Distribution, Facies, Ages, and Proposed Tectonic Associations of Regionally Metamorphosed Rocks in Northern Alaska

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By Cynthia Dusel-Bacon, William P. Brosgé, Alison B. Till, Elizabeth O. Doyle, Charles F. Mayfield, Hillard N. Reiser, and Thomas P. Miller

ABSTRACT

Approximately half of the exposed bedrock in northern Alaska has been regionally metamorphosed. The most widespread metamorphic episode that affected northern Alaska occurred under low-grade, initially high-pressure (blueschist-facies) conditions during Mesozoic time. This episode is thought to have been related to the obduction of one or more oceanic terranes onto the continental margin of North America. Rocks whose metamorphism is considered to have been part of this major episode have an aerial distribution of approximately 10,000 km^2 in the southern Brooks Range, 5,000 km^2 across much of the Seward Peninsula, and 800 km^2 in the Ruby geanticline within the southeastern borderlands of the Yukon-Koyukuk basin.

In the southern Brooks Range and on the Seward Peninsula, continental rocks experienced a clockwise pressure-temperature path that evolved during Middle Jurassic to late Early Cretaceous time from the low- to high-temperature subfacies of the blueschist facies and, finally, due to decreasing pressure, evolved to the greenschist facies. Metamorphism in the southern Brooks Range was associated with north-vergent compression along a south-dipping subduction zone that emplaced the oceanic rocks of the Angayucham terrane (represented by klippen of ultramafic rocks and prehnite-pumpellyite-facies metabasite, metatuff, metachert, and metasedimentary rocks) onto the continental margin. The present structural and metamorphic relation between the continental blueschist- and greenschist-facies rocks and the structurally overlying lower temperature and pressure oceanic prehnite-pumpellyite-facies rocks to the south indicates that postmetamorphic or late metamorphic down-to-the-south, low-angle extensional faulting has dismembered the upper plate and removed much of the section that originally buried the blueschists.

High-pressure metamorphism on the Seward Peninsula probably had a similar origin to that in the southern Brooks Range, but remnants of the overriding plate have not been identified, and the mechanism (such as left-lateral strike-slip faulting or oroclinal bending) by which the high-pressure rocks in the two areas were separated is not known. A significant difference between the thermal histories of these two metamorphic belts also is enigmatic: low-grade metamorphism on the Seward Peninsula was followed by intermediate-pressure amphibolite-facies and, locally, granulite-facies metamorphism as well as plutonism in mid-Cretaceous time, but no such high-temperature events have been documented within the high-pressure belt of the southern Brooks Range.

In the Ruby geanticline, glaucophane, attesting to high-pressure metamorphism, is sporadically 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.

Although the majority of the metamorphic episodes that affected northern Alaska occurred during the Mesozoic, older episodes have been documented or are suspected in a few areas. Late Proterozoic medium-grade metamorphism has been documented in a small area in the southwestern Brooks Range, Middle to Late Proterozoic or early Paleozoic metamorphism just south of the Ruby geanticline, and middle Paleozoic metamorphism in the eastern Brooks Range. High-temperature, high-pressure metamorphism of klippen in the Yukon-Tanana upland is tentatively considered to have occurred in early Paleozoic time. Metamorphic ages of units in several areas, particularly in the Ruby geanticline and the Yukon-Tanana upland, can be bracketed only between the probable Paleozoic age of their protoliths and the late Early Cretaceous age of postmetamorphic granitoids that intrude them.

INTRODUCTION

This report identifies and describes the major, regionally developed metamorphic episodes that affected northern Alaska throughout its evolution. It is one of a series of four reports that presents the metamorphic history of Alaska (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 (up to about mid-1987) of the metamorphic grade, pressure conditions, protolithic and metamorphic age, and speculated or known tectonic origin of regional metamorphism in northern Alaska. Metamorphic units are discussed in the same order as that used for the map explanation. Within each geographic area (fig. 2), units are discussed in order of increasing metamorphic age; units of the same metamorphic age or age range are generally discussed in order of increasing metamorphic grade. Monometamorphic units are discussed before polymetamorphic units.

The metamorphic-facies determination scheme (fig. 3, table 1) on which the map (pl. 1) is based was developed by the Working Group for the Cartography of the Metamorphic Belts of the World (Zwart and others, 1967). This scheme is based on pressure- and temperature-sensitive metamorphic minerals that are petrographically identifiable by most geologists. Regionally metamorphosed rocks are divided into four facies groups based on increasing temperature: (1) laumontite and prehnite-pumpellyite facies (LPP), shown in shades of gray and tan; (2) greenschist facies (GNS), shown in shades of green; (3) epidote-amphibolite and amphibolite facies (AMP), shown in shades of red and orange; and (4) two-pyroxene (granulite) facies (2PX), shown in reddish brown. Where possible, the greenschist-facies and the epidote-amphibolite- and amphibolite-facies groups are divided into three facies series on the basis of pressure. A high-, intermediate-, or low-pressure series is indicated by an H, I, or L in place of the final letter in the symbol used for the previously mentioned facies group. High-pressure greenschist (blueschist)-facies rocks and rocks metamorphosed under blueschist-facies conditions that evolved to intermediate- or low-pressure greenschist-facies conditions during a single episode are shown in shades of blue.

In this compilation, the scheme of Zwart and others (1967) is expanded. Specifically, combinations of letters and symbols are used to indicate metamorphic conditions transitional between different facies groups and series. Where two facies groups or facies series occur together but have not been differentiated, the designation of the more abundant facies is given first, and the two designations are separated by a comma. Where metamorphism evolved from one facies series to another during a single continuing episode (monocyclic polyfacial), the pressure symbol of the earlier phase of the metamorphic episode is given first, and a horizontal arrow points to the pressure symbol of the later phase. Where the metamorphic grade of a unit was transitional between two facies groups, the lower grade designation is given first, and the two designations are separated by a slash. 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. In several instances, numerical subscripts are used to dif-

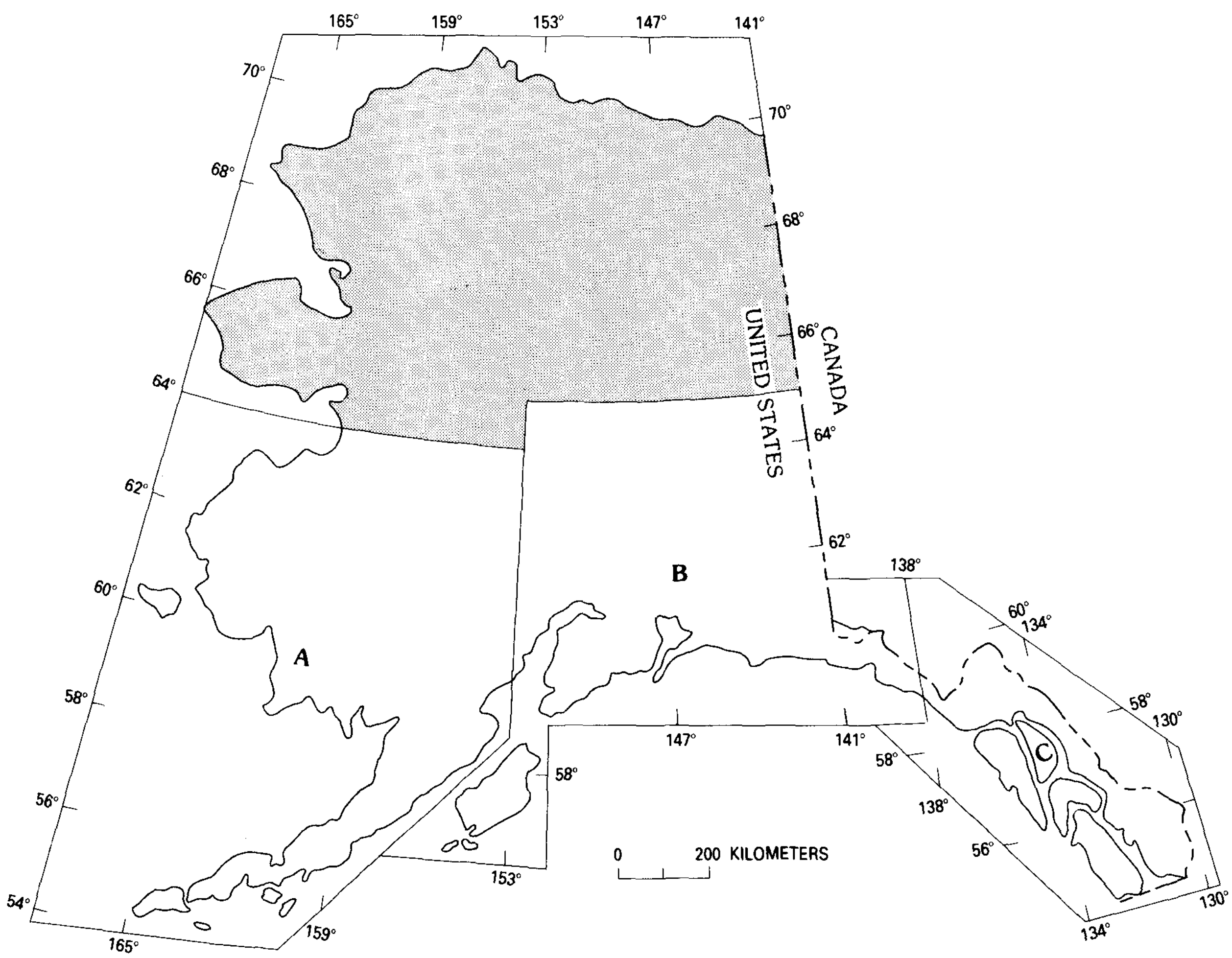

FIGURE 1.—Area of this report (shaded) and other reports in the series of metamorphic studies of Alaska: A, Doyle and others (in press); B, Dusel-Bacon, Csejtey, and others (in press); C, Dusel-Bacon, Brew, and Douglass (in press).

ferentiate between map units that have the same metamorphic grade and metamorphic age but that have different protoliths and are thought to have different metamorphic histories. Protolithic and metamorphic age designations are based on the Decade of North American Geology Geologic Time Scale (Palmer, 1983). Where two metamorphic episodes have affected the rocks, the symbol gives the facies and age of each metamorphic episode, beginning with the older episode.

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

The general sources for metamorphic data in northern Alaska were provided by some of the contributors in unpublished metamorphic compilations, except in area 7 (fig. 4). In most cases, the published geologic maps and papers on which these contributors or the senior author based their metamorphic-unit determinations are referred to in the detailed description of metamorphic units. Additional published geologic maps for the quadrangles shown on this metamorphic facies map are listed by Hopkins (1983).

SUMMARY OF THE MAJOR METAMORPHIC EPISODES THAT AFFECTED NORTHERN ALASKA

The most widespread metamorphic episode that affected northern Alaska occurred under low-grade, initially high-pressure (blueschist-facies) conditions during Mesozoic time. This episode is thought to have been related to the obduction of one or more oceanic terranes onto the

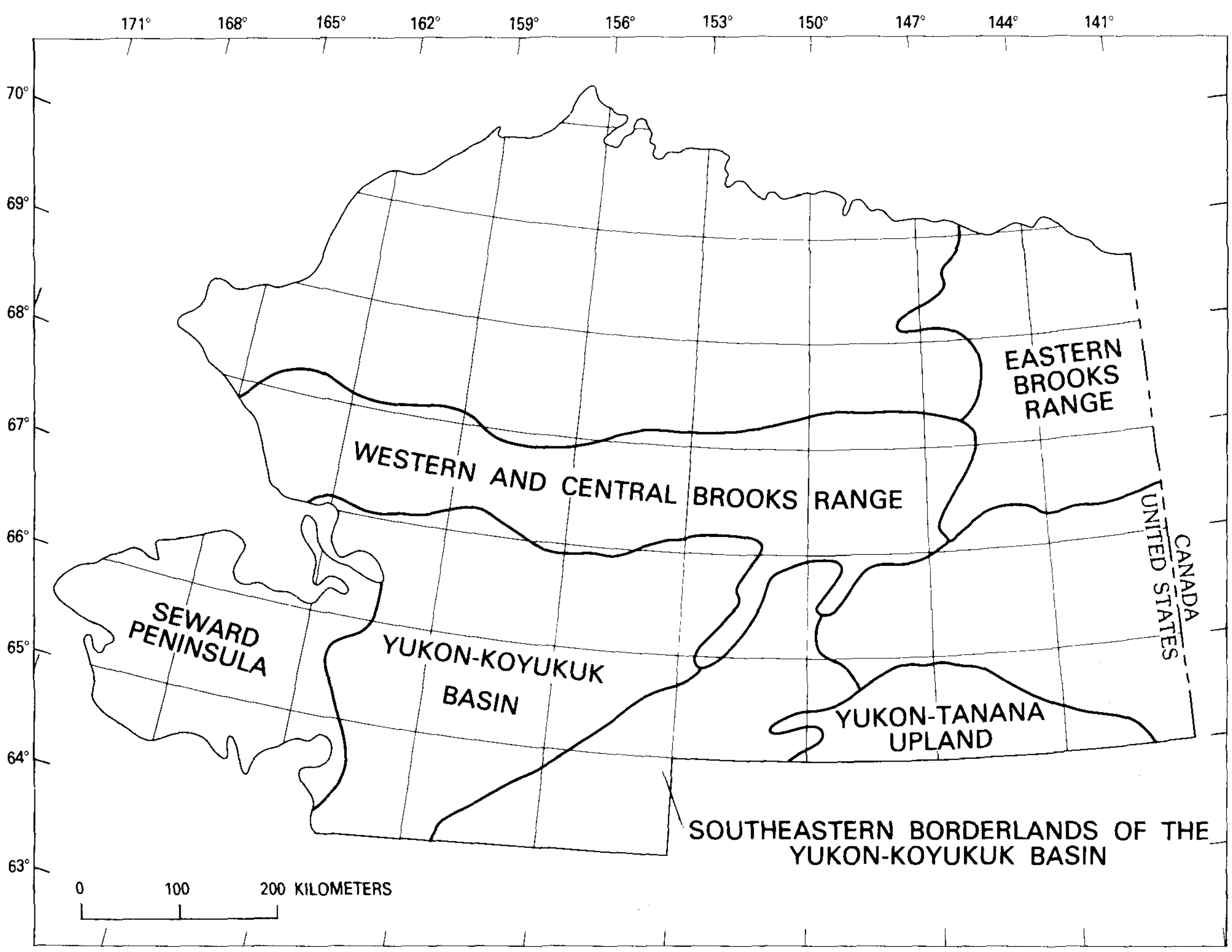

FIGURE 2.—Regional geographic areas in northern Alaska that are discussed in text. Boundaries of 1:250,000-scale quadrangles shown for reference.

continental margin of North America. Units whose metamorphism is considered to have been part of this major episode occur across much of the southern Brooks Range (about 10,000 km^2) and the Seward Peninsula (about 5,000 km^2), and in less extensive areas (about 800 km^2) in the Ruby geanticline located within the southeastern borderlands of the Yukon-Koyukuk basin. These units can be identified by their Middle Jurassic to late Early Cretaceous metamorphic-age brackets or, in a few cases, by their Cretaceous age.

In the western and central part of the southern Brooks Range, this episode followed a clockwise pressure-temperature (P-T) path that evolved during Middle Jurassic to late Early Cretaceous time from the low- to high-temperature subfacies of the blueschist facies and, finally, due to decreasing pressure, evolved to the greenschist facies. Limited structural and metamorphic data suggest that metamorphism was associated with north-vergent compression along a south-dipping subduction zone that emplaced the oceanic rocks of the Angayucham terrane (including Jurassic ultramafic rocks and prehnite-pumpellyite-facies mafic rocks) onto the continental margin. Prior to and probably closely preceding its emplacement onto the continental rocks of the southern Brooks Range, the oceanic sequence was internally imbricated, and the ultramafic rocks were emplaced on top of the mafic rocks, becoming the structurally highest part of the sequence (Patton and others, 1977). A Middle to Late Jurassic age for this tectonic mixing is provided by K-Ar hornblende ages of about 172 to 154 Ma from garnet amphibolite, presumably formed during thrusting, that occurs at the base of the ultramafic sheets (Patton and others, 1977).

Dynamothermal metamorphism in the southern Brooks Range clearly had ceased by late Early Cretaceous time because Albian and Cenomanian conglomeratic rocks in the Yukon-Koyukuk basin record the uplift and progressive erosional stripping of the oceanic rocks and the underlying metamorphosed continental rocks (Patton, 1973; Dillon and Smiley, 1984; Box and others, 1984). This conclusion is consistent with late Early Cretaceous (120-90 Ma) K-Ar cooling ages on mica from the metamorphic rocks (Turner and others, 1979; Turner, 1984; Dillon and Smiley, 1984). The present structural and metamorphic relation between the high-pressure continental rocks and the structurally overlying lower temperature and pressure prehnite-pumpellyite-facies oceanic rocks to the south indicates that postmetamorphic or late metamorphic down-to-the-south, low-angle extensional faulting has dismembered the upper plate and removed much of the section that originally buried the continental rocks.

The P-T path of low-grade metamorphism (blueschist evolving to greenschist facies) on the Seward Peninsula during Middle Jurassic and Early Cretaceous time ap-

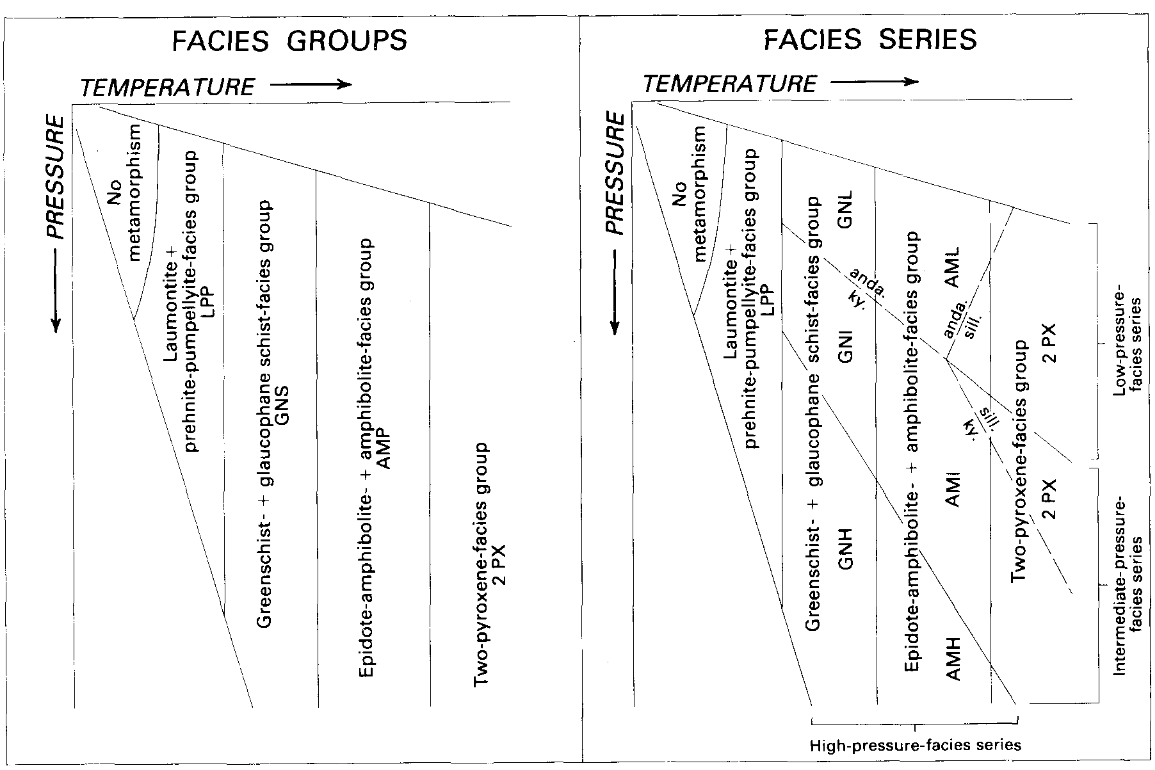

FIGURE 3.—Schematic representation of metamorphic-facies groups and series in pressure-temperature space and their letter symbols used in this report (modified from Zwart and others, 1967). Stability fields of Al_2SiO_5 polymorphs andalusite (anda.), kyanite (ky.), and sillimanite (sill.) shown by dashed lines. (See table 1, p. A32, for explanation of letter symbols.)

pears to have been very similar to that which affected the southern Brooks Range. Rb-Sr whole-rock-mica isochron ages and K-Ar mineral ages suggest that the high-pressure metamorphic cycle reached a maximum during the Middle or Late Jurassic, before about 160 Ma, and was followed by decompression and partial reequilibration between about 160 and 100 Ma (Armstrong and others, 1986). However, a major difference between the thermal histories of the two areas is the fact that low-grade metamorphism on the Seward Peninsula was followed by intermediate-pressure amphibolite-facies and, locally, granulite-facies metamorphism and associated plutonism between about 100 and 80 Ma (Armstrong and others, 1986), whereas such high-temperature events have not been documented within the low-grade belt of the southern Brooks Range.

Less is known about the Ruby geanticline in which blueschist- and greenschist-facies metamorphism occurred. Glaucophane is present sporadically both within the continental rocks of the lower plate and, less commonly, within the lowermost part of the overlying low-grade oceanic rocks. A minimum late Early Cretaceous age for this episode is indicated by K-Ar ages of 134 and 136 Ma on muscovite from glaucophane-bearing schist in the continental plate (Patton and others, 1984) and by the 111-Ma age of a granitoid pluton that intrudes both the continental and oceanic plates (Patton and others, 1977, 1978; Patton, 1984). According to one hypothesis, which is based

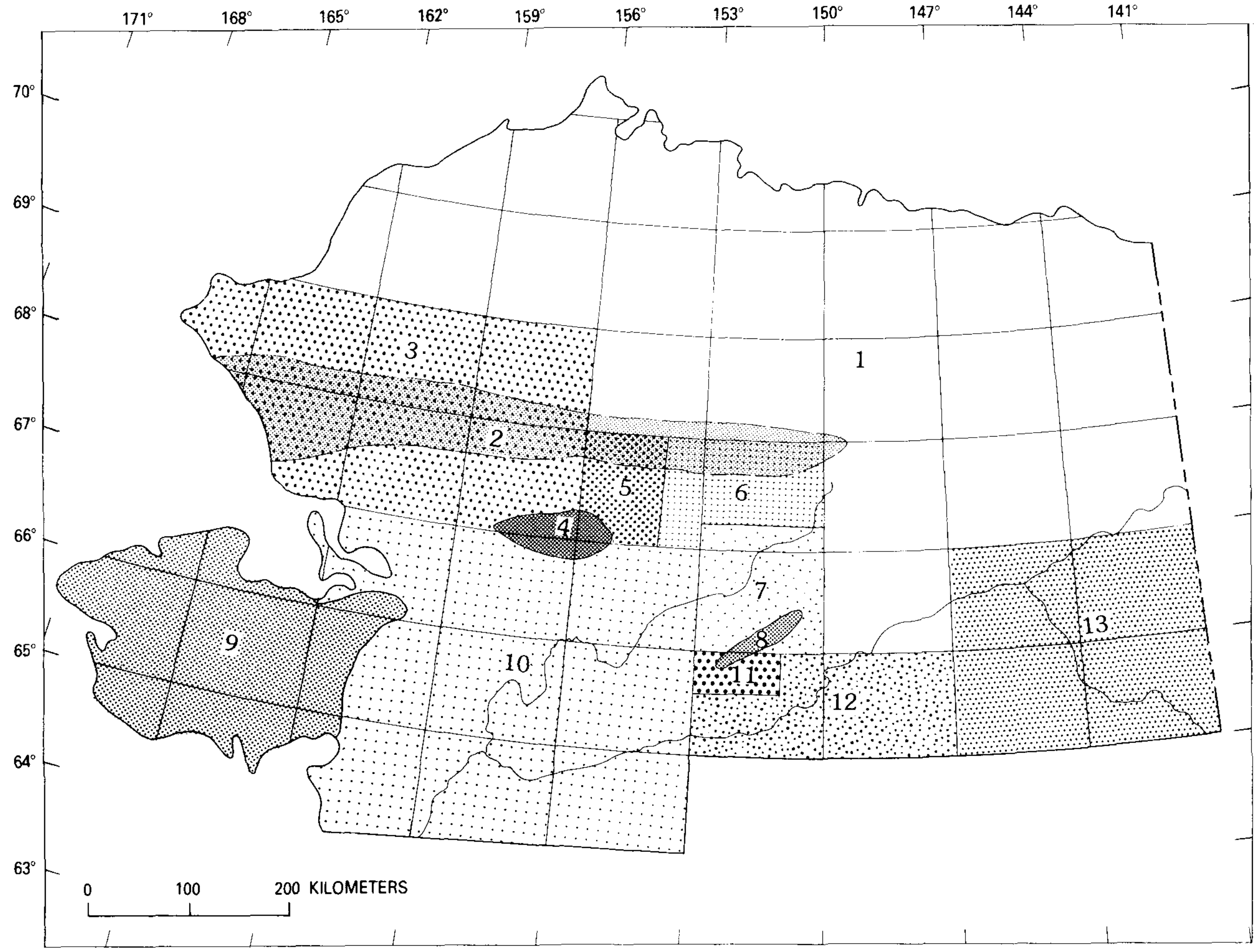

FIGURE 4.—General sources of metamorphic data for the metamorphic facies map of northern Alaska (pl. 1). Boundaries of 1:250,000-scale quadrangles shown for reference.

