Digital data for the Reconnaissance geologic map for the Kuskokwim Bay region of southwest Alaska

Including the Bethel, Goodnews Bay, Nushagak Bay, Hagemeister Island, Baird Inlet, Cape Mendenhall, Kuskokwim Bay, Nunivak Island, Saint Matthew, and Pribilof Islands 1:250,000-scale quadrangles

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Abstract

The rocks of the map area range from Proterozoic age metamorphic rocks of the Kanektok metamorphic complex (Kilbuck terrane) to Quaternary age mafic volcanic rocks of Nunivak Island. The map area encompasses much of the type area of the Togiak-Tikchik Complex. The geologic maps used to construct this compilation were, for the most part, reconnaissance studies done in the time period from the 1950's to 1990's. Pioneering work in the map area by J.M. Hoare and W.L. Coonrad forms the basis for much of this map, either directly or as the stepping off point for later studies compiled here.

Physiographically, the map area ranges from glaciated mountains, as much as 1,500 m high in the Ahklun Mountains to the coastal lowlands of northern Bristol Bay and the Kuskokwim delta. The mountains and the finger lakes (drowned fiords) on the east have been particularly strongly effected by Pleistocene and Holocene glaciation.

Within the map area are a number of major faults. The Togiak-Tikchik Fault and its extension to the northeast, the Holitna Fault, are considered extensions of the Denali fault system of central Alaska. Other sub-parallel faults include the Golden Gate, Sawpit, Goodnews, and East Kulukak faults. Northwest trending strike-slip faults cross-cut and offset northeast trending fault systems.

Rocks of the area can be assigned to a number of distinctive lithologic packages. Most distinctive among these packages are the high-grade metamorphic rocks of the Kanektok metamorphic complex or Kilbuck terrane. It is composed of a high-grade metamorphic orthogneiss core surrounded by greenschist and amphibolite facies schist, gneiss, and rare marble and quartzite. These rocks have yielded radiometric ages strongly suggestive of a 2.05 Ga emplacement age. Poorly known Paleozoic rocks, including Ordovician to Devonian and Permian limestone, are found east of the Kanektok metamorphic complex. A Triassic(?) ophiolite complex is on the southeast side of Kuskokwim Bay; otherwise only minor Triassic rock units are known. The most widespread rocks of the area are Jurassic and Early Cretaceous(?) volcanic and volcaniclastic rocks. The Kuskokwim Group flysch is restricted largely to the northeast part of the map area. It consists primarily of shelf and minor nearshore facies rocks. Primarily exposed in the lowlands west of the Ahklun Mountains, extensive latest Tertiary and Quaternary alkalic basalt flows and lesser pyroclastic rocks form much of the bedrock of the remaining area. On Saint Matthew Island, Cretaceous volcanic and pyroclastic rocks occur that are not found elsewhere within the map area. The Kuskokwim Group and older rocks, including on Saint Matthew Island, but not the Kanektok metamorphic complex, are intruded by widely dispersed Late Cretaceous and/or Early Tertiary granitic rocks. Much of the lowland area is mantled by unconsolidated deposits that include glacial, alluvial and fluvial, marine, estuarine, and eolian deposits. These formed during several episodes of Quaternary glaciation.

Introduction and Previous work

The map comprises the southwestern-most part of mainland Alaska (figure 1), exclusive of the Alaska Peninsula, extending from Nushagak Bay on the east to the Saint Matthew and the Pribilof Islands on the west. In general, it is a relatively poorly known region, but includes the oldest rocks known in Alaska as well as rocks that are geologically very young. The geologic maps used to construct this compilation were, for the most part, reconnaissance studies done in the time period from the 1950's to 1990's. A few detailed studies, such as the Masters thesis work of John Murphy (1987) or topical studies by Box and others (1990) and Moll-Stalcup and others (1996) provide better control on some aspects of the geology. Pioneering work in the map area by J.M. Hoare and W.L. Coonrad forms the basis for much of this map, either directly or as the stepping off point for later studies. A wide range of sources were used to construct this map, including the published mapping of T.F.W. Barth (1956) in the Pribilof Islands, W.L. Coonrad (1957) in the Baird Inlet, Cape Mendenhall, Kuskokwim Bay, and Nunivak Island 1:250,000-scale quadrangles, W.W. Patton, Jr. and others (1975) on Saint Matthew Island, J.M. Hoare and W.L. Coonrad (1959a), and S.E. Box and others (1993) in the Bethel 1:250,000-scale quadrangle and J.M. Hoare and W.L. Coonrad (1961a, b, 1978) in the Goodnews Bay, Nushagak Bay, and Hagemeister Island 1:250,000-scale quadrangles. In addition, we relied on Box (1985a) for revisions to Hoare and Coonrad (1978) in the Hagemeister Island and southern Goodnews Bay 1:250,000-scale quadrangles.

Figure 1 near here. Index map showing the map area relative to Alaska.

The authors gratefully acknowledge discussions with Steve Box and Sue Karl during map preparation. F. Wilson especially acknowledges the introduction to the area by Warren Coonrad and Joe Hoare during the 1975 field season and Coonrad's continued encouragement and support. Technical review of this map compilation was by Arthur Schultz and Jeanine Schmidt.

Physiographic framework

The map area encompasses the glaciated Ahklun and Kilbuck Mountains, the coastal lowlands of the southern Kuskokwim delta and northern Bristol Bay, and a number of large islands in the southern Bering Sea. The Ahklun Mountains, range up to 1,500 m in elevation and form the Ahklun Mountains province of Wahrhaftig (1965). The Ahklun Mountains supported a local ice cap during Pleistocene time that was the source for alpine and large valley glaciers that extended out to sea in Bristol Bay (Kaufman and Manley, 2004; Kaufman and others, 2001a, b; Manley and others, 2001) as well to the east. The finger lakes of the east side of the map area in Wood-Tikchik State Park and southward were affected by Pleistocene and Holocene glaciation and are well-developed landlocked fiords. West of the Ahklun Mountains is the southern part of the Kilbuck Mountains, up to 1,150 m high, which lie in Wahrhaftig's Kuskokwim Mountains province. Although remnant cirque glaciers occur locally in the Ahklun Mountains, only weathered cirques indicate past glaciation in the Kilbuck Mountains. Farther west are the marshy, lake-covered lowlands of northern Bristol Bay and the Kuskokwim River delta in Wahrhaftig's Yukon-Kuskokwim Coastal Lowland province. Glacial deposits are an important component of the unconsolidated deposits of this part of the map area; however, the dominant topographic features are the geologically young basaltic cinder cones and flows of the lowland

and the volcanic islands rising from Wahrhaftig's (1965) Bering Platform province. Nelson Island and Saint Matthew expose older rocks in the only other topographic high points of the western part of the map area. Permafrost is sporadic to discontinuous throughout the map area (Wahrhaftig, 1965) and both permafrost and the cirque glaciers are melting as a result of current climate conditions.

Geologic framework

This map area contains of a number of distinctive lithologic packages. However, we refrain from assigning units to particular terranes because the area remains a region of reconnaissance scale mapping and poor age control. We do provide a summary of descriptions of the terrane assignments others have made in a section below.

One of the more significant geologic features of the region are the high-grade metamorphic rocks of the Proterozoic, possibly Paleoproterozoic, Kanektok metamorphic complex of Hoare and Coonrad (1979), also known as the Kilbuck terrane of Jones and others (1981). Exposed at the western edge of the mountains north of Goodnews Bay, the complex is composed of an orthogneiss core metamorphosed to granulite facies surrounded by greenschist and amphibolite facies schist, gneiss, and rare marble and quartzite (Turner and others, in prep.) and may include some of the oldest rocks in Alaska. A more complete discussion of the unique geology of the Kanektok metamorphic complex is provided in a section below

A variety of poorly known Paleozoic rocks, including Ordovician to Devonian and Permian limestone, crop out east of the Kanektok metamorphic complex. These rocks are included in a complex structural assemblage of Paleozoic and Mesozoic volcanic and sedimentary rocks and melange traditionally assigned to the Gemuk Group (Hoare and Coonrad, 1959a; 1961a, b). The Gemuk Group was originally loosely defined in the 1950's in the northwestern Taylor Mountains quadrangle and southward (Cady and others, 1955); subsequently it areal extent was expanded by Hoare and Coonrad (1959a, b, 1961a, b) and through unpublished mapping of J.N. Platt in the Taylor Mountains and J.N. Platt and E.H. Muller in the Dillingham 1:250,000-scale quadrangles in the late 1950's era. The Gemuk Group came to include many rocks in southwest Alaska ranging in age from Paleozoic to Cretaceous. Wilson and Coonrad (2005) discussed the history of usage of the term Gemuk Group and formally abandoned the Gemuk Group as a stratigraphic unit and term. Many of the rocks that were traditionally included in this unit are now assigned to the Togiak-Tikchik Complex. Within this map area, rocks ranging in age from early Paleozoic to Cretaceous are included in the Togiak-Tikchik Complex structural assemblage. Box and others (1993) subdivided these rocks into a series of lithologic units in the Bethel quadrangle and Wilson and others (2006b) created similar subdivisions in the Taylor Mountains and Dillingham quadrangles to the east. However, other than the few subdivisions made of the MzPz unit by Hoare and Coonrad (1978), similar subdivisions have not been made here for the rocks in the Goodnews Bay quadrangle. However, re-examination of available data, especially the field notes of J.M. Hoare, W.L. Coonrad, W.H. Condon, and others may allow some subdivision in the future. Among the rocks assigned to the Togiak-Tikchik Complex in the Bethel quadrangle are metamorphic rocks of unknown protolith age that locally yield Jurassic metamorphic ages. Jones and Silberling (1981), Box (1985a), and Decker and others (1994) assigned the rocks of the Gemuk Group (now Togiak-Tikchik Complex) largely to the Goodnews terrane; some were also assigned to the Togiak terrane. Box and others (1993) interpreted these as an accretionary complex that was progressively under thrust beneath the volcanic arc rocks to the east.

At Cape Newenham, between Kuskokwim and Togiak Bays, a Triassic(?) ophiolite complex is associated with mafic and ultramafic intrusive rocks of possible Jurassic age in a complex structural relationship, otherwise only minor Triassic rock units are known in the map area. The Jurassic ultramafic rocks were the source for the platinum group metals of the only commercial platinum deposit in Alaska (Hudson, 2001).

The eastern part of the map area consists largely of Triassic(?), Jurassic, and Early Cretaceous(?) volcaniclastic sedimentary rocks assigned to the Togiak terrane by Box (1985a; Box and others, 1993; Decker and others, 1994). Wilson and others (2006b) suggested that these rocks may correlate in part with lithologically similar rocks, called the Koksetna River sequence of Wallace and others (1989), exposed west of the Alaska-Aleutian Range. The two packages of rocks may represent the east and west sides of a Jurassic basin. The Kilbuck Mountains in the north central Bethel quadrangle also consist largely of Jurassic and Early(?) Cretaceous volcaniclastic sedimentary rocks, but also include Middle Jurassic andesite and basalt flows and aquagene tuff (Box and others, 1993). These rocks have been assigned to the Nyac terrane (Box and others, 1993; Decker and others, 1994) and are considered in part distinctive because they are intruded by mid-Cretaceous plutons, such as the Nyac pluton, which are not known to intrude rocks assigned to any other terrane in southwest Alaska. However, these Nyac terrane rocks are poorly known. Some Jurassic fossil collections have been made. A number of igneous intrusive complexes that intrude the terrane are undated and were assigned an early Tertiary to Jurassic age range by Box and others (1993).

Overlying the older rocks of the Ahklun Mountains are 4 distinctive sequences of Lower Cretaceous sedimentary rocks. All of Valanginian age, each has a slightly different mix of lithologies and character. The graywacke of Buchia Ridge (Hoare and Coonrad, 1983) is a fining upward clastic sequence rich in *Buchia* in its lower part and present in a largely undeformed state in a thrust sheet. West of Buchia Ridge is the limy grit and limestone of the Ungalikthluk belt of Hoare and Coonrad (1983) containing lithic clasts of low-grade metamorphic rocks. Farther west are the volcanic and sedimentary rocks of the Mount Oratia belt of Hoare and Coonrad (1983), which is a multi-hued package of widely varying lithology including chert, graywacke, andesitic crystal-lithic tuff and a few flows. Rocks of the Mount Oratia belt rocks overlie the Togiak-Tikchik Complex. The westernmost of the 4 sequences is the calcareous graywacke and siltstone of the Eek Mountains belt of Hoare and Coonrad (1983). They consist of strongly folded and commonly overturned calcareous turbidities of presumed Valanginian age and contain lithic clasts that include metamorphic rocks presumed to be of the Kanektok metamorphic complex (Hoare and Coonrad, 1983).

The Kuskokwim Group, an Early (Albian?) and Late Cretaceous flysch is restricted largely to the northeast part of the map area, although it is widely distributed throughout southwest Alaska. It consists largely of interbedded graywacke and shale and locally, has interbeds of argillite and conglomerate (Cady and others, 1955). In the map area, it consists largely of shelf facies rocks, although nearshore facies conglomeratic rocks are found in the vicinity of the Kanektok metamorphic complex rocks. Box and others (1993) considered these conglomeratic rocks, which include clasts probably derived from the Kanektok metamorphic complex, to be a basal facies of the Kuskokwim Group.

Intruding the Kuskokwim Group and older rocks, including on Saint Matthew Island, are widely dispersed latest Cretaceous and (or) early Tertiary granitic rocks.

Widely dispersed latest Cretaceous and (or) early Tertiary granitic rocks intrude the Kuskokwim Group and most of the older rocks, but not the Kanektok metamorphic complex (Patton and others, 1975; Wilson, 1977; Hoare and Coonrad, 1978; Box and others, 1993). Yielding ages between approximately 60 and 70 Ma, these plutons show a crude compositional zoning. The more mafic plutons tend to occur on the west, whereas more potassium-rich plutons tend to occur in the eastern part of the map area and farther eastward in the Dillingham quadrangle (Wilson, 1977; Wilson and others, 2006b). These plutons are conspicuously absent in the Kanektok metamorphic complex. A number of plutons of unknown age intrude the Jurassic volcanic and volcaniclastic rocks of the Nyac terrane of Jones and others (1981) and Box and others (1993) northwest of the Kilbuck terrane. Some of these plutons may include latest Cretaceous to early Tertiary plutons, but they may also include plutonic rocks as old as Jurassic. Within the region, the Nyac terrane rocks are the only ones intruded by plutons of mid-Cretaceous (~110 to ~120 Ma) age.

Primarily exposed in the lowlands west of the Ahklun Mountains, extensive latest Tertiary and Quaternary alkalic basalt flows and lesser pyroclastic rocks form much of the bedrock of the remaining map area. These volcanic rocks are well known from Nunivak and the Pribilof Islands. Nunivak Island, the Pribilof Islands, and parts of the nearby mainland are composed of olivine basalt flows of latest Tertiary and Quaternary age. The volcanic rocks are part of a belt of alkalic basalt that is distributed in western Alaska as far north as the Seward Peninsula. The rocks of Nunivak Island and the Pribilof Islands were extensively sampled for paleomagnetic analysis and radiometric age determination (Cox and Dalrymple, 1967; Cox and others, 1966) and these analyses were used to help establish the geomagnetic time scale of Cox and others (1968). In addition, xenoliths from the basalt of Nunivak Island have been the subject of a number of studies (see for example, Hoare and Condon, 1973; Francis, 1976; Roden and others, 1980).

On Saint Matthew Island, Cretaceous volcanic and pyroclastic rocks are exposed that are not distinguished elsewhere within the map area. However, rocks of this age may be present within other map units of the mainland. In the westernmost part of the map area, the largely volcanic and intrusive rocks of Saint Matthew Island (Patton and others, 1975), along with Saint Lawrence Island to the north (Patton and Csejtey, 1979) provide the only exposures of the older rocks of the Bering Sea shelf. Correlation of these rocks with others on the mainland indicates continuation of on-land geology offshore.

Unconsolidated deposits of the map area have a major component of glacially derived materials and in the eastern part of the map area are in readily apparent glacial landforms. At maximum Pleistocene glaciation, glaciers flowing east from the Ahklun Mountains merged with glaciers coming from the Alaska-Aleutian Range to the east. West of the Ahklun and Kilbuck Mountains, much of the map area consists of Quaternary surficial deposits of the Kuskokwim delta. Largely not subdivided, these deposits include glacial deposits of late Wisconsin and older age (W.L. Coonrad, oral commun., 2001) and uplifted marine deposits. West of the mountains, the effects of glaciation are more subtle and not well known or mapped. W.L. Coonrad (oral commun., 2001) reported glacial deposits in stream and river cutbanks well away from the mountains in the Kuskokwim delta lowlands. Small alpine glaciers remain in the higher mountains of the region.

Structural setting

Terranes

The rocks in the Ahklun and Kilbuck Mountains area were divided into a series of overlapping terranes and sub-terranes in the 1980's and 1990's by Jones and Silberling (1981) and subsequently by S.E. Box and coworkers (Box, 1985a, b; Box and others, 1993; Decker and others, 1994). Decker and others (1994) summarized the application of terrane terminology to the region, dividing the map area into 4 terranes (fig. 2). However, it must be recognized that development of terrane terminology for this region preceded detailed geologic mapping; as a result some of the map units shown on the geologic map may occur in more than one terrane, reflecting the uncertainty in the geologic knowledge at the time.

Figure 2 near here: Tectonostratigraphic terrane map of southwest Alaska, after Decker and others (1994). Portion of the Kuskokwim Bay region map area included is shown outlined in black.

The map area is cut by a number of major faults and postulated faults which were used in part to define the terranes. Many of these terranes reflect various components of an accretionary arc system. However, the most distinct of the terranes is the Kilbuck terrane, which is synonymous with the Kanektok metamorphic complex. This is the sole terrane of the region not thought to reflect an accretionary arc. It can be described as multiply deformed, upper amphibolite to granulite facies metamorphic rocks and is thought to represent a fragment of continental crust of unknown affinity. It is also the only terrane not intruded by younger, i.e. late Mesozoic or Cenozoic, plutons. The Togiak terrane constitutes the largest single terrane fragment in the map area; it includes many of the rocks of the eastern part of the Goodnews Bay and Bethel quadrangles, much of the Hagemeister Island quadrangle, and all of the Jurassic-age stratified bedrock of the Nushagak Bay quadrangle. It is divided into two sub-terranes, divided by the East Kulukak Fault. According to Decker and others (1994, p. 293), the sub-terranes "differ in sedimentary facies and structural style, but are linked by common provenance and stratigraphic history." The larger Hagemeister sub-terrane apparently represents an Upper Triassic to Lower Cretaceous volcanic island arc built upon an Upper Triassic ophiolitic basement. The Kulukak sub-terrane consists primarily of Jurassic volcaniclastic turbidites; although Box (1985a) suggested a provenance link with the Hagemeister sub-terrane, according to Decker and others (1994), no direct depositional relationship has been observed.

