Geologic Framework of the Alaska Peninsula, Southwest Alaska, and the Alaska Peninsula Terrane

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FRONT COVER

The southwesternmost of the volcanoes of Stepovak Bay. Spire is a basaltic plug in throat of volcano; adjacent ridges are capped by stacked flows. Photograph by Ric Wilson, July 26, 1983.

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Geologic Framework of the Alaska Peninsula, Southwest Alaska, and the Alaska Peninsula Terrane

By Frederic H. Wilson[1], Robert L. Detterman[2], and Gregory D. DuBois[1]

Abstract

The Alaska Peninsula is composed of the late Paleozoic to Quaternary sedimentary, igneous, and minor metamorphic rocks that record the history of a number of magmatic arcs. These magmatic arcs include an unnamed Late Triassic(?) and Early Jurassic island arc, the early Cenozoic Meshik arc, and the late Cenozoic Aleutian arc. Also found on the Alaska Peninsula is one of the most complete nonmetamorphosed, fossiliferous, marine Jurassic sedimentary sections known. As much as 8,500 m of section of Mesozoic sedimentary rocks record the growth and erosion of the Early Jurassic island arc.

A thinner, but still thick (as much as 5,400 m), sequence of Tertiary sedimentary rocks that are predominantly continental overlies the Mesozoic section. A brief regression in early Tertiary time on the Alaska Peninsula and granodiorite plutonism in the Shumagin, Semidi, and Sanak Islands was followed by deposition of fluvial and minor marine clastic strata. This was followed by deposition of transgressive marine clastic strata and initiation of the Meshik arc, shown by an areally extensive outpouring of volcanic and volcaniclastic rocks and debris between late Eocene and earliest Miocene time. Late Miocene time was marked by another brief transgression and northwest- to southeast-directed compression, followed by renewed volcanism and plutonism which initiated the modern Aleutian magmatic arc.

Extensive glacial and glaciomarine deposits of late Pleistocene age create an extensive lowland physiographic province on the northwest side of the Alaska Peninsula and join isolated mountain masses to the Alaska Peninsula on the southwest. Multiple active volcanoes and volcanic peaks dominate the skyline of the Alaska Peninsula and represent the continuation of magmatic activity that has formed the Aleutian arc since late Miocene time.

The Alaska Peninsula has had a long and involved history since Paleozoic time. We propose that the Paleozoic and Mesozoic rocks that constitute much of the Alaska Peninsula be called the Alaska Peninsula terrane. Using the concept of subterranes, we divide the terrane into two distinct but tectonically related subterranes: the Chignik and Iliamna subterranes, which share a limited common geologic history. The Iliamna subterrane has served at most times as a source area for the Chignik subterrane; however, some rock units are in common across the subterranes. The Iliamna and Chignik subterranes are in part separated by the Bruin Bay fault system. The Iliamna subterrane is composed of moderately deformed early Mesozoic marine sedimentary and volcanic rocks and schist, gneiss, and marble of Paleozoic(?) and Mesozoic age, and plutonic rocks of the Alaska-Aleutian Range batholith. Characteristic of the Chignik subterrane are little-deformed, shallow-marine to continental clastic sedimentary rocks ranging in age from Permian to latest Cretaceous. However, deep-marine, volcaniclastic, and calcareous rocks form important components of the older rocks in the subterrane.

The two subterranes of the Alaska Peninsula terrane are characterized by radically different structural and metamorphic styles. The nonplutonic rocks of the Iliamna subterrane are characterized by metamorphism up to amphibolite-facies grade and intense folding. In the Chignik subterrane, the structural style is dominated by large, open, en echelon anticlinal structures, normal faulting, and thrust and high-angle reverse faults that have minor displacement in a northwest to southeast direction. In the Outer Shumagin and Sanak Islands, rocks assigned to the Chugach terrane are characterized structurally by tight, generally northeast-trending folds. Dips in these rocks tend to be steep, rarely less than 35°, and overturned beds are locally common.

The boundaries separating the Alaska Peninsula terrane from other terranes are commonly indistinct or poorly defined. A few boundaries have been defined at major faults, although the extensions of these faults are speculative through some areas. The west side of the Alaska Peninsula terrane is overlapped by Tertiary sedimentary and volcanic rocks and Quaternary deposits.