EXPLANATION

1. W.P. Brosgé and H.N. Reiser, unpublished metamorphic facies map
2. A.G. Harris, unpublished conodont alteration index map
3. C.F. Mayfield, unpublished metamorphic facies map
4. M.W. Hitzman, unpublished metamorphic facies map
5. S.W. Nelson, unpublished metamorphic facies map
6. J.T. Dillon, unpublished metamorphic facies map
7. Patton and Miller (1973)
8. R.A. Loney, unpublished geologic map
9. A.B. Till, unpublished metamorphic facies map
10. E.J. Moll and W.W. Patton, Jr., unpublished metamorphic facies map
11. J.H. Dover, unpublished geologic map
12. R.M. Chapman, unpublished metamorphic facies map
13. H.L. Foster, unpublished metamorphic facies map

on large-scale geologic similarities between the Ruby geanticline and the southern Brooks Range, blueschist- and greenschist-facies metamorphism in the Ruby geanticline was also a result of the obduction of the Angayucham terrane (in this case from the northwest) onto the continental margin. An alternative hypothesis, based on a structural analysis in two different areas of the Ruby geanticline, attributes low-grade metamorphism to obduction of a different oceanic terrane from the southeast and disputes a common tectonic origin for metamorphism in the two regions.

Pre-Mesozoic metamorphic episodes are well documented in several areas in northern Alaska and are possible but unproven in several others. In the southwestern Brooks Range, blueschist- and greenschist-facies assemblages formed during the episode described above overprint amphibolite-facies assemblages that yield Late Proterozoic K-Ar ages on muscovite and hornblende between 729±22 and 594±18 Ma (Turner and others, 1979; Mayfield and others, 1982) and an Rb-Sr whole-rock-mineral isochron age of 686±116 Ma (Armstrong and others, 1986). In the south-central Brooks Range, limited mineralogic and structural evidence allows the possibility that the Mesozoic low-grade episode was superimposed on rocks previously metamorphosed under epidote-amphibolite-facies conditions during Proterozoic or middle Paleozoic time. In the eastern Brooks Range, middle Paleozoic low- to medium-grade metamorphism of three monometamorphic units was apparently associated with plutonism and perhaps with south-directed thrusting in that region. Farther to the south, near the southeastern borderlands of the Yukon-Koyukuk basin, two units that crop out south of the Susulatna fault were not affected by the Mesozoic metamorphic events but clearly were metamorphosed during Middle to Late Proterozoic or early Paleozoic time. Other units of greenschist- and amphibolite-facies rocks may have experienced pre-Mesozoic metamorphism as well, but the first or only metamorphic episode for these units are constrained only to predate the intrusion of plutons that have yielded Early Cretaceous (about 110-Ma) K-Ar ages (Silberman and others, 1979; Patton and others, 1987).

The timing of metamorphic events in the part of the Yukon-Tanana upland discussed in this report is poorly constrained. An early Paleozoic high-temperature, high-pressure metamorphic episode is tentatively postulated for two klippen of eclogitic rocks on the basis of a 470±35-Ma K-Ar age on amphibole from eclogite in the western klippe (Swainbank and Forbes, 1975). A well-documented Late Triassic to Early Jurassic metamorphic episode (Cushing and others, 1984) that corresponds with the closing of an oceanic basin is recorded in thrust sheets that are shown in a small area at the southern edge of this map and in thrust sheets that are shown in a larger area on the adjacent map to the south. Metamorphism of the other units in the region is known only to have occurred sometime during Paleozoic to late Early Cretaceous time.

DETAILED DESCRIPTION OF METAMORPHIC MAP UNITS

WESTERN AND CENTRAL BROOKS RANGE

LPP/GNS (TlK)

The low-grade, probably prehnite-pumpellyite- or greenschist-facies metaconglomerate, semischist, slate, phyllite, and minor metabasalt and meta-andesite (Patton and others, 1968; Hitzman and others, 1982) that make up this unit crop out in the Cosmos Hills just south of the central Brooks Range. The unit forms the highest plate in a stack of structural plates that are separated by folded low-angle normal faults (Box, 1987). A Late Cretaceous protolithic age for these terrigenous sedimentary rocks is indicated by a K-Ar age of 85.5±2 Ma (Patton and Miller, 1968; recalculated using the decay constants of Steiger and Jäger, 1977) on biotite from an interlayered ash-flow tuff within a lithologically equivalent but unmetamorphosed unit to the west. Rocks are sheared and dynamically metamorphosed; metaconglomerate clasts are characteristically stretched and flattened (Patton and others, 1968). The metamorphic minerals white mica, chlorite, and biotite(?) are commonly developed in the matrix of quartz-pebble and quartz-cobble metaconglomerate; the matrix of volcanic metaconglomerate locally contains abundant metamorphic epidote and chlorite, especially near faults where shearing, stretched clasts, and red hematitic staining are common (Hitzman and others, 1982). The rocks of this unit exhibit a northeast-trending stretching lineation defined by elongate quartz pebbles, aligned micas, and by fine streaking on slaty or phyllitic interbeds. Kinematic criteria indicate subhorizontal simple shear and relative upper plate motion to the southwest (downdip) (Box, 1987). The close association between the degree of recrystallization and shearing and the proximity of faults (Hitzman and others, 1982) suggests that some of the metamorphism and deformation may have been related to movement along these faults. The extensional tectonism indicated by the presence of low-angle normal faults may be related to either rapid Late Cretaceous uplift of the southern Brooks Range following deep burial or early Tertiary right-lateral motion on the adjacent Kobuk fault and rapid transtensional basin subsidence under Kotzebue Sound (Box, 1987).

LPP (K)

Weakly metamorphosed limestone, fine- to medium-grained clastic rocks, dolomite, chert, and locally minor diabase sills and dikes compose this unit; protoliths are

Devonian through Early Cretaceous in age (Mayfield and others, 1983). Metamorphic quartz and fine-grained white mica characterize clastic rocks, and pumpellyite, chlorite, and actinolite occur in the less abundant mafic rocks. Boundaries of this metamorphic unit have been drawn to include Devonian and Mississippian rocks for which CAI (conodont alteration index of Epstein and others, 1977) values of 4 or 4.5 have been determined (corresponding to metamorphic temperatures between about 200 and 250 °C) (A.G. Harris, written commun., 1984).

A Cretaceous metamorphic age is assigned to this unit on the basis of the Early Cretaceous protolithic age of the youngest rocks affected by low-grade metamorphism and on geologic reasoning. This reasoning suggests that metamorphism probably occurred as a result of crustal thickening that was produced by the widespread north-directed thrusting that occurred across northern Alaska (discussed in the description for unit GNH→L (eKmJ)) (Mayfield and others, 1983). Low-grade metamorphism of this unit is considered to have taken place during an evolving high- to low-pressure, low-temperature metamorphic episode that resulted from the crustal thickening. Although evidence shows that this thrusting and associated metamorphic episode may have begun as early as the Middle Jurassic elsewhere (Tailleur and Brosgé, 1970; Patton and others, 1977; Mayfield and others, 1983), thrusting and metamorphism in the northwestern end of the thrust belt in which this metamorphic unit occurs postdated the deposition of Lower Cretaceous rocks. Metamorphism clearly had ceased by late Early Cretaceous time because Albian and Cenomanian conglomeratic rocks in the Yukon-Koyukuk basin record the uplift and progressive erosional stripping of oceanic rocks and the underlying polymetamorphic rocks (Patton, 1973; Dillon and Smiley, 1984; Box and others, 1984). This conclusion is consistent with Early to mid Cretaceous (120-90-Ma) K-Ar ages on mica from metamorphic rocks of the Brooks Range (Turner and others, 1979; Turner, 1984; Dillon and Smiley, 1984) and with the occurrence of Albian fossils in the oldest rock unit in the Brooks Range (in the foothills of the Endicott and De Long Mountains) that has not undergone significant thrust transport (Mayfield and others, 1983).

GNS (K)

The greenschist-facies phyllite, quartzite, and minor metalimestone and calcareous metasandstone that make up this unit crop out in the central Noatak quadrangle. Protoliths are Devonian and Mississippian in age (A.G. Harris, unpub. data, 1984). Metamorphic minerals consist of white mica and quartz, minerals that occur over a wide range of pressure and temperature conditions. The greenschist-facies assignment is based on CAI temperatures. The boundaries of this metamorphic unit have been drawn to include Devonian and Mississippian rocks for which CAI values of 4.5 to 5.5 have been determined (corresponding to metamorphic temperatures between about 250 and 400 °C) (A.G. Harris, written commun., 1984). The rocks of this metamorphic unit grade upward into weakly metamorphosed Lower Cretaceous rocks to the north (adjacent LPP (K) unit). For this reason, a Cretaceous metamorphic age is proposed for these higher grade metamorphic rocks. The metamorphic age constraints and history of this unit are the same as those described for unit LPP (K).

GNH→L (eKmJ)

This unit, a polydeformed, blueschist- and greenschist-facies sequence, comprises Devonian and older calcareous, pelitic, and graphitic metasedimentary rocks and volumetrically minor metacarbonate rocks, metarhyolite, metabasite, and granitoid orthogneiss in the southern Brooks Range (Dillon and others, 1980; Hitzman and others, 1982), as well as a subordinate amount of upper Paleozoic and locally Triassic metapelite and metacarbonate rocks along its northern part. Rocks were metamorphosed during a single evolving metamorphic episode that followed a clockwise P-T path that evolved from blueschist- to greenschist-facies conditions and that reflects tectonic loading followed by decompression. Two phases of penetrative deformation (Mayfield, 1975; Gilbert and others, 1977; Turner and others, 1979; Nelsen, 1979; Hitzman, 1980; Dillon and others, 1981; Nelson and Grybeck, 1981; J.T. Dillon, written commun., 1983) are herein interpreted to have been associated with this evolving monocyclic polyfacial metamorphic episode. In the Wiseman area, which is probably somewhat typical of much of the unit, both deformational phases are characterized by isoclinal folding, and their relation to each other suggests refolding of early formed isoclines during decompression (Gottschalk, 1987). Also in that area, lineations and fold axes plunge to the south, and rocks have undergone N-vergent ductile shear deformation concurrent with metamorphism (Gottschalk, 1987). The regional metamorphic grade decreases to the north. The northern limit of this unit is defined, in part, on the basis of a CAI isotherm that delineates the first occurrence of CAI values of less than 5 (corresponding to a temperature of less than 300 °C) for Ordovician through Triassic rocks (A.G. Harris, written commun., 1984).

The majority of rocks in which the high-pressure minerals glaucophane, jadeite, and lawsonite have been identified occurs in a zone within the southern part of this unit. Possible explanations for the restricted occurrence of these minerals are that it is due to compositional controls (most basaltic rocks whose composition favors the development of these minerals are restricted to this zone) and, in part, to structural controls (as proposed by

Hitzman (1980; 1982), who observed that blueschist assemblages occurred within large nappe-like folds). Glaucophane is by far the most commonly developed high-pressure mineral, and it occurs in rocks of several compositions: glaucophane + garnet ± epidote ± stilpnomelane ± actinolite ± chlorite ± white mica ± albite ± sphene ± hematite (metabasite); glaucophane + chloritoid ± actinolite (iron-rich metasedimentary rocks); and glaucophane + chloritoid + garnet ± white mica ± chlorite ± quartz ± hematite (metatuff).

Jadeite + quartz has been identified in one sample of metabasite, and coarse relict jadeite also occurs in metawacke in the Ambler River quadrangle (Gilbert and others, 1977; Turner and others, 1979). Eclogite occurs at one locality about 200 km to the east near Wiseman; its primary mineralogy of jadeitic pyroxene (11-20 percent jadeite component), garnet, and rutile has been partly replaced by zoned amphibole (which has core to rim zoning of glaucophane, actinolite, and sodic hornblende), chlorite, albite, epidote, sphene, magnetite, and pyrite (Gottschalk, 1987).

One or two grains of lawsonite have been reported, and the euhedral outline of some epidote group minerals included within garnet indicates a retrograde reaction from preexisting lawsonite (Nelsen, 1979; Turner and others, 1979; A.B. Till, unpub. data, 1987). Biaxial calcite also has been identified and suggests the former development of high-pressure aragonite (Turner and others, 1979). The assemblage kyanite + chloritoid also occurs locally in iron-rich metasedimentary rocks, but it is not known whether the kyanite formed during the Jurassic to Cretaceous blueschist to greenschist episode, or whether it formed during the possible pre-Devonian episode described below for unit AMP (DЄ) + GNH→L (eKmJ).

The occurrence of probable aragonite and pseudomorphs after lawsonite inclusions within garnet indicates that the high-pressure phase of the P-T path began in the low-temperature subdivision of the blueschist facies and evolved into the high-temperature subdivision of the blueschist facies (subdivisions those of Taylor and Coleman (1968)). Mineral-assemblage data near Wiseman suggest that, in that area, the earliest phase of metamorphism occurred at pressures greater than 8 kb and at temperatures in the range of 450 °C and then continued under blueschist-facies evolving to greenschist-facies conditions at pressures less than 8 kb and temperatures around 480 °C (Gottschalk, 1987).

Assuming that much of at least the southern half of this unit was originally metamorphosed under blueschist-facies conditions (as suggested by the distribution of glaucophane), the degree of reequilibration under greenschist-facies conditions is quite variable and ranges from very little to almost total. Greenschist-facies mineral assemblages in rocks in which high-pressure minerals either never developed or later reequilibrated under greenschist-facies conditions are: quartz + white mica + albite + chlorite ± chloritoid ± calcite ± epidote ± biotite and quartz + white mica + albite + biotite ± garnet ± chlorite in metapelites and albite + chlorite + sphene ± amphibole ± epidote ± quartz ± pyrite ± magnetite in metabasites. Permeability and degree of deformation were two of the important variables controlling the preservation of blueschist assemblages: drill-core data from the area near Ambler indicate that the upper and lower margins of glaucophane-bearing metabasite lenses are more schistose and contain more retrograded glaucophane relative to the more massive cores in which glaucophane is better preserved (M.W. Hitzman, oral commun., 1983).

The latest phase of the greenschist-facies part of the metamorphic episode produced a semipenetrative cleavage (defined by the presence of aligned flakes of muscovite and chlorite and by dislocations in S_1 foliation) and resulted in the growth of largely postkinematic, helicitic, albite porphyroblasts, randomly oriented biotite, and partial to total replacement of garnet by chlorite (Gilbert and others, 1977; Nelsen, 1979; S.W. Nelson, written commun., 1983). Idioblastic, unaltered garnet porphyroblasts that occur in some greenschist-facies metabasite (Gilbert and others, 1977) were probably also formed during this phase.

The spatial association between obducted oceanic rocks (unit LPP (eKmJ)$_2$ and isolated outcrops of ultramafic rocks in the De Long Mountains and the western Brooks Range) (Patton and others, 1977; Roeder and Mull, 1978) and the blueschist-greenschist-facies rocks of this unit and the K-Ar ages assigned to white mica and biotite have been used as evidence to suggest that blueschist-greenschist metamorphism occurred as a result of tectonic loading caused by the northward overthrusting of oceanic rocks of Mississippian to Jurassic age (for example, Patton and others, 1977; Turner and others, 1979; Hitzman, 1983). Stratigraphic evidence in the western Brooks Range indicates that overthrusting of oceanic rocks (or underthrusting of the continental rocks) in that area began in the Middle Jurassic (Tailleur and Brosgé, 1970; Mayfield and others, 1983). Additional evidence for the initiation of thrusting in the Middle Jurassic is provided by K-Ar ages of 172 to 155 Ma for metamorphic minerals from garnet amphibolite from the sole of ultramafic thrust sheets that cap the oceanic assemblages thrust over the Ruby geanticline along the southeastern margin of the Yukon-Koyukuk basin (Patton and others, 1977). Dynamothermal metamorphism clearly had ceased by late Early Cretaceous time because Albian and Cenomanian conglomeratic rocks in the Yukon-Koyukuk basin record the uplift and progressive erosional stripping of oceanic rocks and the underlying rocks of this metamorphic unit (Patton, 1973; Dillon and Smiley, 1984; Box and others, 1984).

This conclusion is consistent with Early to mid Cretaceous (120-90-Ma) K-Ar cooling ages on mica for metamorphic rocks of the Brooks Range (Turner and others, 1979; Turner, 1984; Dillon and Smiley, 1984) and with the fact that the oldest rock unit in the Brooks Range that has not undergone significant thrust transport contains Albian fossils (Mayfield and others, 1983).

Two different tectonic schemes have been proposed to explain the origin of the widespread thrusting of oceanic rocks and the origin of a southward-dipping subduction zone. According to the first scheme (Tailleur, 1969), the dominant movement was south-directed underthrusting that was caused by counterclockwise rotation and oroclinal bending of the Arctic Alaska plate as rifting occurred in the Arctic region (Mayfield and others, 1983; Grantz and May, 1983). According to the second scheme, the dominant movement was north-directed overthrusting during the Early Cretaceous, when a volcanic arc, rooted in oceanic crust, collided with the continental margin of the Yukon-Koyukuk basin along a subduction zone that dipped away from the continental margin (Box, 1984; Patton, 1984). According to this model, the Middle Jurassic dates on the garnet amphibolite indicate that some tectonic mixing of the oceanic rocks (and presumably some metamorphism) took place before arc collision (Patton and others, 1977; Patton, 1984). Improved knowledge of the timing of both the opening of the Arctic Ocean basin and the accretion of the arc-related rocks will allow determination of whether one or both of these proposed tectonic origins for north-south convergence best explains the widespread thrusting episode.

Subduction of continental crust, like the subduction that probably caused the high-pressure metamorphism in the southern Brooks Range, Seward Peninsula, and perhaps elsewhere along the southeastern borderlands of the Yukon-Koyukuk basin (discussed below in those sections), has been documented for the western Alps (for example, Desmons, 1977; Chopin, 1984) and for Oman (Lippard, 1983). The geologic situation described for Oman seems particularly analogous. There, blueschists are proposed to have been formed by the metamorphism of pre-Permian continental basement due to the effects of the partial subduction of the continental margin during the initial stages of ophiolite obduction during Cretaceous time (Lippard, 1983). The problem of getting the blueschists back to the surface remains unresolved, but the contrast between the less dense continental rocks and the more dense oceanic rocks may cause the continental rocks to be exhumed more easily and sufficiently rapidly in order to preserve high-pressure mineral assemblages (Chopin, 1984).

The present structural and metamorphic relation between the high-pressure rocks of this unit and the structurally overlying lower temperature and pressure continental greenschist-facies rocks (unit GNS $(eKmJ)_1$) and prehnite-pumpellyite-facies oceanic rocks (LPP $(eKmJ)_2$) to the south indicates that late-metamorphic or postmetamorphic down-to-the-south low-angle extensional faulting has dismembered the upper plate, removing much of the section that originally buried the blueschists. This extensional late phase of the orogeny has been postulated in abstracts by several workers on the basis of interpretation of map patterns (Carlson, 1985; Miller, 1987; Oldow and others, 1987b) and field and kinematic data in the Cosmos Hills east of Ambler (Box, 1987). Additional evidence in support of late-metamorphic or postmetamorphic movement, herein assumed to be extensional, between upper and lower plate rocks is the fact that in the Cosmos Hills the allochthonous oceanic rocks of unit LPP $(eKmJ)_2$ cut across the metamorphic-mineral zones in the high-pressure rocks (Hitzman, 1984).

LPP (eKmJ)

Weakly metamorphosed phyllite, slate, metasiltstone, metasandstone, metaconglomerate, and minor impure marble make up this unit; protoliths are Devonian and Mississippian in age (Nelson and Grybeck, 1980). Metamorphic minerals include white mica, quartz, and chlorite. The boundaries of this metamorphic unit have been drawn to include Devonian and Mississippian rocks for which CAI values of 4 have been determined (corresponding to metamorphic temperatures between about 200 and 250 °C) (A.G. Harris, written commun., 1984). This unit crops out in the northwestern Survey Pass quadrangle. Metamorphic grade increases to the south, and rocks of this unit are gradational into the greenschist-facies rocks of unit GNH→L (eKmJ) that occur along the southern margin of the unit. Rocks of comparable laumontite- and prehnite-pumpellyite-facies grade probably occur across the entire northern margin of unit GNH→L (eKmJ), but we have chosen to show the prehnite-pumpellyite-facies unit only where CAI data are adequate to define these areas.

A Middle Jurassic to Early Cretaceous metamorphic age is assigned to this unit on the basis of the geologic reasoning discussed in the description of the adjacent unit to the south.

LPP $(eKmJ)_1$

This low-grade unit consists of prehnite-pumpellyite-facies rocks, including Ordovician metavolcanic and metavolcaniclastic rocks of intermediate composition cut by Ordovician and Devonian metabasite sills; a minor amount of Cambrian through Silurian phyllite, phyllitic siltstone, graywacke, sandstone, and argillite; and, in the northern and northeasternmost part of the unit, an unconformably overlying sequence of Mississippian through

Triassic metacarbonate and fine- and coarse-grained metamorphosed clastic rocks (Dutro and others, 1976, 1984; Mull, 1982; Dillon and others, 1986). It occurs as part of a structural window in the Mount Doonerak area in the northeastern Wiseman quadrangle. Diagnostic metamorphic minerals occur only in the Ordovician intermediate metavolcanic rocks and include pumpellyite, chlorite, and zeolite.

The angular unconformity between the lower to middle Paleozoic rocks and the overlying sequence of Mississippian to Triassic rocks has been affected by both extensive normal faulting in the central part (Dillon and others, 1986) and thrust faulting in the eastern part (Julian and others, 1984). Where the unconformity has not been faulted, the earliest schistosity (S_1) is parallel to a corresponding S_1 schistosity in the overlying Mississippian through Triassic rocks; where faulting has occurred along the unconformity, S_1 schistosities are not parallel across the contact (Julian and others, 1984; J.T. Dillon, oral commun., 1984). Two later generations of structures have been identified in the rocks both above and below the faulted unconformity in the eastern part of the window (Julian and others, 1984). These structural data indicate that rocks in the eastern part of the window are part of a duplex structure that formed after the earliest and most pervasive metamorphic foliation and during formation of the second generation of structures, dominated by asymmetric kink folds that have northwest-dipping axial planes (Julian and others, 1984).

