U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

PRELIMINARY GEOLOGIC MAP OF THE MOUNT HAYES QUADRANGLE, EASTERN ALASKA RANGE, ALASKA

By

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With contributions for selected areas from

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Open-File Report 92-594

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code).

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1992

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OPEN-FILE REPORT 92-594
PAMPHLET

INTRODUCTION, PREVIOUS STUDIES, ACKNOWLEDGMENTS, DETAILED DESCRIPTION OF MAP UNITS, AND REFERENCES CITED FOR PRELIMINARY GEOLOGIC MAP OF MOUNT HAYES QUADRANGLE, EASTERN ALASKA RANGE, ALASKA

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INTRODUCTION

This report and companion preliminary map describe the geology of the Mount Hayes quadrangle, eastern Alaska Range, Alaska. It is part of a folio on the geology, geochemistry, geophysics, and mineral resources of the quadrangle prepared as part of the Alaskan Mineral Resource Assessment Program (AMRAP) of the U.S. Geological Survey. Field investigations were conducted during the summers of 1978 through 1982, with additional topical studies in 1985 and 1986.

The Mount Hayes quadrangle is in the eastern Alaska Range which forms a great glacially sculptured arcuate mountain range extending approximately 1,000 km from the Canadian border in the east to the Aleutian Range to the west and southwest. The eastern Alaska range is characterized by rugged peaks ranging to over 4,180 m in elevation and spectacular valley glaciers up to 65 km long. The range is bisected by the Denali fault which is a major geologic and geographic boundary between the Yukon River basin in interior Alaska to the north, and the Copper River basin of southern Alaska to the south.

The bedrock geology is grouped into various tectonostratigraphic terranes (index map). North of the Denali fault the bedrock geology is dominated by the Devonian and older Yukon-Tanana terrane, a complex of multiply deformed and metamorphosed sedimentary, volcanic, and plutonic rocks (Jones and others, 1987; Aleinikoff and Nokleberg, 1985a, b; Nokleberg and Aleinikoff, 1985). To the south, the bedrock geology is dominated by the Mesozoic Maclaren, and Paleozoic and Mesozoic Wrangellia terranes (Jones and others, 1987; Nokleberg and others, 1982, 1985, 1989a). A number of granitic to gabbroic plutons, chiefly of Mesozoic age, intrude the terranes both north and south of the Denali fault. Major faults or sutures separate terranes, and many younger Cenozoic faults occur along the margins of, and within terranes.

This pamphlet augments the accompanying geologic map by providing a more detailed description of map units. In addition it contains sections on previous studies, acknowledgments, and references that are not presented on the geologic map. In the section on the detailed description of map units, localities are generally designated both by geography and by reference to the 24 15-minute quadrangles that constitute the Mt. Hayes 1°x 3° quadrangle. These quadrangles, bounded by 15 minutes of latitude and 30 minutes of longitude, are designated from A-1 in the southeast corner to D-6 in the northwest corner.

PREVIOUS STUDIES

In the last three decades, the Mount Hayes quadrangle has been the focus of many geologic studies. Bedrock geologic maps for parts of the quadrangle have been published by Holmes (1965), Péwé and Holmes (1964), Rose (1965; 1966a, b; 1967), Rose and Saunders (1965), Holmes and Foster (1968), Matteson (1973), Bond (1976), Stout (1976), Richter and others (1977), and Nokleberg and others (1982). Surficial geologic maps of parts of the quadrangle have been published by the U.S. Army Corps of Engineers (1953, 1960a, b), Kachadorian and Péwé (1955), Holmes and Benninghoff (1957), Péwé and Holmes (1964), Holmes and Péwé (1965), Weber (1971), and Carter and Galloway (1978). The companion geologic map is based partly on these published geologic maps, but to a much greater degree on the 1:63,360-scale geologic mapping that was done for the mineral resource assessment study of the area.

Geologic guides, stratigraphic and structural studies, and geophysical studies have also been published for parts or all of the quadrangle. A geologic guide to the bedrock geology and tectonics along the Richardson Highway has been published by Nokleberg and others (1989a), and a geologic guide to the surficial geology along the Richardson Highway has been published by Péwé and Reger (1983). Stratigraphic and structural studies have been published by Bond (1973, 1976), Richter and Dutro (1975), Stout (1976), Nokleberg and others (1981a, b, c, 1983), Nokleberg and Aleinikoff (1985), and Nokleberg and others (1985, 1986a, 1989a). Geophysical studies of all or parts of the quadrangle have been published by the State of Alaska (1974), Barnes (1977), Hillhouse and Grommé (1984), Campbell and Nokleberg (1984, 1985), and Campbell (1987).

A compilation of the numerous fossil and isotopic age studies has been published by Nokleberg and others (1992). In the following description of map units, the tabular references to fossil and age localities refer to the tables in that report. Fossil studies have been published for parts of the quadrangle by Mendenhall (1905), Moffit (1912, 1942, 1954), Benninghoff and Holmes (1961), Rose (1965, 1966a, b, 1967), Rose and Saunders (1965), Richter (1966), Wolfe (1966, 1972), Rowett (1969 a, b, 1975), Rowett and Timmer (1973), Petocz (1970), Richter and Dutro (1975), Bond (1976), Matteson, (1973), Stout (1976), Richter and others (1977), Turner and others (1980), and Nokleberg and others (1982, 1985). Isotopic studies are published for parts of the quadrangle by Ragan and Hawkins, 1966, Holmes and Foster (1968), Kleist (1971), Matteson (1973), Smith and Turner (1973), Turner and Smith (1974), Bond (1976), Turner and others (1980), Foley (1982, 1984), Aleinikoff (1984), Aleinikoff and Nokleberg (1983, 1984, 1985a, b), LeHurray and others (1985), Aleinikoff and others (1981, 1984, 1986,

1987), Nokleberg and others (1985, 1986a, 1989a), and Wilson and others (1985).

Mineral resource studies on the Mount Hayes quadrangle are also available. An exploration geochemistry survey of the area has been published by Curtin and others (1989). A study of the mineral resource potential of the area has been published by Nokleberg and others (1990), and a study of the mines, mineral deposits, and occurrences has been published by Nokleberg and others (1991). Summary studies of mineral deposits in, and metallogenesis of the Mount Hayes quadrangle have been published by Nokleberg and others (1984) and Nokleberg and Lange (1985).

Several geologists have contributed unpublished geologic mapping of parts of the Mount Hayes quadrangle. G.C. Bond contributed unpublished geologic mapping in the south-central part of the quadrangle in the area from Rainbow Mountain to Gulkana Glacier, and in southeastern part of the quadrangle in the area between Gakona Glacier and Chistochina River. D.H. Richter contributed unpublished geologic mapping in the southeastern part of the quadrangle. T.E. Smith contributed unpublished geologic mapping in the southwestern part of the quadrangle in the area bounded by the Maclaren River, the Susitna Glacier, and the western edge of the quadrangle. J.H. Stout contributed unpublished geologic mapping in the south-central part of the quadrangle in the area to the south of the terminus of Black Rapids Glacier and north of the Denali fault. These unpublished geologic maps were used as a guide in the remapping of the entire Mount Hayes quadrangle at a scale of 1:63,360 that was reduced and compiled to a scale of 1:250,000 for this geologic map.

ACKNOWLEDGMENTS

We are greatly indebted to the hard work and excellent science published by present and past geologists in the Mount Hayes quadrangle and adjacent areas. Our work is in part based on their fine efforts and accomplishments. We are also grateful to H.C. Berg, Donald Grybeck, E.M. MacKevett, Jr., A.T. Ovenshine, T.P. Miller, and G.R. Winkler who greatly encouraged and supported the geologic mapping. We thank D.L. Jones and N.J. Silberling for their assistance in mapping of bedrock in part of the southern part of the quadrangle, and for their stimulating geological discussions of bedrock geology and tectonics. We also thank Nairn R.D. Albert, David L. Campbell, Paige L. Herzon, the late Carl Huie, John S. Lull, Willis H. Nelson, George Plafker, and Donald H. Richter, for assisting in part of the bedrock geologic mapping, and L. David Carter, Thomas D. Hamilton, and Warren Yeend for assisting in mapping of surficial deposits, placer deposits, and older Quaternary and Holocene faults. We also thank Gerard C. Bond, Donald H. Richter, James H. Stout, and Thomas E. Smith for contributing unpublished geologic mapping of parts of the quadrangle. We thank Carol L. Burhmaster, Robert C. Roback, and Carl E. Schwab for extensive petrologic studies of bedrock in the quadrangle. We appreciate the excellent discussions and field tours provided by Clint Nauman and Steven Newkirk of some of the massive sulfide deposits in the eastern part of the quadrangle. We also thank helicopter pilots Michael Arline, Richard Rossiter, and Barry Roberts for their superb flying in an extremely difficult and remote area.

DETAILED DESCRIPTION OF MAP UNITS
SURFICIAL DEPOSITS

ALLUVIUM AND COLLUVIUM

Qa **Alluvial deposits (Holocene)**—Flood-plains, fans, and cones. Only large, well-defined cones differentiated from colluvium. Oldest deposits may be outwash from a late advance of the Wisconsin glaciation. Chiefly unconsolidated sand, and gravel.

Qfl **Fluviolacustrine deposits (Holocene)**—Lake, pond, and low-gradient stream deposits, chiefly consisting of sand, silt, and clay

Qc **Colluvial deposits (Holocene)**—Chiefly talus and other slope debris deposits,, also includes alluvium of minor streams, and locally glacial, rock glacier, and mass-wasting deposits. In areas of gentle slopes, consists chiefly of mixed colluvium and alluvium with local bedrock rubble but may include older glacial drift deposits. Locally grades into deposits of Alaskan, Wisconsin, and older glaciations. Chiefly rubble, gravel, sand, silt, and clay

GLACIAL DEPOSITS

Qam **End and lateral moraines of Alaskan glaciation (Holocene)**—Left after recession of existing glaciers. Chiefly rubble and diamicton

Qwm **End and lateral moraines of Wisconsin glaciation (Holocene and Pleistocene)**—Poorly sorted and unstratified till of unconsolidated sand and gravel. Chiefly rubble and diamicton; local sand and gravel. As mapped, may locally include deposits of Alaskan glaciation (Qam). At higher elevations, deposits grade vertically with, and covered by colluvium (Qc)

Qwf **Glaciofluvial deposits of Wisconsin glaciation (Holocene and Pleistocene)**—Generally occurs downslope from end moraines of Wisconsin glaciation. Moderately well-stratified layers and lenses of well-rounded gravel with matrix of silt and sand. Poorly to moderately well sorted with lenses of well-sorted sand locally. Includes minor lateral and ground moraines, and some deposits of Alaskan glaciation (Qam). May include postglacial alluvium and pond deposits locally

Qog **Drift of older glaciations (Pleistocene)**—Glacial deposits exhibiting subdued geomorphic expression, probably of early Wisconsin or Illinoian age occurring beyond limit of Wisconsin moraines. Also includes undifferentiated high-level glacial deposits. At higher elevations, deposits merge with and covered by undifferentiated colluvium (Qc). At lower elevations, deposits merge with and covered by undifferentiated alluvium (Qa). At higher elevations, consists chiefly of unconsolidated diamicton and boulder deposits. At lower elevations, consists chiefly of unconsolidated glaciofluvial deposits of moderately well-stratified and sorted gravel and sand

SEDIMENTARY ROCKS AND METAMORPHOSED SEDIMENTARY,VOLCANIC, AND PLUTONIC ROCKSNORTH OF DENALI FAULT

TERTIARY SEDIMENTARY ROCKS

Scattered exposures of Tertiary continental sedimentary rocks occur north of the Denali fault and consist of, from youngest to oldest, the Nenana Gravel, a sandstone unit, and the sedimentary rocks and coal of the Jarvis Creek coal field (Wahrhaftig and Hickox, 1955). The Nenana Gravel occurs mainly in the northwestern corner of the quadrangle, and north of the Jarvis Creek coal field in the center of the quadrangle. The sandstone unit occurs mainly in fault-bounded prisms along the northern edge of the Alaska Range. The Jarvis Creek coal field occurs between the Delta River and Jarvis Creek, east of the Richardson Highway.

Tn **Nenana Gravel (Pliocene)**—Consists chiefly of poorly cemented conglomerate but includes some sandstone and siltstone. Clast composition within the D-6 quadrangle of (in decreasing order of abundance) is schist, quartzite, granitic rocks, gabbro, and metagabbro. At one locality in the C-3 quadrangle, clasts approximately 80% schist, 10% quartz, and 10% felsic volcanic rocks, mafic volcanic rocks, and diabase. Bedding strikes northeast and dips gently south in the D-6 quadrangle; and strikes northwest and dips moderately to steeply north near contact with fine-grained metasedimentary rocks of the Jarvis Creek Glacier terrane (unit jcs) along the Granite Mountain fault, in the northern C-3 quadrangle. Eroded at top. Maximum exposed stratigraphic thickness of a few hundred meters

Mainly exposed along northern D-6 quadrangle boundary, northeastern C-4 quadrangle, and northeastern C-3 quadrangle. Unconformably overlies granite of Granite Mountain (grgm) and fine-grained metasedimentary rocks (jcs) of Jarvis Creek Glacier subterrane; locally in fault contact with Jarvis Creek Glacier terrane (unit jcs). Unconformably overlain by Pleistocene glacial deposits, and overlies coal-bearing sedimentary rocks of Jarvis Creek coal field (unit Tsju) inferred to be of early Tertiary age (Moffit, 1942; Wahrhaftig and Hickox, 1955), and locally unconformably overlies the sandstone unit of Oligocene to Pliocene age (Ts). Inferred to be of late Tertiary (Pliocene) age. Lithologically similar to rocks assigned to Nenana Gravel occur to west in the Healy quadrangle; assigned a Miocene(?) and Pliocene age by (Csejtey and others, (1992)

Ts **Sandstone (Pliocene, Miocene, and Oligocene)**—Chiefly brown sandstone and graywacke but includes some interbedded conglomerate and dark argillite. Generally fault bounded. Maximum exposed stratigraphic thickness of a few hundred meters.

Fine-to medium-grained, poorly sorted, angular, and grades into graywacke. Composition varies from quartz grains in a clay-rich matrix to quartz, plagioclase, K-feldspar, pyroxene, hornblende, and biotite in a clay-rich matrix. Conglomerate pebbles locally composed of granitic rocks and schist; locally imbricated. Argillite composed of tiny quartz grains and opaque minerals in a yellow-brown, clay-rich matrix.

Unit occurs in scattered exposures up to 3.5 km across in the C-5, C-6, D-5, and D-6 quadrangles. Strikes northeast and dips moderately west in the C-5 quadrangle. Overlies and locally faulted against rocks of the Jarvis Creek Glacier subterrane. Many occurrences too small to depict on geologic map. Largely surrounded by Quaternary deposits. Sparse plant fossils indicate Oligocene, Miocene, and Pliocene age (Table 1 of Nokleberg and others (1992), localities 1, 2, 3, 4, 6)

Tsj **Sedimentary rocks of Jarvis Creek coal field (early Tertiary) (Unit of Wahrhaftig and Hickcox, 1955)**—Chiefly sandstone, mudstone, conglomerate, and coal. Eroded at top. Occurs in an irregular outcrop approximately 10 km long, in the north-central part of C-4 quadrangle. Overlies bedrock of Jarvis Creek Glacier subterrane. Sparse plant fossils indicate a Tertiary age (Table 1 of Nokleberg and others (1992), locality 5). To the west in the Healy quadrangle, lithologically similar rocks in the Nenana coal field are Eocene to late Miocene in age (Wahrhaftig and others, 1969; Csejtey and others, 1992). Estimated maximum exposed stratigraphic thickness of about 600 m. Locally divided into upper, middle, and lower members:

Tsju **Upper member**—Chiefly dark-gray mudstone and sandstone containing scattered coal beds. Eroded at top. Occurs in an irregular outcrop 4 km across in the central C-4 quadrangle. Overlies fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane and the middle member (Tsjm) of the sedimentary rocks of Jarvis Creek coal field. Estimated maximum exposed stratigraphic thickness of about 300 m

Tsjm **Middle member**—Chiefly buff arkosic sandstone, containing claystone and scattered coal beds, and a prominent coal and shale zone at base. Occurs in an elongate, arcuate outcrop 9 km long in the central C-4 quadrangle. Overlies fine-grained metasedimentary rocks (jcs) of Jarvis Creek Glacier subterrane and the lower member (Tsjl) of the sedimentary rocks of Jarvis Creek coal field. Estimated stratigraphic thickness of 300 m or less

Tsjl **Lower member**—Chiefly angular quartz sandstone and conglomerate; some claystone, and coal. Occurs in an irregular outcrop 4 km long in the central C-4 quadrangle. Overlies fine-grained metasedimentary rocks unit (jcs) of the Jarvis Creek Glacier subterrane. Estimated stratigraphic thickness of 150 m or less

ALKALIC MAFIC AND ASSOCIATED PLUTONIC ROCKS

A suite of alkalic mafic and associated plutonic rocks occurs north of the Denali fault in the Windy terrane, and in the Hayes Glacier and southern Jarvis Creek Glacier subterranes of the Yukon-Tanana terrane. The suite consists of lamprophyre, alkalic gabbro, alkalic diorite, and monzonite, and diorite in dikes,

sills, and small plutons. Many dikes and sills too small to depict on the geologic map.

An intricate variety of small plutons and dikes of lamprophyre, alkalic gabbro, monzonite, and diorite, partly surrounded by a ring dike of the granite of Gerstle River (grgr) form a major intrusive suite in the Mount Hajdukovich area. The suite intrudes the fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane. Suite occupies an irregular area of approximately 6 by 12 km within the southeastern C-3 and southwestern C-2 quadrangles.

The lamprophyres and alkalic gabbros and related rocks crosscut all penetrative structures and are younger than the intense Early to mid-Cretaceous deformation and metamorphism of the Yukon-Tanana terrane, described below. The alkalic and related rocks occur only in units that are relatively near the Denali fault, and not in the deeper-level subterranes of the Yukon-Tanana terrane farther north

la **Lamprophyre, alkalic gabbro, and alkalic diorite (early Tertiary and Late Cretaceous)**—Undifferentiated dikes, sills, and small plutons. Predominantly fine- to medium-grained, panidiomorphic granular to porphyritic texture. Composed of phenocrysts, up to 3 mm of hornblende-rimmed clinopyroxene plagioclase, biotite, olivine, orthopyroxene, hornblende, and K-feldspar in a fine-grained, groundmass of K-feldspar, plagioclase, biotite, quartz, calcite, chlorite and Minor white mica and opaque minerals. Common interstitial carbonate alteration. Some dikes almost completely replaced by carbonate.

Unit occurs in several irregular bodies up to 3 km across in the southeastern C-3 quadrangle, and as an irregular body approximately 3 km across on the southern C-2 and C-3 quadrangle boundary. Intrudes fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane.

The lamprophyres, alkalic gabbros, and alkalic diorites exhibit two clusters of K-Ar ages: (1) a suite of Late Cretaceous to early Tertiary biotite ages of 62.9, 67.6, and 69.2 Ma in the Robertson River area in the east-central part of quadrangle (Table 2 of Nokleberg and others (1992), localities 9, 25, 26); and (2) a suite of mid- to Late Cretaceous K-Ar ages of 75.6 Ma for hornblende, 69.3 Ma for biotite, and 107.6 Ma for hornblende in the Tok River area in the east-central part of quadrangle (Table 2 of Nokleberg and others (1992), localities 29, 30, 31). Additional K-Ar hornblende age of 91.6 Ma to the east in the southwestern Tanacross quadrangle (Foley, 1984). These data indicate probable intrusion of the alkalic mafic rocks mainly during the Late Cretaceous and early Tertiary, with one sample apparently intruded in the mid-Cretaceous. No isotopic data available for Mount Hajdukovich area. The granite of Gerstle River (grgr) , part of which forms a partial ring dike around, and small plutons within the igneous suite of Mount Hajdukovich, exhibits K-Ar isotopic ages of 53.4 and 54.3 Ma (Table 2 of Nokleberg and others (1992), localities 21, 24)

md **Monzonite and diorite (early Tertiary and Late Cretaceous)**—Includes lesser quartz monzonite and quartz diorite. Undifferentiated dikes, sills, and small plutons. Fine- to medium-grained; hypautomorphic granular and locally porphyritic. Composed of plagioclase, K-feldspar, hornblende, biotite, quartz, and minor clinopyroxene and sphene. Hornblende and clinopyroxene partially replaced by biotite and hornblende rims clinopyroxene. Locally schistose, fractured and granulated. Locally altered with hornblende and biotite partially altered to chlorite and calcite, and plagioclase to sericite, and minor epidote and calcite. Unit occurs in southwestern C-2 quadrangle in two elongate outcrops up to 2.5 km long which extend westward into C-3 quadrangle; also occurs in stocks to 5 km across in the southeastern C-3 quadrangle

PLUTONIC ROCKS NORTH OF DENALI FAULT

An extensive suite of granitic plutonic rocks occurs in terranes north of the Denali fault as small dikes, stocks, and a few large plutons. Many occurrences are too small to depict on geologic map. The larger plutons are at Buchanan Creek and Molybdenum Ridge, west of the Richardson Highway, Granite Mountain, east of the Richardson Highway, and Macomb Plateau in the east-central part of the quadrangle. The granitic rocks are generally equigranular to porphyritic and medium grained and usually contain both hornblende and biotite. Alteration of feldspars to sericite slight; biotite locally altered to chlorite.

Locally in the Macomb Plateau area and in the northeastern part of the quadrangle, many of the Late Cretaceous (grma) granitic plutons exhibit a weak to moderate schistosity with formation of lower greenschist facies actinolite, chlorite, and white mica along the schistosity. Contact metamorphic aureole generally very narrow or lacking around the older, Late Cretaceous granitic plutons; relation suggests intrusion during the waning stages of regional metamorphism and penetrative deformation while the wall rocks were still warm (Nokleberg and others, 1989a).

The isotopic ages for granitic plutons north of the Denali fault are: (1) U-Pb zircon isotopic ages of about 90 Ma (three determinations) (Table 2 of Nokleberg and others (1992), localities 3, 13, 19); (2) K-Ar hornblende and biotite ages of 84.0, 88.7, 88.8, 92.9, 93.3, and 103.6 Ma (Table 2 of Nokleberg and others (1992), localities 2, 13, 27, 35); and (3) Pb-Alpha ages of 90, 105, and 110 Ma (two determinations), and 115 Ma (Table 2 of Nokleberg and others (1992), localities 1, 5, 6, 8, 11). Excluding the older and relatively less reliable Pb-Alpha ages, these ages range from 84 to 105 Ma and suggest intrusion of the granitic plutons in the mid- to Late Cretaceous. The granitic plutons in the Macomb Plateau region in the east-central part of the quadrangle are isotopically dated only by Pb-Alpha studies and need additional study

In the eastern part of the quadrangle, southeast of the Robertson River, the Mount Gakona fault, and the Jarvis Creek Glacier and Hayes Glacier subterranes are intruded by a the granite of Rumble Creek (grrc). K-Ar isotopic analysis of hornblende from this pluton yields an age of 88.7 Ma (Table 2 of Nokleberg and others (1992), locality 27). If the K-Ar age represents the age of granitic intrusion, movement on the Mount Gakona fault ceased by the Late Cretaceous.

In the Windy terrane, a narrow, near-vertical granitic pluton exhibits K-Ar biotite and hornblende ages of 85.2, 85.9, 89.6, and 94.7 Ma (Table 2 of Nokleberg and others (1992), localities 39, 40, 41). These K-Ar values may be minimum ages for the pluton because of low-grade hydrothermal alteration and (or) low-grade static metamorphism. A nearby granodiorite pluton to the northwest in the Aurora Peak terrane may be of similar age.

GRANITIC ROCKS, UNNAMED

grn1 **Granitic unit 1 (early Tertiary and (or) Late Cretaceous)**—Granite dikes, stocks, and small plutons. Locally schistose. Fine- to coarse-grained. Hypautomorphic granular and locally porphyritic with phenocrysts of plagioclase up to 5 mm. Major minerals are quartz, plagioclase, K-feldspar, biotite, and hornblende. Local weak to intense hydrothermal alteration. Plagioclase partially recrystallized to sericite; biotite to chlorite plus epidote-clinozoisite. Local quartz and calcite veins.

Unit widely distributed in northern part of quadrangle. Mainly occurs in: (1) a thin, intermittently exposed, fault-bounded wedge approximately 1 km wide and 12 km long in fault contact with Aurora Peak terrane (as) to the northeast and Windy terrane (wm) to the southwest within the northwest B-4 quadrangle; (2) stocks up to 4.5 km across, intruding Hayes Glacier subterrane (hgs) in the northeastern A-2 quadrangle; (3) small bodies generally less than 1 km across; and (4) numerous dikes and sills rarely more than 1 m across

grn2 **Granitic unit 2 (early Tertiary and (or) Late Cretaceous)**—Granodiorite dikes, stocks, and small plutons. Fine- to medium grained, hypautomorphic granular texture. Major minerals are plagioclase, quartz, K-feldspar, biotite, and locally hornblende. Minor clinopyroxene and sphene present locally. Local sericite and chlorite alteration. Locally weakly schistose exhibiting lower greenschist facies metamorphism and (or) hydrothermal alteration. Plagioclase partially recrystallized to sericite, epidote-clinozoisite, and calcite; mafic minerals to chlorite and epidote-clinozoisite.

Unit occurs in: (1) a small stock approximately 2.5 km across intruding Aurora Peak terrane (as) along the eastern B-5 - C-5 quadrangle boundary; and (2) plutons up to 6 km across intruding the Lake George subterrane in the northeastern part of the quadrangle

grn3 **Granitic unit 3 (early Tertiary and (or) Late Cretaceous)**—Quartz diorite and diorite dikes, stocks, and small plutons. Fine- to medium-grained, hypautomorphic granular. Major minerals are plagioclase, biotite, and locally hornblende, quartz, white mica, and opaque minerals also present. Minor calcite, chlorite, and sericite alteration.