"The Goodnews terrane is a collage of variably metamorphosed blocks of laminated tuff, chert, basalt, graywacke, limestone, gabbro, and ultramafic rocks, in roughly that order of abundance" (Decker and others, 1994, p. 295). Included rocks, generally in fault bounded blocks, include Devonian to Ordovician , Permian, and Triassic limestone and early Paleozoic, Triassic, and Jurassic chert. Subdivided into 3 sub-terranes by Box (1985a), the Tikchik terrane as defined by Jones and Silberling (1979) was included in the Goodnews terrane as a sub-terrane by Decker and others, 1994). The Cape Peirce sub-terrane is described as "foliated metamorphic rocks *** probably derived from protoliths of probable Permian and Triassic ages" (Box, 1985a). Unfortunately, the description in Decker and others (1994) is not clear, but it appears that the Cape Peirce sub-terrane may include the Triassic ophiolitic rocks upon which the volcanic arc of the Togiak terrane was built. The Platinum sub-terrane is variably described as Lower and Middle Jurassic nonfoliated mafic flows, tuff, and volcaniclastic rocks, apparently containing interbedded calcareous tuff having Permian fossils or as the nonfoliated and less deformed equivalent of the lowest schistose nappe of the Permian to Triassic Cape Peirce terrane (Decker and others, 1994). Clearly, there is an internal conflict in the definition of the sub-terrane; what is known for both of these sub-terranes is that they are intruded by zoned ultramafic bodies of presumed Jurassic age. In map pattern, the Platinum sub-terrane includes two of the Permian map units (Pv, Pvs) we assign to the Togiak-Tikchik Complex. The Nukluk and Tikchik sub-terranes are similar in that both are structurally disrupted units, or mélanges containing blocks ranging in age from early Paleozoic to Jurassic or Early Cretaceous. The blocks include chert and limestone (map units ŦRvs, Pls), clastic sedimentary rocks (map unit Pcs), and Permian and Triassic volcanic rocks (map units Pv, ŦRv). However, the Tikchik sub-terrane is spatially separated from the others parts of the Goodnews terrane; the Togiak terrane lies between it and the rest of the Goodnews terrane.

The Nyac terrane is found along the northwest part of the bedrock outcrop belt of the map area in the Bethel quadrangle. Poorly defined, it is thought to consist of an arc-related Jurassic volcanic and volcaniclastic rock assemblage (Decker and others, 1994). The Golden Gate Fault separates the Nyac and Kilbuck terranes where exposed. The Nyac terrane is distinctive in that is it the only terrane of the region intruded by mid-Cretaceous-age plutons.

The terrane nomenclature for the region is in need of revision based on the mapping of the present compilation. More detailed studies will help to better define the appropriate packages and will better define the appropriate bounding structures. Paleontological and detrital zircon studies should help to better understand the affinities of the mapped rock units.

Overlap assemblages

A number of Cretaceous sedimentary packages occur as overlap assemblages on the defined terranes. The earliest of these are of Valanginian age and occur in 4 belts of common age but distinctive lithology. The graywacke of Buchia Ridge (Kgbr), and the Ungalikthluk (Klg) belt of Hoare and Coonrad (1983) overlap the Togiak terrane, whereas the Mount Oratia (Kvm) and Eek Mountains (Kcgc) belts of Hoare and Coonrad (1983) overlap the Goodnews terrane. Rocks of the Eek Mountains belt include high-grade metamorphic clasts apparently derived from the Kanektok metamorphic complex.

The Kuskokwim Group (Kk) is a largely Late Cretaceous sedimentary unit widespread in southwest Alaska. In the map area, it is found overlapping both the Goodnews and Kilbuck (Kanektok metamorphic complex) terranes. It locally underlies the Kilbuck terrane as well; outcrops of Kuskokwim Group rocks are found along the Kanektok River where the river cuts through the metamorphic complex which forms the ridges above.

The youngest of the overlap assemblages is the Summit Island Formation in the southern part of the map area. Apparently deposited in two adjacent(?) basins, it overlaps the Togiak terrane.

Plutonic rocks of latest Cretaceous or earliest Tertiary age intrude rocks of all terranes east of the Kilbuck terrane; they are conspicuously absent west of the terrane boundary. As mentioned earlier, mid-Cretaceous plutonic rocks are found only in the Nyac terrane within the map area.

Faulting

Faults have been mapped throughout the map area. One of the major faults, the Holitna Fault enters the map area from the northeast and is considered part of the Denali-Farewell fault system of southern Alaska. It has a trace that cuts surficial deposits that indicates it is presently active (F.H. Wilson, unpub. data). Field maps from the 1969 and 1970 seasons of J.M. Hoare and W.H. Condon (unpub. data) indicate northwest side up and right-lateral offset. Cady and others (1955) indicated that it had a high-angle reverse sense of motion. Offset along the Denali fault system is traditionally considered to have a right-lateral sense of motion (see for example Decker and others, 1994); however, a recent aeromagnetic survey (Saltus and Milicevic, 2004; U.S. Geological Survey, 2006) can be interpreted to suggest that parts of the fault system in this area may actually be left-lateral. The Holitna Fault is generally linked with the Togiak-Tikchik and Hagemeister Faults (Hoare and Coonrad, 1978) which strike offshore into Bristol Bay.

Other sub-parallel faults, such as the Golden Gate (Hoare and Coonrad, 1959a), Goodnews, and East Kulukak (Hoare and Coonrad, 1978) faults provide strong evidence for a northeast trending structural grain and are in some cases considered terrane bounding (see Box and others, 1993; Decker and others, 1994). The Golden Gate fault generally trends parallel to the Denali-Farewell fault system and passes through the western Bethel quadrangle. It is a high-angle reverse fault dipping steeply to the southeast. A number of northwest trending faults cross-cut and offset rock units and the northeast trending faults. Key among these are the Mount Oratia and Fork (or Lake) Creek high-angle reverse faults, as well as the Trail Creek strike-slip fault of Hoare and Coonrad (1978). Each of these faults follows topographic lineaments along which the rocks on either side generally indicate right-lateral offset. For example, the northwest trending Trail Creek strike-slip fault appears to have 10 to 15 km of left-lateral movement.

Thrust and high-angle reverse faults are an important structural feature in the map area; however, as will be discussed more fully in the discussion of the Kanektok metamorphic complex rocks, agreement between the available maps is limited at best. Box (1985a) mapped a complex system of thrust and folded thrust faults cutting Mesozoic rock units between Kuskokwim and Togiak Bays. While these faults are shown here as “thrusts”, the rock units that these faults separate have many common characteristics and that they commonly emplace younger over older rocks.

Metamorphism and metamorphic rocks

Description of the metamorphic character of the rocks of the region is incomplete at best. Although poorly known, the most thorough descriptions have been made for the Kanektok metamorphic complex, described later. Available descriptions indicate that many of the rocks of the Bethel quadrangle have undergone low-grade metamorphism, whereas the rocks of the Kisaralik Anticlinorium of Box and others (1993) in the north-central Bethel quadrangle are metamorphosed to greenschist and transitional greenschist-blueschist facies. Similarly, metamorphic rocks in the vicinity of Goodnews Bay (see “Metamorphic rocks of the Togiak-Tikchik Complex” section in the unit descriptions) also are metamorphosed to greenschist and transitional greenschist-blueschist facies. Deformation of rock units is even less well-described; where data is available it is included in the applicable unit description.

A distinctive sequence of lithologic units is exposed on a ridge in the Kilbuck Mountains just east of Greenstone Ridge in the Bethel quadrangle. These rocks were originally mapped as part of the Gemuk Group surrounded by rocks of the Kuskokwim Group by Hoare and Coonrad (1959a). Box and others (1993) recognized them as an antiformally folded structural sequence of variably metamorphosed rocks that they informally referred to as the Kisaralik anticlinorium. The anticlinorium is cored by a structurally imbricate package of Mesozoic to Paleozoic deep-marine sedimentary and mafic volcanic rocks (Box and others, 1993). The folding that created the anticlinorium also folded the rocks of the Kuskokwim Group nearshore facies (Kkn) that unconformably overlie the Mesozoic to Paleozoic core (Box and others, 1993). Deformation and metamorphic grade decrease structurally downward through the structural package. In structural order from top to bottom map units MzPzp, MDm, and MzPzm are strongly foliated and are metamorphosed to greenschist and transitional greenschist-blueschist facies whereas lower units in the anticlinorium MzPzs, MzPzv, MzPzc have a slaty cleavage and are metamorphosed to prehnite-pumpellyite facies (Box and others, 1993). Units are separated by antiformally folded low-angle faults (Box and others, 1993). Units making up the Kisaralik anticlinorium were included in the Goodnews terrane by Box and others (1993). Box and others (1993) used the basal conglomerate of the Kuskokwim Group, which they reported as Late Cretaceous (Cenomanian?) in age, to constrain the younger age limit of these map units. However, fossils of Albian (late Early Cretaceous) age are reported by Murphy (1987) for this map unit (Kkn).

Quaternary geology

The Kuskokwim Bay region has a rich Quaternary geologic history of mafic volcanism, glacial advances, eolian deposition, varying sea levels, and the development of periglacial features. However, in general detailed mapping of surficial geology has not been undertaken, except for the mafic volcanic rocks on Nunivak and the Pribilof Islands (Cox and others, 1966; 1968; Hoare and others, 1968); in much of the map area surficial deposits are not subdivided. A number of topical studies by Kaufman and co-workers (Kaufman and Manley, 2004; Kaufman and others, 2001a; 2001b; 2003; Manley and others, 2001; Levy and others, 2004) and Lea and co-workers (Lea, 1989; Lea and Waythomas, 1990; Lea and others, 1991) have begun establishment of a framework for the Quaternary history and stratigraphy of the map area. In particular, Lea (1989) defined a number of formal and informal stratigraphic units and type sections in the southeast part of the map area. However, to date, maps showing the distribution of these units have not been produced.

Within the map area, glacial deposits range from Holocene to an indeterminate Pleistocene age. The oldest of the deposits form the informally defined Nichols Hills drift of Lea (1989) on the Nushagak Peninsula. These deposits are undated, and designated oldest because they stratigraphically underlie better defined deposits of the Nushagak Formation and lie outboard of glacial deposits that still retain some of their original morphology. The Nichols Hills drift, according to Lea (1989, p. 88) may overlie a still older diamicton exposed at Cape Constantine reported by W.L. Coonrad (oral commun. to P.D. Lea, 1982). Overlying the Nichols Hills drift are the deposits of the Nushagak Formation. This unit, originally called the Nushagak beds by Spurr (1900) and formalized as the Nushagak Formation by Mertie (1938), was originally designated as of Pliocene or Miocene age and thought to represent nearshore marine deposits. However, re-examination of the type area by (Lea, 1989) indicates that the deposits are proglacial intertidal and fluvial sediments. According to an oral communication by Louie Marincovich Jr. (USGS, 1988) to Lea (1989, p. 91), the originally reported molluscan fossil assemblage for the formation is now considered to be of Quaternary age. The Nushagak Formation includes morainal deposits designated as the Ekuk moraines, which Lea (1989) tentatively correlated with the Halfmoon Bay drift of Muller (1952). Locally, younger morainal deposits, informally named the Manokotak and Okstukuk moraines, which may record early? Wisconsin and late Wisconsin maxima, are mapped north of Nushagak Bay (Kaufman and others, 2001a, b).

West of the Ahklun Mountains, prior to this map, virtually no mapping of surficial deposits exists. W.L. Coonrad (USGS, retired, oral commun., 2002?) has reported the presence of glacial deposits in river cuts in the Yukon Kuskokwim Coastal Lowland province of Wahrhaftig (1965). Hoare and Coonrad (1959a, 1961b) showed a reconnaissance level subdivision of surficial deposits in the Bethel and Goodnews Bay quadrangles and where possible that map data is shown here. We show a reconnaissance-level subdivision of surficial deposits in the Baird Inlet and Kuskokwim Bay quadrangles on the basis of topography and surface character. In the Nushagak Bay quadrangle, unpublished mapping of W.L. Coonrad in the northern part of the quadrangle was extended southward based on W.L. Coonrad's field sheets and our topographic interpretation.

Geochronology

There is a long history of geochronologic studies in this map area, yet coverage of geologic units remains scant and data interpretation (table 1) is open to some controversy, particularly on the older rocks.

More than 60 K-Ar age determinations on young mafic volcanic rocks on Nunivak Island and the Pribilof Islands were used to provide precise age control for the paleomagnetic time scale developed by Cox, Dalrymple, and Hoare (Cox and Dalrymple, 1967; Hoare and others, 1968, Mankinen and Dalrymple, 1979). During mineral assessment studies during the mid 1970's, K/Ar dating plutonic rocks was an emphasis, particularly in the Goodnews Bay and Hagemeister Island quadrangles (Hoare and Coonrad, 1978; Kilburn and others, 1993). Wilson and Smith (1976) provided dates on many of the plutonic rocks of the quadrangle. Box and others (1993) also reported K/Ar, $^{40}Ar/^{39}Ar$, and U/Pb dates on igneous and metamorphic rocks in the Bethel quadrangle including a suite of Early Cretaceous plutons in the northernmost part of the map area. Box and others (1993) also reported fission-track cooling ages on a range of rocks. Turner and others (1983) reported studies of the Kilbuck terrane rocks in the Goodnews Bay quadrangle; the extensive analytical data for these studies is presented in Turner and others (in prep.). Other studies (Globerman, 1985; Box, 1985a; Wittbrodt and others, 1989) have added a number of individual dates in parts of the map area, all contributing to understanding of the history of the region.

Most plutonic rocks for which dates are available have yielded ages that straddle the Tertiary and Cretaceous boundary (60 to 70 Ma). Plutons of this age are widespread throughout much of southwest Alaska. A reverse discordance, where hornblende consistently yielded younger ages than co-existing biotite, is common among the plutonic rocks in the eastern part of the Goodnews Bay quadrangle (Wilson and Smith, 1976). The same reverse discordance is shown by one of the Early Cretaceous plutons in the Bethel quadrangle (Box and others, 1993). This discordance suggests an as yet un-explained problem with the age determinations. In normal conditions, where argon is locked in a mineral as it passes through the blocking temperature, hornblende should yield an older age because it has a higher blocking temperature. The age difference between minerals then would be dependent on the cooling rate.

The main focus of geochronologic studies in the mainland portion of the map area has been on the Kanektok metamorphic complex or Kilbuck terrane. D.L. Turner and others (in prep.) measured 77 K/Ar ages on 58 samples of the Kanektok metamorphic complex, as well as dating zircon and sphene by the U/Pb method. They also attempted Rb/Sr geochronology with limited success. Turner and others (in prep.) extensive dating of the Kanektok metamorphic complex yielded widely varying results with respect to the age of rocks dated. If the K/Ar results, including $^{40}Ar/^{39}Ar$, are considered simply as cooling ages, they suggest that an Early Cretaceous thermal event affected the much older metamorphic complex and was of sufficient intensity to reset amphibole (about 500° C). Many of the K/Ar ages determined, both on metamorphic and plutonic rocks, were Mesozoic in age and commonly discordant when multiple minerals from the same sample could be dated. These highly discordant ages may suggest a long slow cooling. A few samples show the same reverse discordance as the plutonic rocks mentioned earlier where hornblende yields younger ages than co-existing biotite or muscovite, or where muscovite yields younger ages than co-existing biotite. However, for most samples, hornblende ages are 100 m.y. or more older than co-existing biotite.

A number of the K/Ar and $^{40}Ar/^{39}Ar$ ages for the Kanektok metamorphic complex fall between 120 and 150 Ma; however, many more samples yielded discordant ages significantly older than 150 Ma. One sample, DT72-82, yields concordant biotite and hornblende ages of about 212 Ma (table 1), suggesting a discrete event. Few other older samples yielded concordant ages; however one was as old as about 480 Ma (Sample DT75-70, Table 1). Minimum mica and amphibole ages are concordant at about 128 Ma.

However, three granulite samples yielded significantly older K/Ar ages than any other rocks in Alaska. Multiple analyses of biotite splits from these pyroxene granulite samples yielded average ages between 2,255±71.2 and 2,474±75 Ma (table 1). A $^{40}Ar/^{39}Ar$ age of the oldest of these samples yielded a plateau age of 2,520 Ma and showed no indication of excess argon. U/Pb ages of zircon from granite gneiss and tonalite gneisses from throughout the complex, including locations not distant from these granulite samples, cluster around 2050 Ma (Turner and others, in prep.; Box and others, 1990; Moll-Stalcup and others, 1996; table 1, herein). Turner and others (in prep.) made a case that the 2.5 Ga biotite samples contain excess argon by analogy with similar rocks from elsewhere and by the suggestion that the incremental heating plateau was an experimental artifact. Multiple studies, as reported in Faure and Mensing (2005), indicate that the $^{40}Ar/^{39}Ar$ method may not be able to distinguish excess argon; therefore, the U/Pb age of 2.05 Ga most likely represents the best estimate of the original emplacement age of the complex.

One sphene U/Pb age of 1,770 Ma was measured by Turner and others (in prep.; Moll-Stalcup and others, 1996) and was interpreted by Turner and others (in prep.) to represent the age of amphibolite-facies metamorphism of the terrane. This interpretation is supported by analysis of a suite of 13 samples collected for Rb/Sr analysis and by a single K/Ar hornblende age. Six of the Rb/Sr samples of Turner and others (in prep.) lie along a 1780 Ma isochron. Moll-Stalcup and others (1996) similarly collected samples for Rb/Sr analysis which they divided into two suites. Their granitic-gneiss suite scatter about a reference line at 1,800 Ma, whereas their tonalite-gneiss suite of samples plot scattered about a 2,070 Ma reference isochron. Moll-Stalcup and others (1996) suggested the above result may indicate that the granitic gneisses are younger than their tonalite-gneiss suite or that the granitic gneiss suite Rb/Sr systematics have been disturbed. However, in common with Turner and others (in prep.), Moll-Stalcup and others (1996) did not consider the fit of the data adequate to yield reliable isochron ages. Both groups of workers collected amphibolite samples and in neither case did the data from these rocks define a statistically valid line on an Rb/Sr isotope plot. Moll-Stalcup and others (1996) indicated that the amphibolites are chemically distinct from the gneisses and form at least three groups based on their chemical affinity. They infer that the amphibolites may represent "*** dikes or sills that were intruded at different times." Amphibolite samples for the complex yield widely varying conventional K/Ar and $^{40}Ar/^{39}Ar$ ages, ranging from 130.6 to 1,778 Ma, suggesting significant thermal effects; where multiple phases could be dated, the discordance is great; see for example sample DT76-70 in table 1.

Most analyzed samples from the tonalite-gneiss and granitic-gneiss suites yield Nd-Sm depleted-mantle model ages range near 2.1 Ga, concordant with the U/Pb zircon ages determined on these rocks and suggesting separation from a mantle reservoir at that time and that the Sm/Nd ratio has been unmodified since that time (Moll-Stalcup and others, 1996). One granitic-gneiss sample yielded a Sm/Nd model age about 2.7 Ga (Box and others, 1990; Moll-Stalcup and others, 1996), which suggests incorporation of an Archean component. Miller and others (1991) reported a similar result of a 2.05 Ga U/Pb age and 2.5 Ga Sm/Nd model age from the Idono complex in the Iditarod quadrangle, northeast of this map area. This result also suggests incorporation of Archean crust. The Idono complex and the Kanektok metamorphic complex are the only rocks known in Alaska having a similar early history.

Kanektok metamorphic complex – enigma in southwest Alaska

The Kanektok metamorphic complex was originally assigned a Precambrian age because it was more metamorphosed than nearby Paleozoic rocks (Hoare and Coonrad, 1959a; 1961b). Subsequently, a number of studies (Hoare and Coonrad, 1979; Box, 1982; Box and others, 1990; Moll-Stalcup and others, 1996) of the Kanektok metamorphic complex and the Idono complex of Miller and others (1991) have shown that they are thin slivers of Paleoproterozoic crust distinct from any in Alaska. To date, no cratonic source has been identified for these high-grade metamorphic rocks. The subsequent history of these rocks is also unclear, as geochronologic studies (Turner and others, in prep.; Moll-Stalcup and others, 1996) have yet been unsuccessful at deciphering their Paleozoic and Mesozoic history.