The metamorphic rocks within the window (units LPP $(eKmJ)_1$ and GNS (eKmJ)) appear to have the same structures as those in the structurally overlying blueschist- and greenschist-facies rocks (unit GNH→L (eKmJ)) outside the window (H.G. Avé Lallemant, oral commun., 1987); therefore, metamorphism of the rocks within the window probably also occurred during Middle Jurassic to Early Cretaceous time as a result of the northward overthrusting of an oceanic sequence, discussed above. The anomalously low (prehnite-pumpellyite facies) metamorphic grade of this unit and the lack of high-pressure minerals in the greenschist-facies rocks of the window are in accordance with the structural observations of Julian and her coworkers (1984) and suggest that the rocks of the window were metamorphosed late in the metamorphic episode under low-temperature and moderate- to low-pressure conditions and then were overthrust, probably from the south, by the more deeply buried blueschist-facies rocks.

GNS (eKmJ)

The greenschist-facies rocks, including Cambrian through Silurian black phyllite, phyllitic metasiltstone, metagraywacke, metasandstone, meta-argillite, and minor metalimestone and metachert, that make up this unit are cut by abundant Devonian sills (metabasite) and are part of the structural window in the Mount Doonerak area in northeastern Wiseman quadrangle. Metamorphic minerals include stilpnomelane and actinolite in metabasite and quartz and white mica in metasedimentary rocks. The constraints on the ages of metamorphism and the metamorphic history of this unit are the same as those described for the above unit.

LPP $(eKmJ)_2$

This unit comprises a weakly metamorphosed assemblage of structurally and stratigraphically complex pillow basalt, gabbro, diabase, tuff, chert, graywacke, argillite, slate, and minor limestone. Basaltic protoliths appear to be Devonian, Carboniferous, and Triassic in age, and sedimentary protoliths range in age from Devonian to Jurassic (Hitzman and others, 1982; Jones and others, 1987; W.W. Patton, Jr., oral commun., 1985). These rocks crop out along the margins of the Yukon-Koyukuk basin and constitute the Angayucham terrane of Jones and others (1987). Volcanic and sedimentary textures are generally well preserved. The degree of metamorphism of this unit, best evidenced in metabasites, varies considerably; some samples have virtually unaltered igneous mineral assemblages, while others have small to relatively large percentages of metamorphic assemblages. Rocks along the southern margin of the Brooks Range contain chlorite + pumpellyite + albite ± sphene ± quartz ± calcite and chlorite + epidote + pumpellyite ± quartz. Rocks along the western margin of the Ruby geanticline contain chlorite + albite ± prehnite ± sphene ± quartz ± calcite and chlorite + actinolite + epidote ± pumpellyite ± quartz ± sphene.

The oceanic basaltic and sedimentary rocks that comprise this unit are interpreted to be the lower thrust sheet of an allochthonous mafic complex, rooted in the Yukon-Koyukuk basin, that was thrust onto the Proterozoic and early Paleozoic continental margin during Middle Jurassic to Early Cretaceous time (Patton and others, 1977; Turner and others, 1979; Patton, 1984, among others). In the Cosmos Hills (southern Ambler River quadrangle), igneous textures and mineralogy are generally best preserved in the upper parts of the fault-bounded sheets, and prehnite-pumpellyite-facies metamorphism of the volcanic rocks is most intense adjacent to the low-angle fault surface between this unit and the underlying continental greenschist-facies rocks (Hitzman, 1983). The low-angle fault has been interpreted as a thrust fault of Late Jurassic or Early Cretaceous age (Hitzman, 1983) and more recently as an extensional (detachment) fault of Late Cretaceous or early Tertiary age (Box, 1987). Regardless of the history of faulting, the spatial relation between intensity of recrystallization and the low-angle fault suggests that low-temperature metamorphism may have accompanied some phase of faulting. Blue amphibole (glaucophane?) locally occurs in basalt near the base of the tectonic contact between the mafic rocks and the underlying continental rocks of the Ruby geanticline (Patton and Moll, 1982) (gl, in the southern Bettles quadrangle). The presence of blue amphibole indicates that some of these rocks were metamorphosed under high-pressure, low-temperature conditions and were probably tectonically intermixed with other parts of this metamorphic unit during the obduction of the inverted allochthonous mafic complex or perhaps during the earlier deformation of the components of the mafic complex (Patton and Moll, 1982). Timing of metamorphism and deformation is bracketed between Middle Jurassic K-Ar ages of metamorphic minerals from garnet amphibolite at the sole of ultramafic thrust sheets (Patton and others, 1977; Patton, 1984) and the late Early Cretaceous age of conglomeratic rocks in the Yukon-Koyukuk basin that record the uplift and progressive erosional stripping of obducted oceanic rocks (including the low-grade metamorphic rocks of this unit) and underlying autochthonous basement (Patton, 1973; Dillon and Smiley, 1984; Box and others, 1984).

GNS $(eKmJ)_1$

The greenschist-facies metagraywacke, phyllite, metasiltstone, and minor metalimestone and chert of Middle Devonian to Triassic protolithic age (Hitzman and others, 1982; Dillon and others, 1981; Patton and Miller, 1973) that compose this unit crop out along most of the central part of the southern margin of the Brooks Range and along the northeastern border of the Yukon-Koyukuk basin. A semipenetrative cleavage is defined by sericite, chlorite, pyrite, and rarely biotite; metamorphic quartz and albite are also present; metamorphic textures are similar to textural zone 2 of metagraywackes as defined by Blake and others (1967) (Dillon and others, 1981). CAI values of about 5 to 5.5, indicating metamorphic temperatures around 400 °C or slightly greater, were determined for Middle and Late Devonian conodonts collected from limestone blocks that occur in a structural zone adjacent to the prehnite-pumpellyite-facies oceanic rocks (unit LPP $(eKmJ)_2$) to the south (written commun., A.G. Harris to W.W. Patton, Jr., 1984).

The metamorphic history of this unit is uncertain. Dillon and others (1981) consider this unit to have only one set of metamorphic structures, in sharp contrast with the polyphase metamorphic history of the rocks to the north (unit GNH→L (eKmJ)). These authors propose that the semipenetrative cleavage in the rocks of unit GNS $(eKmJ)_1$ developed during the latest phase of the metamorphism that affected the rocks to the north. However, the rocks of unit GNS $(eKmJ)_1$ are considered by others (for example, Hitzman and others, 1982; Gottschalk and others, 1984) to have shared a common metamorphic history with the rocks to the north. A Middle Jurassic to Early Cretaceous metamorphic age is assigned to this unit based on the assumption that metamorphism was related to north-south compressional tectonics that resulted in the emplacement of oceanic rocks along the northern margin of the Yukon-Koyukuk basin (for example, Patton and others, 1977; Roeder and Mull, 1978). Dynamothermal metamorphism associated with this compressional event had ceased by late Early Cretaceous time because Albian and Cenomanian conglomeratic rocks around the margins of the Yukon-Koyukuk basin record the uplift and progressive erosional stripping of ophiolite, phyllite, and graywacke from this metamorphic unit and underlying polymetamorphic rocks (Dillon and Smiley, 1984; Box and others, 1984). This conclusion is consistent with Early to mid Cretaceous (120-90-Ma) K-Ar cooling ages on mica from metamorphic rocks of the Brooks Range (Turner and others, 1979; Turner, 1984; Dillon and Smiley, 1984).

AMP (eKmJ)

This unit consists of strongly lineated and penetratively deformed phyllite, metagraywacke, metachert, garnetiferous mica schist, amphibolite, and foliated granite of unknown protolithic age. The map scale does not permit separation of the first three lower grade lithologies from the last three higher grade lithologies. The unit crops out in the eastern Koyukuk River basin (southern Chandalar quadrangle) and constitutes a window of heterogeneous, generally higher grade rocks (Mosquito terrane of Wust and others, 1984) within lower grade rocks (unit LPP $(eKmJ)_2$) of the Angayucham terrane. Characteristic metamorphic mineral assemblages in pelitic schists include quartz + muscovite + plagioclase + chlorite ± staurolite ± biotite ± garnet. Lineations, defined by axes of folds and crenulations and by elongated mineral grains, are subparallel in all rocks and have a northeast trend and a shallow plunge (Wust and others, 1984). Wust and his coworkers propose that the penetrative fabric in these rocks may be related to the Late Jurassic and Early Cretaceous emplacement of the Angayucham terrane. Lithologic similarities between the undifferentiated lower grade metamorphic rocks of this unit and the Angayucham terrane and between the higher grade rocks of this unit and the greenschist- and amphibolite-facies rocks of the Ruby terrane (units GNS $(eKmJ)_2$, GNS (eKmPz), GNI,H (eKmJ), AMP (peK), AMP (peK) + AMP (eKmJ?), and AMP (peK) + GNS (eKmJ)), as well as the sheared nature of terrane contacts, suggest that the Mosquito terrane may contain tectonically slivered and interleaved units derived from both of those terranes (Wust and others, 1984).

AML (eKmJ)

The garnetiferous biotite and biotite-muscovite schist, which commonly contains andalusite and (or) staurolite and rarely sillimanite (Brosgé and Reiser, 1964), and subordinate interbedded metachert (D.L. Jones, oral commun., 1984) that make up this unit crop out in the southern part of the Chandalar quadrangle and are considered to be part of the Ruby terrane of Jones and others (1987). Protolithic ages are unknown. In the more westerly exposure of this unit, syntectonic andalusite porphyroblasts, as much as 1.5 cm in length, are, for the most part, in textural equilibrium with syntectonic fibrolitic sillimanite and have only a minor inversion of andalusite to sillimanite. The coexistence of these two Al_2SiO_5 polymorphs indicates that the P-T path during metamorphism probably did not exceed a pressure of about 3.8 kb and reached a minimum temperature of about 500 °C (Holdaway, 1971). A spatial association between the eastern exposure of these medium-grade schists and a granitic pluton of probable Cretaceous age suggests that low-pressure metamorphism may have occurred during the early stages of widespread plutonism in the Ruby terrane (W.P. Brosgé, oral commun., 1984). However, the penetrative fabric that characterizes these rocks clearly requires dynamothermal rather than simply thermal metamorphism. By analogy with other medium-grade metamorphic rocks of the Ruby terrane that crop out along the southeastern margin of the Yukon-Koyukuk basin, metamorphism may have been a consequence of the obduction of the Angayucham terrane over the North American continental margin.

AMP (DE)+GNH→L (eKmJ)

This unit comprises polymetamorphosed pelitic schist, micaceous quartzite, feldspathic schist, marble, greenschist, orthogneiss, and metabasite. It includes the Kogoluktuk Schist of Hitzman and others (1982) and the interbanded graphitic schist and quartzite unit (characterized by a knotty appearance) of Dillon and others (1981). Protolithic ages are known to be pre-Middle Devonian in the Ambler River, Survey Pass, and Chandalar quadrangles (where the rocks are intruded by Middle Devonian granitoids) and Proterozoic(?) or pre-middle Paleozoic in the Wiseman quadrangle (where the rocks are intruded by granitoids of that age) (Dillon and others, 1980). Metamorphosed plutonic rocks (shown on pl. 1) are included in this unit; Devonian plutons may or may not have been metamorphosed during the earliest metamorphic episode. Metamorphic rocks are generally distinguished from those of the overlying blueschist- and greenschist-facies unit by having a coarser crystallinity, relict epidote-amphibolite metamorphic assemblages, and a more complex structural fabric (Hitzman and others, 1982; Dillon and others, 1987).

First-phase (M_1) assemblages in pelitic schist include quartz, muscovite, plagioclase, and subordinate biotite and garnet in higher grade rocks; calcareous pelitic schists also contain actinolite or hornblende. M_1 assemblages in metabasites include hornblende or actinolite, epidote, plagioclase, muscovite, biotite, garnet, and sphene. Retrograde effects, produced during the subsequent regional blueschist- to greenschist-facies metamorphic episode (M_2) between Middle Jurassic and Early Cretaceous time, include conversion of calcic plagioclase to albite and development of new albite (which helicitically encloses first-phase minerals), replacement of first-phase hornblende or actinolite by aggregates of actinolite, biotite, epidote, and chlorite, replacement of biotite by muscovite and chlorite, replacement of garnet by chlorite, muscovite, and quartz, and growth of euhedral rims of iron-poor epidote or clinozoisite on first-phase iron-rich epidote cores (Hitzman, 1983).

The distinction between M_1 metamorphic assemblages and structures and subsequent M_2 greenschist-facies assemblages and structures is clearly evidenced in the Cosmos Hills in the south-central Ambler River quadrangle. In that area, mica, amphibole, and epidote-group minerals that were formed during the retrograde episode generally define a foliation at a low angle to that formed during the first episode (Hitzman, 1983). In the Wiseman quadrangle farther to the east (Dillon and others, 1987), gneissic lithologic banding is the oldest metamorphic structure. A younger, strongly developed penetrative schistosity generally parallels, but locally crosscuts, earlier banding. Schistosity and banding are disrupted and partly transposed by a younger semipenetrative cleavage that shows some mineral growth. The knotty structure that characterizes many of the rocks of this metamorphic unit in the Wiseman-Chandalar area is present where semipenetrative cleavage cuts schistosity and banding at high angles (Dillon and others, 1987). The two most recent structures probably formed during M_2 metamorphism. Whether the gneissic banding was formed during the M_1 metamorphic episode, postulated to have occurred sometime during Proterozoic to Devonian time, or during an early stage of the M_2 metamorphic episode that produced the penetrative schistosity is not clear (Dillon and others, 1987). In other areas in the Brooks Range, mineralogical and structural differences between the metamorphic episodes are not as evident. A common history for rocks of this unit is tentatively proposed, but much more detailed study is required before a clear understanding of their metamorphic history is possible.

Least understood are the age and tectonic origin of M_1 metamorphism. Rocks in which M_1 mineral assemblages clearly exist are of unknown protolithic age. Equivocal radiometric data allow the possibility that some of the rocks of this unit have Proterozoic protolithic ages (Dillon and others, 1980) and, therefore, may have experienced Proterozoic metamorphism. Marbles for which protolithic ages are known have mineral assemblages that are not diagnostic of metamorphic grade or polyphase metamorphism. The Skajit Limestone, Silurian and Devonian in age (Nelson and Grybeck, 1981), locally is the wallrock for Devonian plutons in the Survey Pass quadrangle, but whether or not this lithologic unit was regionally metamorphosed prior to the Devonian plutonism is unclear. Skarns have developed near the plutons, which suggests that some of the higher grade assemblages in that area are a result of contact metamorphism (hornblende-hornfels facies) rather than dynamothermal metamorphism synchronous with Devonian plutonism.

The origin of the M_2 greenschist-facies overprint is considered to be the same as that described for the overlying blueschist- and greenschist-facies rocks.

AMP (Z) + GNH→L (eKmJ)

Polymetamorphosed quartz-mica schist, subordinate amounts of interlayered quartzite, marble, and metabasite of intrusive and probable tuffaceous origin, and crosscutting intermediate to mafic metaplutonic rocks make up this unit, which is located in the northeastern Baird Mountains quadrangle and constitutes the Hub Mountain terrane of Mayfield and others (1982). Mineral assemblages formed during the earlier metamorphic episode (M_1) include garnet, hornblende, and calcic plagioclase in metabasite and biotite and garnet in pelitic schist (A.B. Till, unpub. data, 1987). M_1 is the oldest metamorphic episode recorded anywhere in the Brooks Range and is the only documented evidence of Proterozoic metamorphism in the region. A Late Proterozoic age for M_1 is indicated by K-Ar muscovite and hornblende ages between 729 ± 22 and 594 ± 18 Ma (Turner and others, 1979; Mayfield and others, 1982) and by an Rb-Sr mineral-whole rock isochron age of 686 ± 116 Ma (Armstrong and others, 1986).

Most M_1 assemblages have been partially or, locally, totally recrystallized during a subsequent Mesozoic metamorphic episode (M_2) to greenschist- and blueschist-facies assemblages. Common M_2 minerals are chlorite, epidote, white mica, albite, sphene, barroisitic amphibole, actinolite, and blue amphibole (A.B. Till, unpub. data, 1987). Recent unpublished mapping has indicated that blueschist-facies assemblages are most prevalent in rocks that lie structurally above and below thrust slices of the amphibolite-facies rocks (A.B. Till, written commun., 1987). M_2 metamorphism is considered to have taken place during the high-pressure evolving to low-pressure metamorphic episode that affected the entire southern Brooks Range between Middle Jurassic and Early Cretaceous time and was associated with the north-vergent compression, discussed above.

EASTERN BROOKS RANGE

LPP $(K)_1$

The Late Jurassic or Early Cretaceous phyllite (containing mud-supported sand grains) and orthoquartzite that compose this unit crop out in the Coleen quadrangle. Rocks are weakly recrystallized and contain finely crystalline white mica and chlorite. Metamorphism probably occurred as a consequence of the Cretaceous tectonism that occurred throughout the Brooks Range.

LPP (eKŦ)

This unit comprises weakly metamorphosed argillite, graywacke, tuff, limestone, radiolarian chert, basaltic rocks, and minor conglomerate. Protolithic ages range from middle Paleozoic to Triassic. These rocks crop out primarily in the northwestern part of the Coleen quadrangle where they form part of the Sheenjek terrane and the eastern part of the Tozitna terrane (Jones and others, 1987). Metamorphic assemblages in basic rocks are chlorite + prehnite ± pumpellyite; pelitic rocks contain fine-grained chlorite and white mica. Metamorphic grade is gradational between the eastern part of the unit and adjacent unmetamorphosed rocks west of the Sheenjek River. Metamorphism is bracketed between the Triassic protolithic age of the youngest rocks and the Early Cretaceous age of conglomerate that overlies the eastern part of this unit. Low-grade metamorphism may have accompanied emplacement of these allochthonous terranes, as is proposed for the Angayucham terrane (unit LPP $(eKmJ)_2$ that rims the Yukon-Koyukuk basin) during late Mesozoic time.

LPP $(eKŦ)_1$

The weakly metamorphosed graywacke, siltstone, shale, radiolarian chert, argillite, and minor limestone and volcaniclastic rocks that make up this unit crop out primarily in the Christian quadrangle. Protolithic ages range from Devonian to Triassic. Metamorphic minerals in pelitic rocks are chlorite, white mica, and quartz. Metamorphism is known to postdate the Triassic age of the youngest protolith and is thought to predate, or to have been synchronous with, overthrusting of the unmetamorphosed and weakly metamorphosed Tozitna terrane to the east. Tectonic burial, caused by overthrusting of the adjacent terrane, is a likely mechanism that would account for the low-grade metamorphism that characterizes this unit. Overthrusting apparently took place by the time the Lower Cretaceous conglomerate was deposited on the Tozitna terrane (W.P. Brosgé, oral commun., 1984).

LPP (eKE)

This unit comprises Proterozoic(?) phyllite, slate, and quartzite. Rocks are weakly recrystallized and contain finely crystalline white mica and chlorite. Metamorphism can only be bracketed between the probable Proterozoic protolithic age and the Early Cretaceous depositional age of sandstone that overlaps the folded platform sequence of which these rocks are a part.

LPP (MD)

Weakly metamorphosed Proterozoic quartz wacke, semischist, phyllite, argillite, and limestone and overlying Paleozoic (pre-Mississippian) clastic, carbonate, and volcanic rocks of the northeastern Brooks Range (Reiser and others, 1971, 1980; Sable, 1977) make up this unit. Metamorphic minerals in mafic volcanic rocks include prehnite, pumpellyite, chlorite, white mica, stilpnomelane, albite, and rarely epidote; metamorphic quartz and fine-grained white mica characterize pelitic and clastic rocks. The metamorphic grade increases to the south, and the contact between this unit and greenschist-facies unit GNS (MD) to the south is probably gradational, although it was subsequently modified by thrust faulting (H.N. Reiser, oral commun., 1983). The metamorphic age is bracketed between the Middle Devonian protolithic age of the youngest rocks that clearly were metamorphosed and the Mississippian age of unmetamorphosed rocks that unconformably overlie this unit (Reiser and others, 1971, 1980).

A peraluminous batholith (unit Dg) intrudes this unit and unit GNS (MD) and gives a Devonian U-Pb upper intercept age on zircon of 380 ± 10 Ma (Dillon and Bakke, 1987). Close timing between the metamorphic-age range indicated for these units and the intrusive age of the batholith suggests metamorphism and plutonism may have been part of the same tectonic episode. Some parts of the batholith are gneissic and mylonitically or cataclastically deformed (Sable, 1977), but whether or not these are metamorphic features or igneous (protoclastic?) features has not been determined. Skarns that developed around the batholith show no textural evidence of regional metamorphism (Sable, 1977), suggesting intrusion postdated metamorphism.

Structural data collected from greenschist-facies rocks in the western end of unit GNS (MD) have been interpreted to indicate that the pre-Mississippian rocks in that area were transported southeastward during Middle Devonian (Ellesmerian?) thrusting (Oldow and others, 1987a). Additional structural studies in the northeastern Brooks Range are needed to determine the validity and extent of the proposed southeastward thrusting in pre-Mississippian rocks and its temporal relation to the metamorphism.

The low-grade rocks of units LPP (MD) and GNS (MD) and perhaps some parts of the adjacent unmetamorphosed rock unit in the Romanzof Mountains area were subsequently involved in Mesozoic and perhaps early Cenozoic deformation and perhaps in some accompanying metamorphism that was part of the widespread orogeny that affected the southern Brooks Range, discussed earlier. Biotite from the Devonian batholith in the Romanzof Mountains yielded K-Ar ages of 131 and 128 Ma (Sable, 1977), and additional samples subsequently collected from the batholith gave a 60 ± 10-Ma U-Pb lower intercept age on zircon and a 59 ± 2-Ma K-Ar age on biotite (Dillon, 1987). Structural data collected near the western part of unit GNS (MD) were interpreted to indicate that both the low-grade rocks of that unit and the unconformably overlying rocks (shown as unmetamorphosed) were involved in Mesozoic-Cenozoic north-directed thrusting (Oldow and others, 1987a).

GNS (MD)

The greenschist-facies Proterozoic and Paleozoic (pre-Mississippian) sedimentary and volcanic rocks that make up this unit crop out in the northeastern Brooks Range. Protoliths are generally the same as those of the prehnite-pumpellyite-facies unit to the north. Characteristic metamorphic minerals in basic rocks are actinolite, chlorite, white mica, quartz, calcite, albite, and stilpnomelane; pelitic rocks contain quartz, white mica, and chloritoid. Metamorphic grade increases from north to south. The metamorphic history of this unit is considered to be the same as that of the prehnite-pumpellyite unit to the north; its metamorphic age is bracketed between the Middle Devonian protolithic age of the youngest metamorphosed rocks and the Mississippian age of unmetamorphosed rocks that unconformably overlie this unit (Reiser and others, 1971, 1980).

GNS (D)

Pelitic schist, slate, quartzite, mafic schist, phyllite, and greenstone of Proterozoic(?) to Late Devonian age make up this unit, which crops out along the east boundary of the map area. Metamorphic grade increases from chlorite-zone assemblages (chlorite, albite, quartz, and sphene in pelitic rocks and quartz, epidote, calcite, and chlorite in basic rocks) to biotite-garnet-zone assemblages (muscovite, quartz, albite, biotite, chlorite, and garnet in pelitic rocks and biotite, muscovite, epidote, chlorite, and sphene in basic rocks) as the distance to crosscutting Late Devonian plutons decreases. This relation and the proximity of the maximum metamorphic age (provided by the youngest protolithic age) to the intrusive age of the undeformed crosscutting plutons indicates that metamorphism was early tectonic to syntectonic with intrusion of the Devonian granitoids.

SEWARD PENINSULA

GNH→I (eKmJ)

This unit is composed of high-pressure blueschist-facies rocks of continental origin that were partly recrystallized under intermediate-pressure greenschist-facies conditions. The quartz-rich pelitic schist, graphitic quartzite, micaceous marble, chlorite-albite schist, mafic schist, pods and lenses of iron-titanium-rich metabasite, and orthogneiss (Sainsbury and others, 1970; Till, 1983, 1984; Forbes and others, 1984) that make up this unit encompass a large (125 by 150 km) area. A Devonian protolithic age has been established for orthogneiss that crosscuts the other lithologies; metasedimentary and metavolcanic rocks are Proterozoic and early Paleozoic (largely Ordovician) in age (Till and others, 1986; Armstrong and others, 1986). Glaucophane is present in all lithologies that have an appropriate bulk composition and is absent only from pure marble, quartzite, and orthogneiss.

