GNH (mJTR)	71AGK120
111	17	S.E. Box	BA	AS	QZ+CL+WM+AC+PU±GL	GNH	-------do.-------	81SB197
111	18	-----do.-----	BA	AS	QZ+CL+EP+GL	GNH	-------do.-------	82SBB25b
111	19	M.M. Donato	BA	AS	GL+EP+CL+SH	GNH	-------do.-------	71AGK111
111	20	S.E. Box	BA	AS	AB+AC+QZ+CL+EP	GNS/LPP	LPP (eKITR)	81SB287
111	21	-----do.-----	BA	AS	AB+SH+CL+CA+AC+TR+EP	GNS/LPP	-------do.-------	81SB944
Nushagak Bay								
112	1	-----do.-----	OT	AS	QZ+PH+PU+CL+AB+WM+CA	LPP	-------do.-------	80SB162
112	2	-----do.-----	OT	AS	QZ+PH+PU+CL+AB	LPP	-------do.-------	80SB263
112	3	-----do.-----	OT	AS	QZ+PH+PU+CL+AB+WM+CA	LPP	-------do.-------	80SB154
Naknek								
113	1	R.L. Detterman	CA	AS	CA+QZ+DI	AMP	GNS,AMP (J)	
Stepovak Bay								
135	1	J.C. Moore	PE	AS	PH+LU+AB(?)+QZ+WM+CL	LPP	LPP (eTIK)	

[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)	CP,	calcic plagioclase (An 11-100)	KF,	potassium feldspar	RU,	rutile
AC,	actinolite	CX,	clinopyroxene	KY,	kyanite	SH,	sphene
AM,	amphibole	CZ,	clinozoisite	LU,	laumontite	SI,	sillimanite
AN	andalusite	DI,	diopside	LW	lawsonite	SL,	spinel
BI,	biotite	EP,	epidote	MR,	magnesio-riebeckite	SP,	stilpnomlane
CA,	carbonate	FS,	feldspar	MU,	muscovite	ST,	staurolite
CB,	carbonaceous and (or) graphitic material	GA,	garnet	PH,	prehnite	TA,	talc
CD,	chloritoid	GL,	glaucophane	PL,	plagioclase (An 0-100)	TR,	tremolite
CL,	chlorite	HE,	hematite	PU,	pumpellyite	WM,	white mica
		HO,	hornblende	QZ,	quartz	ZO,	zoisite

Minerals arranged in order of decreasing abundance.

[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.

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