Figure 3 near here. Gneiss of the Kanektok metamorphic complex north of Thumb Mountain.

Beyond agreement that the Kanektok metamorphic complex is a thin sliver of early Proterozoic crust, Hoare and Coonrad (1978, 1979) and Box, Moll-Stalcup, and coworkers (Box, 1982; Box and others, 1990; Moll-Stalcup and others, 1996) had diametrically opposed interpretations of the character of the contact with surrounding rocks and therefore the tectonic setting of the sliver. The southeast bounding fault of the complex was mapped and described by Hoare and Coonrad (1978, 1979) as a northwest dipping low-angle thrust fault. Hoare and Coonrad (1979) reported that Cretaceous shale of the Kuskokwim Group (map unit Kk) outcrops in a number of places where the Kanektok River cuts through the complex. As Kuskokwim Group rocks also outcrop east of the complex, Hoare and Coonrad (1978; 1979) inferred that the contact was a thrust, placing the Kanektok metamorphic complex over the Cretaceous shale. Conversely, Box and others (1990) and Moll-Stalcup and others (1996) interpreted the rocks were emplaced by southeastward directed under thrusting below Lower Cretaceous and older rocks. Box (1982; see also Box and others, 1990) inferred the metamorphic complex (Kilbuck terrane) collided with and partially underthrust the adjacent rocks which they assigned to the Goodnews and Togiak terranes, an oceanic-arc-subduction complex. However, we have difficulty reconciling the Box interpretation with the mapping of Hoare and Coonrad (1978). Additionally, their interpretation is difficult to reconcile with the available geochronologic data.

For the most part, no contacts of the complex with rocks on the west side of the contact are exposed; the Golden Gate fault system is inferred to form the western boundary of the complex. The only portion of the complex having a contact with a bedrock unit is a very small exposure in the Bethel quadrangle. Hoare and Coonrad (1959a) showed this contact as depositional with the Kuskokwim Group, whereas Box and others (1993) showed it as a fault contact, thrusting the metamorphic rocks over the Kuskokwim along a strand of the Golden Gate fault. As this faulting must postdate the apparent thermal event that affected the west side of the terrane, the nature and cause of this thermal event remains to be determined. In neither case is there evidence to indicate the nature of the contact and what rocks lie on the most of the west side of the complex, especially in the vicinity of the Kanektok River and southward. R.W. Saltus (written commun., 2006) analyzed available aeromagnetic and gravity data, including a gravity traverse along the Kanektok River that crosses the metamorphic complex. In his interpretation, the metamorphic complex is a northwestward dipping crustal block. This interpretation generally supports the mapping of Hoare and Coonrad (1978; 1979) and does not support an interpretation that the rocks of the metamorphic complex are thrust under rocks to the east.

Spatial analysis of the K/Ar ages within the Kanektok metamorphic complex indicates a general pattern of decreasing age with distance from the southeast bounding fault of the complex. Such a pattern has a number of possible interpretations. One possibility is that the easternmost parts of the complex were less affected, if at all, by the inferred Cretaceous (120-130 Ma) thermal event and may have been unroofed long before, as suggested by biotite ages of 190 Ma and older. Inclusion of metamorphic minerals and metamorphic rock clasts in the Valanginian sedimentary rocks of the Eek Mountains belt (map unit Kcgc), deposited at approximately the same time of the inferred thermal event in the western part of the complex, as well as in the younger basal conglomerate (map unit Kkn) of the Kuskokwim Group of Albian age, indicates markedly different histories for the east and west sides of the exposed complex. A different interpretation by Turner and others (in prep.) suggested a cluster of K/Ar ages around 120-150 Ma, with biotite and hornblende ages extending back in time to more than 1.7 Ga, suggested variable Argon loss from an Early Cretaceous to Late Jurassic thermal event. They suggested this might have been related to widespread small intrusions of an alaskite granite that is undated and not shown on available maps. However, given the spatial distribution of the ages, we consider this unlikely. An analysis of K/Ar data for the metamorphic rocks of the Yukon Crystalline Terrane of central Alaska (Wilson and others, 1985) indicated little evidence for widespread resetting of metamorphic rocks due to intrusion of plutons.

Geologic units of the Kuskokwim Bay region

um **Unmapped**—Small areas on Saint Matthew and Hall Islands that are not geologically mapped

Unconsolidated deposits

Qs **Surficial deposits, undivided** (Quaternary)—Unconsolidated, poorly to well-sorted, poorly to moderately well-stratified deposits; consist predominantly of alluvial, colluvial, glacial, marine, lacustrine, eolian, and swamp deposits (Hoare and Coonrad, 1959a, 1961a, b; Box and others, 1993; Coonrad, 1957). Locally includes reworked volcanic debris including block and ash flows. Locally subdivided into:

Qtf **Tidal flat and active estuarine deposits** (Holocene)—Fine-grained silt and mud in tidal flats and active estuaries as shown on topographic maps. Also includes older, topographically higher deposits on land. The abrupt ending of the tidal flat deposits at approximately 163° 20’W longitude in the Kuskokwim Bay quadrangle is an artifact of the topographic maps; it is likely that the tidal flats continue along the coast to the west

Qa **Alluvial deposits**—Flood-plain alluvium of sand, gravel, and boulders. Locally may include sand and small pebbles from beach deposits, clay-rich silt from estuarine deposits, fine-grained eolian sand, and small areas of undivided surficial deposits (Hoare and Coonrad, 1959a, 1961a; Box and others, 1993)

Qrs **Reworked silt**—Chiefly reworked silt, sandy silt, and bog deposits underlying a plain that is transitional with or slightly above areas of flood-plain alluvium of Holocene age and separated from higher plains and residual 'islands' of older silt deposits by an erosional scarp 3 to 15 m high (Hoare and Coonrad, 1959a)

Qb **Beach deposits**—Primarily fine sand to coarse gravel along modern and raised ancient beaches. Locally includes wind blown dune sand. In the Kuskokwim Bay, Baird Inlet, and eastern Nunivak Island quadrangles, these deposits extend 3 km inland as a series of raised beach ridges and may underlie the marine terraces farther inland. Along the Nushagak Peninsula, wind blown sand derived from the adjacent tidal flats forms ridges interspersed with reworked glacially derived gravels

Qes **Estuarine deposits**—Generally fine silt to sand, but may include a significant proportion of mud. Primarily located in the vicinity of Nushagak Bay, these deposits extend well inland along the Nushagak and Igushik Rivers

Qmt **Marine terraces**—Raised terraces composed of many types of surficial deposits; primarily estuarine, tidal flat, and alluvial deposits, but may include glacial debris and outwash. Surfaces may be separated from younger active deposits by a bluff or may be gradational. Range in elevation from less than 8 m on the west to as much as 12 m on the east

Qed **Eolian deposits**—Derived from alluvial sediments in the Pribilof Islands, mostly composed of sand. Elsewhere, primarily derived from glacial deposits or nearby tidal flats. In most places, the sand is loose and moves with the wind. Along the north shore of Saint Paul Island, impressive dunes occur (Barth, 1956). Also widely distributed on the Nushagak Peninsula, where they overlie glacial, estuarine, and beach deposits. Lea (1989) described widespread eolian sand sheets in the Nushagak Lowland and these have also been shown locally on the Nushagak Peninsula (W.L. Coonrad, 2007, unpublished data)

Qsd **Silt deposits**—Chiefly light- to dark-gray silt and sandy silt containing abundant permafrost. Deposits become sandier with depth and locally contain pebbles and wood fragments. Deposits are probably of nonmarine fluvial origin but may include eolian and marine members in some areas. Organic muck containing mammoth remains and nonmarine gastropods is found locally near top of deposits (Hoare and Coonrad, 1959a, 1961b)

Qg **Glacial deposits, undivided**—Glacial drift deposited during the last three glacial advances. Consists of sand, gravel, and boulders. Includes end and lateral moraine deposits, as well as colluvium, talus, landslide debris, alluvium, and local silt (Hoare and Coonrad, 1959a, 1961a, b; Box and others, 1993). Locally subdivided into:

Qgm **Glacial moraine**—Morainal ridges of generally late Wisconsin age, but may include deposits of other ages. Largely mapped from air-photo and topographic map interpretation. Mapping of these deposits in the Nushagak Bay quadrangle is largely derived from the unpublished field data of W.L. Coonrad. Likely composed of poorly sorted silt to cobble and boulder sized material

Qgo **Outwash deposits**—Poorly to well-sorted sand and gravel with some silt and a few boulders, constituting terraces and outwash-fan plains (Hoare and Coonrad, 1959a, 1961a, b)

Qvs **Volcaniclastic sediment** (Quaternary)—Fossiliferous sediments consisting of sand and yellow tuff containing rounded basalt pebbles. On Saint Paul Island, sediments are polymictic, but composed primarily of basaltic boulders and clasts and locally cross-bedded. On Saint George Island, sediments overlie a glaciated surface of peridotite upon which Pleistocene fossil shells have been cemented. The sediments are quite varied; however, a basal conglomerate has boulders of peridotite but primarily consists of basalt boulders. Overlying the basal conglomerate is a sand layer containing casts of fossil shells; however no $CaCO_3$ is left and the casts disintegrate on contact (Barth, 1956). Locally cross-bedded

QTs **Semiconsolidated marine beach deposits** (Quaternary, Pleistocene or Tertiary, Pliocene)—Semiconsolidated marine beach deposits consisting of poorly bedded, soft, pebbly siltstone that caps sea cliffs of volcanic rock (map unit Kv) on Hagemeister Island. Shallow-water marine fossils of Pliocene or Pleistocene age

Sedimentary rocks

Ks **Summit Island Formation** (Upper Cretaceous, Maastrichtian?)—Consists of lenses and inter-tonguing beds of nonmarine conglomerate, sandstone, carbonaceous siltstone, mudstone, and shale containing abundant plant detritus and a few coal seams (Hoare and others, 1983). In the type section, the unit "consists of about 200 m of massive and thick-bedded pebble [to] cobble conglomerate overlain by about 650 m of interbedded sandstone, siltstone, and mudstone and a few conglomerate beds" (Hoare and others, 1983). At the reference section of the unit, its character changes to consist of "about 75 percent carbonaceous mudstone, siltstone, and shale and 25 percent interbedded sandstone and pebble grit" (Hoare and others, 1983). Bedding is discontinuous and best developed in lower part of formation where thick conglomerate beds grade into pebble sandstone and sandstone beds (Hoare and others, 1983). Conglomerate clasts are well-rounded, generally not larger than 10 cm, and primarily derived from flows, tuffs, and sedimentary rocks of Jurassic and Early Cretaceous age (Hoare and others, 1983). Hoare and others (1983) also reported white quartz clasts and sparse schist and plutonic clasts; they suggest the schist clasts are derived from tectonically metamorphosed rocks that occur locally along major faults in this region. Sandstone and siltstone consists of 60 to 70 percent lithic fragments and 10 to 15 percent each of quartz and feldspar (Hoare and others, 1983). Lithic component of the sandstone and siltstone is very fine-grained cherty tuff and other volcanic rock fragments, as well as, argillite, quartzite, and chert (Hoare and others, 1983). Hoare and others (1983) indicated that the hardness of the rocks in the unit varies with their structure and, by implication, location. At the west end of Summit Island and on the west side of the unnamed adjacent headland on the mainland, the rocks dip 45° to 80° and are hard and well indurated. On the east end of the island and elsewhere on the mainland, dips are shallow and the rocks are less well indurated. Box (1985a) divided the unit into two sub-basins along the trace of the Togiak-Tikchik fault, based on contrasting sandstone compositions. Sandstone of his Summit sub-basin (southeast of Togiak-Tikchik fault) is composed mostly of slaty sedimentary lithic fragments, similar to underlying Jurassic sedimentary rocks. Rocks in this sub-basin are more than 1 km thick and consist of a lower conglomeratic member (200 m) of probable alluvial fan to braided stream origin, and an upper carbonaceous shale member, of probable meandering stream-flood plain origin, having channelized sandstone bodies, that become finer-grained and thinner upward. Paleocurrent indicators in the upper member generally indicate transport to the northeast. Sandstone of Box's Hagemeister sub-basin (northwest of Togiak-Tikchik fault) is composed of nonfoliated volcanic detritus similar to underlying Jurassic rocks. This sub-basin section is also more than 1 km thick, consisting of a lower channelized sandstone member (600 m) of probable meandering stream origin, and an upper sandy member (400 m) having coarsening and thickening upward cycles beginning with laminated siltstone-coal intervals which are possibly lacustrine delta deposits. Paleocurrent indicators in the Hagemeister sub-basin generally indicate transport to the northwest (Box, 1985a). Plant fossils from the base of the reference section indicate a latest Cretaceous or early Tertiary age (Jack Wolfe, USGS, oral commun. 1974, cited in Hoare and others, 1983). A dike that cuts the formation yielded an age of 64.6±2 (74ACd 14d, table 1); which suggested to Hoare and others (1983) that a Late Cretaceous age for the Summit Island Formation was more probable. Subsequent dating of a dike cutting the formation by Box (1985a) yielded an older age of 76.6±4.5 Ma (B78-1125G, table 1), further supporting the age assignment for the unit. Pollen identified by R.H. Tschudy (USGS, written commun, 1975, cited in Hoare and others, 1983) formed a unique assemblage. Several of the taxa had been reported from Arctic Canada and western Siberia, but the complete assemblage was unique and therefore he was reluctant to assign the unit a definite Late Cretaceous age. However, on the basis of the fossil and radiometric evidence, Hoare and others (1983) assigned a Late Cretaceous, possibly Maastrichtian age

Kk **Kuskokwim Group, undivided** (Cretaceous, Campanian? to Albian)—Interbedded graywacke and shale, having local interbeds of argillite and conglomerate. Graywacke fine- to medium-grained, gray, commonly micaceous and locally silty; in places is crossbedded, or contains siltstone partings. Contains rare argillite pebbles. Originally described by Cady and others (1955), the Kuskokwim Group is widespread in southwestern Alaska and although largely a flysch deposit, represents a range of local depositional environments. Box and others (1993) subdivided the upper part of unit in the Bethel quadrangle on the basis of provenance and depositional environment; however, data is insufficient to carry those distinctions throughout this map area. They described three provenances called chert-clast, mixed, and volcanic, and described three depositional environments, outer-fan turbidite, inner-fan turbidite, and deltaic. We have placed the deltaic environment, which is restricted to the chert-clast provenance, in the nearshore facies sub-division (Kkn) of this map. The other chert-clast provenance rocks are described as outer-fan facies and consist of thin-bedded, fine-grained, quartzose sandstone and shale with lesser thin- and thick-bedded medium-grained sandstone (Box and others, 1993). The mixed provenance rocks represent two depositional environments; an outer-fan turbidite facies consisting of a shale-rich sequence with lesser thin- to thick-bedded, medium-grained sandstone sections and an inner-fan-channel facies consisting of mixed shale-rich and sandstone-rich sections, with coarse sandstone and pebbly sandstone in thick-bedded, amalgamated sequences with minor interbedded shale (Box and others, 1993). Volcanic provenance rocks consist of interbedded shale, siltstone, sandstone, and conglomerate composed of rounded clasts of volcanic, volcaniclastic, and plutonic rocks deposited in slope and inner-fan environments (Box and others, 1993). The lower part of the Kuskokwim Group was divided into two units by Box and others (1993); an upper shale and siltstone unit consisting of dark-gray to black, finely laminated shale, siltstone, and thin-bedded, very fine-grained sandstone and a basal conglomerate unit of pebble to boulder conglomerate, coarse sandstone, and minor interbedded medium-grained sandstone, siltstone, and shale. Box and others (1993) suggested the shale and siltstone represent sand-poor slope, interchannel, and distal basin-plain environments. Basal conglomerate is assigned to map unit Kkn herein, described below. The age of the Kuskokwim Group is not well constrained; multiple provenances and potentially multiple depositional systems are included within the map unit. Cady and others (1955) assigned an early Late Cretaceous age in part, but acknowledged collections outside their map area that might indicate an age older than Late Cretaceous and as young as Tertiary. Elder and Box (1992) and Box and others (1993) assigned an early Turonian to late Cenomanian age based on inoceramid fossil collections in the Bethel quadrangle, whereas Hoare and Coonrad (1959a) reported Albian and Cenomanian to Coniacian fossils from the same area and Murphy (1989) reported an Albian collection. Other age assignments have ranged as young as Santonian (Decker and others, 1994) or Campanian(?) (Miller and Bundtzen, 1994). Locally subdivided into:

Kkn **Kuskokwim Group, nearshore facies** (Cretaceous, Turonian to Albian)—Thick-bedded quartzose sandstone, pebbly sandstone, and subordinate siltstone and shale of the deltaic facies chert-clast provenance of Box and others (1993). Also includes pebble to boulder conglomerate, coarse sandstone, and minor interbedded medium-grained sandstone, siltstone, and shale of the basal conglomerate of Box and others

(1993). This informal sub-division of the Kuskokwim Group was originally defined by Platt and Muller (USGS unpublished data, 1957, cited in Wilson and others, 2006b) in the northeastern Taylor Mountains quadrangle; subsequent mapping in the Iditarod quadrangle to the north (Miller and Bundtzen, 1994) also described a nearshore facies. As described by Hoare and Coonrad (1959a), chiefly consists of conglomerate facies of interbedded graywacke and siltstone, with lesser amounts of pebble grit conglomerate and a small amount of coal. Well-indurated, commonly light- to dark-gray, and weathers brown. Varies from volcanic wacke to quartz-chert-feldspar-rich sandstone. Fossils collected from basal conglomerate of Box and others (1993) zone are considered Late Cretaceous (Cenomanian) age and fossils from the deltaic facies of Box and others (1993) considered Late Cretaceous (Turonian). Murphy (1989) reported an Albian ammonite, *Paragastroplites*, from this unit in the Bethel quadrangle

Kys **Sandstone, shale, and conglomerate deltaic deposits** (Upper Cretaceous?)—Fluvial and shallow marine deltaic deposits of sandstone, siltstone, shale, and conglomerate. Locally crossbedded and ripple marked. Unit contains abundant plant debris and fresh- and brackish-water mollusks. Unit is widely exposed in a broad belt that extends from northwest of the map area into the northern edge of the Marshall quadrangle (see Patton and others, in press(a), in press(b); Wilson and others, 2006a, c). Shallow water marine mollusks of mid-Cretaceous age found in the Kwiguk quadrangle (table 2)

Kygv **Volcanic graywacke and argillite** (Cretaceous?)—Thinly interbedded fine-grained graywacke and siliceous argillite (Patton and others, 1975) on Saint Matthew Island. Graywacke composed of angular to sub-rounded feldspar, volcanic lithic, and quartz grains in an altered argillaceous matrix (Patton and others, 1975). Argillite is siliceous, dense, breaks with conchoidal fracture, shows small-scale crossbedding and convolute laminations, and is interpreted to be a distal facies of a marine turbidite. No fossils are known in this unit; however, it is thermally altered by granodiorite (map unit TKgd) which yielded an age of 62.2±2.0 Ma (71AMm 45, table 1). Unit appears to stratigraphically underlie pyroclastic rocks, which yield K/Ar ages of 76.0±2.0 and 76.3±2.0 Ma on biotite and hornblende, respectively (71AMm 50, table 1) which, in part, led Patton and others (1975) to assign a Cretaceous(?) age for the unit. Unit may correlate with unit Kygv of Patton and others, in press(a), in press(b); Wilson and others, 2006a, c)