Metamorphic minerals present in metabasite are glaucophane, epidote, almandine, albite, sphene, actinolite (zoned to sodium-actinolite and barroisite), chlorite, white mica, and pseudomorphs of clinozoisite, paragonite, quartz, and locally albite or calcite after lawsonite (Pollock, 1982; Till, 1983; Forbes and others, 1984; Thurston, 1985). Metamorphic mineral assemblages in pelitic rocks (phengite + quartz ± chloritoid ± glaucophane ± almandine ± paragonite ± albite ± graphite) and in impure marble (calcite + phengite ± dolomite/ankerite ± tremolite ± glaucophane ± albite) are compatible with the recrystallization history indicated by metabasite paragenesis. Granitic orthogneiss also contains a high-pressure assemblage that consists of quartz + albite + uniaxial (3T), silicon-rich phengite + biotite ± microcline ± garnet (Evans and Patrick, 1987).

Glaucophane-bearing eclogitic rocks (omphacite + almandine + rutile) have been found at three localities in a zone just east of the Nome River (Pollock, 1982; Thurston, 1985). Mineralogically these rocks are type C eclogites (eclogites from alpine-type orogenic terranes) of Coleman and others (1965) (Forbes and others, 1984). However, their whole-rock compositions overlap those of the glaucophanitic metabasites, and no evidence is present to indicate that the eclogitic rocks are exotic (Thurston, 1985; Forbes and others, 1984). These rocks are thought to be either the result of outcrop-scale metamorphic conditions (420 °C, 9-10 kb) during the early stages of metamorphism that were marginally different (perhaps lower P_{H_2O}) from the metamorphic conditions in the surrounding rocks (Pollock, 1982; Thurston, 1985) or small though complex variations in bulk composition (Evans and others, 1987).

Petrographic, structural, and phase-equilibria data indicate that crystallization of the blueschist- and greenschist-facies assemblages occurred during a single episode of high-pressure evolving to intermediate-pressure, low-temperature metamorphism, similar to that recorded in the southern Brooks Range. Metamorphic conditions during the high-pressure phase of this monocyclic, polyfacial episode started in the glaucophane-lawsonite-sodic pyroxene stability field and, as temperature increased, evolved into the epidote-garnet-glaucophane stability field (Thurston, 1985). The P-T path passed through approximately 9-11 kb at 400-450 °C during the highest pressure phase of the prograde episode and passed into the albite-epidote- (barroisite-) amphibolite or greenschist facies during initial stages of decompression and thermal relaxation (Forbes and others, 1984). Static retrograde alteration under greenschist-facies conditions (primarily overgrowth of chlorite and albite on the blueschist assemblages) occurred during subsequent rapid uplift. The final stages of this metamorphic episode are inferred to have taken place under intermediate-pressure conditions, because subsequent Cretaceous amphibolite-facies metamorphism, discussed below, that overprints the blueschist-facies fabric began in the kyanite stability field.

Metamorphism was synkinematic with penetrative ductile deformation, mesoscopic intrafolial isoclinal folding, and development of flat-lying to shallowly dipping transposition foliation (Thurston, 1985). Stretching lineations and isoclinal fold axes have a north-south trend (Till and others, 1986). The ubiquitous parallelism between stretching lineations and fold axes suggests a highly noncoaxial deformation during which fold axes rotated toward the stretching direction, as pointed out by Patrick (1986). Quartz petrofabrics indicate northward vergence during deformation (Patrick, 1986).

Metamorphism is known to postdate the Middle Devonian (381-Ma) intrusive age of the orthogneiss that crosscuts the other lithologies and to predate contact metamorphism caused by Early Cretaceous (110-100-Ma) plutons. Rb-Sr whole-rock-mica isochron ages and K-Ar mineral ages suggest that the high-pressure metamorphic cycle reached a maximum during the Middle or Late Jurassic, before about 160 Ma, and that this was followed by decompression and partial reequilibration between about 160 and 100 Ma (Armstrong and others, 1986).

Blueschist-facies metamorphism was apparently caused by rapid tectonic loading of a continental plate by an allochthon of indeterminate origin (for example, Forbes and others, 1984). Subsequent unloading by uplift and erosion took place within the short time interval required for the preservation of blueschist-facies assemblages (Draper and Bone, 1981; Forbes and others, 1984). Many geologic characteristics of this unit argue against a subduction/ melange-related explanation for the high-pressure low-temperature metamorphism. Principal characteristics include: the continental affinities of the protoliths; the lengthy interval of time between deposition and metamorphism; and the large size of the unit and relatively uniform metamorphic grade, suggesting that the terrane possesses a low regional dip (Till, 1983; Forbes and others, 1984). Similarities in protolithic lithologies, metamorphic grade, structural style, and apparent metamorphic age suggest a correlation between the metamorphic and tectonic history of this unit and that of unit GNH→L (eKmJ) that crops out across the southern Brooks Range. By analogy with the proposed history of the Brooks Range unit, multiple thrust sheets of oceanic rocks (Angayucham terrane) may have once covered the Seward Peninsula blueschists (Forbes and others, 1984; Till, 1983). The nearest possible remnant of that oceanic terrane is a sliver of north-south-trending blueschist-facies rocks (unit GNH (eKmJ), discussed below) that crops out on the eastern Seward Peninsula; other possible remnants have been proposed by Box (1984). According to his regional tectonic reconstruction, Early Cretaceous volcanic rocks in the Yukon-Koyukuk basin (Koyukuk terrane of Jones and others, 1987) that occur just east of the high-pressure metamorphic rocks of the Seward Peninsula were part of a Jurassic and Cretaceous intraoceanic arc terrane that collided with the continental margin and that almost certainly was genetically related to the high-pressure low-temperature metamorphism in the Seward Peninsula and the Brooks Range, as well as in the southeastern borderlands of the Yukon-Koyukuk basin (Box, 1984).

GNH (eKmJ)

The high-pressure greenschist (blueschist)-facies mylonitic metabasite and minor serpentinite that compose this unit crop out in a narrow, fault-bounded, north-south-trending belt along the east side of the Darby Mountains (Miller and others, 1972; Till and others, 1986). Protoliths are tentatively correlated with the protoliths of the metabasaltic and metasedimentary rocks (unit LPP $(eKmJ)_2$) of the Angayucham terrane that are present around the borderlands of the Yukon-Koyukuk basin and, therefore, are considered to range in age from middle Paleozoic to Jurassic. Mylonitic metabasite in the northern part of the belt (stipple pattern) contains the assemblage crossite-lawsonite-pumpellyite, indicative of the low-temperature subdivision of the blueschist facies, and mylonitic metabasite in the southern part of the belt contains the assemblage crossite-epidote-actinolite, indicative of high-temperature subdivision of the blueschist facies (subdivisions those of Taylor and Coleman (1968)). Relict igneous pyroxene grains are common in mylonitic metabasite in both areas (Till, 1983). The high pressures indicated for this unit by the presence of crossite and lawsonite probably occur within the lower part of the range of pressure conditions indicated for the extensive blueschist-facies unit that crops out in the central Seward Peninsula. However, different crystallization and deformational histories for the two units are indicated by the incomplete recrystallization and brittle deformation of the former in contrast with the complete recrystallization and ductile deformation of the latter (Till and others, 1986). A Middle Jurassic to Early Cretaceous metamorphic age is assigned to this unit on the basis of correlation of its metamorphic history with that of the Angayuchum terrane discussed earlier.

AMI (K)

This unit comprises amphibolite-facies pelitic schist, marble, graphitic quartzite, calc-schist, quartzofeldspathic schist, and amphibolite. Protoliths are thought to be correlative with those of the lower grade, high-pressure unit (GNH→I (eKmJ)) described above and, therefore, are presumed to be Proterozoic and early Paleozoic in age (Till and others, 1986; Armstrong and others, 1986). Diagnostic metamorphic minerals are staurolite, kyanite, and sillimanite (pelitic schist); diopside and olivine (calc-schist); and hornblende, calcic plagioclase, and garnet (amphibolite). An intermediate geothermal gradient that passes above the aluminum silicate triple point (3.8 kb, 500 °C; Holdaway, 1971) is indicated by the appearance of kyanite followed by sillimanite and by the absence of andalusite in pelitic schist.

On the south flank of the Kigluaik Mountains, four mineral zones in pelitic rocks (staurolite, staurolite + kyanite, sillimanite + garnet, and sillimanite + potassium feldspar) define a prograde metamorphic sequence that increases from south to north (Till, 1980; Pollock, 1982). The close spacing of the isograds that separate these zones (three isograds within a 3-km-thick section) indicates a fairly steep geothermal gradient within the kyanite stability field. Thurston (1985) proposed that, in this area, the intermediate-pressure amphibolite-facies minerals were statically superimposed on pelitic rocks whose foliation is considered to have developed during the widespread Jurassic blueschist-facies metamorphic episode that affected much of the Seward Peninsula. According to his interpretation, the kyanite-bearing assemblages were produced during thermal metamorphism associated with Cretaceous plutonism.

However, elsewhere in this unit, intermediate-pressure amphibolite-facies metamorphism was more dynamothermal in nature and predated the development of contact metamorphism associated with those plutons. In the Bendeleben and Darby Mountains, kyanite-bearing assemblages define a penetrative metamorphic fabric and are overprinted by low-pressure, statically recrystallized metamorphic assemblages containing various combinations of cordierite, sillimanite, andalusite, hercynite, and orthoamphibole. The low-pressure assemblages probably formed as a result of high-level thermal metamorphism associated with the intrusion of Cretaceous (approximately 80-Ma) plutons (Till and others, 1986). Intermediate-pressure metamorphism probably took place during the early part of pluton emplacement, occurring between about 100 and 80 Ma (Armstrong and others, 1986). K-Ar ages on biotite and hornblende from metamorphic rocks of this unit in the Kigluaik and Bendeleben Mountains range from 87 to 81 Ma (Turner and others, 1980; Wescott and Turner, 1981). Whether these Late Cretaceous ages indicate the time of cooling following intermediate-pressure regional or low-pressure thermal metamorphism is not clear.

GNS (MzPz)

The quartz-mica schist, quartzite, recrystallized limestone and dolomite, and, locally, calcareous, graphitic, feldspathic, and amphibolitic schist that compose this unit crop out in several areas along the east side of the Seward Peninsula. These rocks are poorly exposed and have not been studied in detail. A middle Paleozoic protolithic age has tentatively been assigned to the limestone and dolomite (Patton, 1967). The age of metamorphism can only be bracketed between the Cretaceous age of unmetamorphosed granitoids that occur in the general region and the presumed Paleozoic protolithic age. These rocks may share a common origin and metamorphic history with the low-grade, high-pressure rocks of the Seward Peninsula and (or) the Brooks Range.

AMP (KP)

This unit comprises small patches of amphibolite-facies hornblende-plagioclase gneiss, pelitic gneiss, and calc-silicate gneiss in the northwestern Bendeleben quadrangle and calc-silicate gneiss (quartz, feldspar, pyroxene, scapolite, sphene, calcite, and garnet), marble (quartz, potassium-feldspar, plagioclase, phlogopite, forsterite, scapolite, and sphene), and metapelite (quartz, feldspar, biotite, sillimanite, and garnet) in the southern Selawik quadrangle (Patton and Miller, 1968). These rocks have not been studied in detail, and it is not known whether they may be remnants of an earlier metamorphic episode (perhaps as old as Proterozoic) or whether they were metamorphosed during the Cretaceous intermediate-pressure amphibolite-facies episode described above. Contact-metamorphic assemblages overprint the assemblages in the Selawik quadrangle and indicate that the amphibolite-facies metamorphic episode predated Cretaceous plutonism (A.B. Till, unpub. data, 1984).

2PX (lK)

The rock types, exposed from the top to the bottom of a cirque in the Kigluaik Mountains, that make up this unit include biotite gneiss, marble, megaboudins and discontinuous layers of pelitic, quartzofeldspathic, mafic, and ultramafic gneiss (lherzolite), and migmatite (Till, 1980; 1983). Protoliths are presumed to be the same as those of units AMI (K) and GNH→I (eKmJ) and, therefore, are Proterozoic and early Paleozoic in age (Till and others, 1986). The biotite gneiss (quartz + potassium-feldspar + sillimanite + biotite + garnet) is an upper amphibolite-facies-grade rock; it crystallized at a temperature above that at which the reaction muscovite + quartz = sillimanite + potassium-feldspar + water takes place, which is estimated to occur above about 625 °C (Chatterjee and Johannes, 1974). Impure marbles contain the assemblage diopside + dolomite, which is indicative of upper amphibolite- or granulite-facies metamorphic conditions. Diagnostic metamorphic mineral assemblages are diopside + orthopyroxene + garnet + biotite (semi-pelitic gneiss) and diopside + orthopyroxene + garnet + hornblende (metabasite). Garnet lherzolite (olivine + orthopyroxene + clinopyroxene + garnet) has partially recrystallized to spinel lherzolite (olivine + orthopyroxene + clinopyroxene + spinel + hornblende) (Till, 1980; 1983). With the exception of the garnet lherzolite, these assemblages equilibrated under granulite-facies conditions at about 700 °C and 8-10 kb (A.B. Till, unpub. data, 1980).

A Late Cretaceous age is inferred for the upper amphibolite- and granulite-facies metamorphism on the basis of (1) relict kyanite occurring as inclusions within garnet that was formed during granulite-facies metamorphism, indicating granulite-facies metamorphism followed (as a later phase) the intermediate-pressure amphibolite-facies metamorphism discussed above, and (2) the interpretation by A.B. Till that metamorphism of this unit was associated with the thermal episode that culminated in the intrusion of approximately 80-Ma plutons. An Rb-Sr whole-rock isochron age of 735 Ma from biotite gneiss was interpreted to be the age of granulite-facies metamorphism (Bunker and others, 1979), but, like Armstrong and others (1986), we interpret this Late Proterozoic age to be the age of the protolith instead.

The environment of crystallization of the garnet lherzolite is unknown. Textural relations indicate that garnet was stable in the lherzolite previous to granulite-facies metamorphism, during which time the spinel-bearing assemblages are presumed to have formed (Till, 1980; A.B. Till, unpub. data, 1987). The garnet-bearing assemblage may be relict of an upper mantle environment or may have been metamorphosed in a deep crustal setting. If metamorphosed in a deep crustal setting, formation of the garnet occurred either during some major tectonic event in pre-Mesozoic time or during the early phases of the Jurassic and Cretaceous metamorphic episode of the Seward Peninsula and southern Brooks Range, simultaneous with formation (at shallower levels) of the extensive blueschist-facies terranes.

SOUTHEASTERN BORDERLANDS OF THE YUKON-KOYUKUK BASIN

GNS (eKmJ)$_2$

The greenschist-facies quartz-mica schist, quartzofeldspathic schist, chlorite schist, and subordinate interlayered quartzite, marble, and fine- to medium-grained semischist that make up this unit crop out primarily in the Beaver and Bettles quadrangles. Protolithic ages are believed to be Paleozoic, including a probable Devonian age for the schistose clastic rocks (Brosgé and others, 1973; Patton and Miller, 1973). Characteristic mineral assemblages in schists are quartz + white mica + chloritoid + chlorite + tourmaline and quartz + white mica + chlorite ± epidote ± calcite ± sphene. This unit is lithologically and mineralogically similar to some of the greenschist-facies rocks of unit GNH→L (eKmJ) in the Brooks Range, but it is differentiated from them because neither polydeformational fabrics nor evidence of early formed high-pressure minerals has been reported.

GNI,H (eKmJ)

Quartz-mica schist, quartzite, phyllite, slate, and mafic metavolcanic rocks of Proterozoic(?) and Paleozoic age and recrystallized limestone, dolomite, and chert of Paleozoic age compose this unit. It crops out in the Kaiyuh Mountains (Patton and Moll, 1982; Patton and others, 1984), in the Kokrines Hills in correlative rocks (Patton and others, 1978) that have been offset by approximately 160 km of right-lateral movement along the Kaltag fault (Patton and others, 1984), and in the Tanana quadrangle just north of the Yukon River (Chapman and others, 1982). Ordovician conodonts have been identified in the Kaiyuh Mountains, and Devonian conodonts have been identified in the Kokrines Hills (A.G. Harris, unpub. data). This unit is defined by the presence of glaucophane, which indicates that, at least locally, high-pressure metamorphic conditions prevailed. Metamorphic mineral assemblages in pelitic schist are: quartz + white mica + chlorite ± chloritoid ± clinozoisite ± plagioclase and locally biotite in the Tanana quadrangle; glaucophane + white mica + garnet + chlorite + chloritoid + quartz in the Kaiyuh Mountains; and glaucophane + white mica + calcite + plagioclase + quartz in the Kokrines Hills. Metabasalts contain the assemblages albite + chlorite + actinolite + epidote-group minerals ± calcite ± sphene, and chlorite + epidote + sphene + plagioclase ± white mica ± glaucophane in the Kaiyuh Mountains. Glaucophane (+ albite + calcite + chlorite + epidote + actinolite + stilpnomelane) also occurs in calcareous greenschist near the headwaters of the Tozitna River in the Tanana quadrangle.

The intermediate- to locally high-pressure metamorphism of these rocks is believed to have occurred as a result of the obduction of thrust sheets of oceanic rocks onto the Proterozoic and early Paleozoic continental margin. High-pressure greenschist (blueschist)-facies mineral assemblages (defined by the presence of glaucophane) are found at the base of the lowermost thrust sheets of oceanic rocks (shown as the adjacent prehnite-pumpellyite-facies units LPP (eKmJ)$_2$ and LPP (eKlTR)) as well as in the underlying metasedimentary greenschist-facies rocks of this unit (Patton and Moll, 1982). The direction from which these oceanic rocks were thrust and determination of which oceanic thrust sheets were involved is unclear however. The first tectonic model that has been proposed relates metamorphism of this unit to the collision of a volcanic arc and obduction of a disrupted ophiolitic mafic-ultramafic complex during Middle Jurassic to Early Cretaceous time (Patton and others, 1977; Patton and Moll, 1982; Patton, 1984; Turner, 1984). According to this model, which is based on regional relations around the margins of the Yukon-Koyukuk basin, the mafic-ultramafic complex is considered to have been rooted in the Yukon-Koyukuk basin and to consist of two separate thrust sheets: (1) a lower sheet of structurally disrupted pillow basalt, diabase, nonlayered gabbro, and chert; and (2) an upper sheet of ultramafic rocks and layered gabbro. Garnet amphibolite occurs locally at the base of the upper sheet of ultramafic rocks and possibly was formed when the two thrust sheets were tectonically juxtaposed prior to their final emplacement onto the continental margin (Patton and others, 1977; Patton, 1984).

The rocks proposed by Patton and others (1977) to make up the lower thrust sheet have since been divided into two separate lithotectonic terranes by Jones and others (1987): (1) the Angayucham terrane to the west (basinward) of this intermediate- to high-pressure greenschist-facies metamorphic unit and (2) the Tozitna terrane to the east of the unit. An alternative explanation for the metamorphism of this unit is that intermediate- to high-pressure metamorphism resulted from thrusting of the Tozitna terrane (shown as unit LPP (eKlTR)) along the east margin of this unit toward the northwest, rather than toward the southeast as proposed by Patton and others (1977). This second hypothesis is based on recent structural analyses of S-C relations and the sense of rotation of large-scale nappe-like folds that indicate northwestward transport directions for the Tozitna terrane (Miyaoka and Dover, 1985; Smith and Puchner, 1985).

A Middle Jurassic maximum age of metamorphism of this unit is proposed on the basis of ages of 172-155 Ma on the garnet amphibolite that occurs at the base of the thrust sheet of ultramafic rocks and layered gabbro (Patton and others, 1977). If additional studies support the possibility that metamorphism was caused by northwestward obduction of the Tozitna terrane, the maximum age of metamorphism would be extended to Triassic time, because thrusting could have been as old as the Triassic age of the youngest rocks of the Tozitna terrane. A minimum late Early Cretaceous age of metamorphism is established on the basis of Albian conglomerates that were deposited along the margins of the Yukon-Koyukuk basin which contain clasts of both the metamorphosed continental margin and oceanic rocks, and on the basis of the late Early Cretaceous age (111 Ma) of a granitoid pluton that intrudes both the continental and overthrust oceanic rocks in the Kokrines Hills (Patton and others, 1977, 1978; Patton, 1984). K-Ar ages of 134 and 136 Ma on metamorphic muscovite from glaucophane-bearing schist in the Kaiyuh Mountains provide additional evidence for an earliest Cretaceous metamorphic episode that was associated with overthrusting of the oceanic rocks (Patton and others, 1984).

LPP (eKlTR)

This unit is composed of a weakly metamorphosed assemblage of oceanic rocks that includes greenstone, metadiabase, metachert, meta-argillite, slate, metagraywacke, metalimestone, metaconglomerate, and metatuff. It occurs as large thrust sheets (Patton and others, 1977) and constitutes the Innoko and Tozitna terranes of Jones and others (1987). Protoliths range in age from Late Devonian to Late Triassic (Jones and others, 1987). The degree of low-temperature metamorphism varies considerably within this unit and appears to be a function of the structural position within the section of oceanic rocks (W.W. Patton, Jr., and S.E. Box, oral commun., 1985). Characteristic metamorphic mineral assemblages in mafic rocks in most areas consist of quartz + albite + prehnite, quartz + albite + chlorite + pumpellyite, and chlorite + actinolite + sphene + albite ± pumpellyite ± epidote/zoisite ± quartz. Neither prehnite nor pumpellyite have been reported to occur in basaltic rocks in the Livengood quadrangle. In that area, calcite, chlorite, albite, clay minerals, and sericite are the common metamorphic minerals in this unit (Brosgé and others, 1969; R. M. Chapman, unpub. data, 1985). Glaucophane (+ stilpnomelane + sphene + chlorite in the Nulato quadrangle and + chlorite + albite ± quartz ± pumpellyite ± actinolite in the Tanana quadrangle) occurs locally in metabasaltic rocks near the structual base of this unit (Patton and Moll, 1982; W.W. Patton, Jr., E.J. Moll, and R.M. Chapman, written commun., 1983) where localized higher pressure conditions must have existed.

As mentioned above, this unit consists of tectonically emplaced thrust sheets of oceanic rocks. The direction from which these rocks were thrust, however, is controversial. According to one proposal, this thrust sheet is one of several that were rooted in the Yukon-Koyukuk basin and thrust southeastward over the continentally derived rocks of the Ruby geanticline (Patton and others, 1977; Patton and Moll, 1982). Recent structural analysis of S-C relations in these and the underlying rocks in the Tanana quadrangle (Miyaoka and Dover, 1985; Smith and Puchner, 1985) and the sense of rotation of large-scale nappe-like folds in the underlying rocks (unit GNI,H (eKmJ)) in the Kaiyuh Mountains in the Nulato quadrangle (Smith and Puchner, 1985; G.M. Smith, written commun., 1986) indicate this oceanic sheet was thrust in the opposite direction, from the southeast toward the northwest.

A Late Triassic maximum metamorphic age is assigned on the basis of the youngest protolith. An Early Cretaceous minimum metamorphic age is assigned assuming a correlation, as proposed by Patton and his coworkers (Patton and others, 1977; Patton and Moll, 1982), between the origin and tectonic history of this unit and those of the lithologically similar prehnite-pumpellyite-facies oceanic rocks of the Angayucham terrane (unit LPP (eKmJ)$_2$) whose low-grade metamorphism predates the intrusion of an Early Cretaceous (111-Ma) granitoid (Patton and others, 1978).