Unit occurs in: (1) scattered outcrops up to 5 km across in the northeastern B-2 and southeastern C-2 quadrangles; (2) dikes and sills up to 1 m wide in east-central C-3 quadrangle; and (3) small bodies less than 1 km across in the northeastern C-1 quadrangle

GRANITIC PLUTONS, INFORMALLY NAMED

grgr **Granite of Gerstle River (early Tertiary)**—Here referred to as granite of Gerstle River. Chiefly biotite granite; includes minor quartz diorite. Fine- to medium-grained, hypautomorphic granular texture. Locally porphyritic with phenocrysts of K-feldspar up to 8 mm. K-feldspar locally poikilitic with inclusions of quartz, plagioclase, and biotite. Major minerals are plagioclase, K-feldspar, quartz, biotite, and locally hornblende. Minor minerals are clinopyroxene, sphene, and opaque minerals. Clinopyroxene partially replaced by igneous hornblende; biotite partially replaces hornblende. Locally fractured and granulated. Local epidote, carbonate, and white mica hydrothermal alteration.

Unit occurs as: (1) a partial ring dike around; and (2) small plutons within the intrusive suite of the Mount Hajdukovich area. An early Tertiary (?) age indicated by K-Ar isotopic dates of 53.4 and 54.3 Ma (Table 2 of Nokleberg and others (1992), localities 21, 24)

grbc **Granite of Buchanan Creek (early Tertiary or Late Cretaceous)**—Here referred to as granite of Buchanan Creek. Chiefly biotite-hornblende granite with lesser granodiorite and quartz diorite. Fine- to medium-grained, hypautomorphic granular texture. Major igneous minerals are quartz, K-feldspar, plagioclase, hornblende, and biotite. Locally altered. Locally fractured and granulated. Plagioclase partially recrystallized to sericite; hornblende and biotite to chlorite.

Unit exposed in an area of approximately 15 km across in the southwest D-1 quadrangle and extends southward and westward into the Mount Hayes C-6 and Healy C-1 and D-1 quadrangles. Intrudes and contains inclusions of fine-grained, schistose metavolcanic rocks and metasedimentary rocks (jcv) of the Jarvis Creek Glacier subterrane; locally intruded by andesite and granite dikes up to 1 m wide.

A Late Cretaceous or early Tertiary age inferred from intrusion into rocks of the Jarvis Creek Glacier subterrane, subsequent to the main phase of the Early to mid-Cretaceous metamorphism. Slight deformation and sericite and chlorite alteration most likely occurred during the waning stages of metamorphism

grmh **Granite of Mount Hayes (early Tertiary or Late Cretaceous)**—Here referred to as granite of Mount Hayes. Chiefly biotite granite with fine- to medium-grained, hypautomorphic granular texture. Major minerals are quartz, plagioclase, K-feldspar, biotite, and minor sphene. Locally altered; plagioclase and K-feldspar partially replaced by sericite. Unit exposed in an area approximately 10 km across in the west-central C-6 quadrangle. Intrudes fine-grained schistose sedimentary rocks and volcanic rocks (hgs) of the Hayes Glacier subterrane. A Late Cretaceous or early Tertiary age indicated by intrusion into the Hayes Glacier subterrane, subsequent to Early to mid-Cretaceous metamorphism

grmr **Granodiorite of Molybdenum Ridge (Late Cretaceous)**—Here referred to as granite of Molybdenum Ridge. Chiefly biotite-hornblende

granodiorite with lesser granite and quartz diorite. Local inclusions of fine-grained metasedimentary rocks (jcs) of Jarvis Creek Glacier subterrane. Medium-grained, hypautomorphic granular texture, locally porphyritic with phenocrysts of plagioclase to 4 mm. Major minerals are plagioclase, K-feldspar, quartz, hornblende, and biotite. Hornblende locally replaced by igneous biotite. Weak local schistosity near contact with unit jcs. Locally fractured and granulated. Local hydrothermal alteration with hornblende and biotite partially replaced by chlorite and plagioclase by white mica. Unit exposed in an irregular body approximately 9 km across. Intrudes and locally faulted against fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane; intruded by granite, rhyolite, dacite, and andesite dikes approximately 1 m wide. A Late Cretaceous age of intrusion indicated from K-Ar biotite and hornblende dates, and U-Pb zircon ages ranging from 84 to 93 Ma (Table 2 of Nokleberg and others (1992), Locality 13)

grgm **Granite of Granite Mountain (Late Cretaceous)**—Here referred to as granite of Granite Mountain. Chiefly biotite-hornblende granite; includes minor quartz diorite. Fine- to medium-grained, hypautomorphic granular texture. Major minerals are quartz, plagioclase, K-feldspar, biotite, and hornblende. Minor minerals are white mica, apatite, sphene, calcite, chlorite, epidote, and opaque minerals. Local hydrothermal alteration; hornblende and biotite partially replaced by chlorite and opaque minerals, and plagioclase by white mica.

Unit forms large, well exposed pluton of approximately 160 km^2 within the C-3, C-4, D-3, and D-4 quadrangles. Bounded by the Granite Mountain fault to the northeast and northwest, and by the Donnelly Dome fault to the southwest. Intrudes fine-grained metasedimentary rocks unit (jcs) of the Jarvis Creek Glacier subterrane to the southeast. Contains small isolated bodies of unit jcs. Intruded by quartz diorite and aplite dikes up to 1 m wide and by a small gabbro stock west of Panoramic Peak in the D-3 quadrangle. Late Cretaceous age of intrusion indicated from a single U-Pb zircon date of 90 Ma (Table 2 of Nokleberg and others (1992), Locality 19)

grma **Granite of Macomb Plateau (Late Cretaceous)**—Here referred to as granite of Macomb Plateau. Chiefly hornblende granite, biotite granite, hornblende-biotite granite, hornblende granodiorite, and minor quartz diorite. Very fine- to medium-grained, hypautomorphic granular texture. Locally porphyritic with phenocrysts of plagioclase and poikilitic K-feldspar up to 8 mm. Poikilitic K-feldspar containing inclusions composed of plagioclase, quartz, and biotite. Major groundmass minerals are quartz, K-feldspar (locally perthitic), plagioclase, biotite, local hornblende partially replaced by biotite and minor sphene, opaque minerals, and clinopyroxene. Quartz diorite exhibits sparse, local compositional layering of hornblende and biotite alternating with quartz and feldspar. Local schistosity defined by alignment of biotite. Local weak to intense planar fracturing, granulation, and alteration with local development of protomylonite. Hornblende and biotite partially replaced by chlorite and minor epidote, plagioclase by sericite and minor calcite and epidote, and K-feldspar by sericite. Locally cut by veins of quartz and calcite.

Unit exposed in numerous outcrops up to 8 km across. Surrounded by glacial deposits, colluvium, and ice within the B-1, C-1, and C-2 quadrangles. Bounded to the north by the Tanana River fault, to the west by the Johnson Glacier fault, and to the south by the West fork and Elting Creek faults. Intrudes metamorphosed pelitic, calcareous, and quartz-feldspar sedimentary rocks (ms) of the Macomb subterrane; intruded by small dikes up to 1 m wide of gabbro, lamprophyre, aplite, and rhyolite. Cretaceous age of intrusion indicated by two Pb-Alpha zircon dates of 90 and 110 Ma (Table 2 of Nokleberg and others (1992), Localities 8, 11

grrc **Granite of Rumble Creek (Late Cretaceous)**—Here referred to as granite of Rumble Creek. Chiefly biotite-hornblende granite and granodiorite. Fine- to medium-grained, hypautomorphic granular texture. Locally porphyritic with phenocrysts of plagioclase and K-feldspar. Major groundmass minerals are quartz, K-feldspar, plagioclase, biotite, and local hornblende. Minor sphene, chlorite, opaque minerals, and white mica. Local hydrothermal alteration. Hornblende and biotite partially replaced by chlorite, plagioclase by calcite and white mica.

Unit exposed in numerous outcrops up to 6 km across. Surrounded by glacial deposits, colluvium, and ice within the north-central A-1 quadrangle. Intrudes metamorphosed volcanic and pelitic sedimentary rocks (jcv) of the Jarvis Creek Glacier subterrane, and metamorphosed volcanic and pelitic sedimentary rocks of the Hayes Glacier subterrane (hgv). Local abundant mafic inclusions along southeast margin. Crosscuts and Mount Gakona fault between Jarvis Creek Glacier subterrane to northeast and Hayes Glacier subterrane to southwest. Late Cretaceous age of intrusion indicated by a K-Ar hornblende age of 89 Ma (Table 2 of Nokleberg and others (1992), Locality 27). If the K-Ar age represents age of granitic intrusion, movement on the Mount Gakona fault ceased by the Late Cretaceous

MAFIC PLUTONIC ROCKS

A suite of mafic plutonic rocks occurs adjacent to the Denali fault in the Windy terrane, and the Hayes Glacier and Jarvis Creek Glacier subterranes of the Yukon-Tanana terrane. Mafic rocks occur as sills, dikes, and plutons of hornblende metagabbro and hornblende metadiorite. Dikes and sills generally up to a few meters wide and several hundred meters long; most too narrow to depict on the geologic map. Dikes and sills mainly fine- to medium-grained; generally sub-concordant to acutely discordant to intense younger schistosity and parallel compositional layering. Common major igneous minerals are hornblende, plagioclase, and minor clinopyroxene, biotite, and quartz.

The mafic dikes and sills are strongly deformed along the younger schistosity, and are partly to totally metamorphosed to lower greenschist facies minerals, mainly chlorite, actinolite, epidote, albite, and sericite. Field relations indicate the mafic dikes and sills are relatively older than Cretaceous granitic rocks which locally crosscut and intrude the mafic dikes and sills. Because of generally intense, low-grade metamorphism,

Argon-based isotopic analyses are unsuitable for determining the age of these mafic plutonic rocks. An attempt to separate zircons from a sample of metagabbro intruding the Windy terrane to the southeast in the northwest Nabesna quadrangle yielded too few zircons for U-Pb isotopic analysis (Nokleberg and others, 1992)

mgb **Gabbro, diorite, metagabbro, metadiorite, metadiabase, and amphibolite (Cretaceous)**—Undifferentiated dikes, sills, and small plutons. Chiefly hornblende metagabbro and metadiabase and minor amphibolite. Variably metamorphosed to greenschist facies and locally schistose.

Metagabbro and metadiabase generally fine- to medium-grained with hypautomorphic granular to diabasic; locally porphyritic. Phenocrysts are plagioclase, hornblende, biotite, and pyroxene up to 2 mm. Major minerals are plagioclase, hornblende, local biotite and minor clinopyroxene, orthopyroxene, quartz, sphene, and opaque minerals. Hornblende and biotite partially replaced by chlorite and epidote, and plagioclase by sericite, calcite, and epidote.

Amphibolite is fine to medium-grained with granoblastic to porphyroblastic containing hornblende porphyroblasts up to 2 mm. Local relict hypautomorphic granular texture. Common major minerals are hornblende and(or) actinolite, and plagioclase and local quartz, biotite, and clinopyroxene. Common minor minerals are chlorite, sphene, white mica, garnet, epidote, calcite, and opaque minerals, and less commonly K-feldspar, tremolite, and vesuvianite. Compositional layering defined by nematoblastic amphibole and biotite alternating with plagioclase and quartz. Hornblende locally replaced by biotite and hornblende, biotite, and garnet variably replaced by chlorite; plagioclase replaced by white mica.

Unit widely distributed adjacent to, and north of the Denali fault. Occurs in stocks and smaller bodies up to 3 km across, and in dikes and sills up to 6 km long and 400 m wide but generally not exceeding 1 m in width.

Dikes locally crosscut schistosity in Windy terrane and in southern Yukon-Tanana terrane that formed during the Early to mid-Cretaceous metamorphism. Dikes also exhibit locally intense lower greenschist facies metamorphism. These relations interpreted syntectonic intrusion in the mid- to Late Cretaceous

gbm **Gabbro of Mount Moffit (Cretaceous?)**—Here referred to as gabbro of Mount Moffit. Fine-to medium-grained, hypautomorphic granular texture. Two dominant lithologies: plagioclase, clinopyroxene and minor biotite; and plagioclase, biotite, local hornblende and minor quartz and K-feldspar. Opaque minerals locally abundant. Strongly zoned and twinned plagioclase phenocrysts to 1.8 mm occur locally. Clinopyroxene partially replaced by igneous biotite locally. Slight, local alteration of biotite to chlorite; and plagioclase to sericite. Unit underlies McGinnis Peak and Mount Moffit in the southwestern C-5 quadrangle, comprising an area approximately 6 km across. Correlative with gabbro, diorite, metagabbro, metadiorite, metadiabase, and amphibolite (mgb)

SOUTHERN YUKON-TANANA TERRANE

The southern Yukon-Tanana terrane is a major block of crystalline rocks that occurs north of the Denali fault (Foster and others, 1987, Nokleberg and others, 1989a). The subterranes of the Yukon-Tanana terrane are interpreted as comprising the tectonically-dismembered remnants of a Devonian and Mississippian continental-margin igneous arc (Nokleberg and Aleinikoff, 1985; Nokleberg and others, 1989a). The upper structural levels, the Hayes Glacier and Jarvis Creek Glacier subterranes, are interpreted as the upper levels of the arc, whereas the lower levels, the Macomb and Lake George subterranes, are interpreted as the deeper levels of the arc. The metasedimentary, metavolcanic, and metaigneous rocks of the southern Yukon-Tanana terrane are multiply metamorphosed and deformed.

The southern Yukon-Tanana terrane is exposed in a major west-northwest trending regional antiform. The Hayes Glacier, Jarvis Creek Glacier, and Macomb subterranes occur on the south limb of the antiform whereas the Lake George subterrane, exhibiting subhorizontal schistosity and compositional layering, occurs near the core of the antiform. Southward, the subterranes occur at successively higher structural levels on the south limb of the antiform; dips steepen progressively to the south, and are near-vertical along the Denali fault.

The structural stacking of these subterranes is significant; stratigraphically higher-level metaigneous rocks occur in structurally higher-level subterranes. For example, metamorphosed deep-level plutonic rocks occur in the Lake George subterrane (Nokleberg and Aleinikoff, 1985; Foster and others, 1987). This subterrane consists of former mesozonal Devonian and Mississippian granitic plutons and Devonian and older wall rocks, now highly deformed and metamorphosed. Metamorphosed hypabyssal Devonian metagranitic rocks occur in the structurally higher Macomb subterrane (Nokleberg and Aleinikoff, 1985). Shallow level, submarine metavolcanic and interlayered metasedimentary rocks occur in the structurally highest Jarvis Creek Glacier and Hayes Glacier subterranes.

These stratigraphic and structural relations suggest that the subterranes of the Yukon-Tanana terrane represent, from north to south, successively higher levels of a single, now highly metamorphosed and deformed Devonian submarine igneous-arc (Nokleberg and Aleinikoff, 1985). Two hypotheses for the origin of the Yukon-Tanana terrane are (Nokleberg and Aleinikoff, 1985): (1) an island-arc, containing a slice of continental crust which contaminated later magmas; or (2) a submerged continental margin arc, with continental detritus being shed into a companion trench and subduction zone system. A modern-day analog for the island arc origin is the New Zealand setting; the analog for the submerged continental margin arc setting is the Aleutian Arc.

Our preferred interpretation is a submerged continental-margin arc (Nokleberg and others, 1989a). Data supporting this are: (1) common lead isotopic studies for feldspar in metaplutonic and metavolcanic rocks indicate a continental component of highly radiogenic lead derived from a continental source, and assimilation of approximately 2.3 Ga-old material

(Aleinikoff and others, 1986, 1987); (2) common lead isotopic studies on sulfide samples from Kuroko-type massive sulfide deposits in the metavolcanic rocks and which also indicate a component of continental, highly radiogenic lead (LeHurray and others, 1985); (3) high initial Sr ratios for augen gneiss and granitic gneiss in the Lake George subterrane, indicating incorporation of crustal material into the granitic magma protolith (Dusel-Bacon and Aleinikoff, 1985; Aleinikoff and others, 1986); and (4) abundant and widespread quartz-detritus-rich sedimentary protoliths containing relict detrital zircons exhibiting U-Pb ages of 2.1 to 2.3 Ga (Aleinikoff and others, 1986, 1987). Common lead isotopic data also indicate a unique origin for the Yukon-Tanana terrane in respect to adjacent units (Aleinikoff and others, 1986, 1987). These data and interpretations also indicate a unique origin for the Yukon-Tanana terrane compared to adjacent terranes (Jones and others, 1987).

A submerged continental-margin arc origin for the Yukon-Tanana terrane differs widely from modern-day igneous arcs, which are almost solely emergent. However, the abundant continentally-derived sediments, and the strong component of continental lead indicate derivation from a major continental source. In addition, the delicate interlayering of metavolcanic and metasedimentary rocks, locally with thin stratiform massive sulfide deposits, indicates widespread submarine volcanism.

LAKE GEORGE SUBTERRANE NORTH OF TANANA RIVER FAULT

The Lake George subterrane (Aleinikoff and Nokleberg, 1985a, b; Nokleberg and Aleinikoff, 1985) occurs in the northeastern part of the quadrangle, and is composed of: (1) poly-deformed, coarse-grained, pelitic metasedimentary rocks consisting of muscovite-quartz-biotite-garnet schist and metaquartzite derived from quartz-rich to clay-rich shale and quartzite (lgs); (2) relatively younger, medium-grained, gneissose granodiorite and diorite (lgr); and (3) still younger, coarse-grained augen gneiss derived from granite and granodiorite (lga). The metasedimentary rocks and metamorphosed plutonic rocks are ductility deformed and regionally metamorphosed at the middle or upper amphibolite facies into mylonitic schist and mylonitic gneiss, and exhibit local retrogression to the lower greenschist facies (Nokleberg and others, 1986a, 1989a).

lga **Augen gneiss and schist (Mississippian)**—Chiefly medium-grained, mylonitic gneiss derived from granite. Major relict igneous minerals are plagioclase, K-feldspar, and biotite. Common metamorphic minerals are white mica, chlorite, hematite, garnet, hornblende, and opaque minerals. Local gneissic segregation of biotite and felsic minerals. Contains abundant K-feldspar augen up to 2 cm long derived from phenocrysts. Plagioclase partially replaced by white mica; hornblende, biotite, and garnet by chlorite.

Unit intensely deformed; exhibits strong schistosity that generally dips gently north or south. Small-scale isoclinal folds occur parallel to schistosity and parallel compositional layering. Metamorphosed at amphibolite facies with local retrogression to lower greenschist facies. Diagnostic amphibolite facies minerals are garnet, biotite, and hornblende. Retrogression to greenschist facies indicated by replacement of hornblende, biotite, and garnet by chlorite, and plagioclase by white mica.

Unit occurs in sparse, widely distributed outcrops up to 3 km across, north of the Tanana River fault in the northeastern C-2 quadrangle and across the D-2 quadrangle. Intrudes pelitic schist and quartzite (lgs) of Lake George subterrane. Intruded by Late Cretaceous and(or) early Tertiary, weakly schistose granitic rocks (grn1, grn2, grn3).

A Devonian or Mississippian age of intrusion inferred from a U-Pb date on zircons of about 360 Ma from metagranite (lgr) of the Lake George subterrane (Table 2 of Nokleberg and others (1992), Locality 4). U-Pb zircon isotopic analysis of orthoaugen gneiss (lga) in the Big Delta quadrangle to the north yields an isotopic age of 333 to 345 Ma (Mississippian) (Aleinikoff and others, 1986). Cretaceous age of metamorphism interpreted from Rb-Sr dates on biotite, K-feldspar, plagioclase, and whole rock of 110 Ma, from unit lgr (Table 2 of Nokleberg and others (1992), locality 4)

lgr **Medium-grained gneissose granitic rocks (Devonian)**—Chiefly metagranite but include some metamorphosed quartz diorite and metagranodiorite. Relict hypautomorphic granular texture. Relict igneous minerals in metagranite of quartz, K-feldspar, plagioclase, biotite, and minor zircon. Metamorphic minerals are chlorite, white mica, epidote-clinozoisite, opaque minerals, and local calcite, garnet, and piedmontite. Major relict minerals in the metamorphosed quartz diorite of quartz, plagioclase, hornblende, biotite, and opaque minerals. Metamorphic minerals are chlorite, epidote-clinozoisite, garnet, and hornblende.

Unit intensely deformed; exhibits strong schistosity defined by segregation of felsic and mafic minerals and by paralleling compositional layering. Variably fractured, granulated, and ductility deformed. Metamorphosed to amphibolite facies. Diagnostic amphibolite facies minerals are biotite, garnet and hornblende. Local retrogression to lower greenschist facies indicated by replacement of biotite and garnet by chlorite; and plagioclase by white mica. Unit occurs in several exposures up to 2 km across, mainly surrounded by Quaternary deposits in the east-central D-1 quadrangle.

U-Pb zircon isotopic analyses of metagranodiorite (lgr) yield an isotopic age of about 360 Ma (Table 2 of Nokleberg and others (1992), locality 4) and indicate intrusion in the Devonian. A Rb-Sr mineral and whole rock isochron analysis of the metagranodiorite indicates regional metamorphism and penetrative deformation of the schistose minerals in this rock at 110 Ma (Table 2 of Nokleberg and others (1992), locality 4) in the Early to mid-Cretaceous

lgs **Pelitic schist and quartzite (Devonian and older)**—Chiefly fine- to medium-grained, poly-deformed, mylonitic, pelitic schists and minor quartzite and calc-schist. Protoliths of quartz-rich shale to clay-rich shale, sandstone, and marl. Structural base not

exposed. Estimated structural thickness of a few thousand meters.

Pelitic schists chiefly garnet-bearing, quartz-white mica-biotite schists and minor white mica-garnet-sillimanite schist, quartz-white mica schist, quartz-andalusite-K-feldspar-biotite schist, and white mica-biotite-staurolite-garnet schist. Calc-schists composed of quartz, chlorite, calcite, and epidote. Minor minerals are sericite, chlorite, epidote, plagioclase, garnet, and opaque minerals. Schistosity parallels compositional layering. In pelitic schists, compositional layering defined by bands and lenses of quartz and feldspar alternating with schistose mica. In calc-schists, compositional layering consists of layers of quartz and minor calcite alternating with layers of schistose chlorite and epidote. Variably strained, fractured, and granulated quartz, plagioclase, and garnet form augen or augen-shaped aggregates up to 1.5 mm. Plagioclase and K-feldspar partially replaced by white mica; biotite by chlorite; garnet by chlorite and white mica and hornblende by chlorite.

Unit intensely deformed; exhibits strong schistosity that dips gently north or south. Small-scale isoclinal folds parallel schistosity and compositional layering in outcrop and thin section. Metamorphosed at middle to upper amphibolite facies and locally retrograded to lower greenschist facies. Diagnostic amphibolite facies minerals are garnet, biotite, andalusite, staurolite, hornblende, and sillimanite. Retrogression to greenschist facies indicated by replacement of hornblende and biotite by chlorite; garnet by chlorite and white mica; and plagioclase by white mica.

Unit occurs in several exposures up to 6 km across in the central D-1 quadrangle. Intruded by augen gneiss and by Late Cretaceous and (or) early Tertiary, weakly schistose granitic rocks (grn 1, grn 2, grn 3) which range in composition from granite to diorite.

Unit protolith older than the Devonian metagranodiorite. To the north in the Big Delta quadrangle, U-Pb zircon analysis of a quartz-feldspar-biotite schist, interpreted as a metatuff layer in metasedimentary rocks of the Lake George subterrane, yields an isotopic age of 365 Ma or Devonian (Aleinikoff and others, 1986)

MACOMB SUBTERRANE SOUTH OF TANANA RIVER FAULT AND NORTH OF ELTING CREEK FAULT

The Macomb subterrane (Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985) occurs south of the Lake George terrane in the eastern part of the quadrangle and is composed of: (1) a unit of older, poly-deformed, medium-grained pelitic schist, calc-schist, and quartz-feldspar-biotite schist of Devonian or older age (ms) derived from shale, marl, and sandstone and (2) a unit of relatively younger, shallow-level, fine- to medium-grained gneissose granite, granodiorite, quartz diorite, and diorite (mg) of Devonian age. Both units ductility deformed and regionally metamorphosed at epidote-amphibolite facies to upper greenschist facies into mylonitic schist (Nokleberg and others, 1986a). The subterrane differs from the structurally subjacent Lake George subterrane to the north in possessing: (1) relatively abundant Devonian hypabyssal metagranitic rocks; (2) abundant calcareous metasedimentary rocks; (3) a lower metamorphic grade; (4) a finer metamorphic grain size; and (5) a more intensely-developed metamorphic fabric.

mg **Medium-grained granitic gneiss (Devonian)**—Chiefly fine- to medium-grained mylonitic gneiss derived from granite, granodiorite, and quartz diorite. Includes minor augen gneiss derived from granite to diorite. Textures vary from protomylonite to mylonitic schist. Relict hypautomorphic granular texture. Porphyroclasts of plagioclase and local K-feldspar, up to 5 mm across, in a fine-grained, variably granulated and recrystallized matrix consisting predominantly of quartz, plagioclase, and locally K-feldspar, and minor schistose biotite and white mica. Relict igneous minerals are plagioclase, K-feldspar (locally perthite), biotite, local hornblende, and sphene. Common metamorphic minerals are biotite, white mica, chlorite, carbonate, garnet, hornblende, and opaque minerals, and less commonly, zoisite, staurolite, clinopyroxene, and allanite. Local poikiloblastic plagioclase includes variable amounts of biotite, epidote, quartz, sphene, garnet, and clinopyroxene. Biotite locally includes quartz and epidote and garnet locally includes epidote. Plagioclase partially replaced by sericite, calcite, and epidote; hornblende by chlorite and epidote; biotite by chlorite and hematite; garnet by biotite and chlorite. Local augen gneiss composed of fine-grained, quartzofeldspathic and biotite-hornblende-rich bands with augen, up to 2 mm long, of variably granulated quartz and feldspar.