Kgbr **Graywacke of Buchia Ridge** (Lower Cretaceous, Valanginian and Hauterivian)—Lithic sandstone, conglomerate, and shale about 5 km thick (Hoare and Coonrad, 1983). Lower part of unit is about 2,400 m thick, composed mainly of well-bedded fine- to medium-grained sandstone with siltstone interbeds, and pebble-cobble conglomerate. In lowest part of section, beds range from 0.1 to 3 to 4 m thick; the upper part of this lower section consists of 1,400 m of increasingly massive conglomerate (Hoare and Coonrad, 1983). Well-rounded clasts, as large as 10 cm, consist of “graywacke and siltstone, cherty tuff, and less abundant porphyritic volcanic rocks” (Hoare and Coonrad, 1983); the graywacke clasts resemble the graywacke of Kulukak Bay (map unit Jkw: Jln, Jmm). The conglomerate, near the top of Buchia Ridge, contains coquinas of *Buchia crassicollis* shells (Hoare and Coonrad, 1983). Box (1985a) interpreted this part of the unit to be of shallow marine origin. Upper part of unit, about 2,500 m thick, is “mostly shale and thin-bedded sandstone" (Hoare and Coonrad, 1983), which is poorly exposed. It is "dominantly fine-grained *** calcareous black shale, thin-bedded calcareous siltstone, sandstone, calcarenite, and minor gritstone" (Hoare and Coonrad, 1983). Box (1985a) interpreted this upper part of the section to be of probable offshore marine origin. According to Hoare and Coonrad (1983), the graywacke of Buchia Ridge "is the thickest, least deformed section of Lower Cretaceous sedimentary rocks known in southwestern Alaska." Outcrop area covers approximately 350 km^2 in a thrust plate separated from its neighbors by reverse faults (Hoare and Coonrad, 1983). Lower part of section contains abundant Valanginian fauna, primarily *Buchia*; upper part of section yields sparse *Inoceramus*, *Belemnites*, and a single Hauterivian ammonite according to Hoare and Coonrad (1983)

Klg **Limy grit and limestone of the Ungalikthluk belt of Hoare and Coonrad (1983)** (Lower Cretaceous, Valanginian)—Chiefly "limestone, greenish limy grit, and conglomerate overlain by noncalcareous graywacke and grit" (Hoare and Coonrad, 1983) exposed in a small area a few kilometers northwest of Buchia Ridge. Limy grit and conglomerate consists of "sub rounded green and maroon lithic fragments and a few well-rounded quartz pebbles" (Hoare and Coonrad, 1983) cemented by gray bioclastic limestone consisting of tiny shell fragments. Lithic clasts are fine-grained tuff and volcanogenic sedimentary rocks metamorphosed to phyllite and low-grade quartz-chlorite-sericite schist (Hoare and Coonrad, 1983). Lithic fragments thought to be derived from "nearby strata that were tectonically metamorphosed by movement on the Ungalikthluk fault" (Hoare and Coonrad, 1983); the matrix does not have a metamorphic fabric suggesting that metamorphism and therefore fault movement were pre-Early Cretaceous (Hoare and Coonrad, 1983). Bioclastic limestone is composed mostly of microscopic shell fragments. *Buchia crassicollis* is found in some limestone beds and Hoare and Coonrad (1983) suggested that the shell fragments in the bioclastic limestone were derived from *Buchia*. The presence of *Buchia crassicollis* indicates these rocks are coeval with the graywacke of Buchia Ridge (Kbr)

Kvm **Volcanic and sedimentary rocks of the Mount Oratia belt of Hoare and Coonrad (1983)** (Lower Cretaceous, Valanginian)—Consists of a variety of lithologies including thin-bedded tuffaceous chert, massive graywacke, conglomerate, argillite, a few volcanic flows and impure limestone beds, and massive, coarse-grained crystal-lithic tuff (Hoare and Coonrad, 1983). Rocks range widely in color, mostly green and gray but also red, yellow, brown, or black (Hoare and Coonrad, 1983). Most distinctive rock type in the belt according to Hoare and Coonrad (1983) is the massive andesitic crystal-lithic tuff, which is at least 1,000 m thick. Fine-grained tuff and some graywacke is commonly laumontized. *Buchia crassicollis* of Early Cretaceous, Valanginian age is found in calcareous graywacke, conglomerate and impure limestone. In cherty tuff, Radiolaria of Early Cretaceous age has been found at 3 localities (Hoare and Coonrad, 1983). As in unit Klg above, the presence of *Buchia crassicollis* indicates these rocks are coeval with the graywacke of Buchia Ridge (Kbr)

Kcgc **Calcareous graywacke and siltstone of the Eek Mountains belt of Hoare and Coonrad (1983)** (Lower Cretaceous, Valanginian)—Turbidites composed of highly calcareous sandstone interbedded with non-calcareous micaceous siltstone and shale. Hoare and Coonrad (1983) inferred the unit to be coarsening upward to conglomerate.

Generally thick-bedded to massive with alternating sandstone and shale intervals 5 to 20 m thick, locally has thin-bedded sections (Hoare and Coonrad, 1983). The base of the unit is not recognized and as such Hoare and Coonrad (1983) suggested that rocks of Jurassic age may be present in the unit. Rocks are strongly folded and commonly overturned (Hoare and Coonrad, 1983). Box and others (1993) reported the presence of lithic clasts likely derived from the Kanektok metamorphic complex, as well as other local units. *Buchia crassicollis* is found in several areas on the northwest side of the belt. Unit is exposed in the Bethel and Goodnews Bay quadrangles and appears to correspond with similar rocks that extend in a broad belt from the southeast corner of Saint Michael quadrangle and the northwest corner of the Holy Cross quadrangle to the south-central part of the Kwiguk quadrangle (map unit Kygc, Patton and others, in press(a), in press(b); Wilson and others, 2006a, c). No fossils have been found in this similar unit in the Saint Michael and Holy Cross quadrangles, but in the Yukon-Koyukuk Basin to the north, similar rock assemblages have yielded marine mollusks of probable late Early or early Late Cretaceous age (Patton and others, in press(a); Wilson and others, 2006c), slightly younger than within this map area

KŦvs **Volcanic and sedimentary rocks, undivided** (Lower Cretaceous to Upper Triassic?)—Thick unit consisting of low-grade metamorphic or contact metamorphosed marine volcanic and sedimentary rocks. According to Hoare and Coonrad (1978), “the volcanic rocks range in composition and type from mafic pillow basalts to more abundant andesitic and trachytic flows, tuffs, and breccias. Interbedded with the volcanic rocks are thick sections of tuffaceous siltstone, tuffaceous cherts, and massive or thin-bedded argillite. Tuffs and tuffaceous sedimentary rocks associated with the intermediate composition volcanic rocks are commonly laumontized.” Radiolarians of Late Jurassic to Early Cretaceous age and fragmentary ammonites of Jurassic age have been collected from this unit in the Goodnews Bay quadrangle (Hoare and Coonrad, 1978). The unit may include some areas of rocks of Triassic and Permian age. In the Bethel quadrangle Box and others (1993) suggested that this unit may be subdivided into the units KJc, KJb, Ja, and Jvs, whereas the mapping of Box (1985a) in the Hagemeister Island and southern Goodnews Bay quadrangles resulted in the subdivisions Jlt, Jvt, and JŦcv. On the map, no contact is shown between these sub-divisions and this undivided unit due to lack of mapping. Locally subdivided into:

Bethel quadrangle:

KJc **Argillite and tuffaceous chert** (Lower Cretaceous and (or) Upper Jurassic)—Thin-bedded green to brown argillite having local 1 to 4 cm thick tuffaceous chert, siltstone, and fine-grained tuff interbeds (Box and others, 1993). A Late Jurassic and (or) Early Cretaceous age is suggested from poorly preserved radiolarians (Box and others, 1993)

KJb **Pillow basalt** (Lower Cretaceous and (or) Upper Jurassic)—Highly altered pillow basalt sequence exposed along a narrow trend about 1 km wide and 10 km long south of Crooked Mountain in the Bethel quadrangle (Box and others, 1993). Interbedded with argillite and thin-bedded chert of map unit KJc. Age inferred from enclosing map unit

Jvs Marine volcaniclastic sandstone, conglomerate, and argillite (Jurassic)—"Turbidite-facies volcaniclastic strata, locally as coarse as fine-grained pebble conglomerate" (Box and others, 1993). Clasts are predominantly intermediate volcanic rock fragments and detrital feldspar, quartz, clinopyroxene, and hornblende. Minor plutonic rock fragments, felsic volcanic and hypabyssal, sedimentary rock fragments and low-grade metamorphic rock fragments are a persistent component (Box and others, 1993). According to Box and others (1993), age control is based on stratigraphic position above Early Jurassic and Late Triassic phyllite and chert of map unit JŦp and below Early Cretaceous and (or) Late Jurassic argillite and tuffaceous chert of map unit KJc

Ja Marine arkosic sandstone and argillite (Jurassic)—"Turbidite-facies arkosic sandstone and shale" (Box and others, 1993). Sandstone apparently derived from weathering of plutonic rocks; consists primarily of detrital plagioclase, quartz, and potassium feldspar, and minor hornblende, biotite, and clinopyroxene, in contrast to sandstone of map unit Jvs, which had a largely volcanic source (Box and others, 1993). Age inferred based on stratigraphic position above Early Jurassic and Late Triassic phyllite and chert (map unit JŦp) and on strike position relative to map unit Jvs

Hagemeister Island and southern Goodnews Bay quadrangles:

Jvt Volcaniclastic turbidites of Togiak Bay of Box (1985a) (Middle Jurassic)—Volcaniclastic turbidite sandstone and conglomerate composed entirely of volcanic and hypabyssal igneous clasts; unit is at least 1.7 km thick (Box, 1985a). Box (1985a) divided a tightly folded section along the seacoast into a buff-colored lower member, 1 km thick, and a bright green upper member, 0.7 km thick. Lower unit consists of thin-bedded fine-grained sandstone and siltstone turbidites and channelized medium- to coarse-grained sandstone and minor chaotic interbeds indicating down-slope mass movement, which suggests an inner- to middle-fan environment (fig. 10, Walker and Mutti, 1973). Upper, more tuffaceous member is mostly thin-bedded fine-grained sandstone and siltstone turbidites, having coarse conglomerate beds in upper part showing poorly defined thinning and fining upward cycles. "Entire sequence interpreted as deposited on proximal channelized portion (i.e., upper to midfan) of turbidite basin fill complex" (Box, 1985a). Similar conglomerate intruded by gabbro at Aeolus Mountain; gabbro yielded 174±8 Ma K/Ar age on amphibole (B78-1171G, table 1). "A few tool marks and interbedded slump folds suggest ENE-directed paleocurrents. *** Unit is folded around sub-horizontal, northeast-trending axes and steep axial planes, and lacks a penetrative cleavage" (Box, 1985a). Box (1985a) constrained the age to Middle Jurassic on the basis of Bajocian pelecypods northeast of his map area in Togiak River valley reported by Hoare and Coonrad (1978). These rocks were included in map unit KJvs of Hoare and Coonrad (1978) and are likely to be present in undivided parts of that unit as shown herein in unit KŦvs

Jlt Laminated tuff and associated rocks of Box (1985a) (Jurassic)—Banded to finely laminated crystal-lithic tuff having interbedded green, white, and black tuffaceous chert (Box, 1985a). Unit contains minor interbedded sections of massive, coarse-grained lithic tuff and (or) pillow basalt (mapped by Box (1985a) as unit Jpb). Highly deformed, commonly having folded slaty or spaced cleavage. Partially altered to prehnite-pumpellyite facies mineral assemblage. Several chert samples have yielded Radiolaria of Jurassic age, one of which is identified as upper Kimmeridgian to upper Tithonian (latest Jurassic) (see Box, 1985a)

JTRcv **Coarse volcaniclastic rocks** (Lower Jurassic to Upper Triassic)—Dense green tuff, tuff breccia, pillow breccia, minor pillow basalt, and associated sedimentary rocks (Box, 1985a). Breccia clasts are mostly angular aphanitic or plagioclase-clinopyroxene porphyritic rocks, which are commonly vesicular. Interbedded aquagene tuff and crystal tuff commonly having devitrified glass shards. Rocks are altered to prehnite-pumpellyite facies mineral assemblages and locally altered to hornblende and biotite hornfels around gabbroic plutons. Unit is exposed on both sides of Togiak-Tikchik and Kulukak faults; age northwest of Togiak-Tikchik fault constrained by underlying Upper Triassic basalt and crosscutting plutons of early Middle Jurassic age; southeast of Togiak-Tikchik fault, constrained only to pre-Valanginian age (Box, 1985a)

Jvc **Volcaniclastic conglomerate, sandstone, and shale** (Upper and Middle Jurassic)—Poorly to moderately exposed sequence of tuffaceous marine sandstone, shale, and conglomerate having minor interbedded basalt and andesite lava flows in the northwest part of the Bethel quadrangle (Box and others, 1993). Unit is as much as 1 to 2 km thick; coarser parts are composed primarily of rounded clasts of basalt and andesite and minor mafic to intermediate composition plutonic rock fragments (Box and others, 1993). Felsic pyroclastic rocks are found locally in the middle part of the unit within the map area and in the lower part of the unit north of the map area (Box and others, 1993). Marine pelecypods of Bajocian age (Middle Jurassic) are found near the base of the sequence and marine pelecypods of late Kimmeridgian to early Tithonian age (Late Jurassic) were reported from the Russian Mission quadrangle north of map area (Box and others, 1993)

Jkw **Graywacke of Kulukak Bay** (lower Upper to Middle Jurassic)—A thick marine sedimentary unit consisting of very hard dark-green or gray, massive graywacke and siltstone containing local conglomerate horizons. Typically consists of sandstone, although coarse pebble conglomerate is locally present. Compositionally, “varies from quartz- and plagioclase-rich wackes to quartz-poor volcanic wackes. Generally contains black argillite or tuff chips” (Hoare and Coonrad, 1978). These rocks are the thick marine sedimentary unit referred to as the "Weary graywacke" by Hoare and others (1975). Unit is widely exposed in the southern Goodnews Bay and the Nushagak Bay quadrangles as well as the adjacent southeastern Dillingham quadrangle (Hoare and Coonrad, 1978). *Buchia*, *Inoceramus*, belemnites, and rare ammonite fragments ranging from Middle to early Late Jurassic age have been found in this unit. Locally sub-divided by Box (1985a) into the following:

Jmm **Turbidites of Metervik Bay of Box (1985a)** (Upper and Middle Jurassic)—Volcaniclastic turbidite-facies sedimentary rocks southeast of Right Hand fault of Box (1985a) which is roughly equivalent to unnamed fault of Hoare and Coonrad (1978) that parallels the valley of Ualik Lake. Box (1985a) reconstructed a 6 km thick section, which he divided into four turbidite environment units (using criteria of Walker and Mutti, 1973, cited in Box, 1985a) from bottom to top: 1.) conglomeratic inner-fan; 2.) well-bedded, outer-fan lobe; 3.) sandy, typically massive, middle-fan channel; and 4.) conglomeratic inner-fan unit. According to Box (1985a), “sandstone compositions almost entirely derived from plagioclase-rich volcanic sources. Minor slaty clasts near base of lowest unit, and minor component of slate, dioritic plutonic and chert detritus in upper unit. Interbedded slump folds suggest southeast-facing paleoslope. *** Tightly folded around gently northeast-plunging axes and sub vertical axial planes." Box (1985a) suggested deformation was probably during latest Jurassic to earliest Cretaceous time, based on occurrence of clasts of similar lithology in the lower unit of the graywacke of Buchia Ridge (map unit Kgbr). Unit located southeast of map unit Jln; separated from by the Right Hand fault of Box (1985a); unit Kbr located northwest of the Kulukak fault and northwest of map unit Jln; hence units Jmm and Kgbr are not in contact

Jln **Dismembered volcaniclastic turbidites** (Lower Jurassic?)—Predominately argillaceous, tuffaceous sandstone-shale sequence that is pervasively deformed and structurally dismembered (Box, 1985a). Sandstone is composed of volcanic detritus and a very minor chert component. "Sedimentary structures variably preserved and indicate deposition from turbidity currents and other mass flow processes" (Box, 1985a). Partially altered to prehnite-pumpellyite mineral assemblages, the unit is divisible into two structural facies types, which occur as alternating, fault-bounded blocks (Box, 1985a). One structural facies is characterized by generally well-bedded sections showing varying degrees of disruption prior to lithification; the second structural facies is distinguished by pervasive cleavage and occurrence of sandstone boudins in an argillaceous matrix (Box, 1985a). Poorly preserved Radiolaria from structural facies 1 have been identified as post-Triassic Mesozoic forms (Box, 1985a). Clasts of slate similar to structural facies 2 occur stratigraphically below Bajocian fossil occurrence in adjacent Middle Jurassic turbidite facies sedimentary rocks (map unit Jmm). Box (1985a) interprets this to indicate that deposition and deformation of these rocks were therefore Early Jurassic in age. This unit and map unit Jmm above are found southeast of the Kulukak fault, their outcrop area corresponds to the area shown by Hoare and Coonrad (1978) for the graywacke of Kulukak Bay

Igneous rocks

Quaternary

QTv **Volcanic rocks, undivided** (Quaternary, Pleistocene or Tertiary, Pliocene)**—**Widely distributed basalt flows in the western part of the map area (Coonrad, 1957). Possibly equivalent in part to flows of map unit Qvb. In the Pribilof Islands, widespread olivine hylobasanite (containing normative nepheline) flows and sills range in thickness from 20 cm to 7 m or more (Barth, 1956); on Otter Island, hylobasanite flows are at least 100 m thick. Dated samples in the Pribilof Islands range from less than 0.10 to 2.25±.10 Ma (table 1). These rocks can be vesicular or dense and many eruptive features, such as hornitos (chimneys surrounded by foam and splatters), blowholes, diatremes, and miniature craters are present (Barth, 1956) suggesting very recent eruption. Other flows lack these features and are overgrown with vegetation. No dates are available on rocks of this unit except in the Pribilof Islands. Locally subdivided into:

Qpd **Pyroclastic rocks** (Quaternary)—Pyroclastic rocks in the Pribilof Islands, largely basaltic tuff (Barth, 1956). A K/Ar whole-rock age of 1.63±.06 Ma (sample P21, table 1) was determined on basalt from this unit