GNS (eKmPz)

The phyllite, greenschist, pelitic schist, quartzite, calcareous schist, greenstone, metachert, and metalimestone of Proterozoic(?) to middle(?) Paleozoic age that make up this unit crop out in the Ruby and Nulato quadrangles (Chapman, 1976; W.W. Patton, Jr., unpub. mapping) and continue along strike into the Ophir and Kantishna River quadrangles outside the map area. Also included in this unit is a similar assemblage of rocks that crops out south of the Yukon River in the Tanana quadrangle (Chapman and others, 1982). Pelitic schists are characterized by quartz + muscovite + chlorite ± epidote ± calcite ± biotite, and metabasites are characterized by epidote + actinolite + chlorite ± zoisite ± biotite ± sphene ± quartz.

Metamorphism is known to postdate the middle(?) Paleozoic protolithic age of the youngest rocks and predate the Cretaceous or Tertiary intrusive age of crosscutting granitoids. On the basis of geologic reasoning, the origin and age of metamorphism of this unit was probably the same as that proposed for the GNI,H unit described above, namely tectonic overthrusting of oceanic rocks during Middle Jurassic to Early Cretaceous time (Patton, 1984; Turner, 1984).

GNS (pO)

The 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) that compose this unit crop out southeast of the Susulatna fault in the southeastern Ruby quadrangle. Characteristic metamorphic mineral assemblages in pelites are quartz + muscovite ± chlorite ± biotite, and rarely garnet and chloritoid + chlorite + muscovite + quartz; metabasites contain the metamorphic assemblage chlorite + epidote + actinolite + albite ± calcite ± sphene ± biotite. Pre-Ordovician metamorphic and protolithic ages for this unit are 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). A minimum metamorphic age of 514 Ma is provided by the oldest of three K-Ar ages on mica from quartz-muscovite-chlorite schist in the Medfra quadrangle (south of the Ruby quadrangle; Silberman and others, 1979). This metamorphic episode may correspond with an M_2 retrograde episode (or the return path along the P-T loop) in the polymetamorphic(?) unit AMP (mPzY) + GNS (mPzY) in the southeastern Ruby quadrangle. U-Pb data on zircon suggest that the rocks in this unit were not affected by the Early Cretaceous metamorphic episode that occurred northwest of the Susulatna fault in the Ruby geanticline (Dillon and others, 1985).

AMP (peK)

This unit comprises little studied amphibolite-facies rocks that crop out in two places along the southeastern borderlands of the Yukon-Koyukuk basin. The northern exposure of rocks included in this unit crops out in the Beaver quadrangle and consists of gneissic quartzite, quartz-biotite schist, and quartz-plagioclase gneiss (Brosgé and others, 1973). Biotite, garnet, and sillimanite are present locally in gneiss and schist. Protolithic ages are unknown but are presumed to be Proterozoic and (or) Paleozoic. No detailed mapping of these rocks has been done, and some of the amphibolite-facies minerals in this area may be due to thermal metamorphism produced by the adjacent Early Cretaceous plutons.

The southern exposure of this unit is in the Ruby quadrangle and consists of pelitic schist, quartz schist, quartzite, felsic orthogneiss, and mafic metavolcanic rocks of Proterozoic or earliest Paleozoic age (G.M. Smith, written commun., 1986). Characteristic metamorphic mineral assemblages in pelitic schist and quartz schist are quartz + muscovite + biotite + staurolite + garnet and quartz + muscovite + biotite + cordierite. The amphibolite-facies rocks in the Ruby quadrangle have a well-developed foliation that generally trends northwestward, roughly subperpendicular to most trends in the region (G.M. Smith, written commun., 1986). According to Smith, metamorphism of these rocks clearly predates the intrusion of nearby latest Cretaceous to earliest Tertiary plutons and clearly is not a thermal effect of the plutons.

The metamorphic history of this unit may be the same as that of the amphibolite-facies rocks in the Ray Mountains or the Kokrines Hills. The age of metamorphism of this unit and of the possible correlative units is uncertain, but it is known, or inferred, to predate the intrusion of Early Cretaceous plutons.

AMP (peK) + GNS (eKmJ)

The polydeformed and polymetamorphosed metasedimentary and meta-igneous rocks of the Ray Mountains area (Chapman and others, 1982; Dover, 1984; Dover and Miyaoka, 1985a; 1985b) that make up this metamorphic unit have been divided into five different tectonic units. The structurally lowest two units, which may be parautochthonous, consist of quartzofeldspathic paragneiss that has a Proterozoic or Paleozoic protolithic age (Dover and Miyaoka, 1985a) and augen orthogneiss (shown by the symbol for metamorphosed plutons) that has a Devonian protolithic age (Patton and others, 1987). The other three units, Paleozoic and (or) Mesozoic in age, compose a structurally complex allochthon and consist of (1) pelitic to quartzitic schist containing subordinate layers of calc-schist, calc-silicate gneiss, marble, and phyllonite; (2) metagabbro, metadiabase, amphibolite, and garnet amphibolite; and (3) quartzite and marble (Dover and Miyaoka, 1985a). On the basis of preliminary analysis of structural and metamorphic data, Dover and Miyaoka (1985a, b) suggest that the metamorphic terrane has experienced at least three deformational episodes (the third episode was not accompanied by significant recrystallization) and two major metamorphic episodes.

In thin section, F_1 isoclines, to which the main schistosity (S_1) is axial planar, are associated with synkinematic amphibolite-facies minerals (M_1) and blastomylonitic fabrics that were produced by ductile deformation. Diagnostic M_1 mineral assemblages in pelitic schist consist of quartz + muscovite + plagioclase + biotite ± garnet. Andalusite of possible M_1 origin has been observed in two samples by J.H. Dover (oral commun., 1985) and in one sample (loc. 14, Tanana quadrangle, table 2, pl. 2) by R.M. Chapman. Although andalusite is common in pelitic rocks as a contact metamorphic mineral within thermal aureoles around the Cretaceous batholith of the Ray Mountains, the small number of pelitic rocks that contain possible M_1 andalusite is not adequate to infer overall low-pressure conditions for the first metamorphic episode. M_1 mineral assemblages in mafic meta-igneous rocks typically include hornblende + calcic plagioclase ± biotite ± chlorite ± garnet ± sphene, which indicate metamorphic conditions near the greenschist- to amphibolite-facies transition (Dover and Miyaoka, 1985a; J.H. Dover, written commun., 1985).

F_1 isoclines produced during the M_1 episode are overprinted by a second generation of folds (F_2) that have an axial planar cleavage (S_2) at a low to moderate angle to S_1 cleavage. Tight F_2 folds increase in abundance toward cataclastic zones in which a cataclastic foliation is the dominant fabric, and this fabric appears to coincide with S_2 cleavage. Second generation structures are invariably associated with greenschist-facies minerals (M_2). Within intensely cataclasized phyllonite zones, retrogressive greenshist-facies minerals replace the garnet, biotite, and staurolite that were produced during the earlier amphibolite-facies metamorphism; new greenschist-facies assemblages also grew synkinematically along shear surfaces. Glaucophane occurs with chloritoid in one M_2 greenschist-facies mineral assemblage at one locality within a phyllonite zone (Dover and Miyaoka, 1985b).

The metamorphic age(s) and metamorphic history of this unit are speculative. Although preliminary analysis of the metamorphic and structural data suggest the polymetamorphic history described above, other possible interpretations of the metamorphic history are: (1) some or all of the five different tectonic and lithologic units discussed above may not have experienced the same M_1 metamorphic episode and (2) M_2 metamorphism may not have affected all areas of this metamorphic unit, and some amphibolite- and greenschist-facies assemblages may have formed during a single metamorphic episode under slightly different pressure, temperature, and shear-stress conditions. Evidence to support this second possibility is the observation by J.H. Dover (written commun., 1985) that greenschist- and amphibolite-facies rocks appear to grade into one another in most areas and that, in fact, it is uncertain whether differences in metamorphic grade reflect differences in pressure controlled by depth and shearing stress during one long-lived dynamothermal episode, reflect superimposed metamorphic episodes, or reflect some combination of both.

Metamorphism is known to predate the late Early Cretaceous (104-Ma) age of the Ray Mountains pluton (Silberman and others, 1979). A Devonian maximum metamorphic age for amphibolite-facies metamorphism of the augen gneiss unit is indicated by the protolithic age of the augen gneiss, but the maximum metamorphic age of the other tectonic units is unknown. Retrogressive metamorphism may have occurred as a result of compressional tectonics that were associated with the obduction of oceanic rocks from the northwest onto the Ruby geanticline during Jurassic to late Early Cretaceous time (Patton and others, 1977). Amphibolite-facies metamorphism may have occurred earlier during the same compressional episode. This obduction episode has been proposed to explain the origin of metamorphism all around the margin of the Yukon-Koyukuk basin (Turner, 1984). Although Dover and Miyaoka (1985b) bracket retrogressive greenschist-facies metamorphism within this same Jurassic and Early Cretaceous age range, they do not consider that simple southeastward thrusting of the oceanic rocks (adjacent units LPP $(eKmJ)_2$ and Ju) is clearly expressed in the fabrics of those oceanic rocks or this metamorphic unit. Structural fabric data in the southeastern part of the Ray Mountains have been interpreted to indicate that the cataclastic fabrics and accompanying retrogressive metamorphism in that area may have taken place as a result of the northwestward obduction of oceanic rocks (unit LPP (eKlTr)) that border the metamorphic rocks on the south (Dover and Miyaoka, 1985b). Further structural, petrologic, and isotopic study of this metamorphic unit clearly is required in order to determine its metamorphic and tectonic history.

AMP (peK) + AMP (eKmJ?)

An undifferentiated assemblage of polydeformed, polymetamorphosed, and moderately to strongly mylonitized quartz-mica schist, quartz-biotite gneiss, quartzite, marble, calc-silicate rocks, amphibolite, and singly metamorphosed granitoid gneiss, including augen gneiss, makes up this unit and crops out in the Kokrines Hills (Patton and others, 1978). Protolithic ages are unknown but are believed to be Proterozoic and Paleozoic. The timing and relation between metamorphic episodes has not been determined, but it is known that metamorphic foliation (S_1) in quartzite and associated schist and gneiss is truncated by fine-grained granitoid gneiss and that foliation in the granitoid gneiss (S_2) is approximately perpendicular to the intrusive contact and to S_1 in some places (J.T. Dillon, written commun., 1983). In pelitic rocks, the M_1 episode produced the assemblages quartz + muscovite + biotite + garnet, quartz + potassium feldspar + garnet +

biotite + sillimanite + plagioclase, and kyanite + sillimanite + biotite + quartz + potassium feldspar. The coexistence of kyanite and sillimanite indicates that P-T conditions were greater than 3.8 kb and 500 °C (Holdaway, 1971). Metamorphic conditions during the M_2 episode are poorly constrained but were sufficient to produce garnet, muscovite, biotite, and quartz in granitoid gneiss (J.T. Dillon, written commun., 1983).

Because the protolithic age of the granitoid gneiss is unknown, a maximum age for the M_1 episode has not been established. Both metamorphic episodes predate the late Early Cretaceous intrusion of the Melozitna pluton (111 Ma) (Patton and others, 1978). Contact-metamorphic effects produced by this pluton locally are difficult to distinguish from the effects produced during regional metamorphism. Broad structural relations suggest that this unit may form an east-northeast-trending gneiss dome (Patton and others, 1978), but the age and origin of doming or remobilization are unknown. The M_2 episode, and perhaps also the M_1 episode, may have occurred during Middle Jurassic to Early Cretaceous time as a result of the overthrusting of the crystalline rocks of the Ruby geanticline by oceanic rocks rooted in the Yukon-Koyukuk basin (Patton and others, 1977; W.W. Patton, Jr., oral commun., 1984). However, because of petrologic similarities between the crosscutting orthogneiss in the Kokrines Hills and rocks that have yielded Proterozoic or Devonian ages in the Brooks Range (Dillon and others, 1980; J.T. Dillon, written commun., 1983), a Proterozoic or early and middle Paleozoic age for the M_1 episode cannot be ruled out.

AMP (mPzY) + GNS (mPzY)

This unit comprises polymetamorphosed and locally mylonitic pelitic schist, calc-schist, sheared grit, quartzite, phyllite, mafic and felsic metavolcanic rocks, and schistose plutonic rocks. Stratigraphic evidence in the Medfra quadrangle (adjacent to the southern border of the Ruby quadrangle) indicates that rocks similar to those of this unit are pre-Ordovician in age (Patton and Dutro, 1979). Middle Proterozoic protolithic ages for metaigneous rocks of this unit are indicated by a K-Ar age of 921 Ma on biotite from metaquartz diorite (Silberman and others, 1979) and an U-Pb upper intercept age of 1265 Ma on zircon from metavolcanic rocks (Dillon and others, 1985).

Polymetamorphism is suggested by replacement textures in pelitic rocks. The M_1 episode (or alternatively, the maximum-T phase of a P-T loop) occurred under amphibolite-facies conditions and produced the assemblage biotite + garnet ± staurolite ± cordierite in quartz-mica schist. Subsequent retrograde metamorphism (M_2) (or alternatively, a later phase of the M_1 episode) resulted in the almost complete replacement of staurolite by chloritoid, garnet by chlorite, and cordierite by white mica and chlorite and in the growth of albite, white mica, chlorite, and zoisite. Textural evidence suggests that the retrogressive greenschist-facies metamorphism was accompanied by shearing. A Late Proterozoic (663-Ma) K-Ar age on muscovite from a recrystallized mylonite along the border of the metaquartz diorite (Silberman and others, 1979) may date the time of uplift and cooling following retrogressive metamorphism of the country rocks and shearing and metamorphism of the plutonic body. An U-Pb lower intercept age on zircon of 390 ± 40 Ma for the metavolcanic rocks has been interpreted to indicate an early and (or) middle Paleozoic metamorphic age (Dillon and others, 1985). Polymetamorphic mineral assemblages or textures have not been described for the radiometrically dated metaigneous rocks, and, at present, age, metamorphic mineral assemblage, and textural data are insufficient to determine the exact timing and number of metamorphic episodes that affected this unit. We have tentatively bracketed the ages of both postulated metamorphic episodes between the Middle Proterozoic protolithic age and the middle Paleozoic minimum age that is indicated by the analytical uncertainty of the U-Pb lower intercept age on zircon.

YUKON-TANANA UPLAND

LPP (lKD)

This unit comprises weakly metamorphosed sedimentary and minor igneous rocks that include various combinations of the following lithologic units: Cambrian(?) argillite, maroon and green slate, quartz-rich sandstone and grit; Ordovician volcanic and volcaniclastic rocks and chert; Silurian and Devonian limestone and dolomite; Devonian conglomerate, graywacke, and shale; and minor basaltic and gabbroic bodies of Paleozoic(?) age. These rocks are described by Chapman and others (1971), Churkin and others (1982), and Foster and others (1983). Sedimentary or igneous textures are generally well preserved; locally metamorphic textures are slightly to moderately mylonitic. Although some rocks are highly folded (those occurring in the Livengood terrane of Jones and others, 1987), a penetrative fabric generally is not present in any of the rocks included in this unit.

Shale generally contains fine-grained, recrystallized white mica; grit and quartzose rocks are semischistose and contain slightly flattened clasts of quartz, feldspar, and rarely argillite in a matrix of quartz and white mica ± chlorite ± albite ± epidote; metabasite contains chlorite, sodic plagioclase, actinolite, and locally epidote and calcite. The presence of actinolite suggests that metamorphic conditions were probably those of the upper prehnite-pumpellyite facies or lower greenschist facies. In the northeastern Livengood quadrangle, prehnite, pumpellyite, and actinolite coexist in one sample of metabasalt (pl. 2, loc. 3), and glaucophane is present in another sample of metabasalt (pl. 2, loc. 5). However, the proximity of these samples to and their association with ultramafic rocks puts the paragenesis of their mineral assemblages in question as they may not have formed during the regional event that affected this unit. Conodont color-alteration indices of Devonian limestones in the Crazy Mountains of the northern Circle quadrangle indicate that metamorphic temperatures reached 300-350 °C (Foster and others, 1983). The age and tectonic origin of low-grade metamorphism is unknown. Metamorphism is known to be bracketed between the Devonian protolithic age of the youngest affected rocks and the Late Cretaceous age of the oldest crosscutting plutons.

LPP (eKPz)

The incipiently metamorphosed black quartzite, meta-argillite, and phyllite, calcareous phyllite and metalimestone, and medium- to coarse-grained grit and quartzite (Foster and others, 1983) that make up this unit crop out as a thrust sheet in the south-central Circle quadrangle (Foster and others, 1987a). Protoliths are Proterozoic and (or) Paleozoic. Metamorphic minerals in quartzose rocks include quartz, white mica, chlorite, and calcite; calcareous phyllite contains the assemblage quartz + calcite + white mica + magnesium-chlorite ± plagioclase. Rocks are thin layered but some quartzites are massive; meta-argillite is locally slaty. Clastic textures in grit and associated quartzite are well preserved; most clasts are angular and are randomly oriented. Vitrinite reflectance measurements on black quartzite and calcareous phyllite (Laird and others, 1986) indicate temperatures of 180 ± 50 °C, which is within the range of sediment diagenesis. A temperature of 230 ± 50 °C is indicated for a sample collected near the postulated fault contact between this unit and adjacent unit GNI (eKPz). Differences in rock types and metamorphic grade between the rocks of this incipiently metamorphosed unit and the adjacent rocks led Laird and her coworkers (1986) to suggest that these rocks may belong to a separate terrane.

The age of metamorphism is unknown. A Paleozoic maximum metamorphic age is proposed on the basis of the probable age of the youngest protoliths. A late Early Cretaceous minimum metamorphic age is established by the fact that regional metamorphism in the Yukon-Tanana upland predates the emplacement of several thrust sheets of differing metamorphic grade, of which this thrust sheet is one (Foster and others, 1987a; Dusel-Bacon, Csejtey, and others, in press). These thrust sheets, interpreted by Foster and her coworkers to be subterranes of the Yukon-Tanana terrane, were juxtaposed before the intrusion of late Early Cretaceous plutons (Foster and others, 1987a).

GNI (eKPz)

This unit is composed primarily of quartzite and muscovite-quartz schist and lesser amounts of interlayered pelitic schist, felsic schist, chloritic or actinolitic greenschist, calc-silicate rocks, and rare marble (Bundtzen, 1982; Foster and others, 1983). These rocks comprise the informally designated Fairbanks schist unit and Cleary sequence of Bundtzen (1982). Protolithic ages are unknown but are probably Paleozoic and perhaps Proterozoic.

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

Most rocks are penetratively deformed, but relict igneous textures are preserved locally in metabasites. Mylonitic textures are widely distributed and are particularly well developed in the Circle quadrangle near the northwestern contact of this unit (shown as a thrust fault), where evidence of syntectonic recrystallization, as well as postmetamorphic shearing, can be observed (Foster and others, 1983). The contact between this unit and the higher grade rocks of unit AMI (eKPz) in places is a postmetamorphic thrust fault, but where no fault is present the contact is a metamorphic gradient that is defined by the first appearance of staurolite.

Four distinct deformational events are recognized in this unit in the Circle quadrangle (Cushing and Foster, 1984). In that area, retrogressive metamorphism is found locally as a result of contact metamorphism around Tertiary plutons, but polymetamorphism of regional extent has not been identified (Foster and others, 1987a). On the basis of work in the Fairbanks quadrangle, south of the area shown on pl. 1 (Dusel-Bacon, Csejtey, and others, in press), other workers propose that regional retrogressive metamorphism did affect this unit and that this metamorphic episode accompanied penetrative deformation that deformed earlier northwest-trending folds into northeast-trending folds (Forbes, 1982; Hall, 1984). This retrograde metamorphic episode would be the same episode that is proposed to have resulted in the Early Cretaceous retrograde metamorphism of the eclogite and related rocks of the klippen (unit AMH (O€) + GNS (eK) described below) that overlie this unit.

Metamorphism and folding postdate thrusting of the dominantly pelitic assemblage that makes up most of unit AMI (eKPz) over the dominantly quartzitic assemblage that makes up most of this unit (GNI (eKPz)). This relation is indicated by the facts that these two metamorphic units appear to have a similar metamorphic and deformational history and that biotite, garnet, and staurolite isograds and folds are unrelated to lithologic contacts between the pelitic and quartzitic assemblages (Foster and others, 1987a). The premetamorphic thrust faults are those that are shown within either of the two units. Additional thrusting of these two units took place after the major metamorphic and deformational episodes.

Metamorphism predates thrusting of prehnite-pumpellyite-facies unit LPP (eKPz) that overlies the southern margin of this unit. That thrust sheet, as well as several other thrust sheets, which are interpreted by Foster and her coworkers to be subterranes of the Yukon-Tanana terrane, was emplaced before the intrusion of late Early Cretaceous plutons (Foster and others, 1987a).

Paleozoic and Early Cretaceous metamorphic age constraints are assigned to this unit on the basis of the general Paleozoic minimum protolithic age of these rocks and the late Early Cretaceous age of the oldest plutons that were emplaced after regional thrusting.

AMI (eKPz)

This unit consists of a penetratively polydeformed and regionally metamorphosed sequence of pelitic schist and gneiss, minor interlayered quartzite and quartzitic schists, and subordinate augen gneiss, calc-silicate rocks, marble, and amphibolite (Foster and others, 1983). A Mississippian (340-Ma) protolithic age has been determined for ortho-augen gneiss in the southeastern Circle quadrangle (Foster and others, 1987b), indicating that these rocks (shown as metamorphosed plutons) are correlative with larger augen gneiss bodies to the south that form a belt across east-central Alaska and the Yukon Territory, Canada (Dusel-Bacon and Aleinikoff, 1985). Other protoliths are probably of Paleozoic and perhaps Proterozoic age (Foster and others, 1983).

Metamorphic grade ranges from the staurolite zone to the sillimanite zone of the amphibolite facies. The highest grade rocks are located in the southeastern part of the Circle quadrangle, and metamorphic grade decreases to the north and west into the greenschist-facies rocks (unit GNI (eKPz), described above) that are interpreted to be the lower grade part of the metamorphic sequence. Characteristic metamorphic mineral assemblages, in order of increasing metamorphic grade are: biotite + garnet + staurolite ± kyanite, biotite + garnet + kyanite ± sillimanite, and biotite + sillimanite ± potassium feldspar ± garnet (in addition to quartz, white mica, and plagioclase) in pelitic schist; hornblende + plagioclase + quartz + epidote ± chlorite or biotite and hornblende + plagioclase + quartz ± biotite and locally garnet or carbonate in mafic schist; and tremolite/actinolite + epidote + plagioclase + quartz + carbonate, clinozoisite + carbonate + quartz + plagioclase ± epidote ± biotite, and amphibole + clinopyroxene + quartz ± garnet ± epidote ± plagioclase ± biotite ± microcline in calc schist. The maximum metamorphic grade appears to be close to the muscovite + quartz = sillimanite + potassium feldspar + water isograd (Foster and others, 1983), indicating peak temperatures of about 600-650 °C (Chatterjee and Johannes, 1974). The coexistence of kyanite and sillimanite is indicative of an intermediate-pressure facies series. Intermediate-pressure metamorphic conditions are also indicated by the amphibole compositions in mafic schist (Jo Laird, unpub. data, 1985; Foster and others, 1987a). Andalusite coexists with kyanite in comparable pelitic schist just south of the Circle quadrangle boundary (Dusel-Bacon, Csejtey, and others, in press), which suggests that the P-T gradient in that area may have been transitional between low- and intermediate-pressure facies series.

The deformational and metamorphic history of this unit (namely, thrusting, followed by metamorphism and folding, followed by postmetamorphic thrusting) and the Paleozoic and late Early Cretaceous metamorphic age constraints assigned to it are the same as those described above for the lower grade part of the metamorphic sequence (unit GNI (eKPz)). The Mississippian protolithic age of the augen gneiss has not been used to establish a maximum metamorphic age for this unit because, according to Foster and others (1987a), the augen gneiss may be in thrust contact with the associated metasedimentary rocks rather than intrusive into them.

AMI (eKPz?)