Intensely deformed exhibiting strong schistosity. Schistosity and parallel compositional layering dip moderately southwest and strike northwest, generally parallel to the Elting Creek fault. Unit forms northwest-trending anticline with metamorphosed pelitic, calcareous, and quartz-feldspar sedimentary rocks (ms) of the Macomb subterrane in the B-1 quadrangle. Minor, small-scale, tightly appressed to isoclinal folds occur in outcrop and thin section scale. Younger asymmetrical folds generally south- or southeast-verging; formed in older schistosity and compositional layering. Irregular contacts and locally abundant dikes indicate shallow intrusion.

Unit metamorphosed at epidote-amphibolite to local amphibolite facies. Diagnostic epidote-amphibolite facies minerals are epidote-clinozoisite, biotite, and garnet. Diagnostic amphibolite facies minerals are staurolite and clinopyroxene. Local retrogressive metamorphism to lower greenschist facies indicated by replacement of biotite, hornblende, and garnet by chlorite. Unit occurs in the B-1 quadrangle in several stocks up to 6 km across, northeast of the Elting Creek fault. Intrudes unit of metamorphosed pelitic, calcareous, and quartz-feldspar sedimentary rocks (ms).

U-Pb zircon isotopic analyses of samples of metagranodiorite and metagranite yield isotopic ages of about 372 Ma (Table 2 of Nokleberg and others (1992), localities 7, 10), and indicate intrusion in the Devonian. A Rb-Sr mineral isochron isotopic analysis of the metagranodiorite with a U-Pb zircon age of 372 Ma indicates regional metamorphism and penetrative deformation of the schistose minerals in this rock at

102 Ma (Table 2 of Nokleberg and others (1992), locality 10) (Nokleberg and others, 1986a)

ms **Metamorphosed pelitic, calcareous, and quartz-feldspar sedimentary rocks (Devonian or older)**—Chiefly fine-grained, mylonitic, metasedimentary schists. Chiefly quartz-mica schist with lesser calc-schist. Protoliths mainly sandstone, siltstone, and marl. Estimated structural thickness of a few thousand meters.

Quartz-mica schists consist of garnet-bearing quartz-white mica schist, garnet-bearing quartz-biotite-white mica schist, quartz-biotite schist, quartz-plagioclase-biotite-andalusite-white mica schist, quartz-white mica-biotite-andalusite-cordierite-sillimanite schist, and minor quartzite. Minor minerals are graphite, chlorite, epidote, calcite, K-feldspar, tourmaline, apatite, zircon, and rarely hornblende and staurolite. Generally consists of fine-grained schistose mica in granular quartz. Local compositional layering parallels schistosity. Garnet porphyroblasts up to 8 mm across, averaging 1-2 mm, and plagioclase porphyroblasts up to 2 mm. Local helicitic garnet contains biotite, quartz, carbonate, and epidote inclusions. Andalusite poikiloblasts include biotite, and myrmekitic intergrowths in andalusite-sillimanite-bearing schist. Quartzite includes sparse, schistose mica, plagioclase, hematite, and opaque minerals. Local older schistosity oriented 45-60 degrees from more prominent younger schistosity. Weak to locally intense granulation and fracturing of quartz and feldspar. Plagioclase partially replaced by sericite and calcite; biotite by chlorite; garnet by chlorite, biotite, and white mica; andalusite by white mica.

Calc-schists consist of fine-grained tremolite-quartz-clinozoisite schist and quartz-calcite schist. Tremolite-quartz-clinozoisite schist contains dimensionally aligned tremolite in granular quartz and clinozoisite. Minor minerals are chlorite, sphene, biotite, clinopyroxene, and opaque minerals. Quartz-calcite schist composed of crude to well defined layers of granular quartz, calcite, and locally epidote-clinozoisite.

Unit intensely deformed; exhibits strong schistosity. Schistosity and parallel compositional layering dip moderately southwest and strike northwest, generally parallel to the Elting Creek fault. In the B-1 quadrangle, this unit forms the southwest limb of a northwest trending anticline. Minor small-scale, tightly appressed- to isoclinal folds occur in outcrop and thin section scale. Younger asymmetrical folds mainly south- or southeast-verging; formed in older schistosity and compositional layering.

Unit metamorphosed mainly at epidote-amphibolite facies, and locally to amphibolite facies. Diagnostic epidote-amphibolite facies minerals are epidote-clinozoisite, biotite, garnet, andalusite, cordierite, and staurolite. Diagnostic local amphibolite facies minerals are hornblende, sillimanite, and clinopyroxene. Local retrogressive metamorphism to lower greenschist facies indicated by replacement of biotite by chlorite; garnet by chlorite and white mica; and andalusite by white mica.

Unit occurs in B-1, B-2 and C-2 quadrangles. Bounded by Jarvis Creek subterrane to the southwest along the Elting Creek fault and to the west along the Johnson Glacier fault. Intruded by medium-grained granitic gneiss (mg), and by non-metamorphosed granitic rocks of the Macomb Plateau pluton (grma). Age of the protolith older than the Devonian metagranitic rocks

JARVIS CREEK GLACIER SUBTERRANE SOUTH OF ELTING CREEK FAULT AND NORTH OF HINES CREEK AND MOUNT GAKONA FAULTS

The Jarvis Creek Glacier subterrane (Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle, south of the Macomb subterrane. The Jarvis Creek Glacier subterrane consists of fine-grained, poly-deformed schists derived from Devonian metavolcanic and metagranitic rocks and Devonian and older sedimentary rocks. The subterrane differs from the structurally subjacent Macomb subterrane to the north in possessing: (1) relatively few Devonian metagranitic rocks; (2) abundant Devonian metavolcanic rocks; (3) a lower metamorphic grade; (4) a finer metamorphic grain size; and (5) a more intensely-developed metamorphic fabric.

This subterrane is subdivided into three units: (1) a metasedimentary rocks unit (jcs) composed chiefly of fine-grained metasedimentary rocks and very minor metavolcanic rocks; (2) a metavolcanic rocks unit (jcv) composed chiefly of fine-grained metavolcanic rocks and moderate amounts of fine-grained metasedimentary rocks; and (3) a small unit of gneissose granodiorite and diorite and subordinate augen gneiss (jcg) in the north-central part of the quadrangle.

The metasedimentary and metavolcanic rocks are almost totally recrystallized and are composed of varying proportions of pelitic schist, quartzite, calc-schist, quartz-feldspar schist, and marble. Protoliths of shale, quartz sandstone, marl, sandstone, volcanic graywacke, and limestone. The metavolcanic rocks consist of varying proportions of abundant metaandesite and metamorphosed quartz keratophyre, less abundant metadacite and metabasalt, and very minor metarhyodacite.

The metasedimentary rock and metavolcanic rock units are ductility deformed and regionally metamorphosed at greenschist facies into mylonitic schist or local phyllonite (Nokleberg and others, 1986a). Locally, large areas of upper greenschist facies and lower amphibolite facies metamorphism occur in the northern part of the Jarvis Creek Glacier subterrane in the area south of Granite Mountain and southeast of Donnelly Dome. The higher-grade metamorphic minerals to the north are progressively replaced by lower-grade metamorphic minerals to the south

jcg **Fine- to medium-grained gneissose granitic rocks (Devonian)**—Chiefly schistose metagranodiorite, and augen gneiss derived from granite. Intensely deformed exhibiting strong schistosity.

Metagranodiorite contains K-feldspar augen and relict phenocrysts up to 2.0 cm across in a fine-grained matrix of schistose biotite and granular and fractured quartz, K-feldspar, plagioclase, hornblende, and opaque minerals. Hornblende largely replaced by biotite and

chlorite. Biotite partially replaced by chlorite; plagioclase by white mica and minor epidote.

Augen gneiss contains K-feldspar augen and relict phenocrysts up to 1.5 cm in a fine-grained matrix of schistose biotite with granular and fractured quartz, K-feldspar, plagioclase, hornblende, and opaque minerals. Variably developed segregations of quartz, feldspar, and biotite. Plagioclase and K-feldspar partially replaced by white mica and minor epidote and calcite. Hornblende and biotite partially replaced by chlorite. Variably metamorphosed at lower amphibolite to lower greenschist facies. Diagnostic metamorphic minerals are hornblende in amphibolite facies rocks and chlorite and epidote in lower greenschist facies rocks.

Unit mainly underlies Donnelly Dome in southern D-4 quadrangle. Also occurs in several stocks up to 5 km across south of the Donnelly Dome fault in the southern D-4 and northern C-4 quadrangles. Unit intrudes fine-grained metasedimentary rocks (jcs) and fine-grained schistose metavolcanic rocks and metasedimentary rocks (jcv)

U-Pb zircon isotopic analysis of a sample of a small body of augen gneiss intruding unit (jcv), in the area southeast of Donnelly Dome, yields an age of 372 Ma (Table 2 of Nokleberg and others (1992), locality 17), and indicates intrusion in the Devonian, contemporaneously with extrusion of the metavolcanic rocks

jcv **Fine-grained schistose metavolcanic rocks and metasedimentary rocks (Devonian)**—Chiefly fine-grained, mylonitic, metavolcanic rocks interlayered with lesser metasedimentary rocks. Metavolcanic rocks consist chiefly of metamorphosed quartz keratophyre, metadacite, and metaandesite with lesser metarhyodacite and metabasalt derived from fine-grained tuffs and flows. Metasedimentary rocks chiefly quartz-mica schists and some calc-schists, marble, skarn, and quartzite. Protoliths for metasedimentary rocks mainly pelite, quartz sandstone, siltstone, marl, and limestone. Metavolcanic rocks occur in layers from about 0.5 to a few meters thick; interlayered with thin- to thick layers of metasedimentary rocks. Estimated structural thickness of a few thousand meters

Unit metamorphosed from lower greenschist to lower amphibolite facies. Differentiated from adjacent schists of the Hayes Glacier subterrane to the south by a greater abundance of metavolcanic rocks, much sparser graphite-rich metasedimentary rocks, a coarser metamorphic mineral grain size, and a higher grade of metamorphism.

Metavolcanic rocks generally characterized by relict microporphyritic texture containing euhedral to subhedral, twinned, and often zoned plagioclase phenocrysts up to 4 mm long in a fine-grained groundmass of quartz, plagioclase, and schistose mica. Common poikilitic and clean, relict plagioclase phenocrysts. Relict quartz and K-feldspar phenocrysts occur locally. Local resorbed outlines of quartz and feldspar phenocrysts. Common metamorphic minerals are quartz, plagioclase, white mica, chlorite, epidote-clinozoisite, calcite, and opaque minerals. Sparse metabasalts composed mainly of actinolite and locally epidote and calcite. Minor metamorphic minerals are sericite, chlorite, sphene, biotite, garnet, hornblende, and opaque minerals. Compositional layering parallels schistosity; defined by bands and lenses of granoblastic quartz and feldspar alternating with schistose mica. Fracturing and granulation of relict phenocrysts common with development of augen and augen-shaped aggregates of quartz and feldspar in finer grained recrystallized matrix. Plagioclase and K-feldspar partially replaced by sericite; biotite, actinolite, and hornblende by chlorite.

Quartz-mica schists consist of: quartz-white mica schist, graphite-quartz-white mica schist, quartz-plagioclase-white mica-chlorite schist, quartz-white mica-chlorite-plagioclase schist, and calcite-chlorite-quartz schist. Minor minerals are calcite, plagioclase, chlorite, graphite and other opaque minerals, and sparse garnet, hornblende, apatite, sphene, cordierite, zircon, and tourmaline. Generally fine-grained. Sparse porphyroclasts of quartz and feldspar to 2 mm. Sparse, local, relict clastic grains of quartz and feldspar. Compositional layering parallels schistosity; generally defined by layers of granoblastic quartz and feldspar alternating with micaceous layers. Variably distorted, fractured, and granulated quartz and feldspar form augen or augen-shaped aggregates that accompany bent mica. Plagioclase partially replaced by white mica and calcite; biotite by chlorite.

Calc-schists and marbles consist of quartz-white mica-calcite schist, quartz-calcite schist, quartz-plagioclase-white mica-calcite schist, quartz-epidote-clinozoisite schist, quartz-white mica-epidote schist, epidote-plagioclase-actinolite schist, hornblende-biotite-calcite schist, hornblende-plagioclase-calcite schist, marble, and biotite marble. Minor minerals are K-feldspar, biotite, graphite, and opaque minerals. Skarns composed of variable proportions of major epidote, garnet, chlorite, calcite, and locally clinopyroxene, actinolite, and wollastonite. Calc-schists and marbles generally fine-grained with sparse porphyroclasts of quartz and plagioclase to 6 mm. Compositional layering generally defined by granoblastic layers of quartz and (or) plagioclase alternating with calcite and combinations of schistose mica, epidote-clinozoisite, amphibole, and opaque minerals. Quartz and calcite grains locally elongate parallel to schistosity and compositional layering. Plagioclase partially replaced by sericite and calcite; hornblende, actinolite, and biotite by chlorite.

Quartzites generally composed of sparse flakes to stringers and bands of schistose white mica and (or) biotite and chlorite in fine-grained granoblastic quartz. Common weak to strong alignment of elongate quartz grains parallel to schistosity. Calcite occurs locally as porphyroclasts and in bands and patches. Common local fracturing and granulation. Minor minerals are graphite, plagioclase, K-feldspar, and opaque minerals.

Unit intensely deformed; exhibits strong schistosity. Schistosity and parallel compositional layering dips gently to moderately north or south locally defining broad antiforms and synforms. In outcrop and thin section, compositional layering and schistosity are generally folded into moderately appressed to tight isoclinal folds with axial planes parallel to the schistosity. Unit occurs mainly structurally above fine-grained metasedimentary rocks (jcs). Folds are formed in an older schistosity and subparallel compositional layering. Later folds are generally asymmetrical with south to southwest

vergence and are superposed on older more tightly appressed folds. In the eastern part of the quadrangle, unit cut by the left lateral, northeast trending West Fork and Robertson River faults. Ductile deformation adjacent to major faults has formed locally abundant phyllonites and blastomylonites.

Unit variably metamorphosed from lower amphibolite to lower greenschist facies. Upper greenschist to lower amphibolite facies minerals are biotite, garnet, cordierite, and hornblende. Lower to middle greenschist facies metamorphic minerals are actinolite, chlorite, graphite, white mica, epidote-clinozoisite, and calcite. Areal retrogressive metamorphism from lower amphibolite to lower greenschist facies indicated by successive replacement of hornblende and biotite by chlorite, and plagioclase by white mica from north to south.

Unit occurs in elongate northwest-trending wedge, approximately 50 km long and up to 5 km wide, located principally between the Trident Glacier fault to the northeast and the Hines Creek fault to the southwest in the western part of the quadrangle. Also occurs along the eastern quadrangle boundary in a block approximately 30 km across, bounded by the West Fork fault to the northwest, the Elting Creek fault to the northeast, and the Mount Gakona fault to the southwest. In contact with the fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane to the north, and with Hayes Glacier subterrane to the south. Intruded by the granodiorite of Molybdenum Ridge (grmr) and by numerous smaller stocks, dikes and sills from granitic to gabbroic composition.

U-Pb zircon isotopic analysis of samples of metavolcanic rocks (jcv), locally interlayered with metasedimentary rocks, yield ages of 364, 372, and about 375 Ma (Table 2 of Nokleberg and others (1992), localities 12, 15, 28), and are interpreted to indicate extrusion in the Devonian

jcs **Fine-grained metasedimentary rocks (Devonian and older)**—Chiefly fine-grained, mylonitic metasedimentary rocks. Unit comprised approximately of 65% quartz-mica schist; 15% quartzite, and 5% each of chlorite-white mica schist, quartz-biotite schist, calc-schist, and marble. Protoliths of mainly pelite, quartz sandstone, graywacke, marl, and limestone. Intense deformation and recrystallization has obliterated most relict minerals and textures. Estimated structural thickness of a few thousand meters.

Quartz-mica schists consist of (in descending order of abundance): quartz-white mica schist; quartz-white mica-chlorite schist; quartz-white mica calcite schist; quartz-white mica calcite-chlorite schist; quartz-white mica-garnet-chlorite schist; and garnet-white mica quartz schist. Common minor minerals are epidote, garnet, K-feldspar, graphite, sphene, and rarely tourmaline and cordierite. Fine-grained. Porphyroblasts chiefly of quartz, plagioclase, garnet, and K-feldspar, and average 1 mm across, rarely exceeding 3 mm across. Rare relict clastic quartz and plagioclase grains. Compositional layering generally parallel to schistosity; defined principally by alternating bands and lenses of schistose micas and granular quartz and feldspar. Variably distorted, fractured, and granulated quartz and plagioclase form augen or augen-shaped aggregates that accompany bent mica and local helicitic garnet. Local. blastomylonites. Plagioclase and andalusite locally replaced by white mica, and biotite by chlorite.

Quartzite grain size averages approximately 1 mm with occasional porphyroclasts up to 2 mm. No relict sedimentary textures. Common major minerals are quartz, biotite, white mica, calcite and minor plagioclase, K-feldspar, chlorite, opaque minerals epidote. Common minor minerals are opaque minerals, K-feldspar, calcite and white mica, and rarely hornblende. Orientation of elongate quartz grains, lenses of calcite, and(or) opaque minerals, and local crystallographic orientation of quartz parallels schistosity. Variable fracturing and granulation of mineral grains common. Plagioclase partially recrystallized to white mica and calcite.

Chlorite-white mica schists very-fine to fine-grained. Local plagioclase porphyroblasts up to 1 mm. Locally occurring major minerals are quartz, epidote-clinozoisite, plagioclase, K-feldspar, with lesser calcite and opaque minerals. Minor minerals are biotite and garnet. Local compositional layering parallels schistosity; defined by bands of quartz alternating with white mica and chlorite.

Quartz-biotite schists mainly fine-grained. Plagioclase porphyroblasts up to 1.5 mm. Local major minerals are plagioclase, chlorite, K-feldspar, and epidote, and minor white mica, garnet, calcite, sphene, and garnet. Compositional layering parallels schistosity; defined by alternating bands of biotite and chlorite or white mica with bands of quartz and plagioclase. Helicitic garnet occurs locally. Biotite partially recrystallized to chlorite; garnet to biotite and chlorite.

Calc-schists and marbles consist of calcite-chlorite schist, plagioclase-quartz-epidote schist, marble, and quartz-rich marble. Minor minerals are white mica, graphite, opaque minerals, and garnet. Fine-grained. Porphyroblasts principally of quartz, plagioclase, and garnet up to 5 mm and average approximately 1 mm. Rare relict clastic quartz grains. In calc-schists, compositional layering parallels schistosity; generally defined by alternations of quartz and (or) chlorite with variable combinations of plagioclase, calcite or epidote. Compositional layering in marbles defined by calcite alternating with quartz-rich, and(or) chlorite-rich layers. Common fracturing and granulation of mineral grains. Plagioclase locally replaced by white mica and calcite; garnet by chlorite.

Unit intensely deformed; exhibits strong schistosity. Schistosity and parallel compositional layering dip gently to moderately north or south, locally defining broad antiforms and synforms. Unit occurs mainly structurally beneath fine-grained schistose metavolcanic rocks and metasedimentary rocks (jcv). Broad, major antiform occurs in B-2, B-3, and B-4 quadrangles, subparallel to the Denali fault. Major companion synform occurs to north in C-3 and C-4 quadrangles, and trends east-west. Towards the south, near the Hines Creek and Denali faults, schistosity and compositional layering dip moderately to steeply south and strikes west-northwest parallel to the faults. In outcrop and thin section, compositional layering and schistosity generally folded into moderately appressed to tight isoclinal folds with axial

planes parallel to the schistosity. Folds formed in an older schistosity and compositional layering rather than bedding. Minor folds generally asymmetrical with south, or southwest vergence. In the central and eastern parts of the quadrangle, unit cut by the left lateral, northeast trending Johnson Glacier, West Fork, and Robertson River faults. Ductile deformation has formed locally abundant phyllonites and blastomylonites adjacent to major faults.

Unit metamorphosed from local lower amphibolite facies tolower greenschist facies. Diagnostic lower to middle greenschist facies metamorphic minerals are actinolite, chlorite, white mica, epidote-clinozoisite, and calcite. Diagnostic upper greenschist to lower amphibolite facies minerals are biotite, garnet, andalusite, cordierite, and hornblende. Areal retrogressive metamorphism ranges from lower amphibolite facies in the north to lower greenschist facies to the south; defined by successive replacement of hornblende, biotite, and garnet to chlorite, and plagioclase to white mica.

Unit well exposed north of Denali fault, particularly in B-1 to B-6 and C-2 to C-4 quadrangles. Faulted against Hayes Glacier subterrane along the Mount Gakona fault in the central and eastern parts of the quadrangle. Faulted against Aurora Peak terrane along the Hines Creek fault in B-4 and B-5 quadrangles, and against Wrangellia terrane along the Denali fault in B-4 quadrangle. Intruded, from west to east, by granite of Buchanan Creek (grbc), granodiorite of Molybdenum Ridge (grmr), granite of Granite Mountain (grgm), granite of Gerstle River (grgr), granite of Macomb Plateau (grma), granite of Rumble Creek (grrc), and by numerous dikes, sills, and small plutons ranging from granitic to gabbroic in composition.

On strike to the west in the Healy quadrangle, metasedimentary rocks correlated with the fine-grained metasedimentary rocks (jcs) of the Jarvis Creek Glacier subterrane contain Devonian to Mississippian conodonts (Sherwood and Craddock, 1979; Csejtey and others, 1992). U-Pb isotopic analysis of clastic zircons in quartzites in unit (jcs) indicates the protolith was derived in part from an Early Proterozoic source rock with radiometric sample ages of 2.0 to 2.3 Ga (Table 2 of Nokleberg and others (1992), localities 22, 23) (Aleinikoff and Nokleberg, 1985a; Aleinikoff and others, 1987).

Isotopic analyses of the schistose minerals in units (jcs) and (jcv) indicate that regional metamorphism and associated penetrative deformation occurred in the Early to mid-Cretaceous. K-Ar isotopic analysis of white mica yields isotopic ages of 106, 107, 115, and 118 Ma (Table 2 of Nokleberg and others (1992), localities 14, 16, 18, 20). Isotopic ages interpreted as the age of metamorphism, rather than as the age of later cooling, because higher-temperature isotopic systems for higher-grade rocks, in the deepest structural levels of the Yukon-Tanana terrane to the north, yield the same Early to mid-Cretaceous ages (Nokleberg and others, 1989a)

HAYES GLACIER SUBTERRANE SOUTH OF HINES CREEK AND MOUNT GAKONA FAULTS AND NORTH OF NENANA GLACIER AND DENALI FAULT

The Hayes Glacier subterrane (Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985) occurs across the east- and west-central parts of the quadrangle, south of the Jarvis Creek Glacier subterrane. The Hayes Glacier subterrane bounded to north by the Jarvis Creek Glacier subterrane along the Mount Gakona fault, and to the south by Wrangellia terrane along the Denali fault, and by Aurora Peak terrane along the Nenana Glacier fault. The Hayes Glacier subterrane consists of fine-grained, poly-deformed phyllite derived from Devonian or older sedimentary and volcanic rocks. The Hayes Glacier subterrane can be subdivided into two major units: (1) a metavolcanic rocks unit (hgv) with moderate to substantial amounts of metasedimentary rocks; and (2) a metasedimentary rocks unit (hgs) with sparse metavolcanic rocks. Rocks in both units are almost totally recrystallized with few to no relict minerals. The subterrane differs from the structurally subjacent Jarvis Creek Glacier subterrane to the north in possessing: (1) no Devonian metagranitic rocks; (2) a greater abundance of graphitic-rich metasedimentary rocks and fewer metavolcanic rocks; (3) a lower metamorphic grade; (4) a finer metamorphic grain size; and (5) a more intensely-developed metamorphic fabric with abundant mylonitic phyllites.

In the eastern part of the quadrangle, the metasedimentary rocks unit consists of varying proportions of pelitic phyllite, quartz-rich phyllite, quartz-feldspar phyllite, and minor calc-phyllite and marble. Protoliths are shale, chert or, less likely, quartz siltstone, volcanic graywacke, marl, and limestone. In the western part of the quadrangle, the metasedimentary rocks unit consists predominantly of poly-deformed black to dark gray pelitic schist, quartz-mica schist, and minor quartzite and calc-schist. Protoliths are shale, quartz siltstone and sandstone, and marble of pre-mid-Cretaceous age. The metavolcanic rocks consist of varying proportions of abundant metaandesite and metamorphosed quartz keratophyre, and sparse metadacite and metabasalt. The metasedimentary rocks and metavolcanic rocks units are ductility deformed and regionally metamorphosed at lower to middle greenschist facies into phyllonite and blastomylonite (Nokleberg and others, 1986a)

hgv **Fine-grained schistose volcanic rocks and phyllite (Devonian)**—Chiefly fine-grained, metavolcanic and metasedimentary phyllonites and blastomylonites. Metavolcanic rocks chiefly metamorphosed quartz keratophyre and metaandesite, and sparse metadacite and metabasalt. Estimated structural thickness of a few thousand meters.