Qvb **Basalt flows, undivided** (Quaternary, Pleistocene)—Widely distributed fine- and medium-grained, columnar jointed tholeiite and alkali-olivine basalt flows. Columnar-jointed subaerial alkali olivine basalt flows have ropy tops and include minor interflow tuff and breccia. Generally non-porphyritic, dark-gray to black and contain fine microcrysts of labradorite, augite, olivine, and accessory magnetite in a diktytaxitic texture (Hoare and Coonrad, 1980). Includes the Togiak Basalt of Hoare and Coonrad (1980) on the floor of the Togiak River valley as well as flows in the Bethel, Nunivak Island, Cape Mendenhall, Pribilof Islands, and Baird Inlet quadrangles. The Togiak Basalt is divisible into a lower unit of low-lying horizontal flows, less than 100 m thick, and an upper unit, about 300 m thick, comprising an isolated volcanic edifice, regarded by Hoare and Coonrad (1978) as a tuya (subglacial volcano). Whole-rock K/Ar age on lower unit was 0.758±0.2 Ma (Hoare and Coonrad, 1978, 1980, Box, 1985a, sample 74AHr 77, table 1, herein). In the Bethel quadrangle, includes fresh olivine tholeiite basalt flows having diktytaxitic texture and containing olivine, subophitic clinopyroxene, plagioclase and iron oxides as well as sparse interstitial volcanic glass yielding a whole-rock K/Ar age of 0.418±0.016 Ma (Box and others, 1993, sample 86ASb 9a, table 1, herein). Unit also includes Tholeiitic Basalt of Mekoryuk on Nunivak Island (Hoare and others, 1968); massive, columnar-jointed flows including both normally polarized rocks of the Brunhes polarity epoch and reversely magnetized rocks of the Matuyama polarity epoch (shown as unit Qvbm). Samples dated by K/Ar for this unit on Nunivak Island yielded ages as old as 1.69±.09 Ma (table 1). Locally subdivided on Nunivak Island into:

Qvbm **Basalt flows,** Matuyama polarity epoch—Reversely and normally magnetized flows of the Matuyama polarity epoch on Nunivak Island (Hoare and others, 1968); similar rocks may occur on the mainland but can not be distinguished because no magnetic studies have been undertaken

Qcs **Alkalic basalt of Karon Lake** (Quaternary)—Cinder cones, flows, and tephra; normally polarized rocks of Brunhes polarity epoch (Hoare and others, 1968). K/Ar ages range from 0.03±.02 to 0.74±.09 Ma (table 1)

QTab **Older alkalic basalt of Karon Lake** (Quaternary, Pleistocene and Tertiary, Pliocene)—Cinder cones, flows, and tephra; reversely and normally polarized rocks of Matuyama(?) epoch (Hoare and others, 1968) on Nunivak Island. A sample of basalt from this unit yielded an age of 0.67±.07 Ma (sample A50, table 1)

Tertiary

Ttb **Tholeiitic basalt of Binakslit Bluff** (Tertiary, Pliocene)—Tholeiitic basalt of Binakslit Bluff on Nunivak Island; massive, columnar-jointed flows; normally polarized flows of Gauss polarity epoch as well as normally and reversely polarized flows older than Gauss polarity epoch (Hoare and others, 1968). Multiple samples yielded ages between 3.24±.10 and 5.01±.15 Ma (table 1)

Talb **Alkalic basalt of Ahzwiryuk Bluff** (Tertiary, Pliocene)—Alkalic basalt of Ahzwiryuk Bluff on Nunivak Island; nubbly mottled flows and pyroclastic ejecta; includes both normally and reversely polarized rocks older than Gauss polarity epoch (Hoare and others, 1968). Two samples from this unit yielded K/Ar ages of 5.19±.15 and 6.28±.18 Ma (samples A15 and A1, respectively, table 1)

Tfi **Felsic intrusive rocks** (Tertiary, Miocene?)—Light-colored, fine-grained, commonly porphyritic felsic intrusive rocks. Chiefly rhyolitic to dacitic dikes and sills. K/Ar age on biotite of 13.00±0.50 Ma (Hoare and Coonrad, 1978, sample 74AHr 26, table 1, herein)

Tad **Aplite on Saint George Island** (Tertiary, Eocene)—Aplite dike, about 400 m wide, has chilled margins where it intrudes peridotite on Saint George Island (Barth, 1956). The dike and peridotite surface is overlain by till and fine-grained sedimentary deposits, which are in turn overlain by basalt and basanite flows of map unit Qvb. Radiometric dating (Hopkins and Silberman, 1978; table 1 herein) indicates an age range of about 49.5±2.0 to 57.2±2.3 Ma

Tnr **Nukluk Volcanic Field, rhyolite** (Tertiary, Eocene)—Moderately altered rhyolite flows, domes, and ash-flow tuff. Rhyolite of the main volcanic field contains phenocrysts of sanidine, riebeckitic amphibole, and rare quartz. A $^{40}Ar/^{39}Ar$ total-fusion age on riebeckite was 54.7±1.6 Ma (Box and others, 1993, sample 87ACz 75m, table 1 herein)

Tnba **Nukluk Volcanic Field, basalt and andesite** (Tertiary, Eocene)—Massive, columnar-jointed, basalt and subordinate andesite flows. Minor latite and dacite. Overlies Tnr in Fog River area. Elsewhere, interbedded with rhyolite (Box and others, 1993)

Tvep **Rhyolite and dacite tuff** (Tertiary)—Chiefly rhyolite and dacite welded tuff and tuff breccia and dark rhyolite vitrophyre on the northern part of Saint Matthew Island (Patton and others, 1975) containing minor intercalated andesite and basalt flows and dikes. On southwestern part of island, chiefly light-colored rhyolite and dacite hypabyssal rocks (Patton and others, 1975). These felsic rocks appear to overlie mafic flows and volcaniclastic rocks mapped herein as unit Kv and may be extrusive and hypabyssal cogenetic equivalent of granodiorite mapped herein as unit TKm (Patton and others, 1975). Age thought to be Eocene or Paleocene (see Wittbrodt and others, 1989)

TMzp **Peridotite on Saint George Island** (Tertiary or older)—Peridotite forming the basement of Saint George Island in the Pribilof Islands. The peridotite is massive, originally was dunite and now largely altered to serpentine and magnetite (Barth, 1956). The erosional surface of the peridotite appears polished, has glacial striae and a brownish-black varnish (Barth, 1956, p. 117). Intruded by an aplite dike of unit Tad, suggesting age is greater than 57 Ma

Tertiary and (or) Cretaceous

TKr **Rhyolite and dacite flows, tuff, dikes, and sills** (Early Tertiary and (or) Late Cretaceous)—Rhyolite and dacite flows and tuff including block-and-ash flows as well as rhyolite domes. Unit includes felsic rocks of the Swift Creek, Tulip, and Eek volcanic fields of Box and others (1993). Consists of fresh to moderately altered, densely welded rhyolitic ash-flow tuff, black glassy vitrophyre, and pale pink to orange, fine-grained, porphyritic albite-bearing rhyolite. The rhyolite commonly has well-developed flow structures and forms rhyolite domes found as small knobs or large domal hills as much as 4 km in diameter which have 300 to 500 m of relief (Box and others, 1993), as well as small stock-like intrusions, dikes, and sills (Hoare and Coonrad, 1959a). The block-and-ash flow in the Tulip volcanic field consists of broken blocks of dacite in an ashy dacitic matrix and was interpreted to be a hot avalanche deposit formed during dome collapse. Dacite and subordinate andesite flows in the Tulip volcanic field, which crop out as columnar-jointed cliffs, are also included here. K/Ar ages range from 54.7±1.6 Ma on a whole-rock to 62.5±1.9 Ma on biotite (table 1)

TKa **Eek and Swift Creek volcanic fields of Box and others (1993); andesite flows** (Early Tertiary and (or) Late Cretaceous)—Small outcrops and columnar jointed andesite flows. Subordinate altered andesite porphyry is exposed in the northern part of the Eek volcanic field. Map unit also includes minor olivine basalt, andesitic lithic tuff, dacite, and a small amount of obsidian and siliceous tuff (Hoare and Coonrad, 1959a). Primarily exposed on the west side of the Bethel quadrangle along ridges and in river cuts in the Eek volcanic field; however, the Swift Creek volcanic field also contains exposures of columnar jointed andesite capping small hills in the southeastern part of the Bethel quadrangle (Box and others, 1993). According to Hoare and Coonrad (1959a) this map unit is moderately folded and unconformable on steeply dipping rocks of Cretaceous age and older. A $^{40}Ar/^{39}Ar$ total fusion age of 59.5±12.3 Ma was determined on plagioclase from andesite in the central Bethel quadrangle (Box and others, 1993, sample 88Al 12, herein)

TKg **Granitic rocks, undivided** (Tertiary and (or) Cretaceous)—Fine- to coarse-grained or porphyritic, light- to dark-gray, rarely pink, granitic rocks. Range in composition from granite to quartz diorite, including granodiorite, quartz monzonite, and quartz monzodiorite. Biotite and hornblende are locally common; muscovite is uncommon. K/Ar and $^{40}Ar/^{39}Ar$ ages range from 60.7 to 75 Ma throughout the map area for rocks of this unit and its sub-divisions (table 1) and 68.7±3.0 and 75.0±2.9 Ma for dated rocks that are in this undivided unit. Unit includes the Fisher Dome and Marvel Creek plutons of Box and others (1993). Also includes map unit TKg of Hoare and Coonrad (1978) except where subdivision of these rocks is possible on the basis of composition. Rocks assigned to this map unit by Hoare and Coonrad (1978) on Hagemeister Island were subsequently assigned to map unit Jmf of Middle Jurassic age by Box (1985a). Locally subdivided into:

TKgr **Granite**—Coarse- to medium-grained granite and granitoid porphyry. Biotite is dominant mafic phase, hornblende is sparsely present; feldspars are microcline and albite-oligoclase (Wilson, 1977). Unit includes the Akuluktok and Gechiak plutons of Wilson (1977) as well as Aniak Lake pluton of Box and others (1993) and the Nayorurun River intrusive complex of Hoare and Coonrad (1978) consisting of granite porphyry dikes, sills, and related tuff and breccia. The Aniak Lake pluton is a coarse-grained, porphyritic to seriate leucocratic biotite granite pluton 10 km^2 in area in the Bethel quadrangle (Box and others, 1993). It has a distinctive speckled appearance due to randomly oriented microperthite feldspar phenocrysts. Porphyritic rhyolite dikes common in the uppermost part of this pluton and in surrounding biotite hornfels. K/Ar and $^{40}Ar/^{39}Ar$ total-fusion ages for this unit range from 60.7±1.8 Ma to 69.6±2.1 Ma (table 1). The Akuluktok pluton yielded reversely discordant ages with biotite at 69.6±2.1 Ma and hornblende at 63.4±3.0 Ma (Wilson, 1977; sample

74B57, table1 herein). To the east of the map area, rocks of this map unit range from 54.5 ± 1.6 Ma on hornblende, considered a minimum age and not an emplacement age by Wallace and others (1989) to 66.64±0.08 Ma on mica (Wilson and others, 2003)

TKgs **Monzonite**—Medium-grained pyroxene-bearing monzonite. Biotite is the dominant mafic mineral; however, these plutons are characterized by the presence of orthopyroxene. Includes the Ualik Lake and Kulukak plutons of Wilson (1977). The chemically and texturally similar Okstukuk Hills and Kulik Lake plutons occur in the adjacent Dillingham quadrangle (Wilson, 1977; Wilson and others, 2006b). Potassium content is high relative to SiO_2, as high as 4.50 percent K_2O at a SiO_2 value of 57.4 percent (Wilson, 1977). A K/Ar age of 71.9±2.0 Ma (sample 74AHr 51, table 1) was determined on a pluton in the Nushagak Bay quadrangle, whereas the Okstukuk Hills pluton in the adjacent Dillingham quadrangle yielded an age of 84.49±0.05 Ma (Iriondo and others, 2003; Wilson and others, 2006b) which is unusually old for this region

TKqm **Quartz monzonite and quartz monzodiorite**—Medium- to coarse-grained, light-gray monzogranite or quartz monzodiorite plutons which may contain biotite, hornblende, sodic amphibole, and (or) clino- and orthopyroxene (Wilson, 1977). Locally contain phenocrysts of perthitic feldspar; biotite to hornblende ratio is variable but generally sub-equal (Wilson, 1977). These plutons are the most common of the Tertiary and (or) Cretaceous plutons of the map area. Includes Crooked Mountain and Canyon Creek plutons of Box and others (1993) in the Bethel quadrangle. As described by Box and others (1993), Crooked Mountain is a large composite pluton having a thin gabbro and diorite margin that partially rims a massive core of augite-biotite-hornblende and (augite-) hornblende-biotite granodiorite, quartz monzonite, and granite. Canyon Creek pluton is a small (~1 km^2), medium- to coarse-grained, intergranular to hypidiomorphic-granular augite-biotite quartz diorite to hornblende-biotite granodiorite. K/Ar and $^{40}Ar/^{39}Ar$ ages range from 63.7 to 71.1 Ma (table 1); the Togiak Lake pluton of Wilson (1977) yielded a discordant K/Ar age of 63.7±2.0 Ma on biotite and 69.5±3.0 Ma on hornblende (74AHr 118, table 1). $^{40}Ar/^{39}Ar$ total-fusion ages of 69.8±2.1 Ma were determined on biotite from Crooked Mountain pluton and 70.3±2.1 Ma on biotite from Canyon Creek pluton (87ATf 51 and 87AJm 36a, respectively, table 1)

TKgd **Granodiorite**—Consists of plutons in the Saint Matthew, Goodnews Bay, and Bethel quadrangles. On Saint Matthew Island, is a fine-grained hornblende granodiorite which yielded a 62.3±2.0 Ma K/Ar age on hornblende (Patton and others, 1975, 71AMm 45, table 1 herein). In the Goodnews Bay quadrangle, the Sunday Creek and Mt. Waskey plutons of Wilson (1977) are medium- to coarse-grained tonalite and granodiorite. The Sunday Creek pluton yielded a K/Ar age on biotite of 72.5±2.2 Ma (GC1-1381, table 1), whereas the Mt. Waskey pluton yielded slightly discordant K/Ar ages of 62.5±1.9 and 65.2±2.0 Ma on biotite and hornblende (GD1-3154, table 1). In the Bethel quadrangle, includes the two phase North Fork pluton of Box and others (1993) and the Cripple Mountain pluton. Aplite dikes are common near these plutons. Main felsic phase of the North Fork pluton is seriate to hypidiomorphic granular (augite-) hornblende-biotite quartz monzodiorite, granodiorite, and minor biotite granite. The North Fork mafic phase is a coarse-grained, cumulate-textured augite quartz gabbro and quartz diorite. Cripple Mountain pluton is an elliptical, coarse-grained, hypidiomorphic-granular hornblende-biotite granodiorite and granite, and lesser quartz monzodiorite and quartz monzonite covering about 40 km^2 in the Bethel quadrangle (Box and others, 1993). The pluton is erosionally recessive wherein the contact aureole and surrounding country rock are more resistant to erosion than the pluton. North Fork and Cripple Mountain plutons yield $^{40}Ar/^{39}Ar$ total-fusion ages of 64.3±1.9 and 62.2 ± 1.9 Ma, respectively (87ATf 56 and 87ATf 72, respectively, table 1)

TKqd **Monzodiorite and quartz diorite**—Consists of the Eek River, Gemuk Mountain, Mount Plummer plutons of Box and others (1993) and the hornblende diorite stocks and dikes assigned a Late Cretaceous age by Box and others (1993) as well as the Wattamuse pluton of Wilson (1977). Plutons are fine- to coarse-grained monzodiorite and diorite, but locally include gabbro. Eek River pluton is a sill 50 to 500 m thick cropping out in discontinuous exposures over 10 km length which intruded and contact-metamorphosed rocks of the Kuskokwim Group (Kk). It is dominantly medium- to coarse-grained, porphyritic to diabasic (hornblende) augite diorite, quartz diorite, and mafic quartz monzodiorite. Gemuk Mountain pluton is elongate, north-trending, erosionally resistant, mafic to intermediate quartz gabbro to mafic granodiorite pluton. The pluton also intruded and contact-metamorphosed the Kuskokwim Group as well as Lower Cretaceous marine volcaniclastic sandstone, conglomerate, shale, and interbedded tuff of map unit Kvm. Mt. Plummer pluton is medium- to coarse-grained, erosionally resistant, hypidiomorphic granular augite-biotite mafic granodiorite, quartz monzodiorite, and quartz diorite; it intruded and contact metamorphosed the Kuskokwim Group. The Mt. Plummer pluton has yielded K/Ar biotite ages of 65.1±2.0 Ma (87ACz 61, table 1) and 66.6±2.0 Ma in the adjacent Russian Mission quadrangle north of the map area (Box and others, 1993). Hornblende diorite stocks and dikes are small, extensively altered, and contain relict euhedral plagioclase; samples yielded a $^{40}Ar/^{39}Ar$ total-fusion age of 68.0±2.0 Ma on hornblende (87AJm 271b, table 1) and a conventional K/Ar age of 71.3±2.1 Ma on biotite (GB7-1479a, table 1)

TKm **Mafic intrusive rocks** (Tertiary, Paleocene, and Cretaceous?)—Dark-colored dikes and sills of diabase, basalt, and dioritic, gabbroic, and biotite lamprophyre (Hoare and Coonrad, 1978). K/Ar age of 64.6±2 Ma on biotite (74ACd 14d, table 1) from the western Nushagak Bay quadrangle. Also includes medium- to coarse-grained pyroxene gabbro dike(?) on Saint Matthew Island (Patton and others, 1975)

Cretaceous

Kv **Volcanic rocks** (Late Cretaceous, Maastrichtian and Campanian)—Volcanic rocks ranging from rhyolite to olivine basalt flows, dacitic to andesitic tuff and tuffaceous sandstone, and rhyolitic domes (Hoare and Coonrad, 1978; Patton and others, 1975; Box 1985a; Box and others, 1993). Includes rhyolite domes and flows of the Tulip volcanic field, lithic air-fall tuff of the Swift Creek volcanic field, and andesite and basalt flows, tuff, tuffaceous sandstone, and rhyolite domes and flows of theKipchuk volcanic field (Box and others, 1993). Also includes moderately to steeply dipping, fresh to weakly altered porphyritic basaltic andesite flows of calc-alkaline affinity and interbedded sandy to boulder-rich volcaniclastic rocks mapped by Globerman (1985) and Box (1985a) in the Hagemeister Island quadrangle which were originally mapped as unit Tv by Hoare and Coonrad (1978). Associated dikes cut underlying units. In the Hagemeister Island and southern Goodnews Bay quadrangles, unit overlies Upper Cretaceous Summit Island Formation (Ks) on Summit Island and adjacent mainland. On Hagemeister Island, consists of individual 2 to 5 m thick subaerial flows aggregating at least 2 km thick with very minor fluvial sandstone interbeds. On Crooked Island, it has similar flows but has more voluminous (25 percent) interbedded epiclastic volcanic sandstone and coarse boulder conglomerate. On mainland coast, northwest of Right Hand Point, consists almost entirely of boulder-rich volcaniclastic sedimentary rocks of probable debris flow origin and very minor flows. On Saint Matthew Island, consists of flat-lying to gently dipping mafic flows of andesite and basalt, and volcaniclastic rocks consisting of andesitic and basaltic tuff and conglomerate. K/Ar and $^{40}Ar/^{39}Ar$ ages range from 64.5±2.0 Ma to 79.2±2.4 Ma (table 1); however, a basalt sill from Saint Matthew Island yielded a whole-rock K/Ar age of 52.2±1.6 Ma (Wittbrodt and others, 1989, sample 12-106, table 1 herein). As this sample yields a significantly younger age than other dated rocks from Saint Matthew Island, Wittbrodt and others (1989) suggested that the basalt sill was derived from a significantly younger event, which intruded this map unit, Kv. In the Bethel quadrangle, internal contacts reflect distinction between flow and tuff units of Box and others (1993); pyroclastic and felsic sub-units are shown with overprint patterns