The structurally complex, crenulated, and isoclinally and recumbently folded sequence of quartz-mica schist, marble, and schistose chert that make up this unit crops out south of the Yukon River in the Tanana and Livengood quadrangles. Metamorphic assemblages developed in pelitic rocks in the Tanana quadrangle include quartz + muscovite + biotite ± plagioclase ± garnet ± chlorite ± staurolite ± kyanite ± sillimanite. Although kyanite and sillimanite do not coexist in the same sample, they are present in rocks at the same locality and indicate that maximum P-T conditions during metamorphism probably exceeded about 3.8 kb and 500 °C (Holdaway, 1971). The metamorphic age of these rocks is bracketed between an assumed middle Paleozoic protolithic age (unit Pzsr of Chapman and others, 1982) and an Early Cretaceous emplacement age for the allochthonous oceanic rocks of the Rampart Group along the northwest boundary of this unit (R.M. Chapman, oral commun., 1984). The metamorphic history of these amphibolite-facies rocks may have been the same as that of the amphibolite-facies rocks in the Kokrines Hills and the Ray Mountains.

LPP/GNS (eJT̄R)

This unit comprises weakly to moderately metamorphosed greenstone and associated metasedimentary rocks, including meta-argillite, metatuff, quartz-sericite schist, quartz-actinolite schist, quartzite, carbonaceous metalimestone, metachert, and metagraywacke (Brabb and Churkin, 1969; H.L. Foster, unpub. data, 1984). A small area underlain by this unit is present along the southern boundary of the Charley River quadrangle. Very little information is known about these rocks in the area shown on this metamorphic facies map. Assumptions about their metamorphic history are based on more detailed mapping and radiometric dating of rocks in the Eagle and Big Delta quadrangles, located to the south and the southwest, respectively (see Dusel-Bacon, Csejtey, and others, in press, for discussion of these areas). Internal thrusting within this unit is common, and the unit consists of a number of isolated thrust remnants. The greenstones, metachert, and metavolcanic rocks of this unit are associated with ultramafic and gabbroic rocks, and this entire group of rocks is considered to be part of a dismembered ophiolitic assemblage (Keith and others, 1981). No fossils have been found in the Charley River or adjacent Eagle quadrangles, but conodonts and radiolarians of Permian age are found in weakly metamorphosed chert in the Big Delta quadrangle (Weber and others, 1978), which is tectonically and metamorphically correlated with this unit.

Metamorphic grade differs between individual thrust remnants. Metamorphic mineral assemblages characteristic of the prehnite-pumpellyite and lower greenschist-facies have been determined for rocks of this metamorphic unit that crop out in the Eagle and Big Delta quadrangles. An Early Jurassic metamorphic age is suggested by a 201 ± 5-Ma $^{40}Ar/^{39}Ar$-plateau age on actinolite (G.W. Cushing, unpub. data, 1984) from greenstone in the southeastern Eagle quadrangle (near the town of Chicken) that is considered to have had the same metamorphic and tectonic history as this unit. Metamorphism of these low-grade rocks may have begun in latest Triassic time and was part of a Late Triassic and Early Jurassic tectonic and thermal event affecting at least part of east-central Alaska (Cushing and others, 1984). The oceanic character of these rocks suggests that they were formed in a closing ocean basin that may have separated the margin of North America (rocks north of the Tintina fault) from a terrane to the south or southeast (H.L. Foster, oral commun., 1985).

AMH (O€) + GNS (eK)

The eclogite-bearing terrane of high-pressure, high-temperature metamorphic rocks that compose this unit crop out as apparent klippen in the southeastern Livengood quadrangle and the southwestern Circle quadrangle. Protoliths are Proterozoic or early Paleozoic in age. In the Livengood quadrangle, the terrane contains calc-magnesian lithologies that include garnet-omphacite (8 to 45 percent jadeite component) eclogitic rocks, garnet-clinopyroxene-amphibole rocks, and garnet-amphibole rocks (all of which may also include various combinations of calcite, quartz, plagioclase, or epidote) (Swainbank and Forbes, 1975; Brown and Forbes, 1986). These rocks are apparently interlayered with basic schists containing glaucophane + omphacite or barroisite + omphacite, with calc-magnesian schists containing tremolite + diopside, with pelitic schists containing kyanite + staurolite + chloritoid + garnet or biotite + garnet + muscovite, and with carbonaceous and micaceous quartzite (Brown and Forbes, 1986). Retrograde chlorite occurs in some rocks. The structural style of the eclogitic rocks is characterized by northwest-trending isoclinal folds that have been deformed by open or overturned northeast-trending folds. Bulk chemistry of the eclogites suggests that they have a sedimentary (marly or subgraywacke) origin (Swainbank and Forbes, 1975). Mineral chemistry and the occurrence of glaucophane indicate that the eclogites are similar to those from group C (alpine-type) eclogites as defined by Coleman and others (1965). Phase equilibria and thermobarometry suggest crystallization temperatures of 600 ± 25 °C at pressures of 15 ± 2 kb, indicating burial depths of 35-45 km and a geothermal gradient during metamorphism of 12-15 °C/km (Brown and Forbes, 1986).

Eclogite in the Circle quadrangle contains garnet, omphacite (40-45 percent jadeite component), quartz, clinoamphibole (barroisite), phengitic muscovite, and minor rutile or sulfides. These rocks occur as discordant mafic layers, interpreted as dikes, within quartz + white mica + garnet (somewhat retrograded to chlorite) schist and quartzite (Laird and others, 1984; Foster and others, 1983). Garnet compositions are comparable to those of group C eclogites of Coleman and others (1965) (Laird and others, 1984). P-T conditions, estimated by Laird and others (1984) on the basis of experimental data, fall within the same range as those determined for the Livengood eclogites.

Metamorphic fabrics in the eclogitic rocks in both areas range from massive to foliated. This unit is extensively sheared along a thrust zone that separates the Livengood and Circle eclogitic sequence from an adjacent sequence of micaceous quartzites and quartz-mica schists (Swainbank and Forbes, 1975; Foster and others, 1983). Previous interpretations of this contact considered the eclogitic terrane to be exposed in a window through unit GNI (eKPz) (Swainbank and Forbes, 1975; Forbes, 1982), but more recent work suggests that the terrane is an allochthonous sheet on top of the unit GNI (eKPz) (Brown and Forbes, 1984).

A Late Cambrian and (or) Early Ordovician metamorphic age for the high-pressure, high-temperature metamorphic episode is indicated by a 470±35-Ma K-Ar age on amphibole from an amphibole-bearing eclogite in the Livengood quadrangle (Swainbank and Forbes, 1975). Early isoclinal, recumbent folds about a northwest-trending axis are attributed to this episode (Swainbank and Forbes, 1975).

Subsequent retrograde metamorphism under epidote-amphibolite- and greenschist-facies conditions resulted in the replacement of initial eclogitic metamorphic minerals by hornblende, albite, epidote, biotite, and chlorite (Brown and Forbes, 1986; Foster and others, 1987a). An Early Cretaceous age is proposed for this retrograde episode on the basis of several K-Ar ages on mica of 115 to 103 Ma that were determined for associated rocks; the development of folds about a northeast-trending axis is attributed to this episode (Swainbank and Forbes, 1975).

The tectonic and metamorphic history of these eclogites may be similar to that of other isolated eclogite occurrences on strike along the Tintina fault in the Yukon Territory, as recently proposed by Erdmer and Helmstaedt (1983) and Brown and Forbes (1984, 1986). Erdmer and Helmstaedt concluded that eclogites in central Yukon Territory experienced a subduction-cycle P-T trajectory that included eclogite metamorphism, uplift through the stability field of glaucophane, and finally greenschist-facies metamorphism. The present distribution and geologic position of the eclogite bodies in east-central Alaska and Yukon Territory suggests that they were emplaced as thrust sheets against or onto the cratonic margin of western North America, as suggested by Erdmer and Helmstaedt. However, timing of metamorphism and tectonic emplacement of these eclogite-bearing terranes is not well enough constrained for more than a tentative correlation. The tentative early Paleozoic metamorphic age suggested for the Alaskan eclogitic rocks would argue against correlation with the Canadian eclogites, which are inferred to have a late Paleozoic or early Mesozoic metamorphic history (Erdmer and Helmstaedt, 1983).

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TABLES 1–2

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 greeschist 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 greenshist facies		
GNH (with stipple, pl. 1)	Above minerals plus pumpellyite and (or) lawsonite.			
		EPIDOTE-AMPHIBOLITE AND AMPHIBOLITE FACIES		
AMP	Staurolite.	Orthopyroxene + clinopyroxene, actinolite + calcic plagioclase + quartz, glaucophane.	Hornblende, plagioclase, garnet, biotite, muscovite, diopside, K-feldspar, rutile, calcite, dolomite, scapolite.	
		Low-pressure amphibolite facies		
AML	Andalusite + staurolite, cordierite + orthoamphibole.	Kyanite.	Cordierite, sillimanite, cummingtonite.	Pyralspite garnet rare in lowest possible pressure part of this facies.
		Intermediate- and high-pressure amphibolite facies		
AMI and AMH	Kyanite + staurolite.	Andalusite.		Sillimanite mainly restricted to intermediate-pressure amphibolite facies.
		TWO-PYROXENE FACIES		
2PX	Orthopyroxene + clinopyroxene.	Staurolite, orthoamphibole, muscovite, epidote, zoisite.	Hypersthene, clinopyroxene, garnet, cordierite, anorthite, K-feldspar, sillimanite, biotite, scapolite, calcite, dolomite, rutile.	Hornblende possible. Kyanite may occur in higher pressure part of this facies and periclase and wollastonite in low-pressure part.

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
Mt. Michelson								
15	1	H.N. Reiser	BA	AS	EP + CA + QZ + PL	LPP	LPP (MD)	
15	2	do.	BA	AS	CL ± PU ± AC	LPP	do.	
15	2	do.	BA	AS	CL + CA + AB ± EP	LPP	do.	
15	3	do.	BA	AS	CL + PU + CA + CM	LPP	do.	
15	4	do.	OT	OC	WM + PL + QZ	LPP	do.	69Be24
15	5	do.	BA	AS	QZ + EP + CA + CL	LPP	do.	
15	6	do.	BA	AS	EP + CL + PL	LPP	do.	69R36
15	7	do.	PE	AS	CL + WM	GNS	GNS (MD)	
15	8	do.	BA	AS	CL + WM + CM + CA + PL	GNS	do.	70Rr450
Demarcation Pt.								
16	1	do.	BA	AS	WM + CL ± PH ± PU	LPP	LPP (MD)	
16	2	do.	BA	AS	CL ± PU ± EP	LPP	do.	
16	2	do.	BA	AS	WM + CL + SP + CA ± PY(?)	LPP	do.	
16	3	do.	PE	OC	CL + WM ± PY	LPP	do.	
16	4	do.	OT	OC	CA + CL ± SP	LPP	do.	
16	5	do.	PE	AS	CL + WM	LPP	do.	
16	6	do.	BA	OC	CL + SP + CA + PU	GNS	GNS (MD)	
16	7	do.	BA	AS	CL + MU + QZ + CA + AC	GNS	do.	71R555
16	8	do.	PE	AS	WM + CL + QZ	GNS	do.	71ABe420
Arctic								
24	1	do.	PE	AS	CD + MU	GNS	do.	
24	2	do.	OT	AS	WM + CL + SP	GNS	do.	
24	3	do.	PE	AS	MU + CL ± BI	GNS	do.	
24	4	do.	BA	AS	CL + EP + AC	GNS	do.	
24	5	do.	BA	AS	CL + AC	GNS	do.	
24	6	do.	BA	AS	CL + CA	LPP	LPP (eKTR)$_1$	
24	7	do.	PE	AS	WM + CL ± BI(?)	GNS	GNH→L (eKmJ)	
24	8	do.	PE	AS	WM + CL ± BI	GNS	do.	
24	9	do.	BA	AS	AC + CL + WM + CA	GNS	do.	
Table Mtn.								
25	1	do.	PE	AS	QZ + MU	GNS	GNS (MD)	
25	2	do.	BA	AS	QZ + EP + CA + CL	GNS	GNS (D)	
25	3	do.	BA	AS	BI + MU + EP + CL + SH	GNS	do.	
25	4	do.	PE	AS	BI + CL + MU + GA ± FS	GNS	do.	
25	5	do.	PE	AS	CL + AB + QZ + SH	GNS	do.	
25	6	do.	PE	OC	WM	LPP	LPP (eKTR)$_1$	
25	7	do.	BA	AS	CL + CA + QZ ± BI ± MU	GNS	GNS (MD)	
Noatak								
26	1	C.F. Mayfield	BA	AS	EP + PU + CL + AM	GNS	GNH→L (eKmJ)	
26	2	do.	OT	AS	QZ + PL + EP + AM + CL	GNS	do.	
26	3	do.	BA	AS	AM + CL + PU	LPP	LPP (K)	
Baird Mts.								
27	1	do.	BA	AS	CL + PU + EP	GNS	GNH→L (eKmJ)	
27	2	R.B. Forbes	PE	AS	(1) GA + WM + QZ + AB + BI	AMP/GNS	AMP (Z) + GNH→L (eKmJ)	
27	2	do.	PE	AS	(2) QZ + WM + AB	GNS	do.	
27	2	do.	BA	AS	(1) HO + PL + QZ + SH	AMP	do.	
27	2	do.	BA	AS	(2) PL + QZ	GNS	do.	
27	3	C.F. Mayfield	BA	AS	(1) QZ + AB + AC + GA + WM + CL + BI + SH	GNS	do.	
27	3	do.	BA	AS	(2) QZ + CL + AC	GNS	do.	
27	3	do.	OT	AS	QZ + AB + AC + CL + MU + SP + SH + GA	GNS	do.	
27	3	do.	OT	AS	QZ + CL + MU	GNS	do.	
27	4	R.B. Forbes	OT	AS	GL + AC + CL + SP + CA + AB + QZ	GNH	do.	
27	5	C.F. Mayfield	BA	AS	AC + EP + AB + CL + MU + CA + QZ	GNS	GNH→L (eKmJ)	
27	6	do.	PE	AS	QZ + PL + MU + CL	GNS	do.	
27	7	R.B. Forbes	OT	AS	CL + CA + GL + AB + QZ	GNH	do.	
27	8	A.B. Till	BA	AS	GL + EP + AB + CL + QZ	GNH	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
27	9	C.F. Mayfield	PE	AS	QZ + AB + MU + CL + EP + BI	GNS	GNH→L (eKmJ)	
27	10	do.	BA	AS	(1) AB + GA + CL + GL + AC + SH + EP	GNH	do.	
27	10	do.	BA	AS	(2) AB + GA + CL + AC + SH + EP	GNS	do.	
27	11	do.	PE	AS	QZ + AC + CL + GA + BI + MU + CA + CD	GNS	do.	
27	12	do.	OT	AS	QZ + AB + MU + CL + EP + GA	GNS	do.	
27	13	R.B. Forbes	PE	AS	QZ + AB + WM + CD	GNS	do.	
Ambler River								
28	1	do.	PE	AS	CD + QZ + CA + CL + WM + AB	GNS	do.	
28	2	C.F. Mayfield	PE	AS	QZ + MU + CD	GNS	do.	76Md256B
28	3	do.	PE	AS	QZ + AB + CD + CL + MU + BI	GNS	do.	
28	4	do.	BA	AS	(1) EP + AB + CL + AC + GL	GNH	do.	
28	5	M.W. Hitzman	PE	AS	QZ + MU + AB + CL	GNS	do.	
28	6	do.	PE	AS	QZ + MU + CL	GNS	do.	
28	7	do.	PE	AS	QZ + MU + AB + EP + CL	GNS	do.	
28	8	R.B. Forbes	BA	AS	(1) GA + GL + CZ + WM + SH	GNH	do.	
28	8	do.	BA	AS	(2) GA + CZ + WM + SH	GNS	do.	
28	9	M.W. Hitzman	BA	AS	AC + GL + CZ + EP + PA + QZ + SH	GNH	do.	
28	10	R.B. Forbes	BA	AS	(1) GA + GL + WM + CL	GNH	do.	
28	10	do.	BA	AS	(2) GA + WM + CL	GNS	do.	
28	11	do.	BA	AS	(1) GA + GL + CZ + WM + AC + CL + AB + QZ	GNH	do.	
28	11	do.	BA	AS	(2) GA + CZ + WM + AC + CL + AB + QZ	GNS	do.	
28	12	do.	BA	AS	(1) GL + JP + WM + QZ + AB	GNH	do.	
28	12	do.	BA	AS	(2) WM + QZ + AB	GNS	do.	
28	13	M.W. Hitzman	PE	AS	QZ + PA + CD + EP + BI	GNH	do.	
28	13	do.	BA	AS	AC + GL + CZ + EP + PA + QZ + AB + SH	GNH	do.	
28	14	do.	PE	AS	QZ + MU + AB + CL + EP	GNS	do.	
28	15	do.	BA	AS	AC + EP + AB + CL + QZ + CA	GNS	do.	
28	16	R.B. Forbes	BA	AS	(1) GA + GL + WM + CL + QZ + CZ + AB	GNH	do.	
28	16	do.	BA	AS	(2) GA + WM + CL + QZ + CZ + AB	GNS	do.	
28	17	M.W. Hitzman	BA	AS	GL + EP + AB + CL + PA + AC + GA	GNH	do.	
28	18	do.	BA	AS	CL + EP + PU	LPP	LPP $(eKmJ)_2$	
28	19	I.L. Tailleur	BA	AS	CL + PU + PL + CA	LPP	do.	
28	20	do.	BA	AS	PU + CL	LPP	do.	
28	21	M.W. Hitzman	PE	AS	(1) QZ + MU + BI + HO + GA	AMP	AMP (DP) + GNH→L (eKmJ)	
28	21	do.	PE	AS	(2) QZ + MU + BI + GA + AB	GNS	do.	
28	22	do.	PE	AS	QZ + MU + AB + EP + CL	GNS	GNH→L (eKmJ)	
28	23	do.	BA	AS	AC + EP + AB + QZ + SH + CL	GNS	do.	
28	24	do.	PE	AS	QZ + MU + AB + EP + CL	GNS	do.	
28	25	M.W. Hitzman	BA	AS	(1) GA + HO + EP + MU + QZ	AMP	AMP (DP) + GNH→L (eKmJ)	
28	25	do.	BA	AS	(2) CZ + AC + AB + MU + QZ	GNS	do.	
28	26	C.F. Mayfield	PE	AS	QZ + AB + CD + CL + MU + BI	LPP	LPP $(eKmJ)_2$	
Survey Pass								
29	1	S.W. Nelson	PE	AS	AB + MU	GNS	GNH→L (eKmJ)	
29	2	W.P. Brosgé	PE	AS	QZ + MU + CL + CD	GNS	do.	
29	3	S.W. Nelson	PE	AS	MU + CD + QZ	GNS	do.	
29	4	W.P. Brosgé	BA	AS	PL + CL + QZ + AM + SH + CA	GNS	do.	
29	5	S.W. Nelson	PE/CA	AS	CL + MU + CA + QZ	GNS	do.	
29	6	W.P. Brosgé	PE	AS	QZ + MU + CD	GNS	do.	
29	7	do.	PE	AS	QZ + MU + CD + CA	GNS	do.	
29	8	S.W. Nelson	OT	AS	FS + GA + HO + BI + QZ	AMP	AMP (DP) + GNH→L (eKmJ)	