Metamorphosed quartz keratophyre composed of relict phenocrysts, up to 3.5 mm and averaging about 1.5 mm, of quartz and plagioclase in a groundmass of very fine-grained granular quartz, feldspar, abundant schistose sericite, and local, K-feldspar and sparse flakes of biotite. Intensely deformed into blastomylonite. Quartz-free metavolcanic rocks, chiefly metaandesite and metabasalt, composed of variable amounts of chlorite, calcite, epidote,

actinolite, biotite, and plagioclase. Local relict plagioclase phenocrysts; commonly fractured and locally recrystallized to augen-shaped aggregates. Intensely deformed into phyllonite. Plagioclase and K-feldspar partially replaced by white mica; biotite by chlorite.

Metasedimentary rocks chiefly quartz-mica phyllonite, quartzite, quartz-calc phyllonite, and marble. Protoliths for the metasedimentary rocks of siltstone, sandstone, graywacke, marl, and limestone.

Quartz-mica phyllonites (and lesser blastomylonites) consist predominantly of quartz-white mica phyllonite with lesser quartz biotite phyllonite, quartz-biotite-K-feldspar phyllonite, and white mica-biotite-quartz-graphite phyllonite. Common minor minerals are plagioclase, chlorite, calcite, epidote, hematite, andalusite, graphite, chlorite, and opaque minerals. Generally fine-grained. Sparse to locally abundant relict clasts of quartz and minor plagioclase, up to 3 mm long, in matrix of fine-grained quartz and schistose white mica and locally biotite. Patches of calcite occur locally. Compositional layering, preferred orientation of elongate quartz grains, and grain-size segregation parallel schistosity. Compositional layering defined by layers of quartz alternating with layers of mica and locally layers of K-feldspar, graphite, and rarely andalusite. Local relict rounded quartz pebbles. Local intense granulation and fracturing of quartz and plagioclase. Plagioclase partially replaced by calcite and white mica. Biotite partially replaced by chlorite.

Quartz-calc-phyllonites (and lesser blastomylonites) consist of quartz-calcite phyllonite, calcite-quartz phyllonite, quartz-calcite-chlorite phyllonite, quartz-calcite-white mica phyllonite, quartz-chlorite-calcite phyllonite, and quartz-graphite-carbonate phyllonite. Minor minerals are plagioclase, biotite, epidote-clinozoisite, actinolite, and opaque minerals. Compositional layering parallels schistosity; defined by layers of quartz and plagioclase alternating with variable combinations of calcite, opaque minerals, and schistose chlorite and white mica. Local irregular calcite patches. Thin layers of quartz and sparse plagioclase, opaque minerals, and schistose white mica in marbles. Common intense granulation and fracturing of quartz and plagioclase. Plagioclase partially replaced by calcite and white mica.

Unit intensely recrystallized and ductility deformed. Metamorphosed at lower to middle greenschist facies. Lower greenschist facies rocks occur mainly in the eastern part of the quadrangle. Diagnostic metamorphic minerals are white mica, chlorite, graphite, epidote-clinozoisite, actinolite, and calcite. Middle greenschist facies rocks occur mainly in the western part of the quadrangle with diagnostic biotite. Schistosity dips moderately to steeply south and strikes east-west to northwest, generally parallel to the Denali and Hines Creek faults. Remnant, small-scale, isoclinal folds, with axial planes parallel to schistosity, formed in an older relict schistosity. Most folds obliterated by intense deformation along younger schistosity.

Unit occurs in fault-bounded wedges in east- and west-central parts of quadrangle. Intruded by gabbro of Mount Moffit (gbm), and smaller gabbroic stocks, dikes, and sills. U-Pb zircon isotopic analysis of samples of metavolcanic rocks (hgv), interlayered and metasedimentary rocks, yield ages of 375 Ma (Table 2 of Nokleberg and others (1992), localities 32, 34, 36); interpreted as Devonian extrusion

hgs **Fine-grained schistose sedimentary rocks and volcanic rocks (Devonian and older)**—Chiefly fine-grained, pale-yellow, pale-green, and graphitic black metasedimentary phyllonite and blastomylonite with minor metavolcanic blastomylonite. Estimated structural thickness of a few thousand meters. Predominant lithologies of quartz-mica phyllonite, quartz-calc-phyllonite, quartzite, marble, and metavolcanic blastomylonite. Protoliths of siltstone, shale, marl, limestone, quartz-rich volcanic rocks, and volcanic graywacke. Intense recrystallization and ductile deformation has obliterated most relict minerals and textures. Local relict meter-scale bedding. Metamorphosed at lower to middle greenschist facies.

Quartz-mica phyllonites composed of subangular to subrounded quartz clasts in a fine-grained matrix of granular quartz and schistose white mica, and locally biotite. Minor minerals are graphite, plagioclase, chlorite, calcite, hematite, opaque minerals, and rare andalusite. Local, millimeter-scale, quartz-rich, mica-rich, and calcite-rich, layers parallel schistosity. Relict subrounded to subangular clastic quartz grains, up to 2 mm. Local fine to coarse bands of graphite along schistosity.

Quartz-calc-phyllonites composed mainly of sparse to abundant relict clasts of quartz and calcite up to 2 mm in matrix very fine-grained quartz, schistose sericite, and abundant calcite. Local fine, graphite-rich layers. Minor local feldspar. Marble granoblastic to schistose and composed of minor quartz, white mica, and graphite.

Quartzite, includes local quartz-mica phyllonite. Compositional layering consists of variably proportioned bands of quartz and white mica, and minor biotite, chlorite, and calcite.

Sparse, metavolcanic blastomylonites composed mainly of relict phenocrysts of plagioclase and lesser quartz and K-feldspar, up to 3 mm long, variably fractured and granulated in a matrix of fine granular quartz and schistose sericite. Minor minerals are calcite, chlorite, and opaque minerals. Resorbed outlines of quartz and plagioclase locally preserved. Plagioclase partially replaced by sericite.

Unit intensely deformed; exhibits strong schistosity. Schistosity dips moderately to steeply south and strikes east-west to northwest, generally parallel to the Denali and Hines Creek faults. Remnant small-scale isoclinal folds in outcrop and thin section with axial planes parallel to schistosity formed in an older, less apparent schistosity. Most folds obliterated by intense deformation along younger schistosity.

Lower greenschist facies metamorphism occurs in the eastern part of the quadrangle. Diagnostic lower greenschist facies minerals are white mica, chlorite, graphite, and calcite. Middle greenschist facies metamorphism occurs in the western part of the quadrangle. Diagnostic biotite.

Unit occurs in fault-bounded wedges in east- and west-central parts of quadrangle. Intruded by the granite of Mount Hayes (grmh), gabbro of Mount Moffit (gbm),

and by smaller bodies, dikes, and sills of granite, gabbro, and lamprophyre. Age of the metasedimentary rocks interpreted as Devonian and older because these rocks locally interlayered with Devonian metavolcanic rocks as determined by U-Pb zircon isotopic analysis. No isotopic data available on the age of metamorphism of metasedimentary and metavolcanic rocks of the Hayes Glacier subterrane. Unit contains penetrative fabric similar to the Jarvis Creek Glacier subterrane, suggesting a similar, Early to mid-Cretaceous age of metamorphism

AURORA PEAK TERRANE SOUTH OF NENANA GLACIER FAULT AND NORTH OF DENALI FAULT

The Aurora Peak terrane (Nokleberg and others, 1985) occurs north of the Denali fault in the western part of the quadrangle. The terrane consists of: (1) a relatively older unit of metasedimentary rocks, chiefly fine- to medium-grained and poly-deformed calc-schist, marble, quartzite, and pelitic schist (as); and (2) a relatively younger unit of regionally metamorphosed and penetratively deformed gneissic granitic rocks derived from quartz diorite, granodiorite, granite, and gabbro, and diorite (ag). The protoliths for metasedimentary rocks are marl, quartzite, and shale. The Aurora Peak terrane was twice ductility metamorphosed and deformed, once during an earlier period of upper amphibolite facies metamorphism into mylonitic schist, and later during a period of middle greenschist facies metamorphism into blastomylonite (Nokleberg and others, 1985). The general parallelism of the schistosity in the gneissic granitic rocks with the Denali and Nenana Glacier faults suggests that metamorphism and deformation occurred during faulting.

Like the Maclaren terrane to the south, the Aurora Peak terrane is interpreted as a displaced fragment of the Kluane schist and the Ruby Range batholith that occur northeast of the Denali fault some 400 km to the southeast in the Yukon Territory (Nokleberg and others, 1985). The Aurora Peak terrane is interpreted to have been tectonically transported before transport of the Maclaren terrane because of occurrence of the structural melange of sedimentary and volcanic rocks of the Paleozoic and Cretaceous Windy terrane between the Aurora Peak and Maclaren terranes.

ag **Metamorphosed granitic rocks (Late to mid-Cretaceous)**—Consists chiefly stocks, dikes, and sills of metadiorite and minor metamorphosed quartz diorite, granite, granodiorite, and gabbro. Metadiorite and metamorphosed quartz diorite composed of variable amounts of hornblende, clinopyroxene, quartz, and biotite and lesser orthopyroxene, quartz, calcite, sericite, clinozoisite, sphene, apatite, and hematite. Fine- to medium-grained with relict hypautomorphic granular texture. Variably recrystallized hornblende and plagioclase. Hornblende rims clinopyroxene and opaque minerals. Plagioclase partially replaced by white mica.

Metagranite and metagranodiorite composed of variable amounts of biotite and white mica, and lesser chlorite, epidote, calcite, sericite, sphene, garnet, andalusite, and actinolite. Relict hypautomorphic granular texture. Granodiorite locally contains relict K-feldspar phenocrysts to 7 mm across. Fine- to medium-grained. Plagioclase and K-feldspar variably replaced by sericite and minor epidote; clinopyroxene by biotite and chlorite; biotite by chlorite.

Metagabbro composed of fine-grained, hornblende and plagioclase and minor biotite, clinopyroxene, calcite, chlorite, quartz, white mica, and sphene. Local compositional layering defined by alternating bands of schistose biotite and nematoblastic hornblende. Clinopyroxene partially replaced by hornblende and biotite; plagioclase by white mica.

Unit moderately deformed; exhibits moderate schistosity that dips steeply to vertically and strikes west-northwest. Variably fractured, deformed, and granulated. Metamorphosed to amphibolite facies. Diagnostic amphibolite facies minerals are biotite, garnet, hornblende, and clinopyroxene. Local retrogressive metamorphism indicated by partial replacement of plagioclase and K-feldspar by sericite and epidote; clinopyroxene by biotite and chlorite; and biotite by chlorite.

Unit occurs principally in the southern C-6 quadrangle. Faulted against the Maclaren terrane to the south along the Denali fault and against Hayes Glacier subterrane to the north along the Nenana Glacier fault. Intrudes metamorphosed sedimentary rocks (as) in stocks, dikes, and sills. Intruded by slightly metamorphosed granite dikes approximately 1 m wide.

U-Pb zircon isotopic analysis of a metadiorite yields a Late Cretaceous age of 71 Ma (Table 2 of Nokleberg and others (1992), locality 38). To the west in the east-central Healy quadrangle, ^{40}Ar-^{39}Ar isotopic analysis of hornblende in correlative (meta)granitic rocks yields an age of 106 Ma (Csejtey and others, 1992, locality 33). Dates interpreted as mid- to Late Cretaceous intrusion of metagranitic rocks in Aurora Peak terrane.

Isotopic analyses of schistose biotite and hornblende in metagranitic rocks indicate either very young metamorphism and associated penetrative deformation, and (or) uplift and cooling of the Aurora Peak terrane in the middle Tertiary. K-Ar isotopic analysis of biotite yields isotopic ages of 18.2, 24.0, and 27 Ma (Table 2 of Nokleberg and others (1992), localities 37, 38). K-Ar isotopic analysis of hornblende yields an isotopic age of 36.8 Ma (Table 2 of Nokleberg and others (1992), locality 37). As the Aurora Peak terrane occurs adjacent to the Denali fault, these K-Ar isotopic dates interpreted as the age of uplift and cooling of the Aurora Peak terrane during Cenozoic migration along the Denali fault (Nokleberg and others, 1985, 1989a)

as **Metamorphosed sedimentary rocks (Triassic to Silurian)**—Chiefly fine- to medium-grained, mylonitic, calc-schist, marble, quartz-mica schist, and quartzite. Protoliths of marl, limestone, pelite, and sandstone. Estimated structural thickness of a few thousand meters.

Calc-schist consists predominantly of quartz-calcite schist grading to marble, but includes some chlorite-calcite schist, plagioclase-calcite schist, biotite-quartz-calcite-hornblende schist, and quartz-epidote-biotite-calcite schist. Minor minerals are white mica, K-feldspar, actinolite, wollastonite, tremolite,

and clinopyroxene, garnet, graphite, sphene, zoisite, and opaque minerals. Marble locally contains clinopyroxene and garnet. Compositional layering generally consists of alternating quartz and calcite-rich layers with lesser schistose mica. Quartz, plagioclase, and calcite commonly elongate parallel to schistosity. Variably fractured, granulated, and recrystallized quartz and plagioclase porphyroclasts form augen and augen-shaped aggregates up to 1.5 mm in blastomylonites. Sparse relict clastic quartz grains occur locally. Plagioclase partially replaced by white mica and clinozoisite; clinopyroxene by actinolite and clinozoisite.

Quartz-mica schists consist of quartz-white mica schist, white mica-quartz schist, quartz-biotite schist, chlorite-white mica-quartz schist, and quartz-chlorite-white mica-graphite schist. Minor minerals are plagioclase, graphite, garnet, calcite, biotite, and opaque minerals. Compositional layering defined by alternating quartz and mica-rich layers. Variably distorted, fractured, and granulated quartz and plagioclase commonly form elongate grains parallel to schistosity. Plagioclase partially recrystallized to white mica.

A thin lens of metabasalt occurs near the Hines Creek fault in the B-4 quadrangle and may be part of a local melange formed along the fault. Metabasalt chiefly fine-grained, amygdaloidal and porphyritic. Relict plagioclase phenocrysts up to 3 mm long occur, in a very fine-grained, recrystallized groundmass of quartz, actinolite, and epidote. Amygdules filled with chlorite and epidote. Local calcite veins. Plagioclase largely replaced by saussurite. Local faint pillow structure.

Intensely ductility deformed. Schistosity and parallel compositional layering dip steeply to vertically and strike west-northwest, parallel to the Hines Creek, Nenana Glacier, and Denali faults. In the B-5 and C-5 quadrangles, schistosity and layering folded around a weakly schistose granitic pluton (grn2, part); in the C-6 quadrangle schistosity folded into a gentle, east-west-trending synform. Small isoclinal folds, formed in an older schistosity, occur with axial planes parallel to dominant schistosity. Local extreme ductile deformation along schistosity produces mylonitic schist and locally, blastomylonite.

Unit exhibits two periods of metamorphism; an older period at upper amphibolite facies, and a younger period at middle greenschist facies. Diagnostic upper amphibolite facies minerals are hornblende, clinopyroxene, garnet, biotite, and wollastonite. Diagnostic middle greenschist facies minerals are chlorite, epidote, biotite, white mica, actinolite, and biotite. Lower grade rocks mainly occur along the margins of the terrane near the Denali, Nenana Glacier, and Hines Creek faults. Retrogressive metamorphism indicated by partial replacement of clinopyroxene by actinolite and clinozoisite, plagioclase by white mica.

Unit occurs in a fault-bounded wedge, in the west-central part of the quadrangle, between the Hines Creek fault to the northeast, Nenana Glacier fault to the north, and the Denali fault to the south. Intruded by stocks, dikes, and sills, of metamorphosed and deformed diorite, granodiorite, and granite, and by stocks, dikes, and sills, of weakly schistose and weakly metamorphosed gabbro. Intrusive contacts locally faulted.

Age of the protolith of the metasedimentary rocks constrained to Silurian through Triassic as indicated from conodont fragments of post-Ordovician morphotype from one marble body (Table 1 of Nokleberg and others (1992), locality 7). Metasedimentary rocks may correlate with a unit of weakly metamorphosed, calcareous sedimentary rocks to the west in the Healy quadrangle that contains Triassic conodonts (Brewer, 1982; Csejtey and others, 1992)

WINDY TERRANE WITHIN SPLAYS OF DENALI FAULT

The Windy terrane (Jones and others, 1987; Nokleberg and others, 1985) occurs within branches of the Denali fault, north of the Maclaren terrane, and south of the Aurora Peak and Yukon-Tanana terranes. Unlike the adjacent terranes to the north and the south, the Windy terrane exhibits primary sedimentary or volcanic textures and structures. Relict sedimentary structures of bedding, graded bedding, and crossbedding. The Windy terrane occurs in narrow slivers that occur discontinuously for several hundred kilometers along the Denali fault (Jones and others, 1987. The terrane consists of two major assemblages: (1) Mesozoic flysch and associated volcanic rocks, interpreted as remnants of the Kahiltna terrane and associated Gravina arc (Stanley and others, 1990); and (2) Silurian(?) and Devonian limestone and marl, possibly derived from weakly metamorphosed parts of the Yukon-Tanana terrane to the north. The terrane is interpreted as a structural melange of diverse rock types and ages that have been tectonically mixed during Cenozoic right-lateral strike-slip movement along the Denali fault (Nokleberg and others, 1989a).

wm **Melange (Cretaceous, Devonian, and Silurian?)**—Structural melange consisting of two assemblages: (1) Fault-bounded lenses of Cretaceous flysch and volcanic rocks consisting mainly of argillite, and weakly metamorphosed quartz siltstone, quartz sandstone, metagraywacke, and metaconglomerate and minor andesite and dacite, and (2) Small to large, fault-bounded lenses of Silurian (?) and Devonian limestone and marl. Estimated structural thickness of about three to four thousand meters.

Argillite composed of quartz grains, up to 0.2 mm, in very fine-grained matrix of quartz, chlorite, graphite, and sericite. Local plagioclase and quartz-rich silty layers, and minor hematite and opaque minerals. Local sandy-to pebbly siltstone composed of subangular quartz clasts in variable matrix of quartz and sericite, and minor calcite, biotite, epidote, actinolite, opaque minerals, and sphene. Metagraywacke composed of angular clasts of quartz, plagioclase, and locally K-feldspar, up to 0.4 mm, in matrix of sparse, very fine-grained quartz, white mica, and calcite. Plagioclase clasts locally twinned and zoned. Minor minerals are epidote, biotite, chlorite, sphene, and opaque minerals. Conglomerate composed of medium- to coarse-grained, angular fragments of argillite, silty argillite, chert, and metavolcanic graywacke in a matrix of very fine-grained quartz and mica. Relict radiolaria in chert clasts.

Sandstone composed of fine- to medium-grained, subangular grains of quartz in a fine-grained matrix predominantly of sericite. Plagioclase and K-feldspar partially replaced by white mica.

Andesite composed of phenocrysts of plagioclase, up to 1.0 mm long, and occasional quartz and biotite in groundmass composed predominantly of plagioclase and minor calcite, epidote, chlorite, white mica and opaque minerals. Dacite composed of phenocrysts of quartz, plagioclase, and biotite up to 1.0 mm across in groundmass of plagioclase microlites with epidote, white mica, and opaque minerals. Relict fine-grained igneous textures. Plagioclase and K-feldspar partially replaced by white mica.

Light- to dark-gray limestone composed mainly of calcite and minor dolomite. Fine- to medium-grained. Local abundant corals. Local sparse grains of quartz and variable amounts of graphite.

Marl mainly black-to light-gray, well bedded. Exhibits sparse cross bedding. Mainly fine-grained, phyllitic white mica and calcite enclosing granular quartz and epidote. Major minerals are quartz, calcite, epidote, and white mica. Minor minerals are chlorite, graphite, sphene, tourmaline, and opaque minerals. Sparse relict angular quartz grains. Grades into calcareous sandstone. Local sparse quartz pebbles.

Both assemblages occur in narrow, interleaved, fault-bounded lenses. Local intense schistosity strikes northwest parallel to branches of Denali fault and dips moderately to steeply northeast in western part of quadrangle and moderately southwest in eastern part of quadrangle. Local intense deformation and development of phyllonite and protomylonite. Local intense shearing and fault gouge along southern margin of unit. Incipient greenschist facies metamorphism. Diagnostic minerals are very fine-grained chlorite, graphite, sericite, epidote, and actinolite.

Unit occurs in two areas: (1) eastern A-1 quadrangle, north of and adjacent to the Denali fault; and (2) across the B-4 - B-5 quadrangle boundary within branches of the Denali fault. In fault contact with Jarvis Creek Glacier and Hayes Glacier subterranes and Aurora Peak terrane north of the Denali fault, and Wrangellia and Maclaren terranes south of the Denali fault. Intruded by a weakly schistose granitic pluton (gm1) in the B-4 quadrangle, and by small granitic and gabbroic dikes and sills.

Unit contains one known fragment of a Cretaceous ammonite (Table 1 of Nokleberg and others (1992), locality 8). Ammonite fragment was found in float, but interpreted as derived from the assemblage of flysch and volcanic rocks (J.H. Stout, written commun., 1976). Assemblage of limestone and marl contains Silurian(?) and Devonian megafossils and microfossils (Table 1 of Nokleberg and others (1992), localities 8, 9, 10, 11). Marble on strike to southeast in Nabesna quadrangle contains Middle Devonian rugose corals (Richter, 1976). Correlative unit of melange of Windy terrane occurs on strike to the west in the Healy quadrangle (Jones and others, 1982, 1987; Csejtey and others, 1992). Melange into three sheared and intermixed units designated: unit m_2 (sandstone, argillite, and subordinate conglomerate), unit l_2 (limestone), and unit um (serpentinized ultramafic rocks). Unit l_2 yields Ordovician or Devonian mollusks, brachiopods and conodonts, Devonian crinoids and corals, Middle Devonian corals and stromatoporoids, late Middle Devonian conodonts, and Late Triassic pelecypods and an ammonite(?). Unit m_2 yields Mississippian and Jurassic radiolarians, and Late Jurassic to Late Cretaceous pelecypods

SEDIMENTARY AND VOLCANIC ROCKS AND METAMORPHOSED SEDIMENTARY, VOLCANIC, AND PLUTONIC ROCKS SOUTH OF DENALI FAULTTERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Scattered outcrops of continental Tertiary sedimentary and volcanic rocks occur south of the Denali fault and consist, from oldest to youngest, of a unit of volcanic rocks (Tv), a conglomerate unit (Tc), and a sandstone and conglomerate unit (Tsc). The sandstone and conglomerate unit locally contains sparse volcanic ash and argillite, and the conglomerate unit locally contains sandstone and argillite. The stratigraphic succession of these units is best established along the southern flanks and to the southeast of Rainbow Mountain in the south-central part of the quadrangle. Elsewhere, these three sedimentary and volcanic rock units may laterally grade into one another.

Tsc **Sandstone and conglomerate (Miocene to Eocene)**—Chiefly continental clastic deposits of light-colored, fine-grained, poorly sorted sandstone consisting of locally interbedded siltstone, pebbly sandstone, pebble to cobble conglomerate, and sparse thin coal layers. Also contains very sparse white rhyodacite ash layers in the vicinity of The Hoodoos. Moderately well cemented, locally by hematite. Locally weathers orange-brown. Abundant cross bedding, ripple marks, and pebble imbrication. Local crude bedded containing lenticular sandstone and conglomerate layers. Locally abundant organic debris including carbonized leaf impressions and tree trunks. Top eroded; base often faulted. Maximum exposed stratigraphic thickness of a few hundred meters.

Conglomerate clasts composed predominantly of andesite porphyry, fine grained granitic rocks, schistose rocks, quartz, and locally abundant ultramafic rocks, and coal. Sparse clasts of dark argillite contain late Paleozoic bryozoans and brachiopods derived from Eagle Creek Formation or upper part of Slana Spur Formation.

Common lithic fragments in sandstone of granite, schist, mafic and ultramafic rocks. Common mineral grains of quartz and plagioclase; minor hornblende and clinopyroxene. Local chlorite, white mica, calcite, and epidote alteration. Interpreted as probable channel deposits laid down by braided streams on alluvial fans. Maximum exposed stratigraphic thickness of several hundred meters.

Unit occurs mainly in scattered exposures up to 4 km across, within the A-3, A-4 and southern B-4, B-5 quadrangles. Unit both depositionally overlies, and faulted against Slana Spur Formation.

Age range of Eocene to Miocene. K-Ar isotopic analysis of hornblende from a white rhyodacite ash layer about one-half mile south of The Hoodoos yields an age of 5.5 Ma (late Miocene) (Table 2 of Nokleberg and others (1992), locality 78). K-Ar isotopic analyses

of hornblende from a rhyodacite tuff from fault-bounded wedge of sandstone in the southwestern part of the quadrangle yields an age of 31.1 Ma (Oligocene) (Table 2 of Nokleberg and others (1992), locality 84). Several localities, mainly in the south-central and southeastern parts of the quadrangle, yield plant and pollen fossils that range in age from late Eocene to Pliocene (Table 1 of Nokleberg and others (1992), localities 58, 64, 70, 75, 85)

Tc **Conglomerate (Eocene)**—Chiefly continental clastic deposits composed of poorly sorted, crudely bedded to massive, polymictic conglomerate and lesser sandstone. Contains abundant clasts of rhyodacite to dacite tuff and flows, Nikolai Greenstone, argillite, volcanic sandstone, andesite to dacite volcanic rocks of Eagle Creek and Slana Spur Formations, quartz diorite, greenschist, gabbro, and ultramafic rocks. Local thin beds of coal in sandstone layers. Clast composition, south of the Chistochina Glacier in the A-2 quadrangle, in descending order of abundance: chlorite schist, gabbro, granodiorite, metadiabase, amphibolite, and metagabbro and minor rhyodacite, granite, diabase, metagranodiorite, and quartz. Clast composition, south of College glacier in the A-3 quadrangle: argillite, limestone, gabbro, and granitic rocks with minor chert, and metavolcanic rocks. Thickness variable. Maximum exposed stratigraphic thickness of a few hundred meters.