Kpd **Intermediate and silicic pyroclastic rocks** (Late Cretaceous)—Intermediate and silicic pyroclastic rocks on Saint Matthew Island including: dacite, andesite, and rhyolite nonwelded tuff breccia and crystal tuff, dacite and rhyolite welded tuff, massive dacite breccia (lahar ?), fine ash-fall tuff, volcanic conglomerate, and andesite and dacite porphyritic and vitrophyritic plugs, dikes, sills, and flows (Patton and others, 1975). K/Ar ages of 76.0±2.0 and 76.3±2.0 Ma on biotite and hornblende (samples 4-16 and 5-33, table 1). Late Cretaceous pollen assemblages from carbonaceous tuffs (R.A. Scott, oral commun., 1973; reported in Patton and others, 1975)

Ksp **Serpentinite** (Late Cretaceous?)—Small, pervasively slickensided bodies of serpentinite, serpentinite-matrix melange, and silica-carbonate-altered serpentinite north of mouth of Crooked Creek (Box and others, 1993). Protolith and intrusion age uncertain; Box and others (1993) infer intrusion during Late Cretaceous tectonism

Kg **Granodiorite and granite** (Early Cretaceous)—Consists of the Nyac pluton in Kilbuck Mountains, only a small part of which is exposed in the northernmost part of the Bethel quadrangle; the bulk of the exposure of the pluton is in the adjacent Russian Mission quadrangle (Box and others, 1993). About 200 km^2 in size, pluton is crudely concentrically zoned from hornblende-biotite granodiorite and granite at margin to hornblende-biotite granite at core (Box and others, 1993). K/Ar age determinations yield a range of ages, from 101.1±3.0 Ma (Decker and others, 1984; Box and others, 1993) on hornblende in the Russian Mission quadrangle north of the map area to 120.0±3.3 Ma on biotite (Wilson, 1977; Box and others, 1993), also in the Russian Mission quadrangle as well as a K/Ar biotite age of 115±3.5 Ma from within the Bethel quadrangle (sample 87ATf 30, table 1) and a U/Pb crystallization age reported as a range of 104 to 129 Ma (upper Concordia intercept) on zircon (see table 1, also for additional data see Box and others, 1993; Patton and others, in press(b); Wilson and others, 2006a)

Tertiary to Jurassic

TJih **Hypabyssal felsic intrusive rocks** (earliest Tertiary? to Late Jurassic?)—Highly altered porphyritic rocks consisting of orange weathering rhyolite and dacite. Rhyolite contains as much as 10 percent phenocrysts, locally in graphic intergrowths, in an altered groundmass of quartz, potassium feldspar, and plagioclase. Dacite contains as much as 5 percent phenocrysts of plagioclase and biotite in a groundmass plagioclase, quartz, and opaque oxides (Box and others, 1993). Some of these rocks have similar trace element signatures to the Slate Creek pluton (unit TJis) of Box and others (1993). Age is uncertain though rocks intrude the rocks of map units Jab and Jvc

TJis **Slate Creek pluton of Box and others (1993)** (earliest Tertiary? to Late Jurassic?)—Small, medium-grained hypidiomorphic-granular, hornblende tonalite and granodiorite pluton, less than 2 km^2. Intrudes rocks of map unit Jab without development of a prominent contact-metamorphic zone. Pluton is relatively quartz-rich, containing 20 to 25 percent quartz, along with green hornblende, plagioclase, and opaque oxides (Box and others, 1993). Pluton erodes similarly to country, hence is not prominent and was considered “erosionally neutral” by Box and others (1993). Age is uncertain

TJik **Little Kasigluk River pluton of Box and others (1993)** (earliest Tertiary? to Late Jurassic?)—Medium-grained, hypidiomorphic granular hornblende diorite and gabbro in a number of small plutons (Box and others, 1993) in the central to western Bethel quadrangle. Age is uncertain

KJba **Basaltic and andesitic lava flows** (Early Cretaceous and (or) Late Jurassic)—Poorly to moderately exposed basalt and andesite lava flows in the west central part of the Bethel quadrangle (Box and others, 1993). Overlies volcaniclastic sedimentary rocks of map unit Jvc and generally spatially associated with rocks of map unit Jab

Jurassic

Jum **Ultramafic rocks** (Jurassic?)—Serpentinite, serpentinized dunite, and other ultramafic rocks form a number of intrusive bodies and tectonic blocks(?) within fault zones separating pillow basalt (Ŧob) and pyroxene gabbro (Ŧog), respectively (Hoare and Coonrad, 1978; Box, 1985a). At Red and Susie Mountains, south of Goodnews Bay, the rocks consist of medium-grained, partially serpentinized dunite, wehrlite, and clinopyroxenite (Box, 1985a); Hoare and Coonrad (1978) reported websterite rather than wehrlite. The margins of these bodies are cut by numerous coarsely pegmatitic hornblendite dikes which have contact metamorphic zones as much as 800 m wide (Box, 1985a). Unit, as mapped herein, also includes serpentinite at Cape Newenham, which apparently had a protolith that was predominately harzburgite, subordinate dunite, and rare clinopyroxenite (Box, 1985a). This serpentinite “varies from blocky, unsheared protoliths [harzburgite?] to slickensided serpentinite enclosing blocks with original fabrics” (Box, 1985a). According to Box (1985a), the northeast flank of the ultramafic body at Susie Mountain appears to grade into hornblende gabbro of map unit Jgb, which yielded an age of 162.4±4.9 Ma (GA7-1450, table 1), significantly younger than the dated dikes which cut the ultramafic body at Red Mountain. K/Ar dates were 176.4±5.3 and 186.9±5.6 Ma (HD6-2272a and HD6-1453e, respectively, table 1) on amphibole from the cross-cutting hornblendite dikes

Jab **Andesite and basalt** (Middle Jurassic)—Massive andesitic and basaltic flows; minor trachyte, trachyandesite, and dacite; some interbedded tuffaceous sedimentary rocks; and, locally, several hundred feet of volcanic breccia at or near base (Box and others, 1993). An estimated 25 percent of the unit is interbedded graywacke, siltstone, impure limestone, and pebble conglomerate (Hoare and Coonrad, 1959a). This rock unit forms a belt of low rolling hills on the west flank of the Kuskokwim Mountains from the Kwethluk River and northward (Hoare and Coonrad, 1959a). Marine pelecypods of Bajocian (Middle Jurassic) age occur in sedimentary strata of this unit (Hoare and Coonrad, 1959a; Box and others, 1993). Assigned to Nyac terrane by Box and others (1993)

Jmv **Interbedded volcanic and sedimentary rocks** (Middle Jurassic)—Basaltic and andesitic volcanic and volcaniclastic rocks on Hagemeister Island (Hoare and Coonrad, 1978; Box, 1985a); extensively altered to prehnite-pumpellyite facies mineral assemblage. Volcanic rocks, characterized by plagioclase + clinopyroxene ± hornblende porphyritic rocks, more common in lower third of exposed section. Interbedded clastic rocks are composed almost entirely of volcanic lithic detritus, except for a lower conglomerate, which contains a minor proportion granitic plutonic rock clasts similar to adjacent pluton. Sedimentary facies range from fluvial deltaic to nearshore marine to subwave base turbidites. Box (1985a) mapped the contact between this unit and similar older volcanic and sedimentary rocks (unit Jlvs) structurally and stratigraphically below it as a low-angle thrust(?) which he suggested is probably a faulted unconformity. Fossils of Middle Jurassic age are locally common (Box, 1985a). Conglomerate includes clasts of granitic rocks similar to nearby Middle Jurassic Hagemeister pluton (Box, 1985a); mapped herein as unit Jlgd

Jgb **Gabbroic rocks** (Middle and Early Jurassic)—Medium- to coarse-grained, locally pegmatitic hornblende gabbro to diorite (Hoare and Coonrad, 1978). Plutons locally contain olivine and commonly are compositionally layered (Hoare and Coonrad, 1978). Box (1985a) described these rocks as slightly altered, containing sericitized plagioclase, hornblende partially replaced by actinolite and chlorite, and prehnite-quartz veinlets. Hoare and Coonrad (1978) reported that these gabbroic intrusions are commonly associated with ultramafic rocks. Five K/Ar amphibole and hornblende ages have a bimodal distribution, having peaks at about 187 and 161 Ma (table 1)

Jlvs **Volcanic and sedimentary rocks** (Lower Jurassic)—Marine unit of mafic flows, some displaying pillow structure, volcanic breccia, and massive fine- to medium-grained volcanogenic sedimentary rocks (Hoare and Coonrad, 1978). Fractures commonly coated with laumontite. Mapped as unit Jlv by Box (1985a) who described the unit as grading from a lower massive, sub-wave-base, angular pebbly mudstone to upper abundantly fossiliferous, shallow marine, well-bedded, locally cross-bedded sandstone and shale. Unit only exposed on Hagemeister Island. An impure sandy limestone that outcrops in the Taylor Mountains quadrangle to the east of map area was originally included in this unit by Hoare and Coonrad (1978) because of the common occurrence of *Weyla* pelecypods of Early Jurassic age; however, the limestone was mapped as a distinctive unit by Wilson and others (2006b)

Jlgd **Hagemeister pluton of Box (1985a)** (Early Jurassic?)—Medium-grained biotite-hornblende granodiorite of Hagemeister Island; slightly altered (i.e. sericitized plagioclase, chlorite partially replacing biotite and hornblende) as described by Box (1985a). Intrudes Lower Jurassic volcanic and sedimentary rocks (map unit Jlvs) with a narrow contact metamorphic zone of hornblende-biotite-plagioclase hornfels. Box (1985a) reported that clasts of similar granodiorite occur in conglomerate of adjacent interbedded volcanic and sedimentary rocks of map unit Jmv. An age reported variously by Box (1985a) as on biotite (p. 26) or hornblende (p. 18) yielded K/Ar age of 183±7 Ma (B78-1152G, table 1); the reported K_2O content for this sample is well below that typical for biotite and conversely, very high for hornblende. As presented, the date must be considered suspect. No similar age granitic rocks are known elsewhere in southwestern Alaska, but rocks of this age are common in the Alaska-Aleutian Range batholith to the east (Wilson and others, 2006b). Pluton originally mapped as part of map unit TKg by Hoare and Coonrad (1978)

Togiak-Tikchik Complex

MzPzt **Togiak-Tikchik Complex, undivided** (Lower Cretaceous to Lower Paleozoic)—Thick, marine unit consisting of volcanic and sedimentary rocks including pillow basalts, intermediate to mafic flows, breccia, crystal-lithic tuff, thin-bedded to massive tuffaceous chert and siltstone, argillite, graywacke, pebble-cobble conglomerate, and limestone. Formerly called the Gemuk Group (Hoare and Coonrad, 1959a, 1961a, b), this unit consists of a wide variety of rock types in a structural collage of blocks. The Gemuk Group as originally defined consists chiefly of dense, dark, massive siltstone having interbeds of chert, volcanic rocks, limestone, graywacke and breccia (Cady, 1955). The assemblage was subsequently redefined as the Togiak-Tikchik Complex on the basis of its structural character (Wilson and Coonrad, 2005). Unit crops out in a wide belt through the Goodnews Bay quadrangle from the Eek Mountains in the north southwest to Goodnews Bay making up most of the northwestern Ahklun Mountains. It is unconformably overlain by rocks of the Late Cretaceous Kuskokwim Group (Kk and Kkn) and Early Cretaceous (Valanginian) calcareous graywacke and siltstone (Kcgc). Permian limestone (Pl) containing *Atomodesma* sp. is interbedded throughout the unit. Hoare and Coonrad (1978, see also www.alaskafossil.org) collected samples containing corals of Permian age and crinoids, bryozoans and *Halobia* of Triassic age. They also collected brachiopods (including several productoid forms, cleiothyridinoid genus, and a spiriferoid), a pleurotomarian gastropod, and pelecypods of late Paleozoic (probably Permian) age. Hoare and Coonrad (1978) mentioned the unit contains volcanic rocks of Triassic, Permian, and Devonian ages. Unit was included in the Goodnews terrane by Box (1985a) and Box and others (1993); however, rocks also mapped as unit MzPz by Hoare and Coonrad (1978) and included in the Togiak-Tikchik Complex were assigned to the Togiak terrane by Box and others (1993; see also Decker and others, 1994). Unit was subdivided by Box (1985a) in the Hagemeister Island and southernmost of the Goodnews Bay quadrangles into units JTRcs (JPcs, herein), JTRmvs (JPmvs, herein), JTRmb (JPmb, herein), Pvs, and Pmv. Where possible, sub-unit assignments were extrapolated from the Box (1985a) map area into the Hoare and Coonrad (1978) map area. Unit MzPz of Hoare and Coonrad (1978) was further subdivided into two mélange units (MzPza; Mzm) by Box and others (1993) in the Bethel quadrangle. Included rock packages are:

Mzm **Mélange** (Mesozoic)**—**Mélange containing chert, cherty tuff, siliceous siltstone, limestone and dolostone, pillowed and massive basalt, gabbro, and graywacke in an argillite matrix (Box and others, 1993; Hoare and Jones, 1981; Wilson and others, 2006b). Chert was described by Hoare and Jones (1981) as gray and thin-bedded with shale partings or red siliceous silt; and massive or thick-bedded gray, black, white and brownish. They also described calcareous sandstone and shale, white crystalline limestone, and pyroclastic rocks altered to greenstone. Consists of unit ŦPzm of Box and others (1993) in the Bethel quadrangle and subdivided from unit MzPz of Hoare and Coonrad (1978) in the Goodnews Bay and adjacent Dillingham and Taylor Mountains quadrangles based on work reported in Wilson and others (2006b). Unit crops out in the Tikchik Lakes area of the Bethel and Goodnews Bay quadrangles and extends into the adjacent Taylor Mountains and Dillingham quadrangles. The mélange may contain rocks of multiple map units, including the argillite and graywacke (KŦag), volcanic rock (Pv and Ŧv), clastic rocks (Pcs), limestone (Pls), greenstone and schist (MDv), and chert (Pzc and ŦPzrc) of Wilson and others (2006b). Unit is structurally complex and is dismembered along anastomosing cleavage (Box and others, 1993). According to Hoare and Jones (1981) "***the rocks were deformed twice by isoclinal folding and offset by northwest trending high-angle faults and northwest-dipping low- and high-angle reverse faults. The older folds trend west or northwest; the younger folds are post-Cretaceous in age, trend northeast, and are commonly recumbent to the southeast." Unit structurally underlies greenstone and schist (MDv) to the northwest beneath a low-angle(?) fault; and is juxtaposed against volcanic and sedimentary rocks (KŦvs) along the high-angle Togiak-Tikchik fault (Box and others, 1993). Where units, such as the limestone of Permian age can be distinguished, they are mapped separately. Reported are Late Triassic and Permian megafossils and radiolarians of Paleozoic(?), Devonian, pre-Late Devonian, and Triassic age including the radiolarians *Eucyrtis* sp., *Mirifusus*(?), *Parvicingula blowi Pessagno*, *Parvicingula* sp., *Ristola*(?) *altissima Rust*, *Ristola* sp., *Spongocapsula* sp.(?) of Early Cretaceous (Berriasian/early Valanginian) to Late Jurassic (late Tithonian) age; and conodonts *Epigondolella*, *Epigondolella abneptis*, *Neogondolella*, *Neogondolella navicula*, *Xaniognathus* sp. indet of Late Triassic, Norian age (Hoare and Jones, 1981; Box and others, 1993; see www.alaskafossil.org). Unit was included in the Tikchik terrane by Box and others (1993)

MzPza **Argillaceous mélange** (Mesozoic to Paleozoic)—Rock unit described by Box and others (1993) as a weakly to intensely fractured foliated black to green argillaceous mélange containing discontinuous phacoids of radiolarian chert, limey sandstone, blocks of limestone, and subphyllitic, amygdaloidal basalt. Unit crops out in the Eek mountains near the southern boundary of the Bethel quadrangle. Unit is unconformably overlain by Cretaceous rocks of the Kuskokwim Group (Kk) and calcareous graywacke and siltstone (Kcgc). Conodonts *Neogondolella bitteri* and *Neogondolella phosphoriensis* of Permian age were found in limy siltstone (Box and others, 1993; see also www.alaskafossil.org). Box and others (1993) reported Permian pelecypods (*Atomodesma* sp. fragments) from a basalt-limestone block originally reported by Murphy (1989) and Permian conodonts recovered from limy siltstone in the matrix of the unit. Unit was included in the Goodnews terrane by Box and others (1993)

JŦp **Phyllite and chert** (Lower Jurassic and Upper Triassic?)—Gray, green, and black phyllite, fine-grained tuff, and tuffaceous chert (Box and others, 1993). Unit crops out in the southeast corner of the Bethel quadrangle near the heads of Upnuk and Chikuminuk Lakes and trends north-northeast where it continues into the adjacent Taylor Mountains quadrangle. Unit depositionally overlies map unit Ŧb in the southeastern Bethel quadrangle and is overlain by map units Jvs and Ja (Box, 1985a). Box and others (1993) constrained age based on unit overlying Ŧb and an Early Jurassic age derived from the single radiolarian collection. On the basis of field notes of J.M. Hoare and W.H. Condon in the adjacent Taylor Mountains quadrangle, the unit could also be described as gray to black cherty phyllitic shale, highly contorted thin-bedded siliceous argillite and local cherty dark calcareous phyllite in association with greenstone of map unit MDv. The phyllite is occasionally sulfide-bearing along fault zones according to the field notes of J.M. Hoare and W.H. Condon (USGS unpublished data, 1969, 1970)

Ŧvs **Volcanic and sedimentary rocks** (Upper Triassic)—"Marine unit consisting of chert, tuffaceous cherty rocks, argillite, siltstone, volcanic wackes, conglomerate, limestone, and mafic flows and breccias" (Hoare and Coonrad, 1978). Limestone is generally white to cream colored and recrystallized; however, it locally may be dark gray and finely crystalline. Possibly occurs in fault bounded settings. Unit crops out in two areas, one near the head of Lake Chauekuktuli in the northeast corner of the Goodnews Bay and adjacent Dillingham quadrangle and a second area near where the Kanektok River has cut through the Ahklun Mountains. Fossils include the ammonite *Arcestes* sp. of Late Triassic age, and pelecypods *Monotis subcircularis* Gabb and *Monotis*(?) sp. of Norian age (see www.alaskafossil.org). Similar rocks are included in the MzPz unit of Hoare and Coonrad (1978, unit MzPzt, herein) as well as in the ŦPzm melange unit of Box and others (1993, unit Mzm in part, herein). Hoare and Coonrad (1978) mapped these rocks as a separate unit only in the vicinity of fossil localities "because the rocks resemble other rocks of Paleozoic and Mesozoic ages with which they are tectonically associated." Unit included both in the Goodnews and Tikchik terranes by Box and others (1993)