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
29	9	W.P. Brosgé	BA	AS	HO + EP + QZ + BI	AMP	AMP (DP) + GNH→L (eKmJ)	
29	10	do.	BA	AS	AB + CL + CA + EP + MU	GNS	GNH→L (eKmJ)	
29	11	S.W. Nelson	CA	AS	QZ + MU + AM + CA	GNS	do.	
29	11	do.	PE	AS	BI + MU + AB + QZ	GNS	do.	
29	12	W.P. Brosgé	BA	AS	BI + HO + AB + QZ + CA + EP + GA + SH	AMP	AMP (DP) + GNH→L (eKmJ)	
29	13	S.W. Nelson	OT	AS	BI + HO + AB + GA + QZ + EP	AMP	do.	
29	14	do.	OT	AS	CA + EP + BI + HO + MU + QZ	AMP	do.	
29	15	do.	OT	AS	BI + MU + QZ	AMP	do.	
29	16	do.	BA	AS	CL + GA + BI + HO + AB	AMP	do.	
29	17	M.W. Hitzman	PE	AS	(1) QZ + MU + FS + BI + GA + HO + SH	AMP	do.	
29	17	do.	PE	AS	(2) QZ + MU + AB + CL	GNS	do.	
29	18	do.	PE	AS	MU + QZ + CL + AB + SH	GNS	GNH→L (eKmJ)	
29	19	do.	BA	AS	AB + EP + CZ + CL + AC + SH	GNS	do.	
29	20	do.	PE	AS	QZ + MU + CL + AB + CZ	GNS	do.	
29	21	do.	BA	AS	AC + GL + AB + EP + QZ + CL + GA + SH	GNH	do.	
29	21	do.	PE	AS	QZ + CL + PA + CD + GL + GA + SH	GNH	do.	
29	22	S.W. Nelson	PE	AS	CL + AB + MU + QZ	GNS	do.	
29	23	do.	BA	AS	GL + CA + CL + AB + QZ	GNH	do.	78AMH013
29	24	W.P. Brosgé	BA	AS	PL + CL + AC + PU	GNS	GNS (eKmJ)$_1$	
29	25	do.	PE	AS	QZ + MU + CL + AB	GNS	GNH→L (eKmJ)	
29	26	do.	BA	AS	AB + AM + BI + QZ + SH + EP + CL + GA + CA	AMP	AMP (DP) + GNH→L (eKmJ)	
29	26	M.W. Hitzman	PE	AS	QZ + MU + AC + CL + EP	GNS	do.	
29	26	do.	BA	AS	AC + AB + CZ + EP + CL + GA + SH	GNS	do.	
29	27	do.	BA	AS	AC + GL + CZ + EP + CL + GA + SH	GNH	GNH→L (eKmJ)	
29	27	W.P. Brosgé	BA	AS	(1) GA + SH + GL	GNH	do.	
29	27	do.	BA	AS	(2) AM + CL + AB + CA	GNS	do.	
29	28	S.W. Nelson	OT	AS	CL + CD + MU + QZ	GNS	do.	
29	29	W.P. Brosgé	PE	AS	(1) GA + GL	GNH	do.	
29	29	do.	PE	AS	(2) AB + CL + QZ + BI	GNS	do.	
29	30	do.	PE	AS	QZ + MU + CB + CL	GNS	do.	
29	31	do.	PE	AS	(1) CL + GL + CD + GA	GNH	do.	
29	31	do.	PE	AS	(2) MU + QZ + AB + BI(?)	GNS	do.	
29	31	do.	PE	AS	(1) GA + SH	GNH	do.	
29	31	do.	PE	AS	(2) MU + QZ + AB + CL + BI	GNS	do.	
29	32	S.W. Nelson	PE	AS	(1) CA + CL + GL + AB + QZ	GNH	do.	
29	32	do.	PE	AS	(2) GA + CD + CL + MU + QZ	GNS	do.	
29	33	S.W. Nelson	BA	AS	GA + GL + CL + CD + MU + QZ	GNH	do.	78AMH101
29	34	W.P. Brosgé	PE	AS	QZ + MU + BI + CL + CA	GNS	do.	
29	35	do.	PE	AS	(1) CD + GA + GL	GNH	do.	
29	35	do.	PE	AS	(2) QZ + AB + MU	GNS	do.	
29	36	do.	BA	AS	CL + SH + PU	LPP	LPP (eKmJ)$_2$	
Wiseman								
30	1	do.	PE	AS	QZ + CA + MU + CL + CD	GNS	GNH→L (eKmJ)	
30	2	do.	BA	AS	PL + CL + EP + CA + SP	GNS	do.	
30	3	do.	BA	AS	AB + CL + CA + PU + ZE	LPP	LPP (eKmJ)$_1$	
30	4	do.	PE	AS	QZ + CD + WM	GNS	GNH→L (eKmJ)	
30	5	do.	PE	AS	QZ + MU + CL + CA + CD	GNS	do.	
30	6	do.	PE	AS	QZ + MU + CD	GNS	AMP (DP) + GNH→L (eKmJ)	
30	7	do.	BA	AS	AB + EP + CL + AC + CA	GNS	GNH→L (eKmJ)	
30	8	do.	PE	AS	(1) GA + AM(?)	AMP	AMP (DP) + GNH→L (eKmJ)	
30	8	do.	PE	AS	(2) QZ + CL + CD	GNS	do.	
30	9	do.	PE	AS	(1) QZ + MU + CD + CL + KY + CA + GA	GNH,I	GNH→L (eKmJ)	
30	9	do.	PE	AS	(2) WM + QZ + BI + CA	GNS	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
30	10	W.P. Brosgé	BA	AS	PL + CL + EP + CA + BI + QZ	GNS	GNH→L (eKmJ)	
30	11	do.	BA	AS	MU + PL + CL + QZ + CA + CD	GNS	AMP (DЄ) + GNH→L (eKmJ)	
30	11	do.	CA	AS	PL + MU + KF + ZO + QZ + CA + CL + SH + GA	GNS,AMP	do.	
30	12	do.	BA	AS	PL + BI + CL + QZ + EP + GA	GNS,AMP	GNH→L (eKmJ)	
30	13	do.	BA	AS	PL + CL + CA + EP + QZ + WM + GA + SH	GNS,AMP	AMP (DЄ) + GNH→L (eKmJ)	
30	14	do.	CA	AS	CP + MU + QZ + EP + CL + BI + CA + SH	GNS	do.	
30	15	do.	BA	AS	EP + PL + AC + CZ	GNS	do.	
30	16	do.	BA	AS	PL + CL + PU + SH	LPP	LPP (eKmJ)$_2$	
30	17	do.	BA	AS	CL + EP + CA + AM + AB + QZ + SH	GNS	AMP (DЄ) + GNH→L (eKmJ)	
30	18	do.	BA	AS	CL + SH + PU + CM	LPP	LPP (eKmJ)$_2$	
Chandalar								
31	1	do.	PE	AS	QZ + CA + MU + CL	GNS	GNH→L (eKmJ)	
31	2	do.	CA	AS	QZ + CL + CA + EP	GNS	do.	
31	3	do.	PE	AS	CD + QZ + MU + FS	GNS	do.	
31	4	do.	PE	AS	QZ + PL + CL + MU	GNS	do.	
31	5	do.	BA	AS	(1) AB + HO + EP + GA	AMP	AMP (DЄ) + GNH→L (eKmJ)	
31	5	do.	BA	AS	(2) CL + BI + SH	GNS	do.	
31	6	do.	PE	AS	(1) QZ + CL + MU + CA + GL	GNH	GNH→L (eKmJ)	
31	6	do.	PE	AS	(2) QZ + CL + MU + BI + GA + CA	GNS	do.	
31	7	do.	BA	AS	AB + CL + MU + CA + QZ	GNS	do.	
31	8	do.	PE	AS	QZ + CL + PL + WM + CA	GNS	do.	
31	9	do.	PE	AS	QZ + AB + MU + CL	GNS	do.	
31	10	do.	BA	OC	PU	LPP	LPP (eKmJ)$_2$	
31	11	do.	PE	AS	QZ + AB + MU + CL + EP + SH	GNS	GNH→L (eKmJ)	
31	12	do.	BA	AS	AB + EP + GA + BI + SH	GNS,AMP	AMP (DЄ) + GNH→L (eKmJ)	
31	13	do.	BA	AS	PL + CL + CA + CZ	GNS	GNH→L (eKmJ)	
31	14	do.	BA	AS	(1) QZ + EP + CA + GA + BI + SH	AMP	AMP (DpЄ) + GNH→L (eKmJ)	
31	14	do.	BA	AS	(2) AB + CL	GNS	do.	
31	15	do.	PE	AS	QZ + AB + MU + CL + CA	GNS	GNH→L (eKmJ)	
31	16	do.	BA	AS	PL + CL + SH + AC + CZ + CA + SP	GNS	GNS (eKmJ)$_1$	
31	17	do.	BA	AS	CL + EP + PU	LPP	LPP (eKmJ)$_2$	
31	18	do.	PE	AS	QZ + FS + MU + CL + ST + TO	AMP	AMP (eKmJ)	
31	18	do.	OT	AS	QZ + PL + CL + MU + BI + GA + AC	AMP	do.	
31	19	do.	PE	AS	QZ + MU + BI + AN + CL + PL + CB	AML	AML (eKmJ)	
31	20	do.	BA	AS	CL + PU + CA + SH	LPP	LPP (eKmJ)$_2$	
31	21	do.	PE	AS	QZ + PL + BI + CL	GNS	AML (eKmJ)	
31	22	do.	PE	AS	QZ + MU + BI + ST + AN + CL + PL	AML	do.	
Christian								
32	1	H.N. Reiser	PE	AS	CL + MU	GNS?	GNH→L (eKmJ)	
32	2	do.	PE	AS	WM + CL	LPP	LPP(eKTR)$_1$	
32	3	do.	PE	AS	CL + WM	LPP	do.	
32	4	do.	PE	AS	CL + WM	LPP	do.	
32	5	do.	BA	AS	AB + CL + EP + AC	GNL,I	GNH→L (eKmJ)	
32	6	do.	PE	AS	WM + CL	LPP	LPP (eKTR)$_1$	
32	7	do.	PE	AS	CL + WM	LPP	LPP (eKTR)	
32	8	do.	PE	AS	CL + WM	LPP	do.	
32	9	do.	PE	AS	WM + CL + QZ	LPP	LPP (eKTR)$_1$	
32	10	do.	PE	AS	MU + BI + AN	AML	AML (eKmJ)	
Coleen								
33	1	do.	BA	AS	CL + PH	LPP	LPP (eKTR)	67ABe90A
33	2	do.	PE	AS	WM + CL	GNS	GNS (D)	67ABe143

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
33	3	H.N. Reiser	PE	AS	CL + WM	LPP	LPP (K)$_1$	67ABe152
33	4	W.P. Brosgé	PE	AS	QZ + MU + CL + BI + GA + EP	GNS	GNS (D)	67ABe290
33	5	do.	PE	AS	MU + AB + BI + EP + CL + GA	GNS	do.	67ABe285,286
33	6	do.	PE	OC	WM	LPP	LPP (eKꝐ)	67ABe188
33	7	do.	PE	OC	WM	LPP	do.	67ABe179
33	8	do.	PE	AS	CL + WM	LPP	do.	67ABe58A
33	9	do.	BA	AS	CL + PH ± PU	LPP	LPP (eKTR)	67ABe261
Kotzebue								
35	1	A.B. Till	BA	AS	AC + GA + EP + WM	GNS	GNH→I (eKmJ)	83ADn73
35	1	do.	OT	AS	QZ + CB + MU	GNS	do.	83ADn51
35	2	do.	CA	AS	DO + CA + TR + FO	GNS	do.	83ADn43C
35	2	do.	OT	AS	SE + TA + DO	GNS	do.	83ATi169B
35	2	do.	OT	AS	TR + CL + HE	GNS	do.	83ATi169F
35	2	do.	BA	AS	AC + AB + GA + CL + EP + SH	GNS	do.	83ATi168C
35	2	do.	PE	AS	QZ + MU + CD + CL + GA	GNS	do.	83ATi174
35	2	do.	BA	AS	AC + AB + EP + CL + GL + CA	GNH	do.	83ACl74
Selawik								
36	1	do.	PE	AS	QZ + KF + SI + BI + GA + PL	AMP	AMP (KꝐ)	
36	2	do.	BA	AS	HO + PL + SC + SH	AMP	do.	
Shungnak								
37	1	M.W. Hitzman	PE	AS	(1) QZ + MU + GA + HO + BI	AMP	AMP (DꝐ) + GNH→L (eKmJ)	
37	1	do.	PE	AS	(2) QZ + MU + EP + BI	GNS	do.	
Bettles								
39	1	W.W. Patton, Jr.	BA	AS	AM + CL + EP	LPP	LPP (eKmJ)$_2$	67APa58
39	2	do.	BA	AS	CL + QZ + PU + AC(?)	LPP	do.	70APa310
39	3	do.	BA	AS	EP + BI + CL	LPP	do.	67APa96
39	4	do.	PE	AS	QZ + MU + CD + CL + TO	GNS	GNS (eKmJ)$_2$	68APa277
39	5	do.	PE	AS	QZ + MU + CL + EP + AB	GNS	do.	68AMm151
39	6	do.	PE	AS	QZ + MU + CL + EP(CZ?) + SH	GNS	do.	68AMm153
39	7	do.	PE	AS	QZ + MU + CD + CL + TO	GNS	do.	68APa278
39	8	R.A. Loney	BA	AS	GL? CS? + PU	LPP,GNH	LPP (eKmJ)$_2$	82Rm82C
39	8	do.	BA	AS	CL + AC + EP	LPP	do.	82Rm86A
39	9	do.	BA	AS	PU + CL	LPP	do.	82Rm72A
Beaver								
40	1	E.O. Doyle	BA	AS	CL + SE	LPP	LPP (eKlTR)	71ABe493
40	2	W.P. Brosgé	PE	AS	QZ + PL + BI + CL + GA + ST	AMP	GNS (eKmJ)$_2$	72ABe7A
40	3	do.	PE	AS	QZ + CA + CL + MU + PL(AB?)	GNS	do.	72ARr8
40	4	E.O. Doyle	BA	AS	CL + SH	LPP	LPP (eKlTR)	72ARr23
40	5	do.	BA	AS	CL + PU	LPP	do.	72ABe25
40	6	do.	BA	OC	CL	LPP	do.	72ABe39
40	7	do.	BA	AS	CL + WM + PU + SE + SH	LPP	do.	72YA9
40	8	W.P. Brosgé	BA	AS	AC + CL + CM	GNS/LPP	do.	
40	8	E.O. Doyle	BA	AS	PU + CL + WM	LPP	do.	73ABe336X
40	8	do.	BA	AS	PU + CL + CM + WM	LPP	do.	72YA1
40	9	do.	BA	AS	QZ + PL + EP + PU + CL + SH	LPP	do.	72YA3
40	10	W.P. Brosgé	PE	AS	QZ + MU + CD	GNS	GNS (eKmJ)$_2$	71ABe507X
40	11	do.	OT	AS	QZ + PL + BI + SI + GA	AMP	AMP (peK)	72ABe58BX
Teller								
43	1	A.B. Till	OT	AS	PL + BI + QZ + DI + HY + GA + KF + SH	2PX	2PX (1K)	
43	1	do.	PE	AS	QZ + KF + PL + BI + GA + SI + CB	2PX	do.	
43	1	do.	OT	AS	FO + OP + DI + HO + SL	2PX	do.	
43	1	do.	OT	AS	(1) GA + FO + OP + DI	2PX	do.	
43	1	do.	OT	AS	(2) FO + OP + DI + SL + HO	2PX	do.	
43	1	do.	CA	AS	DI + SC + KF + QZ + SH + CA	2PX	do.	
Bendeleben								
44	1	do.	OT	AS	QZ + BI + CA + KF + MU	GNS	GNH→I (eKmJ)	
44	1	do.	OT	AS	QZ + MU + CB	GNS	do.	
44	1	do.	PE	AS	QZ + MU + GA + CB + TO	GNS	do.	
44	1	do.	PE	AS	QZ + MU + CD + CL	GNS	do.	
44	2	do.	BA	AS	HO + PL + SH	AMP	AMP (KꝐ)	
44	2	do.	PE	AS	QZ + MU + BI + GA + PL	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
44	3	A.B. Till	PE	AS	QZ + MU + CL + CD + CB	GNS	GNH→I (eKmJ)	
44	4	do.	OT	AS	AB + CL	GNS	do.	
44	4	do.	CA	AS	CA + CB + QZ + WM	GNS	do.	
44	5	do.	PE	AS	QZ + MU + PL + CL + CD + CA + ZO	GNS	do.	
44	6	do.	PE	AS	QZ + MU + CL + GA + TO + EP	GNS	do.	
44	6	do.	CA	AS	QZ + CA + TR + EP	GNS	do.	
44	7	do.	PE	AS	QZ + MU + CL + GA + TO	GNS	do.	
44	7	do.	PE	AS	QZ + MU + CL + GA	GNS	do.	
44	8	do.	PE	AS	QZ + MU + GA + BI + ZO	GNS	do.	
44	9	do.	PE	AS	QZ + MU + CL + BI + GA + TO	GNS	do.	
44	10	do.	PE	AS	QZ + MU + BI + GA + PL + EP + KY	GNI,H	do.	
44	10	do.	CA	AS	CA + TR + QZ + WM + KY	GNI,H	do.	
44	10	do.	OT	AS	QZ + PL + CL + BI + KY	GNI,H	do.	
44	10	do.	BA	AS	HO + GA + PL + SH + QZ + KY	GNI,H	do.	
44	10	do.	PE	AS	QZ + MU + CL + TO + KY	GNI,H	do.	
44	11	do.	CA	AS	CA + TR + WM + PL	GNS	do.	
44	11	do.	PE	AS	QZ + MU + BI + GA	GNS	do.	
44	12	do.	CA	AS	CA + QZ + WM	GNS	do.	
44	13	do.	BA	AS	CS + SH + CL + LW + PU	GNH	GNH (eKmJ)	
44	14	do.	CA	AS	GL + PU + SH + CL	GNH	GNH→I (eKmJ)	
44	14	do.	OT	AS	QZ + WM + PL + CA + CB	GNS	do.	
44	14	do.	OT	AS	AB + CL + QZ + CA + CB	GNS	do.	
44	15	do.	PE	AS	QZ + MU + CL + CD + GL + EP	GNH	do.	
44	15	do.	BA	AS	GA + GL + CL + EP + SH	GNH	do.	
44	15	do.	OT	AS	QZ + PL + GA + GL + EP + CL + WM	GNH	do.	
44	16	do.	PE	AS	QZ + SI + KF + BI + MU	AMP	AMI (K)	
44	17	do.	PE	AS	QZ + MU + BI + ST + GA	AMP	do.	
44	18	do.	BA	AS	HO + CX + PL + SH + QZ	AMP	do.	
44	19	do.	BA	AS	CX + GA + PL	AMP	do.	
44	20	do.	PE	AS	QZ + KF + SI + BI + GA	AMP	do.	
44	21	do.	CA	AS	CA + DI + SC + PL + FO + CB	AMP	do.	
44	21	do.	PE	AS	QZ + MU + BI + ST + KY	AMI	do.	
44	21	do.	OT	AS	QZ + BI + OP	AMP	do.	
44	22	do.	PE	AS	QZ + KF + ST + KY + BI	AMI	do.	
44	22	do.	OT	AS	BI + GE + CO + SL + TO + PL + QZ	AMP	do.	
44	22	do.	PE	AS	QZ + KF + SI + GA + BI	AMP	do.	
44	22	do.	CA	AS	CA + FO + TR + PP + CH	AMP	do.	
44	22	do.	BA	AS	CX + HO + GA + PL + SH	AMP	do.	
44	23	do.	PE	AS	QZ + KF + SI + BI + GA + TO	AMP	do.	
44	24	do.	PE	AS	QZ + KF + SI + BI + GA	AMP	do.	
44	25	do.	PE	AS	QZ + KF + SI + BI + GA	AMP	do.	
44	26	do.	BA	AS	CS + LW + PU + SH + AB + AC + CL	GNH	GNH (eKmJ)	
44	26	do.	BA	AS	CS + LW + SH + CL + EP	GNH	do.	
44	27	do.	BA	AS	CL + LW + AB + AC + SH + SP	GNH	do.	
44	27	do.	BA	AS	AC + LW + PU + SH + QZ	GNH	do.	
44	28	do.	PE	AS	QZ + MU + CL + BI + EP + CB	AMP	AMI (K)	
44	29	do.	PE	AS	QZ + KF + SI + BI + GA	AMP	do.	
Melozitna								
47	1	E.J. Moll	PE	AS	QZ + MU + CD + CL	GNS	GNI,H (eKmJ)	68AMm14
47	2	do.	PE	AS	QZ + MU + CL	GNS	do.	68APa23
47	3	do.	PE	AS	QZ + MU + BI + GA	AMP	AMP (peK) + AMP (eKmJ?)	68AMm41
47	4	do.	PE	AS	QZ + MU + CL + CD	GNS	GNI,H (eKmJ)	68APa56
47	5	do.	PE	AS	QZ + MU + CZ + CL + PL	GNS	do.	68AMm42
47	6	do.	BA	AS	QZ + AC + PL + BI + SH + EP + CA	GNS	do.	74APa63
47	7	do.	PE	AS	(1) QZ + MU + BI + PL	AMP	AMP (peK) + AMP (eKmJ?)	68APa58
47	8	do.	BA	AS	EP + SP + AM + PL + SH	GNS	GNI,H (eKmJ)	74APa65

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
47	9	E.J. Moll	BA	AS	AC + CA + CZ + CL + PL	GNS	GNI,H (eKmJ)	74APa61
47	10	do.	BA	AS	AC + EP + CL + AB + GA + CA	GNS	do.	74APa103b
47	11	do.	BA	AS	AB + AC + CZ + CA + CL + SH	GNS	do.	74APa104b
47	12	do.	PE	AS	GL + MU + CA + PL + QZ	GNH	do.	74APa51a
47	13	do.	PE	AS	QZ + MU + CD + CL + EP	GNS	do.	74APa73b
47	14	do.	BA	AS	CZ + GA + CL + AB + AC	GNH	do.	74APa74
47	15	do.	OT	AS	QZ + MU + GA + PL + CA + SH + EP	AMP	AMP (PeK) + AMP (eKmJ?)	74APa72a
47	16	do.	PE	AS	QZ + PL + BI + GA + EP	AMP	do.	74APa84b
47	17	do.	BA	AS	AC + AB + EP + SH	GNS	do.	74APa105a
47	18	do.	PE	AS	(1) QZ + BI + GA	AMP	do.	74APa96B
47	18	do.	PE	AS	(2) MU + CL	GNS	do.	
47	19	do.	OT	AS	QZ + KF + DI + SH + EP	AMP	do.	74APa94
47	20	do.	PE	AS	QZ + KF + GA + BI + EP + FS	AMP	do.	74APa93a
47	21	do.	OT	AS	QZ + BI + AC + SH + EP + CL	AMP	do.	74APa77c
47	22	do.	OT	AS	QZ + CL + GA + BI + EP + CL	AMP	do.	68APa80
Tanana								
48	1	R.M. Chapman	PE	AS	BI + QZ + PL + AN + MU + TO + EP + CL	AMP	AMP (peK) + GNS (eKmJ)	71ACh211
48	2	J.H. Dover	PE	AS	(1) and (or) (2) QZ + BI + MU + FS + CL	GNS	do.	82ADo012A
48	3	do.	PE	AS	(1) and (or) (2) QZ + PL + MU + BI	GNS	do.	82ADo021A
48	4	R.M. Chapman	CA	AS	CA + PL + DI	AMP	do.	71ACh207A
48	5	J.H. Dover	PE	AS	(1) and (or) (2) QZ + BI + MU + PL	GNS	do.	81ADo65A
48	6	R.M. Chapman	OT	AS	QZ + KF + PL + BI + MU	AMP	do.	71ACh222
48	7	J.H. Dover	PE	AS	(2) QZ + MU + CL + BI + GL + CD	GNH	do.	83ADo207A
48	8	R.M. Chapman	OT	AS	QZ + KF + AM + PL + DI + MU + EP + TO CL + CM + WO(?)	AMP	do.	70ACh101
48	8	do.	OT	AS	QZ + PL + PP + BI(?) + AC + MU + ID	GNS(?)	do.	70ACh123
48	9	do.	BA	OC	PH	LPP	LPP (eKlTR)	70ACh291
48	10	do.	PE	AS	QZ + WM + CA + CL + PL	GNS	do.	82ACh5A
48	11	do.	OT/PE	AS	QZ + CL + MU + SH	GNS	AMP (peK) + GNS (eKmJ)	82ACh3
48	11	do.	CA	AS	CA + QZ + CL + MU	GNS	do.	82ACh13
48	11	do.	CA	AS	CA + QZ + DI + MU + AM(?)	AMP	do.	82ACh14A
48	11	do.	OT	AS	QZ + BI + MU + AN	AML	do.	82ACh14D
48	12	J.H. Dover	PE	AS	(1) and (or) (2) QZ + MU + CL + PL + CD	GNS	do.	83ADo115A
48	13	R.M. Chapman	BA	AS	AM + PL + CZ + SH + BI + CL + WM	AMP	do.	71ABe44
48	14	do.	PE	AS	QZ + MU + KF + BI + AN + CL + PL + WM	AML	do.	71ABe10C
48	14	do.	PE	AS	QZ + KF + PL + CL + MU + BI + SH + WM	GNS	do.	71ABe10A
48	14	do.	PE	AS	QZ + BI + MU + CL + WM	AMP	do.	71ABe14H
48	14	do.	BA	AS	PL + BI + HO + QZ + WM + CL	AMP	do.	71ACh115
48	15	do.	BA	AS	AM + QZ + CL(?) + BI + AB + TO + WM	GNS/AMP	do.	71ABe5
48	15	do.	BA	AS	HO + PL + CZ + CL + GA	AMP	do.	71ABe16D
48	16	do.	PE	AS	QZ + CL + WM + TO + CZ + BI	GNS	do.	71ABe19A
48	16	do.	BA	AS	HO + PL + QZ + GA + EP + CL	AMP	do.	82ACh20B
48	16	do.	OT	AS	PL + QZ + BI + MU + GA + EP + CA + CL + CM	AMP	do.	71ACh64
48	16	do.	PE	AS	QZ + WM + AB + CL + GA + TO + SH + BI	GNS	do.	70ACh149
48	17	do.	OT	AS	QZ + BI + AM(HB?) + CL	GNS	GNI,H (eKmJ)	82ACh7
48	18	do.	PE	AS	BI + ST + WM + QZ + GA + PL + CL + CU(?)	AMP	AMI (eKPz?)	72ABe67A
48	18	do.	PE	AS	QZ + WM + GA + CL + TO + BI + CD(?)	GNS(?)	do.	72ABe67D