On hill about 6 km west of Broxson Gulch, conglomerate unit composed predominantly of clasts of ultramafic rocks occurs (Moffit, 1912; Stout, 1976). In Slate Creek area, unit includes "round wash" conglomerate which contains clasts mainly of metagabbro and diabase, chlorite-epidote schist, amphibolite, granodiorite, and quartz. In area west of Delta River, unit lacks clasts of Maclaren Glacier metamorphic belt that occurs directly north, suggesting that the Maclaren Glacier metamorphic belt was faulted into its present position after deposition (Stout, 1976).

Unit occurs in several exposures up to 2 km across north of the McCallum-Slate Creek fault across the A-2 and A-3 quadrangle, and in smaller exposures west of the Delta River. Overlies Tertiary volcanic rocks (Tv) and rocks of Slana Spur Formation; locally in fault contact with rocks of Slana Spur Formation. Local source of placer gold, particularly in Chistochina district and Broxson Gulch area (Mendenhall, 1905; Moffit, 1912; Yeend, 1981; Nokleberg and others, 1991).

Unfossiliferous, probably Eocene in age. Relatively younger than the underlying, volcanic rocks unit of Eocene age. Relatively older than the overlying sandstone and conglomerate unit of Eocene to Miocene age

Tv **Volcanic rocks (Eocene)**—Chiefly vitric-lithic-crystal ash-flow tuff, breccia, agglomerate, flows, dikes, and sills, and minor volcanic sandstone, conglomerate, and fossiliferous limestone. Igneous rocks mainly volcanic flows and tuffs. Thickness variable. Maximum exposed stratigraphic thickness of a few hundred meters.

Dacites and andesites generally porphyritic. Composed of phenocrysts and fragments of plagioclase, quartz, and sparse K-feldspar and biotite in relict glassy groundmass, largely replaced by chlorite and lesser sericite and epidote, and local trachytic plagioclase microlites. Locally amygdaloidal. Local veins of quartz and calcite.

Tuffs composed of fragments of sanidine, orthoclase, plagioclase, quartz, and biotite with clear glass shards and lesser lithic fragments from 0.1 to 3 mm across in matrix composed of isotropic, brown glass. Hypautomorphic granular texture. Plagioclase twinned; locally zoned. Perlitic fractures in larger shards. Lithic fragments mainly siltstone, altered diorite, and andesite or dacite. Slightly welded. Local weak schistosity. Local intense hydrothermal alteration. Plagioclase partially replaced by sericite, saussurite, and epidote; biotite by chlorite. Abundant hydrothermal alteration in vicinity of The Hoodoos.

Unit occurs in scattered outcrops up to 3.5 km across, mainly north of the McCallum Creek-Slate Creek fault in south-central part of the quadrangle, and in fault-bounded lenses within splays of the Broxson Gulch thrust in the southwestern part of the quadrangle. Overlain by Tertiary sandstone and conglomerate (Tsc) and conglomerate (Tc); locally in fault contact with units Tsc and Tc, and rocks of Slana Spur subterrane. K-Ar isotopic whole-rock analysis of a rhyodacite tuff from about one mile southeast of The Hoodoos yields an age of 49 Ma (Eocene) (Table 2 of Nokleberg and others (1992), locality 77)

GRANITIC PLUTONIC ROCKS SOUTH OF THE DENALI FAULT

Numerous, small to large granitic plutons of Mesozoic and early Cenozoic age occur south of the Denali fault in the Clearwater, Maclaren, and Wrangellia terranes. Most of the rocks are unfoliated and igneous-textured. These plutons are much younger than the stratified coeval volcanic and plutonic rocks in each terrane, and are interpreted to have formed relatively late in the tectonic history of the region. The larger of these granitic plutons are the granite of Susitna Glacier, the granite porphyry of Caribou Lake, and the granodiorite of Rainbow Mountain. Numerous smaller granitic bodies occur across the southern part of the quadrangle south of the Denali fault.

A small hydrothermally-altered granitic pluton (grs1, part) occurs in the Maclaren terrane in the western part of the quadrangle and intrudes the argillite and metagraywacke unit of the Maclaren Glacier metamorphic belt. Granite medium-to coarse-grained, hypautomorphic igneous-textured granular to seriate and locally aplitic and porphyritic. Major primary minerals are quartz, biotite, K-feldspar, and plagioclase. Accessory minerals are sphene, garnet, apatite, and opaque minerals. Many quartz phenocrysts are relatively large with resorbed outlines. Feldspar partially replaced by secondary white mica; biotite by chlorite.

A fault-bounded and weakly gneissose pluton (grs3, part) of diorite and quartz diorite locally intrudes the Clearwater terrane. The pluton exhibits a well preserved hypautomorphic granular texture. Granulation and strong undulose extinction are locally developed along a vein-like shear structure. Major minerals are quartz, plagioclase, and biotite. Sericite partially replaces plagioclase. Age of pluton assumed to be Jurassic and (or) Cretaceous in age.

Several small- to moderate-size Mesozoic granitic plutons (grs1, part) that are locally weakly to extensively hydrothermally altered intruded Wrangellia terrane. These granitic plutons are interpreted as being at least partly coeval and co-magmatic with the Upper Jurassic and Lower Cretaceous flysch and volcanic rocks of the Gravina-Nutzotin belt, and the Lower Cretaceous marine and subaerial andesite volcanic flows and volcaniclastic rocks of the Chisana Formation, part of the Gravina-Nutzotin belt to the southeast in the Nabesna quadrangle (Richter, 1976). Suite of granitic plutons named the Gravina arc by Stanley and others (1990). Sparse K-Ar hornblende isotopic analyses yield ages of 129 and 146 Ma (Late Jurassic and Early Cretaceous) (Table 2 of Nokleberg and others (1992), localities 83, 85). However, some Mesozoic(?) granitic plutons in the Wrangellia terrane are similar in petrology to the Pennsylvanian granitic plutons (lPg) and could be of late Paleozoic age.

Alkalic gabbro dikes locally intrude the southwestern part of the East Susitna batholith of the Maclaren terrane in the west-central part of the quadrangle. A K-Ar biotite isotopic analysis yields an age of 52.8 Ma (early Tertiary) (Table 2 of Nokleberg and others (1992), locality 46). These dikes, too thin to depict on the geologic map, are similar in petrology and age to the locally abundant alkalic dikes that occur north and east of the Denali fault in the southern Yukon-Tanana quadrangle in the east-central part of the quadrangle. This relation may indicate a minimum Cenozoic dextral offset of approximately 60 km along the Denali fault

grs1 **Granitic unit 1 (Cretaceous, and Late Jurassic)**—Chiefly granitic and minor monzonite and diorite dikes, stocks, and small plutons. Fine- to medium-grained, hypautomorphic granular texture. Major minerals are quartz, complexly twinned plagioclase, K-feldspar, local hornblende, biotite, and white mica, and minor sphene, zircon, apatite, and opaque minerals plagioclase. Local hydrothermal alteration. Weak local deformation resulting in fractured and strained quartz and plagioclase. Locally metamorphosed to lower greenschist facies. Plagioclase partially replaced by sericite, epidote-clinozoisite, and saussurite; hornblende by epidote-clinozoisite, actinolite, and chlorite; biotite by chlorite. Local quartz and calcite veins. Pluton north of the McCallum-Slate Creek fault in the A-2 quadrangle contains gabbro xenoliths.

Unit widely distributed south of the Denali fault in Wrangellia and Maclaren terranes in numerous smaller bodies generally less than 1 km across, and in dikes and sills about 1 m wide. Locally intruded by small mafic and felsic dikes

grs2 **Granitic unit 2 (Cretaceous, and Late Jurassic)**—Chiefly hornblende-biotite granodiorite and hornblende granodiorite and minor granodiorite and granite dikes, stocks, and small plutons. Includes sparse syenodiorite and quartz diorite (Richter and others, 1977). Fine- to medium-grained, hypautomorphic granular texture. Major minerals are plagioclase, quartz, K-feldspar, biotite, and hornblende; minor minerals are white mica, zircon, sphene, and apatite. Locally deformed, exhibiting fractured and strained quartz and feldspar and bent biotite. Locally weakly metamorphosed to greenschist facies. Plagioclase partially replaced by sericite, saussurite and epidote; biotite and hornblende by chlorite, epidote-clinozoisite, and actinolite. Sparse quartz and calcite veins. Widely distributed south of the Denali fault throughout Wrangellia terrane. Unit occurs in plutons up to 5 km across, and in numerous dikes and sills up to 500 m long and 50 m wide. Dikes usually less than 1 m wide

grs3 **Granitic unit 3 (Cretaceous, and Late Jurassic)**—Quartz diorite and diorite dikes, stocks, and small plutons. Fine- to medium-grained, hypautomorphic granular texture; locally seriate and porphyritic. Composed of plagioclase and hornblende phenocrysts up to 7 mm long in groundmass of quartz and plagioclase. Local, crude flow-alignment of tabular plagioclase. Local weak deformation resulting in fractured and strained quartz and plagioclase and kink-banded clinopyroxene. Major minerals are plagioclase and quartz, and locally hornblende and biotite. Minor minerals are K-feldspar, clinopyroxene, sphene, zircon, apatite, and opaque minerals. Normal and oscillatory zoning in plagioclase. Locally granulated phenocrysts. Local greenschist facies metamorphism; locally schistose. Plagioclase partially replace by sericite, epidote-clinozoisite, and saussurite; hornblende by chlorite, actinolite, and epidote-clinozoisite; biotite by chlorite. Widely distributed south of Denali fault in Clearwater and Wrangellia terranes. Unit occurs in scattered exposures up to about 1 km across, in numerous smaller bodies, and in dikes and sills about 1 m wide

GRANITIC PLUTONS, INFORMALLY NAMED

grsg **Granite of Susitna Glacier (early Tertiary)**—Here referred to as granite of Susitna Glacier. Chiefly biotite-white mica granite. Fine- to medium-grained, hypautomorphic granular texture. Major groundmass minerals are quartz, K-feldspar, plagioclase, and biotite. Minor chlorite and opaque minerals. Local hydrothermal alteration, plagioclase partially replaced by white mica.

Unit forms large pluton exposed in numerous outcrops up to 7 km across. Surrounded by glacial deposits, colluvium, and ice within the north-central B-6 and southern C-6 quadrangles. Intrudes schist and amphibolite unit (sa) of East Susitna batholith of Maclaren terrane. Truncated by Denali fault along northern margin. K-Ar hornblende and biotite isotopic analyses yield nearly concordant ages of 35.5, 35.6, and 36.1 (Table 2 of Nokleberg and others (1992), localities 48, 54). Early Tertiary ages similar to youngest ages for gneissose granitic rocks in the East Susitna batholith of the Maclaren terrane; may represent intrusion of part of the batholith in a small area that was tectonically quiet

grcl **Granite porphyry of Caribou Lake (Early Cretaceous and (or) Late Jurassic?)**—Here referred to as granite porphyry of Caribou Lake. Chiefly biotite granite porphyry. Fine-grained; locally medium-grained. Porphyritic with K-feldspar phenocrysts up to 3 mm diameter. Local

hypautomorphic granular texture. Major groundmass minerals are quartz, plagioclase, biotite. Minor hornblende, sphene, epidote, opaque minerals including hematite, and white mica. Local extensive hydrothermal alteration. Biotite and hornblende partially replaced by chlorite, feldspar by calcite and white mica.

Unit exposed in numerous outcrops up to 5 km across. Intrudes Nikolai Greenstone of Slana River subterrane of Wrangellia terrane within the southeastern A-3 quadrangle. Locally surrounded by glacial deposits and colluvium. No isotopic age data

grm **Granodiorite of Rainbow Mountain (Cretaceous and (or) Mississippian)**—Here referred to as granodiorite of Rainbow Mountain. Northern part of pluton chiefly granite and granodiorite. Fine- to medium-grained, hypautomorphic granular texture. Major minerals are quartz, K-feldspar, and plagioclase. Minor minerals are epidote, white mica, chlorite, sphene, and opaque minerals. An Early to mid-Cretaceous age of intrusion or reheating indicated by a K-Ar hornblende age of about 110 Ma (Table 2 of Nokleberg and others (1992), locality 75).

Southern and southeastern part of pluton chiefly biotite-hornblende quartz diorite and granodiorite. Fine- to medium-grained, hypautomorphic granular texture. Other major minerals are quartz, K-feldspar, and plagioclase. Minor minerals are epidote, white mica, chlorite, sphene, and opaque minerals. Local gneissose texture with moderate schistosity. Quartz and K-feldspar occur interstitially to plagioclase. Local abundant hydrothermal(?) alteration of plagioclase to saussurite, lesser sericite and epidote; biotite and hornblende to chlorite and epidote. Metamorphosed at lower greenschist facies. From 30 to 100 percent of hornblende metamorphosed to chlorite and actinolite; from 20 to 100 percent of plagioclase metamorphosed to white mica and epidote. A possible Late Mississippian age of intrusion indicated by a K-Ar hornblende age of 326 Ma (Table 2 of Nokleberg and others (1992), locality 76).

Both parts of pluton surrounded by glacial deposits, colluvium, and ice within the north-central B-4 quadrangle and intrude lower volcaniclastic rocks member of Slana Spur Formation and shallow-level intrusive stocks, dikes, sills, and small plutons (Early Permian?) of Slana River subterrane of Wrangellia terrane

TERRANE OF ULTRAMAFIC AND ASSOCIATED ROCKS WITHIN BRANCHES OF DENALI FAULT

A terrane of ultramafic and associated rocks (um) occurs in the southeastern part of quadrangle, as a fault-bounded sliver (um) along the Denali fault, and as klippen south of the Denali fault. This unit consists chiefly of ultramafic and mafic rocks, with lesser metasedimentary rocks and granitic rocks. It represents part of a string of alpine peridotites that occur along or near the Denali fault for several hundred kilometers in east-central Alaska (Richter and others, 1977; Nokleberg and others, 1982, 1985). The terrane occurs in two settings: (1) a narrow, fault-bounded lens along branches of the Denali fault in the eastern part of the quadrangle in the Gillette Pass area (Richter and others, 1977) and (2) as two subhorizontal klippen a few kilometers south of the Denali fault in the east-central part of the quadrangle in the area between Gakona and Chistochina Glaciers (Rose, 1967; Nokleberg and others, 1982). Klippen floored by subhorizontal thrust faults, and occur structurally on the northern margin of Wrangellia terrane. The ultramafic and mafic rocks exhibit a locally well-defined, medium- to coarse-grained schistosity that parallels a weak schistosity in the granitic rocks.

The ultramafic rocks are chiefly dark-green serpentinized pyroxenite and peridotite, light- gray to green dunite, dark-green schistose amphibolite, and lighter hornblende-plagioclase gneiss derived from gabbro. Interlayered with the gneiss are sparse, thin lenses of light-green and gray marble and zones of dark-gray graphitic schist. The ultramafic and mafic rocks are intruded by light-gray tonalite and granite. The ultramafic and mafic rocks are ductility deformed and regionally metamorphosed.

The terrane of ultramafic and associated rocks, of Mesozoic age, is interpreted as a crustal-suture belt composed of fragments of either oceanic or deep-level continental lithosphere (Richter, 1976). The lithosphere fragments are probably derived from the basement of terranes juxtaposed along the Denali fault, such as the Yukon-Tanana or Wrangellia terranes (Nokleberg and others, 1989a). The two klippen south of the Denali fault may represent remnants of amalgamation of the Wrangellia terrane along the ancestral, continentward-dipping Denali fault.

um **Ultramafic and associated rocks (Mesozoic?)**—Chiefly variably serpentinized pyroxenite, peridotite, dunite, schistose amphibolite, serpentinite, and hornblende-plagioclase gneiss derived from gabbro. Rare thin lenses of light-green and gray marble and narrow lenses of dark gray graphitic schist interlayered with the gneiss. Locally intruded by gabbro dikes, tonalite, and granite. Intensely deformed and fault-bounded. Estimated structural thickness of a few thousand meters.

Peridotite and pyroxenite form crudely layered elongate bodies associated with amphibolite and hornblende-plagioclase gneiss. Pyroxenite occurs as discrete masses and as thin layers in peridotite. Peridotite, including minor dunite, largely altered to serpentinite. Fine-to medium-grained, with relict hypautomorphic granular texture. Relict igneous minerals are olivine, clinopyroxene, and hornblende and minor biotite and orthopyroxene. Metamorphic minerals mainly serpentine and chlorite. Remnant olivine in the peridotite ranges between Fo_{80} and Fo_{85}. Olivine partially to completely replaced by serpentine; pyroxene, hornblende, and biotite by chlorite.

Dunite forms two elongate masses separated from the pyroxenite-peridotite body by amphibole-rich metamorphic rock. Dunite light-gray to greenish-gray and massive; average grain size of 1 to 2 mm. Local ductility-deformed fabric containing large olivine grains, less than 10 mm, surrounded by finer-grained olivine. Local planar shattering of olivine grains. Unevenly distributed grains of chromite locally arranged in short layers. Relict primary minerals

mainly olivine and minor plagioclase, clinopyroxene, orthopyroxene, and biotite. Plagioclase saussuritized. Veinlets and cracks throughout body generally filled with serpentine, chlorite, talc, and iddingsite. Local gabbro dikes.

Amphibolite and hornblende-plagioclase gneiss range from massive dark-green amphibolite to finely banded gneissic rocks. Fine- to medium-grained exhibiting granoblastic textures. Banding thickness and amphibole-feldspar ratio extremely variable. Rare thin lenses of light-green and gray, epidote-bearing marble and zones of dark-gray, graphitic schist interlayered with gneiss. Local abundant amphibole-rich pegmatite. Major minerals are green hornblende, calcic plagioclase, quartz, minor clinopyroxene, sulfides, and black oxides. Plagioclase partially replaced by saussurite, sericite, and chlorite; hornblende by chlorite. Carbonate occurs throughout the rock in granular masses and veinlets. Unit forms host to ultramafic rocks. Intruded by tonalite and granite.

Serpentinite occurs in isolated, fault-bounded lenses and masses within or adjacent to major fault zones. Intensely deformed and schistose. Protoliths of dunite, pyroxenite, and peridotite. Contains local minor relict plagioclase, calcite, white mica, and chlorite.

Tonalite and granite form small elongate plutons intruding the amphibole-rich metamorphic rocks. Mottled light-gray to light-greenish-gray. Includes high-soda and high-alumina variants.. Fine to medium-grained, porphyritic to porphyroblastic. Composed of large phenocrysts or porphyroblasts of sodic plagioclase, generally altered to white mica and clinozoisite, in a groundmass of fine-grained quartz, and minor pyroxene and amphibole. Pyroxene and amphibole generally altered to chlorite. Weakly metamorphosed.

Unit exhibits well-developed schistosity, generally strikes west-northwest and dips north or south. Schistosity defined by ductility deformed, fractured, and granulated mafic minerals. Locally blastomylonite. Upper amphibolite facies metamorphism. Diagnostic minerals are metamorphic clinopyroxene, olivine, hornblende, and calcic plagioclase. Retrogressive lower greenschist facies metamorphism. Diagnostic minerals are serpentine, chlorite, epidote, talc, and, albite.

Unit occurs in sparse outcrops up to 4 km across, in the A-1, A-2, and A-3 quadrangles, adjacent to and south of the Denali fault. Faulted against rocks of Wrangellia and Maclaren terranes.

K-Ar isotopic analyses of biotite and hornblende from pyroxenite yield nearly concordant ages of 123 and 126 Ma (Table 2 of Nokleberg and others (1992), localities 80, 81). Early Cretaceous ages interpreted as apparent age of regional metamorphism and penetrative deformation of terrane. Age of the protolith of the ultramafic and mafic rocks older, perhaps Paleozoic(?). Relatively younger granitic bodies form elongate plutons and exhibit a weaker fabric compared to the ultramafic and mafic rocks. Relations suggest granitic rocks possibly intruded during regional metamorphism and penetrative deformation in the Early Cretaceous. The Early Cretaceous ages of metamorphism and deformation for the terrane of ultramafic and associated rocks similar to interpreted age of regional metamorphism and penetrative deformation of the Yukon-Tanana terrane to the north. Both may have been metamorphosed and deformed during the same event

MACLAREN TERRANE SOUTH OF DENALI FAULT AND NORTH OF BROXSON GULCH THRUST

The Maclaren terrane occurs south of the Denali fault in the central and western parts of the quadrangle. The Maclaren terrane consists two major units: (1) the penetratively-deformed and regionally-metamorphosed granitic plutonic rocks of the East Susitna batholith to the north; and (2) the schist, amphibolite, phyllite, argillite, and metagraywacke of the Maclaren Glacier metamorphic belt to the south (Nokleberg and others, 1982, 1985, 1989a). The contact between the East Susitna batholith and the Maclaren Glacier metamorphic belt is a faulted intrusive contact named the Meteor Peak fault (Nokleberg and others, 1982, 1985).

The Maclaren terrane is interpreted as a tectonically detached part of a prograde Barrovian-type metamorphic belt and a companion composite batholith, both intensely metamorphosed and deformed (Smith and Turner, 1973; Smith, 1981; Nokleberg and others, 1985). The increase of metamorphic grade in the Maclaren Glacier metamorphic belt toward the East Susitna batholith indicates metamorphism occurred in response to syntectonic emplacement of the batholith. In addition, similar middle amphibolite facies metamorphism occurs in both the schist and amphibolite unit of the Maclaren Glacier metamorphic belt and the East Susitna batholith, and both contain a parallel or subparallel schistosity. This relation indicates that both were regionally deformed and metamorphosed together during the synkinematic intrusion of the batholith over a relatively long time span from the Late Cretaceous to the middle Tertiary.

The East Susitna batholith and the Maclaren Glacier metamorphic belt are interpreted as having formed in a continental-margin, Andean-type arc setting (Nokleberg and others, 1985). The locally abundant andesitic and basaltic debris in metagraywacke, the abundant quartz detritus in both argillite and metagraywacke, the sparse occurrence of andesite and basalt flows, and sedimentary structures indicating turbidite deposition, all suggest that the protolith for the argillite and metagraywacke unit was volcanogenic flysch derived from an Andean-type arc. A continental-margin arc setting is also indicated by common lead compositions for zircon and feldspar (Aleinikoff and others, 1987). Isotopic analysis of lead from samples of the East Susitna batholith show moderate radiogenic values, and derivation from a source of about 1.2- Ga age (Aleinikoff and others, 1987).

EAST SUSITNA BATHOLITH, AND SCHIST, QUARTZITE AND AMPHIBOLITE SOUTH OF DENALI FAULT AND NORTH OF METEOR PEAK FAULT

The East Susitna batholith consists of five major units: (1) gneissose granitic rocks (gg); (2) migmatite

(mig); (3) migmatitic schist (mgsh); (4) schist and amphibolite (sa); and (5) schist, quartzite, and amphibolite (sq) that occur in roof pendants of metasedimentary rocks. The gneissose granitic plutonic rocks of the East Susitna batholith are derived from diorite, granodiorite, and minor granite and locally grade into units of migmatite, migmatitic schist, and schist and amphibolite. The schist and amphibolite unit consists mainly of older, more intensely regionally metamorphosed and penetratively deformed gabbro and diorite and lesser high-grade pelitic sedimentary rocks.

East Susitna batholith ductility deformed and metamorphosed into mylonitic gneiss and schist at the upper amphibolite facies, and local retrograde metamorphism at lower greenschist facies (Nokleberg and others, 1985). East Susitna batholith displaced part of the Kluane arc of Plafker and others (1989).

gg **Gneissose granitic rocks (early Tertiary and Late Cretaceous)**—Chiefly gneissose granodiorite and quartz diorite and minor granite. Fine- to medium-grained, with relict hypautomorphic granular, seriate, and porphyritic textures containing relict phenocrysts of plagioclase and K-feldspar up to 6 mm across. Relict igneous minerals are plagioclase, quartz, K-feldspar (locally perthitic), biotite, hornblende rimmed by biotite, and clinopyroxene rimmed by biotite and hornblende. Minor zircon, and apatite. Relict igneous hornblende rimmed by igneous biotite; clinopyroxene by biotite and minor hornblende. Clinopyroxene and hornblende commonly poikiloblastic containing abundant inclusions of feldspar and quartz. Strong undulose extinction in feldspar and quartz augen. Relict igneous plagioclase with complex twinning, normal zoning, and oscillatory zoning. Sparse crosscutting dikes of nonfoliated gabbro, diabase, rhyodacite, and rhyolite. Locally grades to migmatite.

Unit exhibits single pervasive schistosity that generally strikes northwest to southwest, dips moderately to steeply west and parallels younger structures in part (msh) of the Maclaren Glacier metamorphic belt to south in the B-6 quadrangle. Penetratively deformed. Locally grades to blastomylonite. Schistosity defined by parallel-aligned biotite, white mica, and elongate grains and augen of quartz and feldspar.

Unit metamorphosed at middle to upper amphibolite facies. Diagnostic amphibolite facies minerals are recrystallized clinopyroxene, hornblende, calcic plagioclase, and garnet. Locally retrogressively metamorphosed to greenschist facies. Diagnostic lower greenschist facies minerals are white mica, epidote-clinozoisite, and chlorite. Biotite, hornblende, and clinopyroxene partially replaced by chlorite; plagioclase by epidote and white mica; K-feldspar by white mica. Local intense granulation along margins of feldspar and quartz augen.

Unit well exposed between the Denali fault to the north and the Meteor Peak fault to the south within the B-4, B-5, and B-6 quadrangles. Unit also occurs within branches of the Meteor Peak fault in the B-6 quadrangle. Intrudes, and locally faulted against schist and amphibolite (sa) of Maclaren Glacier metamorphic belt.