Ŧv **Basalt and chert** (Upper Triassic)—"Massive and pillow basalt and basaltic breccia interbedded with thin-bedded tuffaceous chert and shale" (Box and others, 1993). Unit crops out near the heads of Upnuk and Nishlik Lakes along the southwestern edge of the Bethel quadrangle and continues eastward into the adjacent Taylor Mountains quadrangle. West of Milk Creek fault, basalt is hydrothermally altered, containing secondary chlorite, quartz, and calcite, but it retains original subophitic and fine-grained plagioclase porphyritic textures (Box and others, 1993). East of Milk Creek fault, a strong foliation and recrystallization has produced fine-grained schist or phyllite composed of chlorite, epidote, calcite, and pumpellyite (Box and others, 1993). "Whole-rock trace-element chemistry is characterized by flat to light REE-depleted chondrite-normalized REE pattern, and by high La/Nb elemental ratios, characteristic of island-arc tholeiitic basalts" (Box and others, 1993). Box and others (1993) linked the units on either side of the Milk Creek fault on the basis of similar stratigraphic position and trace-element chemistry. Box and others (1993) reported interbedded shale yielded pelecypods of Late Triassic age just east of Aniak Lake as well as in the Taylor Mountain quadrangle east of map area (W.L. Coonrad, written commun., 1991 cited in Box and others, 1993). In the Taylor Mountains quadrangle, unit is associated with a limestone that yields *Monotis* and *Halobia* fossils of Late Triassic age (Wilson and others, 2006b). Unit was included in the Togiak terrane by Box and others (1993)

Pv **Volcanic rocks** (Permian)**—**Pillow and columnar-jointed amygdaloidal, mildly altered basalt flows, breccia, diabasic intrusive, and a few sandy tuffs; unit Pb of Box (1985) and Pv of Hoare and Coonrad (1978). Unit crops out near Goodnews Bay and north of Nuyakuk Lake. In the Goodnews Bay area, unit is interbedded with volcaniclastic sedimentary rocks (unit Pvs herein; Box, 1985). Hoare and Coonrad (1978) did not separate these rocks from their undivided MzPz unit in the vicinity of Goodnews Bay. In the Nuyakuk Lake area, unit lies stratigraphically above and grades downward into the Permian limestone (unit Pls herein; Mertie, 1938, p. 45-46). Near lowest part of section north of Nuyakuk Lake fossils identified in an interbed or fault sliver of limestone include brachiopods *Calliprotonia* sp., *Neochonetes*(?), *Neophricadothyris* sp., *Neospirifer*(?) sp., *Thamnosia* sp., *Waagenoconcha*(?) sp., and *Yakovlevia* sp. of Permian age; foraminifera *Schwagerina jenkinsi* Thorsteinnson of Permian age; stenoporoid bryozoans of Permian age; and echinoderm debris of Permian age (see sample 79AHr 2, www.alaskafossil.org). Outcrops in vicinity of Goodnews Bay were included in the Goodnews terrane by Box (1985a), outcrops near Nuyakuk Lake lie within his Togiak terrane

Pls **Limestone** (Permian)**—**Thin-bedded and massive light- to dark-gray, locally cream-colored fine-grained recrystallized limestone; unit Pl of Hoare and Coonrad (1978) and Box (1985a). Tuffaceous and locally cherty; unit has a fetid odor upon breaking (Hoare and Coonrad 1978, Box, 1985a). Unit is widely distributed throughout the map area and is commonly intercalated in the Togiak-Tikchik Complex and mélange units (MzPzt, MzPza, Mzm). Hoare and Coonrad (1978) reported the unit "commonly closely associated with mafic volcanic rocks into which it grades through medium of calcareous breccias and tuffs." Commonly contains the pelecypod *Atomodesma* of Permian age as well as crinoid stems, brachiopods, other pelecypods, and possible bryozoan reported (J.M. Hoare and W.H. Condon, unpub. data; Box, 1985a; see also www.alaskafossil.org). Unit included in the Goodnews terrane by Box (1985a); however, rocks of this unit are also found within his Togiak terrane (Box and others, 1993; Decker and others, 1994)

Pvs **Volcaniclastic sedimentary rocks** (Permian)**—**"Volcaniclastic sedimentary rocks, ranging from coarsely bedded volcanic breccias to finely bedded calcareous tuffaceous rocks. Limestone cobble conglomerate locally north of Goodnews Bay. Red to black laminated argillite with radiolarian ghosts locally north and east of Goodnews Bay. Age constrained by several occurrences of fragmentary *Atomodesma* sp. Prehnite-pumpellyite facies" (Box, 1985a). Interbedded with Permian mafic volcanic rocks (Pv). Unit included in the Platinum subterrane of the Goodnews terrane by Box (1985a); however, rocks that are similar and stratigraphically correlated, are found in the western Taylor Mountains quadrangle associated with map units Pls and Pv and apparently extend into the eastern Bethel quadrangle (map unit Pcs of Wilson and others, 2006b). These rocks were assigned to the Togiak terrane by Box (1985a)

Pcs **Clastic rocks** (Permian?)**—"**Well-bedded, cleaved sandstone, shale thin limestone interbeds, and cobble conglomerate *** sandstone and conglomerate are composed predominantly of chert clasts (containing radiolarian ghosts and internal quartz veins) and minor phyllite and porphyritic volcanic clasts; shale-rich section have thin limestone turbidite beds and thin sand to gravel beds of volcaniclastic composition" (Box and others, 1993). Unit crops out in the Bethel quadrangle north and south of the head of Upnuk Lake and extends outside the map area into the adjacent Taylor Mountains quadrangle where it is mapped as the clastic rocks unit (Pcs) of Wilson and others (2006b). Unit depositionally overlies the greenstone and schist unit (MDv) (Box and others, 1993). Permian limestone (Pls) is interbedded with this unit in many places in the Taylor Mountains quadrangle to the east (Wilson and others, 2006b). Conodonts of Middle(?) Triassic and Early Mississippian to Late Devonian age were reported by Box and others (1993). With respect to the Devonian conodonts, Anita Harris (USGS, written commun. 1989) suggested they may have been derived from redeposited clasts or "interweaved" tectonic slices (see comments for sample 87AMM 69 at www.alaskafossil.org). Unit was included in the Tikchik terrane by Box and others (1993)

MDv **Greenstone and schist** (Lower Mississippian or Upper Devonian)—Box and others (1993) described this unit as consisting of "Weakly to moderately foliated and flattened pillowed and massive basalt, andesite, dacite, rhyolite flows, and breccia with greenschist metamorphic-mineral assemblages." They also stated that the rocks that have a volcanic protolith have whole-rock trace-element signatures indicating an arc-alkaline arc affinity. In the adjacent Taylor Mountains quadrangle, Wilson and others (2006b) described "Fine- to coarse-grained, massive green to purple altered greenstone, occasionally calcareous or schistose, rarely interbedded with green chert, argillite, and tuff. Greenschist with occasional chert boudins is a minor part of unit as is shale-chip agglomerate. Greenstone is locally cut by quartz and calcite veins containing epidote and copper sulfides" based on the 1969 and 1970 field notes of J.M. Hoare and W.H. Condon. Unit crops out near the head of Chikuminuk Lake. Unit is interbedded with the basal part of unit Pcs, clastic rocks and phyllite of map unit J₨p may overlie this map unit (Wilson and others, 2006b). Age inferred by Box and others (1993) on the basis of conodonts of Late Devonian to Early Mississippian age near the base of unit shown herein as Pcs (Note, the Pcs unit was mapped as of Triassic to Devonian age by Box and others, 1993). Age assignment questionable because conodont-bearing samples may have been collected from redeposited clasts or "interweaved" tectonic slices (see comments by Anita Harris for sample 87AMM 69, www.alaskafossil.org). Unit may be Permian in age because of association with clastic rocks of presumed Permian age due to association with Permian limestone (Pls) interbeds in the Taylor Mountains quadrangle (Wilson and others, 2006b) Unit included in the Tikchik terrane by Box and others (1993)

DOl **Thin-bedded limestone** (Devonian to Ordovician)**—**"Thin-bedded to massive, fine-grained gray limestone, highly fractured and veined with white calcite, contains algal reefs and reef breccias. Locally contains interbedded tuffs and mafic volcanic rocks. Recrystallized to marble with interbedded quartzite and quartz-chlorite schist ***" Hoare and Coonrad (1978). Algal mounds indicate shallow water deposition (Decker and others, 1994). Unit is in scattered outcrops along a north-northeasterly trend from Goodnews Bay to the northern edge of the Goodnews Bay quadrangle. Unit thrust over Permian limestone (Pls) and calcareous schist unit (ŦPcs) and intruded by gabbro of Jurassic age (Jgb). Hoare and Coonrad (1978) reported sparse fossils of Middle Devonian to Early(?) Ordovician age One sample collected by Stephen Box in northern part of the Goodnews Bay quadrangle boundary contains the conodonts *Acanthodus lineatus* (Furnish), *Drepanoistodus* sp., *Variabiliconus bassleri* (Furnish), "*Scolopodus" cf. "S." sulcatus* Furnish, *Eucharodus parallelus* (Branson and Mehl), and *Rossodus*(?) sp. of Early Ordovician age (see sample 89AJM 60a, www.alaskafossil.org). A sample collected by J.M. Hoare contained ostracodes, echinoderms, fragments of brachiopods, algae, and small colonies of tabulate coral, possibly the genus *Dania* of Silurian age (A.K. Armstrong, written commun., 1975) Unit was included in the Goodnews terrane by Box (1985a)

Metamorphic rocks of the Togiak-Tikchik Complex

[In general, stratigraphic position is given; this indicates the stratigraphic position inferred for the protolith. Where an age is given, this is the metamorphic age of the unit.]

Rock units of the Kisaralik anticlinorium of Box and others (1993) (Mesozoic and (or) Paleozoic)—A structurally imbricate package of Mesozoic to Paleozoic deep-marine sedimentary and mafic volcanic rocks (Box and others, 1993). Units listed here are in structural order in the anticlinorium top to bottom. Unless otherwise noted, the following unit descriptions are quoted from Box and others (1993)

MzPzp **Chloritic phyllite—"**Relatively homogenous unit of finely foliated and crenulated phyllite ***. Found east of southern part of Greenstone Ridge in south-central part of the map area [Bethel quadrangle]. Protolith was probably fine-grained tuffaceous sediment of uncertain age. Whole-rock major- and trace-element chemical compositions are similar to those of modern mid-ocean ridge basalts and strikingly similar to those of lavas from unit MzPzb. Structurally overlies unit MDm and is intruded by serpentinite (Ksp). Depositionally overlain by conglomeratic rocks [Kkn] of Kuskokwim Group. Age is uncertain, but older than Late Cretaceous age of unit [Kkn]." Unit is strongly foliated and metamorphosed to greenschist and transitional greenschist-blueschist facies. (Note, on this map, the Kuskokwim Group nearshore facies rocks of map unit Kkn are assigned an age that includes Albian or late Early Cretaceous)

MDm **Marble and metabasaltic dikes (Lower Mississippian and (or) Upper Devonian)—"**Light-gray to white calcitic and dolomitic marble cut by pre-metamorphic basaltic dikes. Only found in small area east of Greenstone Ridge in central part of map area [Bethel quadrangle]. Locally contains as much as 20 percent clastic grains of feldspar, quartz, and plutonic rock fragments. Rare metamorphic blue amphiboles (magnesioriebeckite) in metabasaltic dikes indicate relatively high-pressure, low-temperature metamorphism (Sarah Roeske, written commun., 1988). Ranges from 100 to 300 m thick. Unit found structurally above unit MzPzm and structurally below unit MzPzp; original depositional relations are uncertain. Age constrained by conodonts of latest Devonian to earliest Mississippian age (Stephen Box and others, unpublished data, reported in Box and others, 1993)" Unit is strongly foliated and metamorphosed to greenschist and transitional greenschist-blueschist facies

MzPzm **Metachert and phyllitic metachert—"**Finely crystalline, thin-bedded quartzites (metachert) and finely interlayered quartzite and black phyllite. Found east of southern part of Greenstone Ridge in central part of map area [Bethel quadrangle]. Composed of fine aggregates of quartz with seams to centimeter-thick bands rich in fine-grained white mica. Recrystallized radiolarian tests present in some horizons. Thickness is uncertain. Structurally overlies units MzPzs and MzPzv on north and is structurally overlain by unit MDm on south. Unconformably overlain by conglomeratic rocks [Kkn] of Kuskokwim Group along Kisaralik River. Age constrained by presence of radiolarians (Phanerozoic) and by Late [Early] Cretaceous age of overlying unit [Kkn]." Unit is strongly foliated and metamorphosed to greenschist and transitional greenschist-blueschist facies

MzPzs **Arkosic sandstone and slate—"**Strongly cleaved, medium-grained, generally thin-bedded, arkosic sandstone and slate. Exposed on prominent ridge east of Greenstone Ridge in central part of map area [Bethel quadrangle]. Detrital grains in sandstones include monocrystalline quartz (30 to 50 percent), plagioclase (10 percent), and potassium feldspar (5 percent), and minor mica, slate, and volcanic rock fragments. Alteration products include secondary prehnite, calcite, quartz, and white mica. Turbidite depositional features locally preserved. Thickness is uncertain. Intercalated (structurally?) over 100-m-thick zones with thin-bedded chert-argillite sections (MzPzm); unconformably overlain by conglomeratic rocks [Kkn] of Kuskokwim Group. Age is uncertain, but older than Late [Early] Cretaceous age of unit [Kkn]." Unit has a slaty cleavage and is metamorphosed to the prehnite-pumpellyite facies (Box and others, 1993)

MzPzv **Volcaniclastic sandstone and argillite—"**Turbiditic, thin-bedded, medium- to fine-grained, volcaniclastic sandstones, and dark-green to black argillites with weak to nonexistent slaty cleavage. Exposed along prominent ridge east of Greenstone Ridge in central part of map area [Bethel quadrangle]. Detrital grains include volcanic rock fragments containing plagioclase phenocrysts, plagioclase, and minor potassium feldspar, clinopyroxene, and quartz. Thickness is uncertain. Structurally overlain and underlain by unit MzPzs; structurally overlain by unit MzPzm along Kisaralik River; unconformably overlain by conglomeratic strata [Kkn] of Kuskokwim Group north of Kisaralik River. Age is uncertain, but older than Late [Early] Cretaceous age of unit [Kkn]." Unit has a slaty cleavage and is metamorphosed to the prehnite-pumpellyite facies (Box and others, 1993)

MzPzc **Chert and argillite—"**White, gray-green, and blue-green crystallized chert in 2- to 5-cm-thick beds interbedded with black to dark-green phyllite or slate beds of similar thickness. Exposed on prominent ridge east of Greenstone Ridge in central part of map area [Bethel quadrangle]. Structurally(?) intercalated with unit MzPzs; unconformably overlain by conglomeratic rocks [Kkn] of Kuskokwim Group. Age constrained by presence of recrystallized radiolarian (Phanerozoic) and Late [Early] Cretaceous age of overlying unit [Kkn]." Unit has a slaty cleavage and is metamorphosed to the prehnite-pumpellyite facies (Box and others, 1993)

TrPmb **Metabasaltic schist** (Triassic? to Permian?)—Partially to completely recrystallized schistose rocks derived from mafic igneous and associated sedimentary rocks, including pillow basalt, angular volcanic breccia, pebbly mudstone, fine-grained tuffaceous sedimentary rocks, diabase, gabbro, and rare chert (Box, 1985a). Mineral assemblages indicate greenschist to transitional greenschist-blueschist facies metamorphism (Box, 1985a). Unit crops out on the south and west side of Goodnews Bay and near Cape Peirce. Low-angle faults separate unit from overlying nonfoliated mafic rocks (ophiolite units Trob, Trod, Trog) and from underlying schistose clastic rocks (TrPvs). Schistose fabrics indicative multiple deformation events include: moderately to shallowly dipping foliation and a locally developed lineation; sporadically developed crenulation cleavage and crenulation microfolds; and northeast-trending open folds folding both deformation fabrics (Box, 1985a). Metamorphic fabric is similar to that of structurally underlying meta-volcaniclastic glaucophane-hornblende epidote schist (TrPvs) and calcareous schist (TrPcs) (Box, 1985a). Similarity of metamorphic fabrics suggests all three units were deformed during the same event (Box, 1985a). West of Goodnews Bay, the unit structurally overlies Permian volcaniclastic rocks (Pvs) and underlies Permian limestone (Pls). Metamorphic age is constrained between Middle Jurassic and Middle Triassic based on age constraints as described for unit TrPvs below. Intruded by nonfoliated Middle Jurassic hornblende gabbro (Jgb). Schist yielded K/Ar mica ages of 150±8 and 155±8 Ma (table 1), possibly related to a Late Jurassic thermal event suggested by Box (1985a); however, the ages are suspect because the K_2O content of the mica (2.94 and 1.71 percent) is much lower than typical for mica (8 to 10 percent), suggesting alteration. Box (1985a) suggests the protolith age is similar to the structurally overlying ophiolite (units Trob, Trod, and Trog) because the lithologic similarity of the protolith. However, on the basis of Box's (1985a) terrane model, the similarity of protolith may not be relevant, as he assigned this unit to his Goodnews terrane and the ophiolite to his Togiak terrane. An alternative protolith age assignment could be Permian or older, based on metamorphic ties to unit TrPvs and association with Permian rocks of the Goodnews terrane

TrPvs **Volcaniclastic glaucophane-hornblende-epidote schist** (Triassic? to Permian?)—Metamorphosed conglomerate, sandstone, and shale. Unit includes map units JTrmvss and JPvss of Box (1985a), which he reports grade together in the vicinity of Goodnews Bay. Protolith for both was derived from a feldspar-rich volcanic source (Box, 1985a). Rounded cobble meta-conglomerate contains mostly plagioclase-phyric amygdaloidal volcanic clasts (Box, 1985a). Mineral assemblages indicate greenschist to transitional greenschist-blueschist facies metamorphism (Box, 1985a). Unit shows evidence of multiple metamorphic events and has a more pronounced structural fabric to the southwest (Box, 1985a). The latest metamorphic event created a strong fabric by syn-metamorphic flattening or mylonitization and a lineation formed by clast elongation and mineral alignment (Box, 1985a). This latest metamorphic fabric deformed non-coplanar isoclinal folds and slaty cleavage of a previous metamorphic event (Box, 1985a). Metamorphic fabric is similar to the structurally overlying metabasaltic schist (ŦPmb) and underlying calcareous schist (ŦPcs) suggesting all three units were deformed during the same Late Jurassic metamorphic event (Box, 1985a). However, this is contradicted by K/Ar cooling age of amphibole of 231.2±6.9 Ma (sample 82SB-147, Table 1) suggesting Middle Triassic metamorphism; age is constrained to be older than the intrusion of Middle Jurassic gabbroic rocks (unit Jgb). On and adjacent to Susie Mountain, unit is intruded by pyroxenite and hornblende gabbro bodies which yielded Middle Jurassic K/Ar amphibole ages. Box (1985a) indicates unit structurally overlies Permian mafic volcanic rocks (Pv) and volcaniclastic rocks (Pcs), which he concludes suggests the protolith age could be as old as Permian. Unit crops out near Cape Peirce and on the south and west sides of Goodnews Bay. Unit was included in the Cape Peirce subterrane of the Goodnews terrane by Box (1985a)