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
48	19	R.M. Chapman	CA	AS	CA + QZ + WM + CL + TO	GNS	GNS (eKmPz)	72ABe72A
48	19	do.	OT	AS	QZ + PL + WM + TO	GNS	do.	72ARr58
48	20	do.	PE	AS	BI + ST + GA + QZ + MU + CL + TO + SI(?)	AMP	AMI (eKPz?)	72ACh35
48	20	do.	PE	AS	BI + QZ + EP + PL + GA	AMP	do.	11AE-59
48	20	do.	OT	AS	QZ + MU + CL + BI + ST + KY	AMP	do.	72ACh38
48	20	do.	PE	AS	QZ + BI + WM + CL + KF + SI + TO	AMP	do.	72ACH31
48	21	do.	OT	AS	QZ + PL + CL + EP + SH + SP(?)	GNS	GNS (eKmPz)	72ARr67B
48	21	do.	CA	AS	CA + QZ + FS + CL + SP	GNS(?)	do.	72ARr68
48	22	do.	CA	AS	CA + PP + QZ + WM + CL	GNS	do.	72ACh74
48	23	do.	PE	AS	QZ + MU + PL + CL + TO + EP	GNS(?)	do.	72ABe88
48	24	do.	PE	AS	QZ + CL + WM	LPP,GNS	do.	72ABE118X
48	25	do.	PE	AS	QZ + MU + AC(?) + EP + BI + CA	GNS	do.	71ACh155
48	26	do.	PE	AS	QZ + WM	LPP	do.	72ARr76A1
48	27	do.	PE	AS	CL + EP + PL + AC	GNS	do.	72ABe106Y
48	27	do.	OT	AS	QZ + MU + BI	GNS(?)	do.	72ABe106X
48	27	do.	OT	AS	QZ + MU	LPP	do.	72ACh107
48	28	do.	OT	AS	QZ + MU + BI + TO	GNS	GNI,H (eKmJ)	82ACh12
48	29	do.	OT	AS	QZ + MU ± CL	GNS	do.	42AC340
48	29	do.	BA	AS	AM(HO) + CA + CL + AB + QZ + EP + CZ	GNS	do.	42AC336
48	30	do.	PE	AS	QZ + CL + MU + TO	GNS	do.	42AC384
48	30	do.	CA	AS	CA + QZ + MU	GNS	do.	43ACh12
48	31	do.	BA	AS	AC + CL + EP + AB(?)	GNS	do.	71ACh281
48	31	do.	OT	AS	QZ + MU + BI + TO + EP + CL + HE	GNS	do.	71ACh198
48	31	do.	OT	AS	QZ + MU + WM + CL	GNS	do.	
48	32	do.	OT	AS	QZ + PL + CA + MU + CL	GNS(?)	GNS (eKmPz)	71ACh190
48	32	do.	PE	AS	MU + QZ + PL + CA + EP	GNS	do.	71ABe4B
48	32	do.	BA	AS	AM + AC/TR + CL + QZ	GNS	do.	71ACh185
48	33	do.	BA	AS	PL + CL + PU	LPP(?)	LPP (eKlTr)	71ABe30F
48	34	do.	BA/CA	AS	AB + CA + CL + GL + EP + AC + SP	GNH	GNI,H (eKmJ)	71ACh110
48	35	do.	BA	AS	GL + AC + CL + AB + HM	GNH	LPP (eKlTr)	71ABe35C
48	35	do.	BA	AS	CL + PU + QZ + GL	GNH	do.	71ABe35E
48	35	do.	BA	AS	PL + CM + CL + PU	LPP(?)	do.	71ABe34
48	36	do.	BA	AS	AC + CZ + SH + AB	GNS	GNI,H (eKmJ)	43ACh64
48	36	do.	CA	AS	QZ + CA + MU + CL + CD	GNS	do.	42AC513
48	36	do.	BA	AS	CL + CA + PL + EP	GNS	do.	71ACh104
48	37	do.	BA	AS	AB + CL + AM/AC(?) + CA + SH + CZ	GNS	do.	42AC12
48	37	do.	PE/OT	AS	MU + QZ + CD + CL	GNS	do.	42AC14
48	37	do.	BA	AS	AB + CL + EP + HO + BI + SH	GNS(?)	do.	42AC5
48	38	do.	PE	AS	MU + QZ + CL + CD	GNS	do.	42AC2
48	38	do.	PE	AS	AB + CL + CZ + CA + MU + QZ + SH	GNS	do.	42AC9
Livengood								
49	1	F.R. Weber	PE	OC	WM	LPP	LPP (lKD)	68AWr131
49	2	do.	PE	OC	WM	LPP	do.	69AWr413
49	3	R.M. Chapman	BA	AS	PH + AC + CL + PU + SH	LPP	do.	68AGk433
49	4	F.R. Weber	PE	OC	WM	LPP	do.	68AWr192
49	5	R.M. Chapman	BA	AS	GL + CA + CL + SH + PL + WM + QZ + AC	LPP	do.	79CH104A
49	6	do.	OT	AS	QZ + CL + WM + GA + EP + ZO + AC(?) + FS	GNS	do.	70ACh18
49	7	do.	OT	AS	QZ + EP + SH + TO + CM	GNS(?)	do.	68AWr204
49	8	F.R. Weber	PE	OC	WM	LPP/GNS(?)	do.	69AWr350
49	9	R.M. Chapman	OT	AS	QZ + PL + WM + CL + CM	GNS(?)	do.	68AWr151
49	10	F.R. Weber	OT	AS	WM + CL	GNS	do.	68AWr70
49	10	R.M. Chapman	OT	AS	QZ + TO + WM + QZ	LPP(?)	do.	79CH97

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
49	11	R.M. Chapman	OT	AS	QZ + KF + WM + CM + FS	LPP/GNS(?)	LPP (KD)	68AWr64A
49	12	F.R. Weber	OT	OC	WM	LPP/GNS(?)	GNI (eKPz)	68AWr51A
49	13	R.M. Chapman	CA	AS	QZ + MU + CL + CA + BI + SH	GNS	do.	67ACh259
49	13	do.	PE	AS	QZ + MU + CL + KF + BI(?)	GNS	do.	62ACh194
49	14	R.B. Forbes	PE	AS	QZ + CL + WM + AB + GA	GNS	do.	
49	15	do.	BA	AS	(1) JP + GA + CA + ZO	AMH	AMH (O€)+ GNS (eK)	
49	16	do.	BA	AS	(1) JP + GA + QZ	AMH	do.	
49	16	do.	CA	AS	(1) JP + GA + CA + ZO	AMH	do.	
49	17	F.R. Weber	PE	AS	MU + QZ + FS + GA	GNS	GNI (eKPz)	58ARb17A
49	17	R.M. Chapman	PE	AS	QZ + MU + PL	GNS	do.	76ACh208
49	17	do.	CA	AS	QZ + CA + PL + MU	GNS(?)	do.	76ACh209
49	18	do.	PE	AS	PL + QZ + MU + CL + TO	GNS	do.	76ACh207A
49	19	do.	OT	AS	QZ + PL + WM + CL	LPP	LPP (lKD)	76ACh205
49	20	F.R. Weber	OT	OC	WM	LPP	do.	63AWr149
49	21	do.	OT	OC	WM	LPP	do.	68AWr251C
49	22	R.M. Chapman	BA	AS	AC + EP + CL + PL + CA	GNS(?)	do.	63ACh2
49	22	do.	BA	OC	CA + CL	LPP(?)	do.	63ACh3
49	23	F.R. Weber	BA	AS	AC + CA	GNS(?)	GNI (eKPz)	67AWr71A
49	24	do.	PE	OC	QZ + MU	GNS(?)	do.	67AWa58
49	25	do.	OT	OC	WM	LPP	LPP (lKD)	67AWr94
49	26	do.	OT	OC	WM	LPP	do.	60ATb152
49	27	R.M. Chapman	BA	AS	CL + WM + AC(?) + QZ	LPP/GNS(?)	do.	60ATb192b
49	28	do.	BA	OC	CL + AC(?) + QZ	LPP/GNS(?)	do.	67AWr109
49	29	F.R. Weber	PE	OC	WM	LPP	do.	
49	29	R.M. Chapman	OT	AS	QZ + FS + WM + BI + CL + CM	LPP(?)	do.	82ACh52A
49	30	do.	OT	AS	QZ + WM + CM + EP	LPP/GNS(?)	do.	82ACh31
49	31	F.R. Weber	PE	OC	WM	LPP(?)	do.	70AWr204
49	32	R.M. Chapman	OT	AS	QZ + CA + PL + WM + CM + CL	LPP(?)	do.	82ACh33
49	32	do.	BA	AS	PL + BI + QZ + CA + WM	LPP(?)	do.	60ATb332B
49	32	do.	BA	AS	WM + CL + CA + EP	LPP(?)	do.	62ATb245
Circle								
50	1	H.L. Foster	BA	AS	AM + EP + PL + QZ + BI	GNS	GNI (eKPz)	79AFr7034B
50	2	do.	PE	AS	QZ + WM + CL + PL	GNS	do.	80AWr2D
50	3	do.	PE	AS	QZ + WM + CL + BI + GA + PL	GNS	do.	79AFr12F
50	4	do.	PE	AS	QZ + WM + CL + GA + PL + CA	GNS	do.	80AFr157
50	5	do.	PE	AS	QZ + WM + CL + BI + PL	GNS	do.	80AFr8
50	6	do.	BA	AS	AM + CL + EP + PL + QZ + BI	GNS	do.	80AFr43
50	7	do.	PE	AS	QZ + WM + CL + BI + GA + PL	GNS	do.	80AFr7012
50	8	do.	BA	AS	AM + CL + EP + PL + BI + CA	GNS	do.	79AFr7113C
50	9	do.	PE	AS	QZ + WM + CL + BI + PL	GNS	do.	79AWr350A
50	10	do.	PE	AS	QZ + WM + BI + CL + ST	AMP	AMI (eKPz)	79AWr173B
50	11	do.	PE	AS	QZ + WM + BI + GA + KY + PL + ST	AMI	do.	79AWr168B
50	12	do.	PE	AS	QZ + WM + BI + PL + CA	GNS	GNI (eKPz)	79AFr352A
50	13	do.	PE	AS	QZ + WM + CL + BI + GA + KY + PL	AMI	AMI (eKPz)	79AFr543A
50	14	do.	PE	AS	QZ + WM + CL + BI + KY + SI	AMI	do.	79AFr7137E
50	15	do.	PE	AS	WM + CL + BI + GA + KY + SI + PL	AMI	do.	79AFr242C
50	16	do.	PE	AS	QZ + CL + BI + GA + ST + PL	AMP	do.	79AWr369E
50	17	do.	PE	AS	QZ + WM + CL + BI + KY	AMI	do.	78AFr4079
50	18	do.	OT	AS	QZ + WM + BI + PL + KF	AMP	do.	78AFr56C
50	19	do.	PE	AS	QZ + WM + CL + BI	GNS	LPP (eKPz)	78AWr137B
50	20	do.	PE	AS	QZ + WM + BI + GA + PL	AMP	AMI (eKPz)	79AFr204
50	21	R.B. Forbes	BA	AS	QZ + AC + AB + CZ	GNS	GNI (eKPz)	
50	22	H.L. Foster	PE	AS	QZ + WM + CL + BI + GA + PL	AMP	AMI (eKPz)	79AFr102B
Charley River								
51	1	do.	PE	OC	BI + QZ + WM ± ST ± GA ± FS ± CL	AMP	do.	
51	2	do.	PE	OC	WM + QZ + BI ± GA ± ST ± CL	AMP	do.	
51	3	do.	BA	OC	PL + EP + CL + QZ ± AC ± CA	GNS	LPP/GNS (eJTR)	
51	4	do.	PE	OC	QZ + WM	GNS	do.	
51	5	do.	PE	OC	BI + QZ + PL + WM ± GA	AMP	AMI (eKPz)	

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
51	6	H.L. Foster	PE	OC	BI + WM + QZ + FS ± GA ± CL	AMP	AMI (eKPz)	
Nome								
52	1	A.B. Till	CA	AS	CA + FO + DO + PP + SL + CL	AMP	AMI (K)	
52	1	do.	CA	AS	CA + FO + PP + DO	AMP	do.	
52	1	do.	PE	AS	QZ + KF + PL + SI + BI + GA + CB	AMP	do.	
52	1	do.	BA	AS	HO + PL + BI + SH + QZ	AMP	do.	
52	2	do.	PE	AS	BI + GA + SI + QZ + MU + PL + CB	AMP	do.	
52	2	do.	PE	AS	ST + GA + BI + MU + QZ + CB	AMP	do.	
52	2	do.	PE	AS	QZ + MU + BI + ST + KY + GA	AMI	do.	
52	2	do.	PE	AS	QZ + MU + BI + ST + GA	AMP	do.	
52	3	do.	PE	AS	CL + WM + QZ + AB + GA + CD	GNS	GNH→I (eKmJ)	
52	3	do.	PE	AS	QZ + WM + AB + CL + CA + SH + BI	GNS	do.	
52	3	do.	CA	AS	CA + AB + QZ + WM	GNS	do.	
52	3	do.	BA	AS	LW + GL + GA + AB + CL + SH + PA + EP	GNH	do.	
52	4	do.	PE	AS	QZ + WM + EP + CL + CA + GL + GA + AB	GNH	do.	
52	4	do.	CA	AS	CA + EP + AB + QZ + WM + GL	GNH	do.	
52	4	do.	BA	AS	JP + EP + GL + GA + AB + WM + CL + SH + QZ	GNH	do.	
52	5	do.	BA	AS	JP + GL + GA + AB + WM + SH + EP + AC	GNH	do.	
Solomon								
53	1	do.	OT	AS	ST + CO + BI + GA + QZ	AMP	AMI (K)	
53	2	do.	BA	AS	GL + AC + CL + EP + AB + SH	GNH	GNH→I (eKmJ)	
53	2	do.	PE	AS	QZ + MU + CL + CD + AB + CB	GNS	do.	
53	3	do.	PE	AS	QZ + WM + CL + EP + CA + AB	GNS	do.	
53	3	do.	PE	AS	QZ + MU + CL + CD + GA	GNS	do.	
53	3	do.	CA	AS	CA + WM + QZ + AB + CB + ZO	GNS	do.	
53	3	do.	BA	AS	EP + GL + GA + AC + SH + QZ + AB + TO + CL	GNH	do.	
53	4	do.	PE	AS	QZ + MU + CL + EP	GNS	do.	
53	4	do.	PE	AS	QZ + MU + CL + AB + CB + SH + TO	GNS	do.	
53	5	do.	BA	AS	GL + AC + GA + EP + WM + CL + SH	GNH	do.	
53	5	do.	BA	AS	GL + GA + EP + WM + CL + QZ	GNH	do.	
53	6	do.	PE	AS	QZ + KF + SI + BI + CO	AMP	AMI (K)	
53	7	do.	PE	AS	QZ + MU + ST + GA + BI + PL + TO	AMP	do.	
53	8	do.	PE	AS	QZ + MU + ST + GA + BI + PL + TO	AMP	do.	
53	9	do.	BA	AS	HO + GA + CX + PL + CA	AMI	do.	
53	9	do.	PE	AS	QZ + MU + KY + BI	AMI	do.	
53	9	do.	OT	AS	KY + GE + BI + QZ + TO	AMI	do.	
53	9	do.	OT	AS	ST + BI + OP + KY	AMI	do.	
53	9	do.	PE	AS	QZ + MU + KF + BI + SI	AMP	do.	
53	9	do.	PE	AS	QZ + KF + SI + GA + BI	AMP	do.	
53	10	do.	BA	AS	AC + EP + CL + AB + PU	GNS	GNH (eKmJ)	
53	11	do.	OT	AS	QZ + PL + CX + BI + OP + KF + HO	2PX	AMI (K)	
53	12	do.	OT	AS	QZ + CB + MU	GNS	GNH (eKmJ)	
53	12	do.	PE	AS	QZ + MU + CL + AB + CA + TO	GNS	do.	
53	12	do.	BA	AS	GL + EP + GA + AB + CL + SH	GNH	do.	
53	13	do.	PE	AS	QZ + KF + SI + BI + GA	AMP	AMI (K)	
53	14	do.	PE	AS	QZ + MU + CL + GA + CD + TO	AMP	GNH (eKmJ)	
Nulato								
55	1	E.J. Moll	OT	AS	QZ + CL + SH + CA	GNS	GNI,H (eKmJ)	79APa544B1
55	1	do.	PE	AS	GL + SP + EP + SH + CL + AM + PL	GNH	do.	79APa544C

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
55	2	E.J. Moll	BA	AS	QZ + MU + CL + CA + ZO + SH + PL	GNS	GNI,H (eKmJ)	79APa527A
55	3	do.	OT	AS	MU + QZ	GNS	do.	79APa526A
55	3	do.	OT	AS	MU + QZ + CL	GNS	do.	79APa526B
55	4	do.	BA	AS	QZ + MU + CL + CA + SH + PL	GNS	do.	79APa529A
55	4	do.	BA	AS	CL + EP + SH + PL + GL(tr)	GNH	do.	79APa529B
55	5	do.	BA	AS	GL + SP + SH	GNH	LPP (eKlTr)	79APa505B
55	6	do.	PE	AS	QZ + MU + CD + CA	GNS	GNI,H (eKmJ)	79APa537B
55	7	do.	OT	AS	QZ + MU + CL + CO	AMP	do.	79APa533
55	8	do.	BA	AS	CL + EP + SH + PL + MU	GNS	do.	79APa535
55	8	do.	CA	AS	QZ + MU + CA + EP + CL	GNS	do.	79APa535B
55	9	do.	PE	AS	QZ + MU + CL + CD	GNS	do.	79APa541A
55	9	do.	OT	AS	QZ + MU	GNS	do.	79APa541B
55	10	do.	BA	AS	CL + EP + SH + PL + CA + MU	GNS	do.	79APa531
55	11	do.	PE	AS	QZ + MU + CL + CD	GNS	do.	79APa538A
55	12	do.	BA	AS	GL + SP + SH + CL	GNH	LPP (eKlTr)	79APa507A
55	13	do.	BA	AS	PU + CL + QZ + SH	LPP	do.	79APa522
55	14	do.	BA	AS	GA + AM + ZO + QZ + SH	AMP	do.	74APa127e
55	15	do.	PE	AS	MU + GA + AM + EP + PL + SH	GNS	GNI,H (eKmJ)	79APa542
55	16	do.	PE	AS	GA + GL + MU + CL + CD + QZ	GNH	do.	79APa551A1
55	16	do.	PE	AS	GL + EP + CL	GNH	do.	79APa551B1
55	16	do.	PE	AS	GA + GL + EP + CA + QZ	GNH	do.	79APa552B2
55	16	do.	PE	AS	GL + GA + EP + AM + MU	GNH	do.	79APa551B6
55	17	do.	PE	AS	MU + GA + EP + CL + CD + QZ	GNS	do.	79APa554a
Ruby								
56	1	R.M. Chapman	BA	AS	EP + AC + CL + SH	GNS	LPP (eKmJ)$_2$	
56	2	do.	PE	AS	BI + QZ + CO + SI + MU + TO + KF + CB	AMP	AMP (peK) + AMP (eKmJ?)	
56	2	do.	PE	AS	QZ + CL + CB + ST + MU + SH	AMP	do.	
56	3	do.	PE	AS	QZ + BI + CL + GA	AMP	do.	
56	3	do.	CA	AS	DI + CA + GA + SH + QZ	AMP	do.	
56	4	E.J. Moll	PE	AS	(1) KY + BI + QZ + KF	AMP	do.	74APa121
56	4	do.	PE	AS	(2) SI + BI + QZ + KF	AMP	do.	74APa121
56	5	R.M. Chapman	PE	AS	HO + PL + QZ	AMP	do.	
56	5	do.	PE	AS	BI + SI + QZ	AMP	do.	
56	5	do.	PE	AS	BI + GA + SI + PL + QZ + MU + ST	AMP	do.	
56	6	do.	PE	AS	BI + SI + CO + QZ	AMP	do.	
56	6	do.	PE	AS	BI + SI + QZ + MU + GA + CO + TO	AMP	do.	
56	7	do.	BA	AS	PU + CL + QZ + ZO + SH	LPP	LPP (eKlTr)	
56	8	do.	BA	AS	AC + CL + ZO + QZ + SH + PU(?)	LPP	do.	
56	9	do.	BA	AS	CL + EP(?) + SH + PU(?)	LPP	do.	
56	10	do.	PE	AS	QZ + EP + CL + MU	GNS	GNS (eKmPz)	
56	11	do.	PE	AS	QZ + MU + CL + TO	GNS	do.	
56	12	G.M. Smith	PE	AS	QZ + MU + BI + ST + GA	AMP	AMP (peK)	
56	13	R.M. Chapman	BA	AS	AC + EP + CL	LPP,GNS	LPP (eKlTr)	
56	14	do.	PE	AS	QZ + MU + AB	GNS	GNS (eKmPz)	
56	15	do.	BA	AS	CL + EP + SH + AC	GNS	do.	
56	16	do.	PE	AS	QZ + MU + CL	GNS	do.	
56	17	do.	PE	AS	QZ + CA + CL + MU	GNS	AMP (peK)	
56	18	do.	PE	AS	QZ + BI	GNS	do.	
56	19	do.	BA	AS	EP + AC	GNS	GNS (eKmPz)	
56	20	G.M. Smith	PE	AS	QZ + MU + BI + CO + GA	AMP	AMP (peK)	
56	21	R.M. Chapman	PE	AS	QZ + CL + MU	GNS	GNS (eKmPz)	
56	22	do.	BA	AS	AC + ZO + CL + SH + QZ	GNS	do.	
56	23	do.	OT	AS	CA + CL	GNS	do.	
56	24	do.	BA	AS	QZ + CL + PH(?)	LPP	do.	
56	25	do.	BA	AS	EP + BI + CL + QZ	GNS	do.	
56	26	do.	BA	OC	CL	LPP(?)	LPP (eKlTr)	
56	27	do.	CA	AS	CZ + AC + SC + SH	GNS	GNS (eKmPz)	
56	28	do.	CA	AS	EP + CA + CL + AC	GNS	do.	
56	29	do.	BA	AS	BI + EP + AC + GA	GNS	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
56	30	R.M. Chapman	BA	AS	HO + EP + BI + DI(?)	GNS	GNS (eKmPz)	
56	31	do.	PE	AS	MU + QZ + HE + CB	GNS	do.	
56	32	do.	CA	AS	CL + CA + MU + QZ + AB	GNS	do.	
56	33	do.	CA	AS	CL + CA + AC + EP + QZ	GNS	do.	
56	34	do.	BA	AS	AC + EP	GNS	do.	
56	35	do.	PE	AS	QZ + MU + CB	GNS	do.	
56	36	do.	BA	AS	AC + CZ + CL + SH	GNS	do.	
56	37	do.	PE(?)	AS	QZ + MU + AB + KF	GNS	GNS (pO)	
56	37	do.	PE(?)	AS	QZ + MU + BI + EP + HO	AMP	do.	
56	38	do.	PE(?)	AS	(1) BI + GA + ST + QZ + MU	AMP	AMP (mPzY) + GNS (mPzY)	
56	38	do.	PE(?)	AS	(2) CL + CD + QZ + MU	GNS	do.	
56	38	do.	PE	AS	(1) BI + GA + QZ + PL	AMP	do.	
56	38	do.	PE	AS	(2) CD + CL + AB + ZO	GNS	do.	
56	38	do.	PE	AS	(1) QZ + MU + ST(?)/AN(?)	AMP(?)	do.	
56	38	do.	PE	AS	(2) QZ + MU + CZ + CL + CD(?) + AB	GNS	do.	
56	38	do.	PE	AS	(1) QZ + GA + MU + BI	AMP	do.	
56	38	do.	PE	AS	(2) QZ + MU + CL	GNS	do.	
56	39	do.	BA	AS	AB + EP + AC + CL + CA	GNS	GNS (pO)	
56	39	do.	OT	AS	QZ + EP + MU + CL + AB	GNS	do.	
56	39	do.	OT	AS	BI + QZ + ZO + CL	GNS	do.	
56	39	do.	OT	AS	QZ + EP + CL + AB	GNS	do.	
56	40	do.	PE	AS	(1) GA + BI + MU + QZ	AMP	AMP (mPzY) + GNS (mPzY)	
56	40	do.	PE	AS	(2) CL + MU + QZ	GNS	do.	
56	40	do.	PE	AS	(1) QZ + BI + MU + CO + PL	AMP	do.	
56	40	do.	PE	AS	(2) QZ + MU + CL + AB	GNS	do.	
56	41	do.	BA	AS	(1) HO + QZ + SH + ST(?) + PL	AMP	do.	
56	41	do.	PE	AS	(1) BI + GA + SI + QZ + PL + MU	AMP	do.	
56	42	do.	BA	AS	QZ + EP + MU + AB + SP	GNS	GNS (pO)	
56	42	do.	OT	AS	QZ + EP + MU + AB + AC	GNS	do.	
56	42	do.	BA	AS	QZ + EP + AC + MU + CA + SH + AB	GNS	do.	

[1]Localities numbered consecutively within each 1:250,000-scale quadrangle

[2]Rock types: BA, basic; CA, calcic; OT, other; PE, pelitic

[3]Metamorphic minerals:

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

Minerals arranged in order of decreasing abundance. (1), (2), first and second phases of a polymetamorphic episode or early and late phases of a single evolving metamorphic episode.

[4]Refer to text for explanation of symbols.

[5]In a few cases, the area of the metamorphic-facies unit in which the assemblage occurs is too small to show on the map.