U-Pb zircon, U-Pb sphene, and K-Ar mica and hornblende isotopic analyses yield a wide range of ages between 70.0 and 29.2 Ma (Table 2 of Nokleberg and others (1992), localities 42, 44, 45, 49, 53, 56-69). Oldest isotopic age of 70 Ma from a U-Pb zircon analysis of a gneissose granodiorite (Table 2 of Nokleberg and others (1992), locality 45). Oldest, nearly concordant K-Ar hornblende and biotite isotopic ages from a single sample of 65.9 and 56.9 Ma (Table 2 of Nokleberg and others (1992), locality 50). To the west in Healy quadrangle, oldest K-Ar hornblende isotopic age 87.4 Ma (Turner and Smith, 1974; Csejtey and others, 1992). Ages interpreted as Late Cretaceous intrusion of this part of the East Susitna batholith, and continued syntectonic intrusion, regional metamorphism, and penetrative deformation in early Tertiary (Nokleberg and others, 1985, 1989a).

Other, younger isotopic ages range from about 56 Ma to 30 Ma. A U-Pb isotopic analysis of deformed and metamorphosed sphene yields an age of metamorphism of 56 Ma from the sample of gneissose granodiorite that exhibits a U-Pb zircon igneous age of 70 Ma (Table 2 of Nokleberg and others (1992), locality 45). Metamorphic biotite from this sample yields a K-Ar age of 56.9 Ma. These and similar ages interpreted as regional metamorphism and penetrative deformation of this granodiorite that occurred after intrusion (Nokleberg and others, 1985).

The youngest K-Ar isotopic ages of 29.2 and 36.6 Ma for muscovite, biotite, and hornblende (Table 2 of Nokleberg and others (1992), localities 56-65, 67-69) tend to occur close to the Denali fault; interpreted as either continued, syntectonic intrusion of parts of East Susitna batholith, or unroofing and cooling of East Susitna batholith during lateral migration along the Cenozoic Denali fault. General parallelism of schistosity in the batholith with the Denali fault suggests that some metamorphism and deformation of the batholith occurred during faulting (Nokleberg and others, 1985)

sa **Schist and amphibolite (Late Cretaceous or older)**—Chiefly garnet-biotite-plagioclase schist and hornblende amphibolite. Relatively older, more mafic, and more highly metamorphosed variation of gneissose granitic rocks (gg) which locally intrude this unit. Intensely regionally metamorphosed and penetratively deformed gabbro, quartz gabbro, diorite, and quartz diorite recrystallized to garnet-biotite-plagioclase schist and amphibolite. Includes local pelitic schist and pelitic gneiss. Fine-to medium-grained. Mainly schistose aggregates of clinopyroxene, hornblende, biotite, plagioclase, and quartz, and lesser calcite, garnet, chlorite, epidote, white mica, and calcite. Very sparse relict hypautomorphic granular texture. Relict igneous plagioclase, biotite, hornblende, quartz, and clinopyroxene.

Unit intensely regionally metamorphosed and penetratively deformed. Schistosity generally strikes north or northwest and dips moderately north. Locally migmatitic. Local intense granulation and strong undulose extinction in quartz and feldspar augen. Metamorphosed to amphibolite facies. Diagnostic amphibolite facies minerals are hornblende, biotite, and garnet. Local retrogressive metamorphic overprint at lower greenschist facies with partial replacement of

clinopyroxene by biotite and hornblende; garnet by chlorite and white mica; plagioclase by white mica and calcite. Well exposed north of the Meteor Peak fault in the central and northern B-6 and eastern B-5 quadrangles

mig **Migmatite (Cretaceous?)**—Transitional rock unit between migmatitic schist (mgsh) and gneissose granitic rocks (gg). Grades from gneissose granitic rocks (gg), containing fragments of nearly completely assimilated schist and amphibolite, to highly contorted schist and amphibolite with diffuse veins of granodiorite to diorite. Contains abundant small to large diffuse dikes of granitic rock. Granitic rock dikes grade laterally into gneissose granitic rocks (gg) of East Susitna batholith. Locally contains pods and veins of rose quartz. Swirly schistosity. Fine- to medium-grained. Major minerals are plagioclase, quartz, and biotite. Lesser hornblende, K-feldspar, white mica, garnet, and minor chlorite also present. Plagioclase partially replaced by white mica.

Unit occurs in outcrops up to 1 km across in the northwestern B-6 quadrangle. Interpreted as a possible partial melting product that formed during the Late Cretaceous and early Tertiary intrusion of the East Susitna batholith

mgsh **Migmatitic schist (Cretaceous?)**—Grades from schist and amphibolite (sa), containing diffuse granitic dikes concordant to schistosity, to contorted and partly assimilated schist and amphibolite. Grades laterally into migmatite (mig). Contains fewer granitic dikes than migmatite (mig). Attitude of schistosity consistent in large outcrops. Diffuse granitic dikes composed of fine- to medium-grained hypautomorphic granular to schistose aggregates of biotite, plagioclase, quartz, and K-feldspar. Major minerals are hornblende, biotite, plagioclase, quartz, clinozoisite, white mica, and lesser garnet, K-feldspar, and chlorite. Transitional rock-type between migmatite (mig) and schist and amphibolite (sa).

Unit occurs in a cluster of exposures, individually up to 3 km across, and jointly comprising two large bodies up to 10 km across within gneissose granitic rocks (gg) and schist and amphibolite (sa) in the northwestern B-6 quadrangle. Unit interpreted as possible partial melting products that formed during Late Cretaceous and early Tertiary intrusion of the East Susitna batholith.

Ages similar to those in the unit of gneissose granitic rocks (gg). The oldest nearly concordant K-Ar hornblende and biotite isotopic ages from a single sample of 65.9 and 56.9 Ma (Table 2 of Nokleberg and others (1992), locality 50). Other K-Ar hornblende ages range from 61.7 to 58.5 Ma (Table 2 of Nokleberg and others (1992), localities 43, 47, 51, 52), and K-Ar biotite ages of 31.9, 33.7, and 55.9 Ma (Table 2 of Nokleberg and others (1992), localities 53, 56). Younger isotopic ages interpreted as either continued syntectonic intrusion, or unroofing and cooling

sq **Schist, quartzite, and amphibolite (Triassic?)**—Unit of relatively older calc-silicate schist, quartzite, and amphibolite. Moderately to intensely deformed with a moderate schistosity. Fine- to medium grained. Intruded by various metamorphosed granitic rocks of East Susitna batholith. Estimated structural thickness of a few hundred meters.

Calc-silicate schist and amphibolite mainly fine- to medium-grained and strongly schistose. Major minerals in calc-silicate schist of plagioclase, hornblende, clinopyroxene, quartz, and calcite. Minor minerals are garnet and clinozoisite. Garnet partially replaced by clinozoisite. Derived mainly from marl.

Quartzite varies from fine- to medium-grained. Schistose texture. Contains both fractured and undulatory quartz. Contains minor K-feldspar, biotite, hornblende, and epidote.

Amphibolite consists of schistose plagioclase, hornblende, and biotite. Minor minerals are clinopyroxene and opaque minerals. Clinopyroxene mostly replaced by hornblende and plagioclase. Derived mainly from marl.

Unit occurs in west-central part of quadrangle, south of Denali fault in small roof pendants in the East Susitna batholith. Lithologically similar rocks on strike in Healy quadrangle to west contain Pennsylvanian to Triassic conodonts (Sherwood and Craddock, 1979; Csejtey and others, 1992), and fragments of bivalves of Late Triassic age (Jones and others, 1987). Correlated with Nenana terrane of Jones and others (1987). Intruded by gneissose granitic rocks (gg) of East Susitna batholith

MACLAREN GLACIER METAMORPHIC BELT SOUTH OF METEOR PEAK FAULT AND NORTH OF BROXSON GULCH THRUST

The Maclaren Glacier metamorphic belt occurs to the south of the East Susitna batholith and is a pro-grade Barrovian type metamorphic belt. From south to north, the principal units of Late Jurassic or older argillite and metagraywacke (ma), phyllite (mph), and quartz-mica schist, calc-schist, and amphibolite (msh) (Nokleberg and others, 1982, 1985). Contacts between the three map units generally faults exhibiting intense shearing and abrupt changes of metamorphic facies at each contact.

The protolith for the sedimentary and volcanic rocks of the metamorphic belt is in part Late Jurassic or older in age. To the west in the southeastern Healy quadrangle, an alkali gabbro pluton intrudes the southern part of the metamorphic belt, yielded discordant K-Ar isotopic ages of 146 Ma for hornblende and 133 Ma for biotite (Turner and Smith, 1974; Smith, 1981; Csejtey and others, 1992). These relations suggest that at least part of the protolith is Late Jurassic and possibly older. A minimum age for the protolith is indicated by intrusion of dikes of the Late Cretaceous and early Tertiary East Susitna batholith into the quartz-mica schist, calc-schist, and amphibolite unit of the metamorphic belt.

The Maclaren Glacier metamorphic belt is ductility deformed into protomylonite and phyllonite in the argillite and metagraywacke unit, phyllonite in the phyllite unit, and mylonitic schist in the quartz-mica schist, calc-schist, and amphibolite unit. A general increase in metamorphic grade occurs from the argillite and metagraywacke unit in the south to the quartz-mica schist, calc-schist, and amphibolite unit in the north, grading from lower greenschist facies in the argillite and metagraywacke unit to lower or middle amphibolite

facies metamorphism in the quartz-mica schist, calc-schist, and amphibolite unit (Nokleberg and others, 1985). Relations interpreted as result of regional metamorphism and penetrative deformation during syntectonic intrusion of East Susitna batholith to the north (Nokleberg and others, 1985 1989a).

msh **Quartz-mica schist, calc-schist, and amphibolite (Late Jurassic or older)**—Chiefly quartz-mica schist, amphibolite, and calc-schist. Protoliths chiefly pelite, sandstone, graywacke and minor marl, andesite, and gabbro. Grain size of 0.1 to 0.3 mm. Estimated structural thickness about 6,700 m.

Quartz-mica schists consist of white mica-quartz schist, biotite-white mica-quartz schist, garnet-white mica-quartz schist, biotite-quartz schist, plagioclase-white mica-quartz schist, and plagioclase-chlorite-quartz-white mica schist. Generally fine-grained. Major minerals are plagioclase and garnet porphyroblasts and quartz augen up to 4 mm across. Minor minerals are calcite, epidote-clinozoisite, apatite, graphite, opaque minerals, hornblende, staurolite, and tourmaline. Sparse relict clastic quartz and plagioclase grains. Complicated twinning and zoning in relict plagioclase. Local helicitic and rolled garnet. Locally abundant poikiloblastic plagioclase whose cores contain relict phyllite defined by schistose aggregates of graphite, white mica, and clinozoisite. Sparse sillimanite and kyanite observed in rocks of appropriate bulk composition by Stout (1976), but not observed in this study.

Amphibolite, derived from marl, composed of schistose hornblende, garnet, biotite, quartz, plagioclase, and calcite. Rolled hornblende and garnet porphyroblasts exhibit relict schistosity. Amphibolite derived from gabbro. Ebibits relict hypautomorphic granular texture. Major minerals are plagioclase, hornblende, white mica, and minor chlorite. Calc-schist composed of hornblende-clinozoisite schist and calcite schist. Minor minerals are white mica, quartz, chlorite, and plagioclase.

Unit intensely deformed with a strong schistosity. Two generations of isoclinal folds occur with opposite vergences, with axial planes parallel to schistosity. Older generation folds generally show north vergence whereas younger generation folds generally show south vergence. Near the Broxson Gulch thrust to the south, the axial planes of folds, schistosity, and subparallel compositional layering in the metamorphic belt generally dip moderately to steeply north, whereas to the north, these structures dip steeply south, parallel to the Meteor Peak fault. This change in the dip of schistosity and other structures defines a large overturned antiform that extends from just west of the Delta River to near the western edge of quadrangle.

Unit metamorphosed to amphibolite facies. Diagnostic minerals are hornblende, staurolite, calcic plagioclase, biotite, and garnet. Local retrogressive metamorphism to greenschist facies. Diagnostic greenschist facies minerals are chlorite, epidote-clinozoisite, and white mica. Hornblende partially replaced by biotite and chlorite; garnet by biotite; biotite by white mica; plagioclase by sericite and epidote.

Unit well exposed between the Meteor Peak fault and the Broxson Gulch thrust in the southwestern part of the quadrangle. Intruded by small dikes and sills of the East Susitna batholith and by locally pegmatitic granodiorite. Faulted against gneissose granitic rocks (gg) and phyllite (mph) to the north, and rocks of Wrangellia terrane to south.

K-Ar isotopic analyses of biotite and muscovite from the schist and amphibolite unit range from 48.0 to 30.6 Ma (Table 2 of Nokleberg and others (1992), localities 70-72). One K-Ar hornblende isotopic analysis yields an age of 69.6 Ma (Table 2 of Nokleberg and others (1992), locality 70). The oldest isotopic age of 69.6 Ma may represent prograde regional metamorphism and penetrative deformation during syntectonic intrusion of parts of the East Susitna batholith, described above. The younger K-Ar mica ages may represent either retrograde metamorphism and (or) unroofing and cooling of the Maclaren terrane during lateral migration along the Cenozoic Denali fault. Late Jurassic or older age for protolith

mph **Phyllite (Late Jurassic or older)**—Chiefly fine-grained white mica-quartz phyllite, and minor quartz-plagioclase-white mica phyllite, clinozoisite-chlorite-quartz phyllite, calcite-chlorite phyllite, and quartz-rich marble and metaandesite. Protoliths mainly siltstone, metavolcanic siltstone, marl, limestone, and andesite. Estimated structural thickness about 2,400 m.

Fine-grained, grain size approximately 0.05 to 0.1 mm. Minor metamorphic minerals are garnet, graphite, and sphene. Porphyroblasts of quartz, plagioclase, and garnet up to 1.5 mm across. Relict clastic quartz grains up to 2 mm across. Complexly twinned and zoned plagioclase porphyroclasts. Local grain-size variation parallels schistosity. Local carbonate rich layers. Local relict patches or areas of argillite and metagraywacke (ma). Metaandesite composed of plagioclase microlites with mafic minerals replaced by chlorite and opaque minerals. Local extensive sericite alteration. Metavolcanic graywacke contains clasts of relict igneous plagioclase exhibiting complicated twinning, normal, and oscillatory zoning.

Unit intensely deformed; exhibits strong schistosity. Numerous isoclinal folds and axial plane faults parallel to schistosity. Variably fractured and granulated quartz and plagioclase. Schistosity generally parallels Broxson Gulch thrust and dips moderately to steeply north. Locally intensely sheared. Local relict bedding. Metamorphosed to upper greenschist facies. Diagnostic minerals are biotite and garnet. Local retrogressive lower greenschist facies indicated by partial replacement of garnet by clinozoisite, and plagioclase by white mica.

Unit well exposed in the B-5 and B-6 quadrangles between the Broxson Gulch thrust and the Meteor Peak fault. Generally faulted against quartz-mica schist, calc-schist, and amphibolite (msh) to the north, and argillite and metagraywacke (ma) to the south. Interpreted as an intermediate, metamorphic-grade part of metamorphic belt, between units ma and msh

ma **Argillite and metagraywacke (Late Jurassic or older)**—Chiefly argillite, metagraywacke and metaandesite locally. Protoliths of siltstone, calcareous mudstone, and volcanic graywacke. Average grain size 0.01 to 0.05 mm. Estimated structural thickness about 2,000 m.

Argillite composed principally of graphite-quartz argillite and lesser calcite-biotite-white mica argillite. Major minerals are graphite, quartz, epidote, chlorite, plagioclase, white mica, calcite, and biotite. Locally graded beds having quartz-rich bases and graphite-rich tops. Sparse relict clastic grains.

Metagraywacke composed of white mica, clinozoisite, quartz, graphite, plagioclase, chlorite, and lesser calcite and opaque minerals. Abundant relict resorbed quartz phenocrysts, and lesser relict igneous plagioclase exhibiting normal and oscillatory zonation, and complicated twinning. Locally abundant graded bedding, load casts, bimodal grain distribution, and wavy cross lamination (Nokleberg and others, 1982; Smith, 1981).

Unit strongly schistose. Schistosity generally strikes northeast and dips moderately to steeply north or south. Locally refolded into isoclinal folds. Intensely faulted and sheared. Variably fractured and granulated quartz and plagioclase. Metamorphosed to lower greenschist facies. Diagnostic minerals are graphite, chlorite, clinozoisite, and white mica. Plagioclase partially replaced by white mica.

Unit occurs in the southwestern B-6 and northwestern A-6 quadrangles between the Broxson Gulch thrust and the Meteor Peak fault to the north. Generally faulted against phyllite (mph) to the north and against rocks of the Clearwater and Wrangellia terranes to the south along the Broxson Gulch thrust. Intruded by local, small rhyodacite and granite dikes of Late Cretaceous or early Tertiary age

CLEARWATER TERRANE WITHIN BRANCHES OF BROXSON GULCH THRUST

The Clearwater terrane (Jones and others, 1987; Nokleberg and others, 1982, 1985) occurs in the western part of the quadrangle as a narrow, fault-bounded lens along the Broxson Gulch thrust between the Maclaren terrane to the north and the Wrangellia terrane to the south. The Clearwater terrane consists of highly-deformed chlorite-calcite-quartz schist, quartz-muscovite schist, Upper Triassic marble, greenstone derived from pillow basalt, and sparse metadacite. Metamorphosed at lower greenschist facies. Diagnostic minerals are sericite, epidote, chlorite, and actinolite. Clearwater terrane interpreted as a small fragment of a Late Triassic island arc.

csv **Schistose metasedimentary and metavolcanic rocks (Late Triassic)**—Chiefly fine-grained quartz-white mica-schist, chlorite-calcite-quartz schist, marble, greenstone, and sparse metadacite. Protoliths of quartz siltstone, calcareous sandy siltstone, limestone, fine-grained basalt, and fine-grained dacite. Strongly faulted and fault bounded. Estimated structural thickness of a few thousand meters.

Quartz-white mica schist composed of relict clastic grains of quartz, plagioclase, and K-feldspar in a matrix of very fine-grained quartz and abundant schistose sericite. Feldspars form granular streaks and augen, largely replaced by sericite, and accompanied by concentrations of brown iron oxide. Sparse patches of calcite. Abundant fracturing and granulation. Average grain size 0.02 to 0.5 mm. Chlorite-calcite-quartz schist composed of relict grains of calcareous sand up to 5 mm across in a schistose matrix of very fine-grained chlorite, calcite, and quartz. Major minerals in schist of quartz, white mica, calcite, and chlorite.

Marble composed of calcite grains up to 7 mm across in very fine-grained schistose matrix of calcite and sparse grains and augen of quartz. Very fine- to fine-grained, average grain size varies from 0.02 to 2 mm. To the west in the southeastern Healy quadrangle, marble layers in sedimentary rocks correlative with the Clearwater terrane contain *Heterastridium* sp. of Late Triassic age (Jones and others, 1987; Csejtey and others, 1992).

Greenstone composed of plagioclase phenocrysts and sparse glomerocrysts, up to 1.5 mm and averaging 0.5 mm long, in groundmass of clinopyroxene largely replaced by chlorite, actinolite, epidote, and locally by turbid, brown, cryptocrystalline material. Relict ophitic texture. Local pillow structure. Sparse calcite and chlorite veins. Major minerals are clinopyroxene, partially replaced by chlorite, actinolite, and epidote, and plagioclase.

Metadacite composed of relict quartz and plagioclase microphenocrysts, averaging 1.0 to 1.5 mm across, in a matrix of very fine-grained granular quartz and varying proportions of schistose white mica, chlorite, and calcite. Major relict minerals are quartz and plagioclase; secondary minerals are calcite, quartz, white mica, chlorite, apatite, and opaque minerals. Relict plagioclase phenocrysts euhedral to anhedral; usually exhibits albite twinning. Local extensive calcite replacement of relict plagioclase phenocrysts and matrix.

Unit exhibits weak schistosity strikes northeast to east and dips moderately to steeply north. Local phyllonite occurs parallel to schistosity. Clasts in metamorphosed fine-grained detrital rocks flattened parallel to schistosity. Metasedimentary rocks locally display relict bedding.

Unit occurs in a fault-bounded block within branches of the Broxson Gulch thrust in the northwestern A-6 quadrangle. Faulted against Maclaren terrane to the northwest and Wrangellia terrane to the southeast. Unit includes a small exposure of fault-bounded diorite and quartz diorite (grs3, part)

WRANGELLIA TERRANE

The Wrangellia terrane (Jones and others, 1987; Nokleberg and others, 1982, 1985, 1989a) is subdivided into the Slana River subterrane to the north, and the Tangle subterrane to the south (Nokleberg and others, 1982, 1985), and occurs across the southern part of the quadrangle. The Slana River subterrane is bounded to the north by the Broxson Gulch thrust and to the south by the Eureka Creek fault. The Tangle subterrane occurs south of the Eureka Creek fault. The Wrangellia terrane is weakly regionally metamorphosed at lower greenschist facies (Nokleberg and others, 1985). Metamorphic minerals generally fine-grained and disseminated; abundant relict minerals occur in most rocks.

The Slana River and Tangle subterranes exhibit significantly different stratigraphies, as described below, which indicate important differences in origin (Nokleberg and others, 1985): (1) In the Tangle

subterrane, the upper Paleozoic rocks formed in deep water, at some distance from a site of submarine island-arc volcanism, whereas in the Slana River subterrane, the upper Paleozoic rocks formed along an axis of submarine volcanism. (2) In the Tangle subterrane, Triassic rifting and basaltic volcanism were initially submarine and closer to the axis of rifting, whereas in the Slana River subterrane, Triassic rifting and basaltic volcanism were initially subaerial and probably commenced later and farther from the axis of rifting. (3) During the later stages of rifting, basaltic volcanism was much more voluminous in the Tangle subterrane than in the Slana River subterrane. And (4) in the Slana River subterrane, oceanic and continental-margin sedimentation continued through the Jurassic and Cretaceous, whereas no similar event is preserved in the Tangle subterrane.

These differences in geologic history suggest that the Tangle and Slana River subterranes: (1) represent distal and proximal parts, respectively, of the same late Paleozoic island-arc; (2) represent proximal and distal parts, respectively of the same Triassic rift system; and (3) have been considerably shortened tectonically, and juxtaposed during terrane migration and accretion.

Three major geologic events occurred in the origin and evolution of the Wrangellia terrane. These events were first summarized by Richter and Jones (1973) and later amplified by Nokleberg and others (1985). Each event contributed to the formation of one of the three major stratigraphic units in Wrangellia.

The first event was formation of the late Paleozoic submarine volcanic and associated sedimentary rocks and plutonic rocks of the Skolai arc (Bond, 1973, 1976; Richter and Jones, 1973; Nokleberg and others, 1985; Barker and Stern, 1986). The main evidence for an island-arc origin of the late Paleozoic volcanic and associated rocks is : (1) submarine deposition of the volcanic flows, tuff, and breccia, and associated volcanic graywacke and argillite of the Slana Spur Formation and Tetelna Volcanics (Bond, 1973, 1976); (2) little or no quartz in the volcanic rocks and associated shallow-intrusive bodies; (3) locally abundant features that indicate turbiditic deposition of sedimentary and volcanic debris to form volcanic graywacke; and (4) the absence of abundant continental crustal detritus in upper Paleozoic stratified rocks (Richter, 1976; Nokleberg and others, 1982). In addition, common lead isotopic compositions for late Paleozoic granitic rocks intruding Wrangellia terrane are low in radiogenic lead, and are derived from a mixture of oceanic mantle and pelagic sediment leads, without an older continental component (Aleinikoff and others, 1987).

The second event was rifting that formed the Upper Triassic Nikolai Greenstone and associated gabbro dikes and cumulate mafic and ultramafic sills (Richter and Jones, 1973; Jones and others, 1977; Nokleberg and others, 1985). The main evidence for a rift origin of the Nikolai Greenstone and associated intrusive rocks is: (1) the vast extent and great thickness throughout Wrangellia terrane (Jones and others, 1977); (2) the relatively constant originally igneous composition and texture (Jones and others, 1977; MacKevett, 1978; Winkler and others, 1981; Nokleberg and others, 1982a); (3) an average chemical composition, approximating a typical tholeiite (MacKevett and Richter, 1975; Silberling and others, 1981); (4) REE analyses compatible with (back-arc) spreading (Barker and others, 1989); and (5) the narrow age range for extrusion of the basalt (Jones and others, 1977). However, recent studies by Richards and others (1991) suggest formation in a mantle plume setting. The main evidence cited for a plume origin is: (1) lack of sheeted dikes and rift structures; (2) no indication of crustal extension; and (3) a relatively short-lived period of mainly mafic volcanism that commenced with submarine and ended with subaerial eruption.

The third event was formation of a marginal flysch basin in which was deposited the Upper Jurassic and Lower Cretaceous argillite, graywacke, conglomerate, and andesite of the Gravina-Nutzotin belt onto the northern edge of the Wrangellia terrane (Berg and others, 1972; Richter and Jones, 1973; Nokleberg and others, 1985). The abundant volcanic-derived detritus in the flysch, the associated andesite volcanic and volcaniclastic rocks of the Lower Cretaceous Chisana Formation, and the sparse coeval granitic plutonic rocks are interpreted as portions of the Gravina or Chisana arc which formed along the margin of Wrangellia terrane (Plafker and others, 1989; Stanley and others, 1990). The main evidence for deposition of the Gravina-Nutzotin belt within a flysch basin on the accreting margin of Wrangellia terrane is the derivation of clasts in conglomerate, some from Wrangellia terrane, and some from a continental source (Berg and others, 1972; Richter, 1976). The local andesitic and volcanic detritus in graywacke, and the abundant andesite flows and breccia in the upper part of the belt (Berg and others, 1972; Richter, 1976) suggests a short-lived island arc built on the leading edge of Wrangellia terrane as it neared North America.