ŦPcs **Calcareous schist** (Triassic? to Permian?)**—**Recrystallized schistose and phyllitic calcareous sandstone, shale, limestone, limestone conglomerate, greenish tuffaceous rocks, mafic volcanic rocks, and volcanic conglomerate. Includes units JŦmc of Box (1985a) and Pzcs of Hoare and Coonrad (1978). Turbidite characteristics are locally preserved in clastic metasedimentary rocks (Box, 1985a). Mineral assemblages indicate greenschist to transitional greenschist-blueschist facies metamorphism (Box, 1985a); however, structurally the unit shows evidence of multiple metamorphic events (Box, 1985a). The latest metamorphic event created a strong fabric by syn-metamorphic flattening or mylonitization and a lineation formed by clast elongation and mineral alignment (Box, 1985a). This latest metamorphic fabric deformed tight folds and axial planar slaty cleavage of a previous deformation event (Box, 1985a). Metamorphic fabric is similar to the structurally overlying meta-volcaniclastic glaucophane-hornblende epidote schist (ŦPvs) and metabasaltic schist (ŦPmb) suggesting all three units were deformed during the same metamorphic events (Box, 1985a). Metamorphic age is constrained as described above for unit ŦPvs. Unit crops out in two locations, near Cape Peirce and near Jacksmith Bay. Near Jacksmith Bay, unit is structurally overlain by Devonian to Ordovician limestone (DOl) and the Kanektok metamorphic complex (Ƥk and Ƥkm). Intruded by nonfoliated Middle Jurassic gabbroic rocks (Jgb). Age of protolith may be Permian or older (Hoare and Coonrad, 1978; Box, 1985a) because of metamorphic ties to unit ŦPvs and association with Permian rocks of the Goodnews terrane. Unit was included in the Cape Peirce subterrane of the Goodnews terrane by Box (1985a)

Jgs **Green amphibole-bearing schist** (Late Jurassic)**—**Schist recrystallized in part to greenschist metamorphic facies mineral assemblage of albite-epidote-chlorite-actinolite. Schist contains interbeds of thin-bedded, white or green, meta-chert having white mica-rich laminae (Box and others, 1993); overlain by crystalline limestone, phyllite, and minor amounts of chlorite, graphite, and quartz-sericite schist (Hoare and Coonrad, 1959a). Mapped as Mesozoic to Paleozoic metabasalt and minor meta-chert (MzPzb) by Box and others (1993); protolith was diabase and basalt having MORB trace-element (REE) signature (Box and others, 1993). Although protolith age is unknown, it was suggested to be Devonian to Ordovician by Hoare and Coonrad (1959a). Greenstone Ridge near the center of the Bethel quadrangle is composed of this map unit. Unit is bounded on west by Golden Gate fault; nearshore facies Kuskokwim Group rocks (Kkn) depositionally overlie unit at the north end of its exposure. Age of metamorphism may be Late Jurassic because of 146.0±15.0 Ma age of an actinolite (sample B78-1213, Table 1). Unit was included in the Goodnews terrane by Box and others (1993)

Ophiolite complex of Box (1985a)

Dismembered ophiolite of Box (1985a) (Lower Jurassic to Middle Triassic)—The following units were described as the Newenham ophiolite complex, a dismembered ophiolite, by Box (1985a; Decker and others, 1994). The defined ophiolite assemblage also included the serpentinized ultramafic rocks of Cape Newenham which are here included in map unit Jum. Hoare and Coonrad (1978) mapped the trondhjemite as a distinct map unit, but included the remaining lithologies in their MzPz or Jum units. Box (1985a) placed these rocks in his Hagemeister subterrane of the Goodnews terrane. As described by Hoare and Coonrad (1978), little information is available about specific lithologies and their distribution in the MzPz unit, hence the ophiolite may also occur outside of the area covered by Box's dissertation area and therefore be more extensive than shown. Box (1985a) inferred the igneous rocks of the complex to be cogenetic and inferred the ophiolite complex to be Late Triassic in age on the basis of the Radiolaria in the included chert. Subdivided into:

JTrot **Trondhjemite**—Light-gray, medium-grained trondhjemite consisting of abundant quartz, plagioclase, and minor chlorite, sericite, and clinozoisite (Hoare and Coonrad, 1978; Box, 1985a). Found in small bodies mapped in a number of areas of the Hagemeister Island and Goodnews Bay quadrangles by Hoare and Coonrad (1978). Box (1985a) indicated that in addition to the mapped bodies, other small bodies occur within altered diabase near Cape Newenham. At Tokomarik Mountain, Box (1985a) described the trondhjemite as "a northeast-dipping slab faulted above and below against schistose rocks ***." Box (1985a) tentatively assigned a Late Triassic age based on what he thought was a probable co-genetic relationship with the Upper Triassic pillow basalt (Trob) and other components of the ophiolite whereas Hoare and Coonrad (1978) assigned a Jurassic age based on the association of the trondhjemite with Jurassic gabbro and ultramafic rocks

Trob **Pillow basalt** (Triassic)—Aphanitic to porphyritic pillow basalt, containing interbedded pillow breccia, aquagene tuff, and inter-pillow and interbedded red and white radiolarian chert as described by Box (1985a). Porphyritic basalt has plagioclase and clinopyroxene phenocrysts in an intergranular to subophitic groundmass of plagioclase, clinopyroxene, and secondary replacement minerals. Basalt is commonly amygdaloidal; abundant vesicles are filled with a combination of chlorite, clinozoisite, prehnite, pumpellyite, and calcite. Box (1985a) reported a number of radiolarian collections; however, only 2 were age diagnostic, yielding Middle Triassic to Early Jurassic and Middle to Late Triassic. Box (1985a) considered the pillow basalt to be Late Triassic

Trod **Diabasic intrusive rocks** (Triassic)—Subophitic, holocrystalline plagioclase-clinopyroxene diabase (Box, 1985a). Shown here west of Jagged Mountain at Cape Newenham, at Chagvan Mountain, on the coast south of Downdraft Mountain, and along the coast east of Cape Peirce; Box (1985a) also mapped 0.3 to 1.0-m-wide diabase sills and dikes containing basalt and chert screens west of Matogak River mouth, thick diabase sills intruding chert at Pyrite Point, and diabase dikes cutting gabbro south of Chagvan Bay, which are not shown. Box (1985a) described the unit as "mostly massive and highly altered to low greenschist facies assemblage." Unit is altered to hornblende hornfels west of Matogak River mouth, which Box (1985a) reported is due to an underlying, but not shown, gabbroic pluton; a K/Ar amphibole age on the hornfels was 187±10 Ma (sample 81SB 116b, table 1). Unit believed to be co-genetic with associated, overlying Upper Triassic pillow basalt (Ŧob) (Box, 1985a)

Ŧog **Pyroxene gabbro** (Triassic)—Altered clinopyroxene gabbro, locally containing up to 5 percent orthopyroxene which is commonly kinked and fractured and locally rimmed or replaced by pale-green amphibole (Box, 1985a). Plagioclase partially to completely replaced by fine aggregate of albite, epidote, chlorite, calcite and iron oxides. Compositional layering is rare in contrast to gabbro of map unit Jg. Locally grades into diabase (Ŧod) south at Chagvan Mountain due to increasing proportion of crosscutting diabasic dikes. Box (1985a) mapped gabbro as a thrust sheet above the Osviak fault emplaced over schistose rocks of map unit ŦPcs around Security Cove and Cape Peirce. Locally, mylonite is found along contact and similar mylonite is found sporadically along contact between gabbro and structurally underlying diabase near Cape Newenham. Box (1985a) believed gabbro was co-genetic with associated diabase (Ŧod), pillow basalt (Ŧob), trondhjemite (JŦot) and serpentinized ultramafic rocks, all part of a dismembered ophiolite

Kanektok metamorphic complex of Hoare and Coonrad (1979)

Ƿk **Kanektok metamorphic complex, undivided** (Paleoproterozoic)—Gneiss and schist derived from sedimentary, volcanic, and plutonic rocks metamorphosed to upper greenschist through granulite facies (Hoare and Coonrad, 1978; Turner and others, in prep.). "Includes medium- to coarse-grained, massive and well-foliated, biotite-hornblende gneisses, garnetiferous amphibolites, quartz-mica schists, and marble" (Hoare and Coonrad, 1978). It is an antiformal crystalline complex cored by high-grade orthogneiss intercalated with metavolcanic and metasedimentary rocks, and flanked by greenschist-facies rocks (Turner and others, in prep.). Rocks in core of complex include varieties of orthogneiss whose protoliths may have ranged in composition from granite to diorite (Turner and others, in prep.; Moll-Stalcup and others, 1996). As described by Turner and others (in prep.), orthogneiss of the core is intercalated with pyroxene granulite, garnet amphibolite, garnet-mica schist (locally kyanite-bearing), and rare quartzite and marble (marble locally mapped separately as unit Ƿkm). The core of amphibolite facies rocks which apparently grade into greenschist facies rocks that dip away from the core on the northwest and southeast. These lower grade rocks contain a variety of schist and quartzite, as well as calc-phyllite, marble, and meta-conglomerate (Turner and others, in prep.). Mineral foliation tends to parallel compositional layering and both consistently strike northeast; "*** dip of the foliation changes from northwest to southwest two to four times across the width of the complex" (Hoare and Coonrad, 1979) south of Kanektok River. Compositional layering and foliation are disrupted by northwest trending faults including a significant left lateral offset at the Kanektok River. North of the river, the rocks are more highly deformed and the dip and trend of foliation are more variable (Hoare and Coonrad, 1979). The Kanektok metamorphic complex is fault bounded on the southeast against calcareous schist (unit ŦPcs), the Kuskokwim Group (unit Kk), and the undivided Togiak-Tikchik Complex (unit MzPzt) in the Goodnews Bay quadrangle, and green amphibole-bearing schist (Jgs) in the Bethel quadrangle. It is depositionally overlain by the Kuskokwim Group (unit Kkn) in the Bethel quadrangle. The Kanektok metamorphic complex crops out as a narrow belt trending northeast extending from near Jacksmith Bay in the Goodnews Bay quadrangle northward 160 km to the southern part of the Bethel quadrangle. The Idono complex of Gemuts and others (1983; Miller and others, 1991; Miller and Bundtzen, 1994; Wilson and others, 1998) is similar in some respects to the Kanektok metamorphic complex and crops out north of the map area in the Iditarod quadrangle. Locally subdivided into:

Ꝑkm **Marble**—White, gray, and brownish garnetiferous marble generally associated with quartzose schist (Hoare and Coonrad, 1978). Mapped separately only where it forms the dominant rock unit; similar rocks also occur as thin, discontinuous bands in the lower grade marginal rocks of the complex and rarely in the high-grade core. Locally may contain incipient diopside, white mica, phlogopite, quartz, plagioclase, and epidote as minor phases (Turner and others, in prep.)

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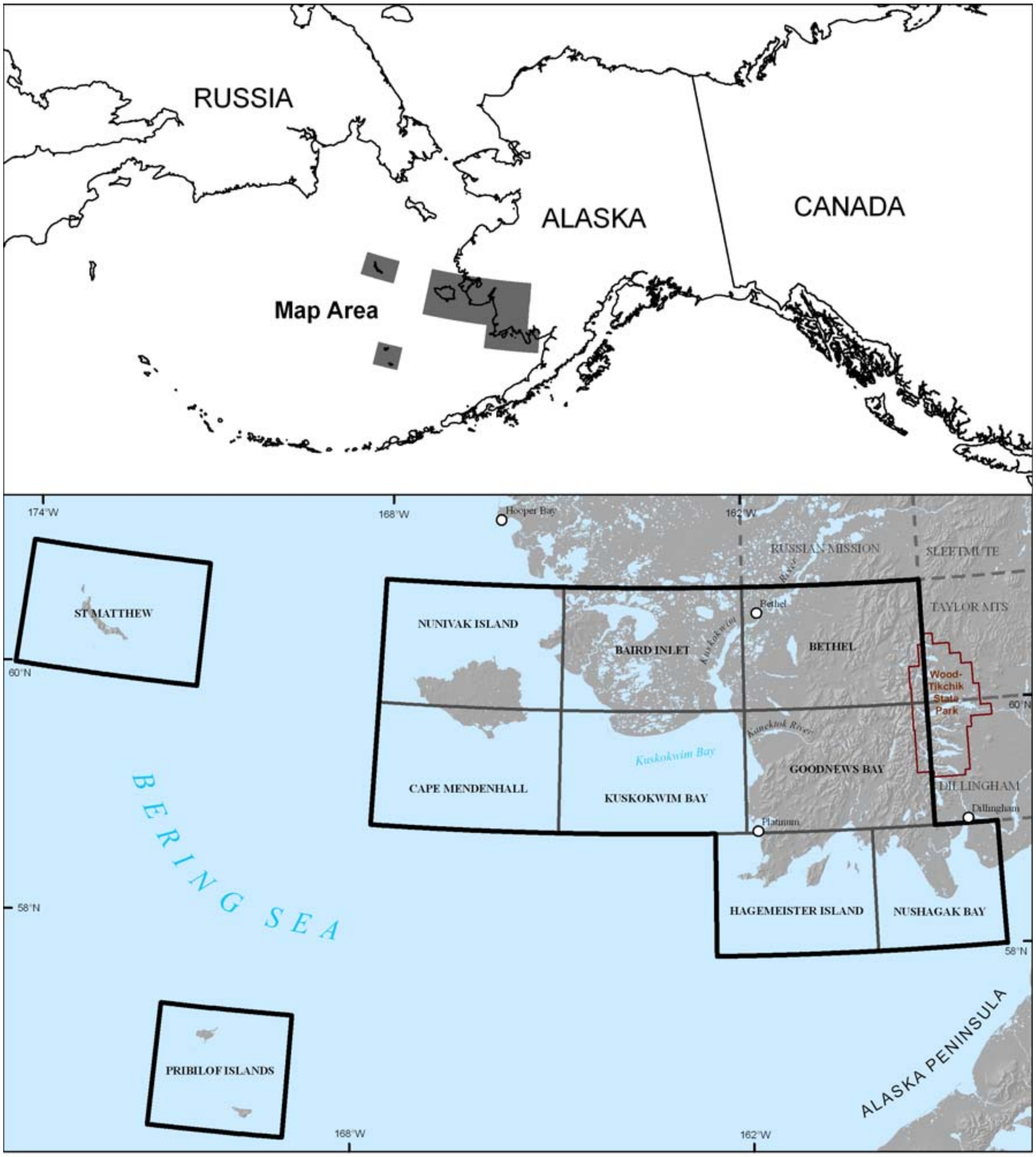

Figure 1. Index map showing 1:250,000-scale quadrangle coverage of the map and prominent physiographic features of the map area.

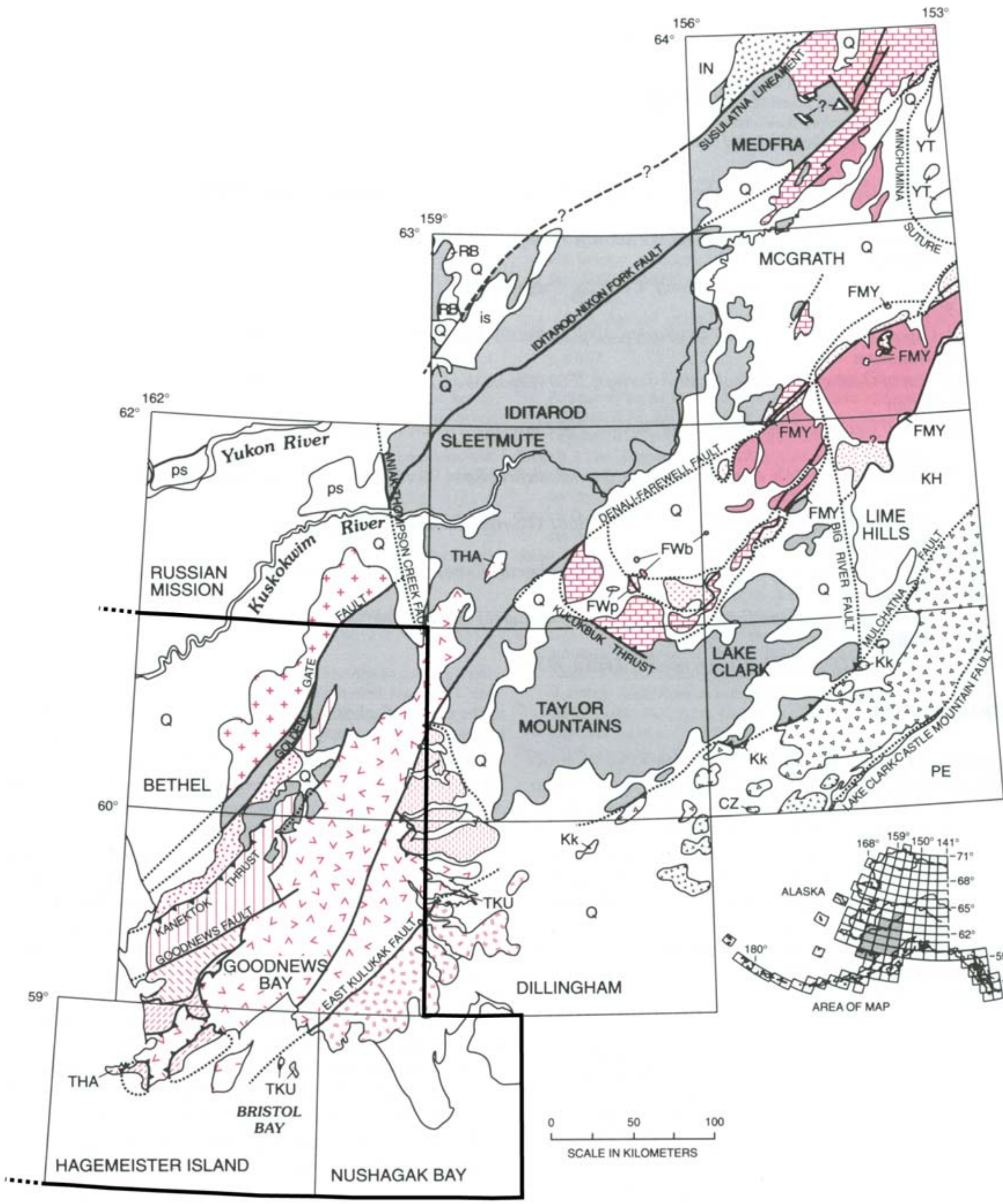

Figure 2. Tectonostratigraphic terrane map of southwestern Alaska, after Decker and others (1994). Portion of the Kuskokwim Bay region map area included is shown outlined in black.

EXPLANATION

OVERLAP ASSEMBLAGES

Q Quaternary Surficial Deposits

K Kuskokwim Group

Cz Cenozoic Deposits

TERRANES OF SOUTHWEST ALASKA

Alaska Range and Kuskokwim Mountains

Farewell Terrane

FMY Mystic Sequence

White Mountain Sequence

FWb Basinal Facies

FWt Transitional Facies

FWp Platform Facies

Bristol Bay Region

NY Nyack Terrane

Togiak Terrane

THA Hagemeister Subterrane

TKU Kulukak Subterrane

Goodnews Terrane

GNU Nukluk Subterrane

GTC Tikchik Subterrane

GPT Platinum Subterrane

GCP Cape Pierce Subterrane

KI Kilbuck Terrane

ADJACENT TERRANES

KH Northern Kahiltna Terrane

Kk Southern Kahiltna Terrane

MC McKinley Terrane

PE Peninsular Terrane

IN Innoko Terrane

PN Pingston Terrane

RB Ruby Terrane

YT Yukon-Tanana Terrane

UNITS OF UNCERTAIN TERRANE AFFINITY

is Idono Sequence

ps Portage Sequence

——— Contact

— ? - - Fault—Dashed where approximate, dotted where concealed, queried where uncertain.

▲▲····· Thrust fault—Dotted where concealed. Sawteeth on upper plate.

Figure 3. Gneiss of the Kanektok metamorphic complex north of Thumb Mountain.