WITHIN BRANCHES OF THE BROXSON GULCH THRUST

umm **Ultramafic and mafic igneous rocks occurring along Broxson Gulch thrust (Cretaceous to Triassic?)**—Chiefly dunite, olivine-clinopyroxene cumulates, serpentinite, metagabbro, and metadiabase. Ultramafic rocks possess both cumulate and metamorphic textures; interpreted as probable exposures of dismembered alpine peridotite. Relationship of the mafic rocks to the ultramafic rocks unclear. Mafic rocks of relatively younger dikes within the alpine peridotite; locally may be part of unit of gabbro, diabase and metagabbro (ga) that intrudes Late Triassic and older rocks throughout the Wrangellia terrane. Estimated structural thickness about 1,500 m.

Dunite medium- to coarse-grained; exhibits a well developed crystalloblastic texture. Primary minerals are olivine, commonly kink-banded and magnetite. Variably altered from nearly fresh to completely serpentinized. Magnetite content varies from about one to ten percent. A weak schistosity and planar fracturing occur locally. Massive sulfides occur locally.

Olivine-clinopyroxene cumulates composed of olivine-clinopyroxene cumulate, clinopyroxene-olivine cumulate, plagioclase-olivine-clinopyroxene cumulate, and plagioclase-orthopyroxene-clinopyroxene-olivine cumulate. Generally medium-grained exhibiting orthocumulate textures. Subhedral

to anhedral olivine generally surrounded by anhedral pyroxene. Less abundant euhedral to subhedral pyroxene surrounded by olivine. Plagioclase, comprising up to 20 percent, generally occurs interstitially; however in one sample it occurs both interstitial to, and poikilitically included, in olivine and clinopyroxene. Olivine varies from about 30 to 90% with an average of 70%; clinopyroxene varies from about 5 to 30% with an average of 25%; orthopyroxene generally present in amounts less than 5%. Minor opaque minerals, biotite, and brown hornblende occur locally. Olivine locally replaced by serpentine and pyroxene and plagioclase by saussurite.

Serpentinite fine- to medium-grained, locally with mesh texture. Local faint relict cumulate igneous texture. Contains up to 10% opaque minerals some of which occur along vein-like networks. Locally highly sheared.

Metagabbro composed principally of hornblende metagabbro and minor hornblende-clinopyroxene metagabbro and clinopyroxene metagabbro. Mainly relict fine- to medium-grained, hypautomorphic granular and lesser subophitic texture. Relict minerals are hornblende, plagioclase, and clinopyroxene and local olivine, quartz, biotite, ilmenite, and other opaque minerals. Metamorphic minerals are actinolite, saussurite, sericite, chlorite, clinozoisite-epidote, and serpentine. Clinopyroxene locally replaced by primary hornblende.

Metadiabase composed of hornblende-plagioclase metadiabase and clinopyroxene-plagioclase metadiabase. Fine- to medium-grained, diabasic texture. Relict minerals are plagioclase, clinopyroxene, and hornblende. Metamorphic minerals are actinolite, sericite, chlorite, epidote, and saussurite.

Metagabbro and metadiabase variably metamorphosed at lower greenschist facies. Diagnostic minerals are actinolite, saussurite, sericite, chlorite, and clinozoisite-epidote. Plagioclase partially to completely replaced by saussurite, sericite, chlorite, and epidote; clinopyroxene and hornblende by actinolite, saussurite, epidote, and chlorite; biotite by chlorite, and olivine by serpentine, epidote, and chlorite.

Unit occurs in scattered, fault-bounded exposures within branches of the Broxson thrust in the B-4, B-5, and B-6 quadrangles. Interpreted either as: (1) fault-bounded remnants of cumulate mafic and ultramafic rocks occurring in the Wrangellia terrane; (2) fault-bounded remnants of other terranes that were tectonically enclosed along the Broxson Gulch thrust; (3) a remnant of the terrane of ultramafic and associated rocks that occur along northern margin of Wrangellia terrane in eastern part of quadrangle; or (4) some combination thereof.

Part of unit may be co-magmatic with the unit of cumulate mafic and ultramafic rocks and the Nikolai Greenstone, and therefore Late Triassic(?) in age. However, K-Ar isotopic analyses of hornblende in gabbro dikes in picrite sills at two localities in the B-4 quadrangle yielded ages of ages of 91.9 and 97.7 Ma (Table 2 of Nokleberg and others (1992), localities 73, 74). Because the cumulate mafic and ultramafic rocks exhibit local, low-grade metamorphism, these Late Cretaceous ages could represent the age of the low-grade regional metamorphism of the Wrangellia terrane. Alternatively, the ultramafic rocks at these localities, which occur in narrow fault-bounded lenses near the Denali and Broxson Gulch faults, could represent younger, fault-bounded Late Cretaceous intrusions

UNITS SOUTH OF BROXSON GULCH THRUST AND DENALI FAULT AND NORTH OF THE PAXSON LAKE FAULT

JTrm **McCarthy Formation (Early Jurassic and Late Triassic)**—Chiefly rhythmically, thin- to medium-bedded, calcareous argillite and impure limestone, mainly spiculitic, skeletal, or intraclastic lime packstone (Silberling and others, 1981). Estimated maximum stratigraphic thickness of a few hundred m.

Limestone contains abundant, poorly preserved and recrystallized fossils up to 0.5 mm across, each composed of one to several calcite crystals. Fossils occur in fine-grained, turbid, green-brown calcareous matrix containing sparse veins of coarser calcite. Fossil material tentatively identified as radiolarians, sparse sponge spicules, and rare benthic foraminifers. Calcareous shales contain distinctive occurrence of *Monotis M. subcircularia(?)*, and indicate a Late Triassic age for part of this unit in this quadrangle (Table 1 of Nokleberg and others (1992), localities 121, 122).

Unit occurs in a narrow, fault-bounded lens along branches of the Broxson Gulch thrust in the western part of the quadrangle between the Clearwater terrane to the north and the Wrangellia terrane to the south. The nearest other occurrence of the McCarthy Formation about 220 km to the southeast in the type area in the McCarthy quadrangle, where the age ranges from Late Triassic to Early Jurassic (MacKevett, 1978)

GABBRO, DIABASE, AND METAGABBRO, AND CUMULATE MAFIC AND ULTRAMAFIC ROCKS

Locally extensive gabbro dikes, small sills, large, cumulate mafic and ultramafic sills, and small plutons intrude the Nikolai Greenstone and older rocks throughout Wrangellia terrane. Interpreted as co-magmatic with the basalts that formed the Nikolai Greenstone (Nokleberg and others, 1982, 1985)

ga **Gabbro, diabase, and metagabbro (Late Triassic?)**—Chiefly hornblende gabbro, clinopyroxene gabbro, and hornblende-clinopyroxene gabbro and sparse quartz gabbro and hornblende quartz diorite. Dark-gray, fine- to medium-grained, and mainly relict hypautomorphic granular texture, but locally porphyritic, ophitic to subophitic, and diabasic. Porphyritic variants contain relict phenocrysts of plagioclase up to 3 mm long. Relict primary minerals are clinopyroxene and plagioclase; local hornblende, biotite, quartz, magnetite, and sparse olivine. Metamorphic minerals are chlorite, white mica, actinolite, quartz, calcite, epidote, and zeolites. Clinopyroxene commonly twinned and zoned and locally rimmed by igneous hornblende. Hornblende locally replaced by igneous biotite.

Locally intensely metamorphosed and weakly schistose. Variably fractured and granulated. Metamorphosed to lower greenschist facies.

Diagnostic minerals are chlorite, epidote, actinolite, white mica, and calcite. Clinopyroxene partially replaced by actinolite, chlorite, and epidote; hornblende by chlorite, epidote, and actinolite; plagioclase by white mica, epidote, and saussurite.

Numerous sills, too small to be depicted on map, occur in the lower limestone member of the Eagle Creek Formation in southeastern part of quadrangle. Intrudes Nikolai Greenstone and older rocks in both Slana River and Tangle subterranes. Interpreted as forming in late-magmatic stage of eruption of mafic lavas that formed Nikolai Greenstone (Nokleberg and others, 1985). Only larger bodies shown on the geologic map. In some areas, may be late Paleozoic in age and part of the igneous suite in the Slana Spur Formation and Tetelna volcanics

cu **Cumulate mafic and ultramafic rocks (Late Triassic?)**—Chiefly consists of: (1) fault-bounded lenses of olivine-cumulate and olivine-pyroxene cumulate in Slana River subterrane, particularly in the area between Delta and Maclaren Rivers and, (2) large sills of olivine cumulate, olivine pyroxene cumulate, and pyroxene plagioclase cumulate south of Fish Lake in Tangle subterrane. Includes the Fish Lake Complex of Stout (1976). Estimated thickness of a few thousand meters

Olivine cumulate composed of fine- to medium-grained aggregates of euhedral to subhedral olivine and sparse chromite in a matrix of overgrown olivine, clinopyroxene or plagioclase. Locally aligned tabular olivine. Local layering defined by variation in grain size and serpentinization. Generally intensely serpentinized with olivine replaced by serpentine, magnetite, and talc, and matrix replaced by chlorite and(or) sericite. Common undulose extinction and kink-banding in olivine. Relict cumulate texture in intensely serpentinized samples. Variably fractured, granulated, and deformed.

Olivine-pyroxene cumulate composed of fine-to medium-grained aggregates of euhedral to subhedral olivine, clinopyroxene, and sparse chromite in a matrix of overgrown olivine and clinopyroxene and locally plagioclase. Olivine variably fractured. Locally intensely altered with olivine replaced by serpentine and magnetite; clinopyroxene by actinolite and chlorite; and plagioclase by very fine-grained epidote and white mica.

Pyroxene-plagioclase cumulate composed of fine- to medium-grained aggregates of euhedral to subhedral clinopyroxene, plagioclase, and sparse chromite in a matrix of overgrown clinopyroxene or plagioclase. Local minor orthopyroxene.

Locally intensely metamorphosed to lower greenschist facies exhibiting granoblastic texture. Diagnostic minerals are chlorite, epidote, actinolite, white mica, and calcite. Locally weakly schistose. Most of unit occurs in Tangle subterrane, in vicinity of Fish Lake in central part of quadrangle. Intrudes Nikolai Greenstone and older rocks in both Slana River and Tangle subterranes. Interpreted as comagmatic with magmas that formed Nikolai Greenstone (Nokleberg and others, 1985)

SLANA RIVER SUBTERRANE SOUTH OF BROXSON GULCH THRUST AND DENALI FAULT AND NORTH OF EUREKA CREEK FAULT

The Slana River subterrane (Nokleberg and others, 1982b, 1985) consists mainly of: (1) upper Paleozoic marine volcanic and sedimentary rocks; (2) associated late Paleozoic hypabyssal and plutonic rocks, (3) disconformably overlying massive basalt flows of the Triassic Nikolai Greenstone and, (4) coeval gabbro and cumulate mafic and ultramafic rocks, Triassic limestone, and younger Mesozoic flysch.

KJs **Marine metasedimentary rocks (Early Cretaceous and Late Jurassic)**—Principally deep-marine turbidite deposits consisting of graded beds of metamorphosed dark-gray to gray argillite, siltstone, and graywacke that locally alternate with beds of massive graywacke, pebbly graywacke, pebble to cobble conglomerate and sparse andesite. Graded beds well developed locally; consist of rhythmically alternating units that range from 1 cm to more than 30 cm in thickness. Massive graywacke and conglomerate beds up to 20 m thick. Thickness probably greater than 1,000 m; top not exposed.

Argillite composed of fine-grained, relict quartz and plagioclase clasts in matrix of chlorite and white mica. Minor minerals are epidote-clinozoisite, calcite, and sparse biotite. Millimeter-scale bedding defined by graphite-rich layers. Incipient schistosity at 18° to 20° to bedding defined by preferred orientation of sericite, and by elongation of quartz and plagioclase grains. Argillite grades to schist adjacent to Chistochina Glacier. Schist composed of metamorphic quartz, chlorite, epidote, fibrous amphibole, and minor calcite.

Boulder to cobble, and pebble conglomerates composed chiefly of granitic clasts in a matrix of sand-sized schist, slate, quartz and local plagioclase and interstitial chlorite. Quartz grains partially recrystallized. Sandstone composed of relict clastic quartz and plagioclase grains. Plagioclase partially replaced by white mica and epidote. Matrix generally consists of variable proportions of very fine-grained schistose aggregates of chlorite, epidote, sericite, quartz, calcite and opaque minerals. Andesite exhibits relict ophitic texture; mainly plagioclase microlites in groundmass of chlorite and minor white mica.

Unit locally intensely faulted and isoclinally folded. Local weak to moderately developed schistosity. Metamorphosed to lower greenschist facies. Diagnostic minerals are chlorite, epidote, white mica, actinolite, and calcite.

Unit occurs in eastern part of quadrangle along a 2- to 4-km-wide bands south of, and adjacent to, the Denali fault. Unconformably overlies Upper Triassic limestone and Nikolai Greenstone. Locally faulted along margins. Forms northwestern part of a thick sequence of flysch and associated rocks of the Gravina-Nutzotin belt which extends several thousand kilometers to the southeast (Berg and others, 1972; Monger and Berg, 1977). One locality in the southeastern part of the quadrangle yields Late Jurassic megafossils (Table 1 of Nokleberg and others (1992), locality 77). In the Nabesna quadrangle to the southeast, unit contains locally abundant Buchia

assemblages ranging in age from Late Jurassic to Early Cretaceous (Richter, 1976)

Trl **Limestone (Late Triassic) (Unit of Richter and others, 1977)**—Chiefly dark-to light-gray micrite, dismicrite, or microsparite. Conformably overlies the Nikolai Greenstone (Trn). Fine- to medium-grained, medium- to massive-bedded (10 cm to 2 m) containing lenses and nodules of gray and black chert and irregular patch works of disseminated fine-grained quartz. Locally recrystallized, commonly brecciated, and veined by coarsely crystalline calcite. Basal part of unit generally contains clasts of Nikolai Greenstone. Many outcrops too small to depict on map. Thickness approximately 20 to 150 m.

Generally metamorphosed to lower greenschist facies; locally weakly schistose. Unit often occurs in narrow fault-enclosed lenses and slivers in subjacent Nikolai Greenstone in southeastern part of quadrangle. Locally contains moderately abundant Late Triassic megafossils and microfossils (Table 1 of Nokleberg and others (1992), localities 78, 79, 111-119).

Trn **Nikolai Greenstone (Late Triassic) (Unit of Rohn, 1900)**—Similar to Nikolai Greenstone in Tangle subterrane. Chiefly massive dark-gray-green, dark-gray-brown, reddish-brown, and maroon-gray subaerial, amygdaloidal basalt flows separated locally by thin beds of reddish-brown nonmarine volcaniclastic rocks. Defined predominantly from intermixed aa and pahoehoe flows with individual flow units ranging from a few centimeters to more than 15 m thick. Base generally marked by discontinuous conglomerate-breccia, with fragments of basalt, and underlying sedimentary rocks. Shale and chert occur interlayered with greenstone in sparse exposures in south-central part of the quadrangle. Chiefly interbedded black carbonaceous shale, gray thin-bedded argillite, light-colored chert, and light-gray limestone with minor gray siltstone and conglomerate (Richter and others, 1977). Approximately 1,500 m thick.

Common relict igneous textures in greenstones, generally fine-grained ophitic to intergranular, locally grading to porphyritic, and glomeroporphyritic with a felty groundmass of plagioclase microlites. Relict igneous minerals are clinopyroxene, plagioclase, and magnetite and very sparse olivine. Local undulose extinction in plagioclase and clinopyroxene. Locally resorbed plagioclase. Amygdules up to 6 mm across filled by calcite, chlorite, epidote, quartz, and(or) zeolite.

Unit pervasively metamorphosed to lower greenschist facies. Metamorphic minerals are chlorite, epidote, quartz, sericite, calcite, and actinolite. Clinopyroxene partially replaced by actinolite, epidote, and chlorite; plagioclase by epidote, sericite, and chlorite. Olivine partially serpentinized. Rare metamorphic prehnite and pumpellyite. Locally weakly schistose. Sparse quartz veins. Local abundant pervasive epidote and chlorite alteration associated with regional metamorphism. Amygdules filled by chalcopyrite, bornite, malachite, and(or) azurite in areas of pervasive epidote-chlorite alteration.

Unit widely distributed between the Denali and Eureka Creek faults in the south-central and southeastern part of the quadrangle. Disconformably overlies the Eagle Creek Formation (Pe); overlain by Upper Triassic limestone (Trl). Contains Middle or Late Triassic fossils in the Tangle subterrane, described below. In southeastern part of quadrangle, unit locally composed of Middle Triassic shale, limestone, and chert, up to 40 m thick (Richter and others, 1977), too small to depict on map.

Pe **Eagle Creek Formation (Early Permian) (Unit of Richter and Dutro, 1975)**—Occurs in southeastern and south-central parts of quadrangle. Disconformably overlies the Slana Spur Formation. Abundant mega- and microfossils, mainly brachiopods, corals, and foraminifers, indicating an Early Permian age (Table 1 of Nokleberg and others (1992), localities 17-51, 73-74, 80-84, 87-94, 96-106, 109-110). Correlative with the limestone of Hasen Creek Formation of Skolai Group in southern Wrangell Mountains (MacKevett, 1978).

Chiefly conformable sequence of alternating marine argillite and limestone. In south-central part of quadrangle, east of Gulkana Glacier, consists of a lower limestone member composed of calcilutite, calcarenite, and calcirudite, and an upper member of argillite (Bond, 1976). Bioclastic material composed of a heterogeneous mixture of coral, bryozoan, brachiopod, echinoid, crinoid, fusulinid, and algal(?) fragments (Bond, 1976; Richter and Dutro, 1975). Fine- to medium-grained. Thin- to medium-bedded. Local planar cross-bedding in limestone. Limestones deposited in shallow water at or near wave base (Bond, 1976). Upper part of unit grades into thin (less than 40 m thick) radiolarian chert, shale, and limestone (Richter and others, 1977) of Permian age (N. J. Silberling, written commun., 1981). In eastern part of quadrangle, differentiated into two limestone and two argillite members, described below (Richter and others, 1977). Disconformably overlain by Nikolai Greenstone; conformably overlies the Slana Spur Formation. Thickness approximately 900 m. In southeastern part of quadrangle, subdivided by Richter and others (1977) into four members:

Upper argillite member, chiefly thin-bedded and dark-gray with thin lenses and laminae of gray siltstone and minor bioclastic limestone, calcareous siltstone, and pyritic sandstone. Locally contains a thin (0 to 40 m) upper unit of shale, limestone, and chert. Thickness about 125 m.

Upper limestone member, chiefly thin-bedded gray and siliceous. Locally weathers ocherous yellow-orange. Contains thin argillite interbeds and discontinuous lenses of massive light-gray-weathering limestone as much as 50 m thick. Argillite content increases in lower part of member. Locally metamorphosed to a conspicuous white, crystalline, granoblastic marble. Thickness probably ranges between 75 and 150 m.

Lower argillite member, chiefly thin-bedded, dark-gray, shaley argillite, and gray-green, locally calcareous siltstones. Also contains subordinate dark-gray bioclastic limestone (bryozoan biostromes), and thin-bedded gray limestone. Gray limestone increases in abundance in upper part of member, forming a ribboned unit that grades into limestone-argillite beds of upper limestone member. Locally cut by a number of irregular intrusive masses, dikes, and sills of

equigranular gabbro and porphyritic diorite. Thickness approximately 400 m.

Lower limestone member, chiefly massive to thin-bedded gray limestone. Locally contains nodules and lenses of black and light-gray chert. Also contains subordinate beds of dark-gray calcareous, volcanic graywacke, sandstone, and siltstone, and clastic limestone. Clastic beds generally graded and locally cross bedded. Gabbro sills, some as much as 25 m thick, relatively numerous. Thickness approximately 275 m.

Argillite composed mainly of relict clastic quartz, lesser plagioclase, and sparse hornblende in a recrystallized, variable matrix of chlorite, epidote-clinozoisite, sericite, actinolite, sphene, opaque minerals, and sparse biotite and garnet. Schistose argillite defined by alignment of sericite and elongate mineral grains.

Limestone composed mainly of detrital calcite with lesser quartz and plagioclase. Metamorphic minerals are chlorite, sericite, white mica, zeolites, and opaque minerals. Locally recrystallized calcite. Local bioclastic material replaced by zeolites.

Calcareous volcanic graywacke composed mainly of relict clasts of carbonate, twinned and zoned plagioclase, and sparse K-feldspar and quartz, up to 2 mm, in a recrystallized matrix of very fine-grained carbonate, epidote, white mica, chlorite, opaque minerals, and clay(?) minerals. Local fractures filled by iron oxide, carbonate, and zeolites.

Volcanic sandstone composed mainly of rounded to subangular relict clasts of twinned plagioclase and minor quartz in a recrystallized matrix of chlorite, carbonate, and lesser white mica, epidote, and opaque minerals.

Local schistose siltstone composed mainly of equidimensional to slightly elongate quartz porphyroclasts up to 0.6 mm long in matrix of aligned white mica, fine opaque stringers, and lenticular patches of chlorite and white mica. Minor minerals are epidote-clinozoisite, actinolite, biotite, and garnet.

Unit metamorphosed mainly to greenschist facies. Diagnostic minerals are chlorite, epidote-clinozoisite, actinolite, white mica, and sparse biotite and garnet. Plagioclase partially replaced by white mica, saussurite, epidote-clinozoisite, and clay minerals; hornblende by chlorite and actinolite; biotite by chlorite.

Pl **Shallow-level intrusive stocks, dikes, sills, and small plutons (Early Permian?)**—Sparse to locally abundant andesite, and lesser dacite and rhyolite, stocks, sills, and dikes that intrude the Slana Spur Formation and Tetelna Volcanics. Unit occurs mainly in the south-central and southeastern parts of the quadrangle. Only larger bodies shown on geologic map.

Medium-gray, fine- to medium-grained dacite porphyry composed of euhedral to anhedral, variably resorbed quartz phenocrysts, up to 5 mm across, twinned and zoned plagioclase, and minor K-feldspar phenocrysts and glomerocrysts, up to 3 mm across, in a very fine-grained groundmass composed predominantly of granoblastic quartz and feldspar. Weathers pale-yellow.

Dark-gray-green andesite porphyry composed of locally abundant twinned and zoned plagioclase phenocrysts and glomerocrysts up to 5 mm long and local relict hornblende phenocrysts, up to 2 mm long, in a groundmass composed predominantly of chlorite and locally sparse to felty plagioclase microlites weathers orange. Minor minerals are quartz, biotite, opaque minerals, and rare clinopyroxene. Local relict hypautomorphic granular texture. Sparse amygdules filled with calcite, chlorite, and quartz.

Granoblastic overprint metamorphic texture with local weak schistosity. Metamorphosed to lower greenschist facies. Diagnostic minerals are chlorite, epidote-clinozoisite, actinolite, sericite, and calcite. Plagioclase partially replaced by variable combinations of saussurite, sericite, epidote-clinozoisite, and calcite; K-feldspar by sericite, epidote-clinozoisite and calcite; hornblende by chlorite and actinolite; biotite by chlorite; clinopyroxene by chlorite and epidote-clinozoisite.

Locally intensely, hydrothermally altered to very fine-grained aggregates of sericite, chlorite, epidote, actinolite, albite, potassium feldspar, montmorillonite, kaolinite(?), and calcite. Local disseminated sulfide minerals and sparse quartz-sulfide mineral veins. Sulfide minerals are pyrite, chalcopyrite, and sphalerite. Local intense iron-staining from weathering of accessory iron-sulphide minerals.

The shallow-level intrusive rocks occur in the Slana Spur Formation and Tetelna Volcanics, but not in the younger, Lower Permian Eagle Creek Formation; interpreted as co-magmatic with volcanic rocks of the Slana Spur Formation and of Early Permian (?) age

PPs **Slana Spur Formation (Early Permian to Middle Pennsylvanian) (Unit of Richter and Dutro, 1975)**—Chiefly a thick sequence of marine calcareous and noncalcareous volcaniclastic rocks and lesser limestone, tuff, and volcanic breccia. Occurs in the southeastern and south-central parts of the quadrangle. Ages of megafossils and microfossils in both members of formation, mainly brachiopods, corals, and foraminifers, range from Middle Pennsylvanian through Early Permian (Table 1 of Nokleberg and others (1992), localities 13-16, 52-57, 59-63, 65-69, 71-72, 76, 86, 107-108). A K-Ar hornblende isotopic analysis of a weakly metamorphosed mafic nodule in the Slana Spur Formation yields an age of 94.4 Ma (Table 2 of Nokleberg and others (1992), locality 82), and may represent the age of the low-grade regional metamorphism of the Wrangellia terrane. Unit correlative with volcaniclastic member of Station Creek Formation of Skolai Group in southern Wrangell Mountains (MacKevett, 1978). Disconformably overlies Tetelna Volcanics. Chiefly andesite tuff, flows, and breccia, and volcanic-rich sedimentary rocks including mudstone, sandstone, graywacke, and conglomerate, and locally fossiliferous limestone. Thickness 700 to 1,400 m.

Highly sheared adjacent to the Broxson Gulch thrust. General weak granoblastic texture with local weak schistosity. Lower greenschist facies metamorphism defined by fine-grained granoblastic occurrence of chlorite, epidote-clinozoisite, actinolite, white mica, and calcite throughout unit. Plagioclase and K-feldspar partially replaced by white mica, epidote, saussurite, and calcite; hornblende by chlorite, epidote, and actinolite. Variably strained, fractured,

and granulated quartz and feldspar and bent mica. Local relict hydrothermal alteration and Fe-staining adjacent to shallow-level intrusive rocks. Hydrothermal alteration defined by very fine-grained aggregates of epidote, chlorite, actinolite, albite, K-feldspar, calcite, and sericite. Locally divided into:

ℙPsu **Calcareous volcaniclastic rocks member**—Predominantly gray-green, clastic, locally fossiliferous limestone and marble, and gray-green, coarse-grained, calcareous volcanic sandstone. Includes minor volcanic conglomerate, light-gray-green lapilli tuff, and andesite. Clastic rocks generally contain angular to subangular clasts, have abundant graded bedding, abundant contorted stratification, slump structures; poorly sorted. Volcaniclastic rocks contain abundant andesitic, dacitic and pumice rock fragments, with relict pyroclastic, pilotaxitic, trachytic, scoriaceous, and glassy textures. Thickness 350 to 450 m.

Limestone to marble composed of calcite with minor quartz, plagioclase, and sericite. Local skarn, developed in lenses up to 1 m thick along diabase-marble contact, composed of fine- to medium-grained, schistose calcite and minor epidote, hornblende, wollastonite, garnet, and clinopyroxene.

Volcanic sandstone composed of fine-grained, rounded to subangular clasts of twinned and zoned plagioclase and minor quartz in matrix predominantly of chlorite. Authigenic analcite replaces and cements clasts in some calcareous sandstone.

Calcareous volcanic graywacke composed of abundant twinned and zoned plagioclase clasts up to 1.5 mm long in a fine-grained, sparsely fossiliferous matrix of calcite and minor epidote and white mica. Presence of graded bedding, poor sorting, and slump structures indicates sedimentary and volcaniclastic strata deposited from turbidity currents in a low-energy environment below wave base located near active volcanic vents (Bond, 1973, 1976).

Andesite has intergranular to ophitic porphyritic texture. Composed of twinned and zoned plagioclase phenocrysts locally resorbed and sparse glomerocrysts up to 3.5 mm long, and locally, hornblende phenocrysts, up to 2 mm long, in a fine-grained to felty groundmass of plagioclase, quartz, and white mica. Locally amygdules filled with clinozoisite and chlorite.

Andesite tuff composed of angular to subangular plagioclase fragments in matrix predominantly of clay minerals, opaque minerals, and locally abundant calcite. Hornblende(?) completely replaced by chlorite.

Diabase composed of fine-grained plagioclase and clinopyroxene and minor opaque minerals, chlorite, and epidote. Relict minerals are plagioclase and sparse hornblende, quartz, clinopyroxene, and opaque minerals. Metamorphic minerals are chlorite, epidote, calcite, and white mica.

Dacitic to rhyodacitic ash to lapilli tuffs green to gray, mainly broken plagioclase, quartz, K-feldspar, and lithic fragments in matrix of very fine-grained aggregate of quartz, feldspar, chlorite, and locally leucoxene. Plagioclase commonly twinned. Pumice fragments preserved as irregular platelets and disks of chlorite with porous or tubular texture. Lithic fragments angular; composed of a variety of volcanic rocks exhibiting porphyritic, trachytic, pilotaxitic, glassy, microvesicular, and scoriaceous textures. Locally stratified due to variation in grain size, color, and grading. Local normal and double grading. A 200-m-thick, unstratified lapilli tuff, in the northwest A-3 quadrangle, exhibits distinctive large aerial extent, lack of K-feldspar, and coarse pumice fragments ranging from less that 1 cm to nearly 1 m long (Bond, 1976).

Green to grayish green debris flow deposits composed of poorly sorted angular fragments, from 5 to 20 cm across and locally inbricate, in a matrix of sand, silt, and mud. Angular fragments composed of volcanic rock fragments, plagioclase, quartz, and fossil debris. Matrix mainly microcrystalline quartz, fine chlorite, and(or) sericite, and leucoxene. Individual beds range in thickness from a few cm to about 18 m. Upper parts of beds often graded, with thin, laminated tops (Bond, 1976).

Gray, brown, or green, poorly sorted sandstone and graywacke beds, from 2 cm. to over 1 m thick; interbedded with subordinate, massive or laminated, silty claystones from a few inches to several feet thick. Beds graded but lack internal current features such as crossbedding, convoluted bedding, parallel lamination, or ripple-drift lamination. Grain size ranges from pebbles to fine sand. Clasts mainly angular to subangular. Clasts composed of andesitic(?) fragments, plagioclase, and quartz. Volcanic rock fragments exhibit pyroclastic, pilotaxitic, trachytic, glassy, and sparse scoriaceous and pumiceous textures. Matrix chiefly a dark, microcrystalline aggregate of chlorite and leucoxene and minor amounts of quartz and feldspar (Bond, 1976).

Unit metamorphosed to lower greenschist facies. Well exposed in the south-central and southeastern part of the quadrangle, south of the Denali fault and Broxson Gulch thrust, and north of the Eureka Creek fault. Underlies Eagle Creek Formation (Pe). Overlies volcaniclastic rocks member (ℙPsl)

ℙPsl **Volcaniclastic rocks member**—Dark-gray, dark-green, and maroon volcanic and volcaniclastic rocks. Chiefly volcanic flows interbedded with lapilli tuff, volcanic breccia, graywacke, argillite, and limestone to marble. Local massive to bedded conglomerate, graywacke, and siltstone. Volcaniclastic rocks contain abundant volcanic rock fragments and relict pumice, exhibiting trachytic, scoriaceous, and relict glassy textures. Limestone to marble lenses, as much as 25 m thick, mainly gray thin- to medium-bedded locally volcanic-rich limestone. Local graded bedding in volcaniclastic rocks. Presence of graded bedding in volcaniclastic rocks and fossil fragments in volcanic breccias indicate volcaniclastic and volcanic rocks deposited on sea floor as blanket deposits around volcanic vents (Bond, 1973, 1976). Thickness 300 to 950 m.

Lapilli tuff composed of crystals and crystal fragments of quartz, plagioclase, and K-feldspar(?) up to 3 mm across, and lithic volcanic rock fragments up to 9 mm across and lesser microcrystalline quartz fragments. Matrix mainly chlorite and minor sericite, calcite, and opaque minerals.

Andesitic flows composed mainly of phenocrysts and sparse glomerocrysts of zoned and twinned plagioclase, up to 4 mm long, in groundmass of very fine-grained quartz, chlorite, epidote, sericite, and

opaque minerals. Volcanic textures range from hypautomorphic granular to porphyritic. Sparse to abundant plagioclase microlites form local pilotaxitic to felty groundmass textures. Phenocrysts of hornblende and biotite, up to 1 mm long, occur locally. Quartz phenocrysts, up to 6 mm across, with resorbed outlines in dacite.

Basaltic flows composed of clinopyroxene and sparse hornblende phenocrysts, up to 1.8 mm, across in trachytic groundmass of calcic plagioclase. Local amygdules filled with quartz and chlorite. Relict igneous minerals are plagioclase, hornblende, clinopyroxene, and biotite. Metamorphic minerals are quartz, chlorite, epidote, sericite, calcite, and opaque minerals.

Volcanic graywacke composed of rounded to subangular relict clastic plagioclase, quartz, and sparse K-feldspar in a very fine-grained, largely recrystallized matrix of chlorite, feldspar, quartz, white mica, carbonate, and clay. Locally calcite-rich. Local resorbed outlines on quartz clasts. Relict volcanic plagioclase commonly twinned and zoned.

Argillite composed of variable combinations of very fine-grained, angular to subangular quartz, plagioclase, and K-feldspar in a recrystallized matrix of calcite, white mica, chlorite, epidote, and opaque minerals. Local abundant calcite veins. Weak schistosity defined by aligned mica and elongate opaque minerals.

Limestone composed of fine-grained calcite with minor quartz, white mica, chlorite and opaque minerals. Locally grades into medium- to coarse-grained light gray to white marble. Locally contains volcanic clasts, up to 5 mm across, composed of quartz and plagioclase. Local carbonaceous coating on calcite grains. Local veins of coarser-grained calcite and sparse quartz. Locally metasomatized to sulfide-silicate skarn adjacent to shallow intrusive rocks. Local disseminations and pods of sulfide minerals, mainly pyrite, chalcopyrite, bornite, and sphalerite.

Unit metamorphosed to lower greenschist facies. Well exposed in the south-central and southeastern part of the quadrangle, south of the Denali fault and Broxson Gulch thrust, and north of the Eureka Creek fault. Overlies Tetelna Volcanics (ℙt)

ℙt **Tetelna Volcanics (Pennsylvanian) (Unit of Mendenhall, 1905)**—Chiefly dark-green, dark-gray-green, and purplish-gray-green volcanic flows, mud and debris avalanches, locally graded, and lapilli-pumice tuffs interbedded with fine- to coarse-grained volcaniclastic rocks. Volcanic flows generally massive and porphyritic. Thickness greater than 1,000 m. Base not exposed.

Volcanic flows, mainly andesite, composed of phenocrysts and glomerocrysts of twinned and zoned plagioclase and local hornblende, up to 4 mm long, in a fine-grained groundmass of chlorite, epidote, felty plagioclase microlites, and sparse microphenocrysts of clinopyroxene. Local amygdules filled with chlorite. Relict minerals are plagioclase, hornblende, clinopyroxene, and sparse quartz. Metamorphic minerals are quartz, actinolite, epidote-clinozoisite, sericite, calcite, and opaque minerals. Tuffs contain pumice and andesitic lithic fragments from millimeters to tens of centimeters across.

Unit metamorphosed to lower greenschist facies. Diagnostic minerals are chlorite, epidote-clinozoisite, actinolite, sericite, and calcite. Plagioclase replaced by epidote, sericite, calcite, and saussurite; hornblende by chlorite and actinolite; clinopyroxene by epidote and actinolite. Weak granoblastic metamorphic texture with variably strained and fractured quartz, plagioclase, hornblende, and clinopyroxene.

Unit occurs mainly in the southeastern corner of the quadrangle in scattered outcrops up to 3 km across. Underlies Slana Spur Formation (ℙPsl). Interpreted to be of Pennsylvanian age because of occurring stratigraphically beneath, and containing volcanic rocks lithologically similar to those in the Slana Spur Formation (Richter, 1976; Richter and others, 1977). Correlative with the volcanic flows member of the Station Creek Formation of the Skolai Group in the southern Wrangell Mountains (MacKevett, 1978)

ℙg **Granitic plutons south of Denali fault (Pennsylvanian)**—Chiefly granite. Generally medium-grained, hypautomorphic granular texture, locally porphyritic. Composed of euhedral to subhedral phenocrysts of K-feldspar up to 5.0 mm, with sparse inclusions of plagioclase and biotite, in a groundmass of quartz, K-feldspar, plagioclase, biotite, sparse opaque minerals and rare zircon. Slight alteration of plagioclase to sericite; biotite to chlorite. Complex twinning and zoning in plagioclase and moderately undulose quartz. Metamorphosed to lower greenschist facies; diagnostic minerals are chlorite, actinolite, and sericite. Occurs in isolated outcrops west of the Chistochina River in the A-2 quadrangle.

U-Pb zircon isotopic analysis yields an age of 309 Ma (Table 2 of Nokleberg and others (1992), locality 79); interpreted as intrusive age. Unit probably northwest extension of the Pennsylvanian Ahtell pluton in the northwestern Gulkana quadrangle (Richter, 1966; Beard and Barker, 1989). K-Ar hornblende isotopic analysis of the granodiorite at Rainbow Mountain in B-4 quadrangle yields a value of 326 Ma (Table 2 of Nokleberg and others (1992), locality 76). This value, if correct, would be a Late Mississippian age, and would be older than the surrounding wallrocks of the Slana Spur Formation. However, the isotopic analysis may be erroneous, and the granitic pluton could be younger

TANGLE SUBTERRANE SOUTH OF EUREKA CREEK FAULT AND NORTH OF PAXSON LAKE FAULT

The Tangle subterrane (Nokleberg and others, 1982b, 1985) consists mainly of a relatively thin sequence of Upper Paleozoic and Lower Triassic sedimentary and tuffaceous rocks, and a relatively thick sequence of unconformably overlying pillow basalt and subaerial basalt flows of the Triassic Nikolai Greenstone and locally overlying limestone. The Tangle subterrane includes the Amphitheater Group of Smith (1974), Stout (1976), and Silberling and others (1981).

Trl **Limestone (Late Triassic)**—Fine- to medium-grained, medium- to massive-bedded. Generally composed of calcite clasts in a very fine-grained matrix

of calcite and minor quartz. Moderately to highly recrystallized. Locally weakly schistose. Contains irregular veins of fine-grained quartz. Commonly veined by coarsely crystalline calcite. Locally extensively metasomatized along veins to hedenbergite-garnet skarn. Major minerals in skarn of calcite, wollastonite, hedenbergite, and garnet; minor minerals are actinolite, plagioclase, and chlorite. Exposed in one locality, faulted against the Nikolai Greenstone and unit grs3 in southwestern part of the quadrangle. Maximum exposed thickness of several hundred m.

Unit contains Late Triassic cephalopods and pelecypods (Table 1 of Nokleberg and others (1992), localities 120, 123). To the west in the southeastern part of the Healy quadrangle, similar limestone layers within the basal member of the Nikolai Greenstone contain megafossils and microfossils also of Late Triassic age (Csejtey and others, 1992)

Nikolai Greenstone (Late Triassic) (Unit of Rohn, 1900)—Unconformably overlies aquagene tuff, argillite, limestone, chert, andesite tuff, and greenstone (Pzt). Divided into:

Trnf **Subaerial basalt flows member**—Similar to Nikolai Greenstone in Slana River subterrane. Chiefly dark gray-green, gray, purple, black, or brown, massive amygdaloidal basalt flows lithologically similar to Nikolai Greenstone in Slana River subterrane. Fine- to medium-grained. Includes sparse basaltic breccia and basaltic aquagene tuff. Sparse limestone, siltstone, shale, and chert occur in south-central part of quadrangle, southeast of Summit Lake. As mapped, includes rocks assigned to Boulder Creek Volcanics and Paxson Mountain Basalt by Stout (1976). Maximum exposed stratigraphic thickness greater than 4,350 m; top eroded.

Basalt flows composed of local phenocrysts and glomerocrysts of complexly twinned and zoned plagioclase, up to 7 mm long (average 1 to 2 mm), in a relict ophitic to intergranular groundmass of plagioclase microlites, hornblende, clinopyroxene, ilmenite, magnetite, and very fine-grained chlorite and opaque minerals. Local, very fine-grained hematite or limonite in the groundmass impart the maroon color. Locally contains concentrically zoned amygdules filled with epidote, calcite, chlorite quartz, zeolites, and occasionally Cu-sulfides. Layers of amygdaloidal concentrations parallel primary layering. Amygdules locally stretched parallel to flow direction.

Unit metamorphosed to lower greenschist facies. Generally weak granoblastic texture superposed on relict ophitic, intergranular, and diabasic textures; locally schistose. Locally mylonitic. Variably fractured and granulated quartz and feldspar. Diagnostic metamorphic minerals are chlorite, epidote-clinozoisite, actinolite, white mica, and rare prehnite and pumpellyite. Plagioclase replaced by white mica, epidote, sericite, calcite, and saussurite; hornblende by chlorite and actinolite; clinopyroxene by chlorite, actinolite, and epidote. Sparse to locally abundant quartz veins up to 30 m thick, composed of minor chlorite, epidote-clinozoisite, calcite, pyrite, chalcopyrite, bornite, and malachite.

Unit well exposed in the southwestern part of the quadrangle. Faulted against Slana Spur Formation along the Eureka Creek fault and against the Maclaren Glacier metamorphic belt of the Maclaren terrane along the Broxson Gulch thrust

Trnp **Pillow basalt flows member**—Chiefly interlayered dark gray-green pillow basalt flows, and minor basalt flow breccia, aquagene and epiclastic tuff, breccia, argillite, and radiolarian chert; equivalent pillowed andesite flows form upper part of Tangle Lakes Formation of Stout (1976). Thickness about 1,020 m.

Pillow basalts exhibit relict ophitic, subophitic, and intergranular textures. Locally porphyritic. Composed of relict plagioclase, hornblende, and clinopyroxene phenocrysts, from 2 to 7 mm long, in chlorite-rich groundmass. Relict igneous minerals are plagioclase, hornblende, and clinopyroxene. Glassy pillow rims replaced by very fine-grained chlorite, actinolite, plagioclase, and epidote. Plagioclase phenocrysts complexly twinned and zoned. Contains amygdules filled by calcite, chlorite, epidote, quartz, zeolites, and sparse Cu-sulfides. Sparse concentric zoning in amygdules.

Aquagene tuff composed of relict pillow rind fragments containing microlites of plagioclase and clinopyroxene. Glass-rich pillow rinds replaced by very fine-grained chlorite, actinolite, feldspar, and epidote.

Epiclastic tuff composed of thin layers, 1 to 3 mm thick, of well sorted, very fine-grained plagioclase and clinopyroxene, extensively replaced by epidote, chlorite, and actinolite.

Volcanic breccia, interbedded with finer-grained tuffs, composed of angular clasts in a light- to dark-green aphanitic matrix. Fragments, average a few inches across and up to 3 feet in diameter; composed of siliceous tuffs, andesite flow rocks, other breccias, and rare tuffaceous limestone (Stout, 1976).

Argillite composed of very fine-grained schistose aggregates of plagioclase, calcite, graphite, and sparse chlorite, sericite, and opaque minerals. Locally finely laminated and calcite-rich.

Gray radiolarian chert composed of granoblastic aggregates of very fine-grained quartz and sparse sericite, chlorite, calcite, epidote, and opaque minerals and with very sparse highly recrystallized radiolaria.

Unit metamorphosed to lower greenschist facies. Generally weak granoblastic texture superposed on relict igneous textures; locally schistose. Variably fractured and granulated. Diagnostic minerals in mafic lithologies of chlorite, epidote-clinozoisite, actinolite, white mica, and graphite. Plagioclase partially replaced by epidote, saussurite, and white mica; hornblende and clinopyroxene by chlorite and actinolite.

Unit well exposed in the southwestern part of the quadrangle. Faulted against Slana River subterrane along the Eureka Creek fault and against the Maclaren Glacier metamorphic belt of the Maclaren terrane along the Broxson Gulch thrust. Underlies subaerial pillow basalt flows member (Trnf).

Sparse layers and lenses of argillite from small hill one locality yield very sparse Middle or Late Triassic *Daonella* or *Halobia* (Table 1 of Nokleberg and others (1992), locality 124). Late Triassic fossils occur in

same unit to west in southeastern Healy quadrangle (Csejtey and others, 1992)

Pzt **Aquagene tuff, argillite, limestone, chert, andesite tuff, and greenstone (late Paleozoic) (Unit of Nokleberg and others (1982)**—Chiefly andesite flows, mud and debris avalanche deposits, and tuff interbedded with fine- to coarse-grained volcaniclastic rocks. Contains lesser interlayered basaltic aquagene tuff, gray-green andesite tuff, gray-green basalt, dark-gray siliceous argillite, light-gray to white calcite, limestone, and marble, and red and black chert. Thickness greater than 875 m; base not exposed.

Aquagene tuff composed of fine- to medium-grained fragments of pillow rinds and basalt up to 7 mm across. Highly altered to very fine-grained aggregates of chlorite, plagioclase, actinolite, graphite, and sericite. Local abundant fine-grained quartz fragments.

Light to dark-gray andesite tuff composed of sparse to abundant plagioclase phenocrysts and crystal fragments, up to 2 mm long, in a very fine-grained granoblastic matrix of actinolite, chlorite, and epidote. Local hornblende phenocrysts. Local felty groundmass composed of plagioclase microlites. Minor zircon and opaque minerals.

Basalt composed of fine-grained ophitic plagioclase and clinopyroxene partly recrystallized to granoblastic epidote, chlorite, actinolite, and sericite. Local clinopyroxene phenocrysts up to 2 mm long. Local relict ophitic to intergranular texture. Amygdaloidal. Sparse pillows exposed at base. Metamorphic minerals are epidote, chlorite, actinolite, sericite, calcite, and graphite. Generally thick-bedded to massive.

Argillite composed of abundant, very fine-grained clastic plagioclase in a matrix composed either of graphite, epidote, and chlorite, or graphite, quartz, and clay. Very fine-grained. Locally tuffaceous.

Light-gray limestone and marble composed of granoblastic to schistose aggregates of medium-grained calcite and sparse dolomite containing local chert nodules, thin chert beds, and minor quartz grains.

Calcareous siltstone composed of approximately equal proportions of granoblastic to schistose calcite and quartz.

Gray to green-gray chert composed of granoblastic aggregates of very fine-grained quartz and sparse sericite, chlorite, calcite, epidote, and opaque minerals and very sparse highly recrystallized radiolaria. Solitary corals occur in limy chert.

Unit generally granoblastic; local weak schistosity. Metamorphosed to lower greenschist facies. Diagnostic minerals are chlorite, epidote, actinolite, white mica, and graphite. Plagioclase partially replaced by white mica; clinopyroxene and hornblende replaced by chlorite and actinolite.

Unit well exposed on east side of Maclaren River, in canyons in foothills to north of East Fork of Eureka Creek, on north side of Amphitheater Mountains, and in narrow canyons cutting foothills to northwest of Wildhorse Creek. Underlies Nikolai Greenstone. Locally folded. Intruded by extensive dikes of gabbro and large sills of diabase and gabbro grading downward into cumulate mafic and ultramafic rocks. Basal unit of the Tangle subterrane. Equivalent to middle and lower parts of Tangle Lakes Formation of Stout (1976). Sparse limestone lenses at one locality contain fragments of late Paleozoic bryozoans (Table 1 of Nokleberg and others (1992), locality 125). On strike to the west in Talkeetna Mountains D-2 quadrangle, correlative unit contains limestones with Early through Late Permian conodonts (Kline and others, 1990)

GULKANA RIVER TERRANE SOUTH OF PAXSON LAKE FAULT

A small part of the Gulkana River terrane, called the metamorphic complex of Gulkana River by Nokleberg and others (1986b), occurs in the south-central part of the quadrangle, south of the Wrangellia terrane. The Paxson Lake fault separates the Gulkana River and Wrangellia terranes. The metamorphic complex of Gulkana River consists of massive to weakly schistose, weakly metamorphosed hornblende andesite (mha). Samples of metaandesite were too low in zirconium to warrant U-Pb zircon isotopic analysis. The complex has been correlated with the lithologically similar Haley Creek metamorphic assemblage in the northern Valdez quadrangle to the southeast (Nokleberg and others, 1989b; Plafker and others, 1989). Both have: (1) similar upper Paleozoic metavolcanic and metasedimentary protoliths; (2) lithologically similar suites of older schistose gabbro and diorite plutons and younger schistose granitic plutons; (3) a similar Late Jurassic K-Ar age of metamorphism and deformation; and (4) a similar geologic history. The major differences between the metamorphic complex of Gulkana River and the Haley Creek metamorphic assemblage are the more abundant metasedimentary rocks in the Haley Creek metamorphic assemblage, and locally higher grade, synplutonic metamorphism for the Haley Creek metamorphic assemblage (Nokleberg and others, 1989b).

The metasedimentary and metavolcanic rocks of both the metamorphic complex of Gulkana River and the Haley Creek metamorphic assemblage are derived from Early Pennsylvanian or older quartzofeldspathic, pelitic, and calcareous marine sedimentary rocks with subordinate mafic and intermediate volcanic rocks that are intruded by Pennsylvanian and Late Jurassic metaplutonic rocks (Nokleberg and others, 1989b; Plafker and others, 1989b). Together, the metamorphic complex of Gulkana River and the Haley Creek metamorphic assemblage have been interpreted as the southern and deeper stratigraphic/structural levels of the Wrangellia terrane (Plafker and others, 1989b). Data supporting this interpretation are: (1) the occurrence of the metamorphic complex along the southern margin of the Wrangellia terrane for several hundred kilometers; and (2) the occurrence of the Pennsylvanian and younger rocks of the Wrangellia terrane to the north and generally structurally, if not stratigraphically above the metamorphic complex.

Alternatively, the metamorphic complex of Gulkana River may be a separate terrane juxtaposed between the Wrangellia terrane to the north and the Peninsular terrane to the south. The following data support this interpretation: (1) the metamorphic complex contains a penetrative fabric and a higher grade of metamorphism than Wrangellia terrane. (2) the metamorphic complex contains a suite of syntectonic,

two-mica granitic rocks that do not occur in the Wrangellia terrane. And (3) the upper Paleozoic rocks of the Wrangellia terrane do not stratigraphically overly the metamorphic complex. Instead, the Paxson Lake fault occurs between the metamorphic complex and Wrangellia terrane. Additional studies are needed to resolve these differing interpretations

mha **Metamorphosed hornblende andesite (late Paleozoic?)**—Porphyritic. Composed of relict hornblende phenocrysts, up to 4 mm long, in a plagioclase microlite-rich groundmass of chlorite, actinolite, quartz, and calcite. Minor relict clinopyroxene occurs in groundmass. Amygdules filled with epidote, calcite, quartz, and chlorite.

Metamorphosed mainly to lower greenschist facies. Locally retrogressed to lower greenschist facies. Plagioclase partially replaced by white mica and epidote; hornblende by chlorite, actinolite, and epidote. Metamorphic grade increases to lower amphibolite facies in highly deformed areas adjacent to metamorphosed granitic and gabbroic plutons within the Gulkana quadrangle to the south. Schistosity strikes east-west and dips steeply to vertically, parallel to Paxson Lake fault. Locally intensely schistose. Local mylonitic schist.

Unit occurs in several outcrops along the southern A-4 and A-5 quadrangle boundaries. Faulted against Tangle subterrane along concealed Paxson Lake fault. Includes pre-Pennsylvanian(?) greenschists and amphibolites of Stout (1976). Faulted along northern margin. Estimated structural thickness of a few hundred meters

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