Introduction

This map (pl. 1) of the Alaska Peninsula is based on the mapping conducted as part of the Alaska Mineral Resource Assessment Program (AMRAP). Mapping on the Alaska Peninsula under AMRAP began in 1977 in the Chignik and Sutwik Island 1:250,000 quadrangles (Detterman and others,

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1981a). Continued mapping in the Ugashik, Bristol Bay, and northwestern Karluk quadrangles (Detterman, Case, and others, 1987), the Mount Katmai, eastern Naknek, and northwestern Afognak quadrangles (Riehle and others, 1987; 1993) and the Port Moller, Stepovak Bay, and Simeonof Island (Wilson and others, 1995) quadrangles on the Alaska Peninsula was also conducted as part of AMRAP. The Cold Bay and False Pass quadrangles were initially mapped by McLean and others (1978); however, extensive modification of their map has resulted from field work by F.H. Wilson, G.D. DuBois, R.L. Detterman, and W.H. White (DuBois and others, 1989; unpub. data, 1990), T.P. Miller and M.E. Yount (written commun., 1989) and airphoto and Landsat interpretation by F.H. Wilson. We have also incorporated the mapping of Kennedy and Waldron (1955) and Waldron (1961) in the Cold Bay and False Pass quadrangles.

Geologic observations for mapping were made by helicopter-aided foot-traverses and at spot localities. Coverage of areas between surface observations was made using helicopter overflights, interpretation of vertical aerial photography, and also enhanced and extensively processed Landsat imagery in the Port Moller area (York and others, 1984; Wilson and York, 1985). Field investigations were conducted from bases at Battle Lake, approximately 8 km north of the map area, (1985, 1986), Becharof Lake (1985, 1986), Chignik (1977, 1978), Cold Bay (1990), King Cove (1988), King Salmon (1983, 1985), Naknek Lake (1984), Port Heiden (1977, 1978), Port Moller (1984, 1985), and Sand Point (1982, 1984 to 1986, 1988). In addition, field work in 1977–1981, 1983, and 1984 was also conducted using the U.S. Geological Survey Research Vessel *Don J. Miller II*. The mapping of Burk (1965) provided an excellent base to start the AMRAP mapping. However, important changes have been made to Burk's pioneering work.

The reliability of the geologic mapping is variable, based, in part, on the field time spent in each area of the map, the available support, and the quality of the existing base maps. In addition, our developing understanding of the geology of the Alaska Peninsula has required revision of earlier maps, such as the Chignik and Sutwik Island quadrangles map (Detterman and others, 1981a) to reflect this new knowledge. We have revised the stratigraphic nomenclature (Detterman and others, 1996) and our assignment of unit names to some rocks has been changed. The major remaining uncertainties in the stratigraphy occur primarily at the southwest end of the Alaska Peninsula and concern the Belkofski Formation and the agglomerate of Cathedral Valley. The major area of mapping uncertainty is also at the southwest end of the Alaska Peninsula in the Cold Bay and False Pass quadrangles, and is due to the reconnaissance nature of the work that has been done there and uncertainty due to the inaccuracy of the topographic base maps. Comparison of the 1:250,000-scale topographic map with the few existing 1:63,360-scale sheets, NOAA nautical charts, and Landsat and side-looking radar images shows that errors in the position of the shoreline can exceed 1 km. As a result, the transfer of data from the map of McLean and others (1978) to our revised digital base map produced minor changes in the position of contacts. We attempted to transfer mapped contacts and maintain topographic relationships between units. For example, cliff lines were followed for units that appeared to be "cliff-formers."

All geologic maps on which this compilation is based were published using the Universal Transverse Mercator projection (UTM; Zones 3, 4, and 5). However, because of the distortions the UTM projection would produce on a map of small scale and large area, the data for this map has been converted to a more appropriate Albers Equal-area projection for publication.

Definition and discussion of the Alaska Peninsula (Peninsular) terrane in this paper is not without its difficulties. As knowledge of the geology of the Alaska Peninsula and other parts of southern Alaska have increased, the identity of the Alaska Peninsula terrane as a fault-bounded entity having a distinctive stratigraphy and unique geologic history (see Berg and others, 1978; Jones and others, 1983) becomes less convincing. Based on our knowledge of the rocks that characterize the terrane we (1) question the location of the bounding faults that define the Alaska Peninsula terrane, (2) question whether generally accepted parts of the Peninsular terrane, such as the (informal) Border Ranges ultramafic and mafic complex of Burns (1985), the Raspberry Schist of Roeske (1986; Roeske and others, 1989), the Seldovia Schist of Roeske (1986; equivalent to Seldovia schist terrane of Cowan and Boss, 1978), and other units associated with the Border Ranges Fault System should be included in the Alaska Peninsula terrane, and (3) also find there to be apparent genetic ties to several tectonostratigraphic terranes of southern Alaska, including the Wrangellia, Chugach, and southern Kahiltna terranes. By rigorous terrane analysis, we also find it is difficult to show that the Alaska Peninsula terrane has a unique stratigraphic and geologic history compared to its neighboring terranes. However, we believe definition of the Alaska Peninsula terrane can be a useful aid to the understanding of the geology and geologic history of the region. Therefore, although we use the term terrane in this report, we use it in a purely descriptive sense without the genetic implications inherent in some usage's of the term "terrane" (see discussion by Dover, 1990).

The Alaska Peninsula Terrane

The Alaska Peninsula, long thought to be an area with a simple geologic and tectonic history (see for example Burk, 1965, p. 75–78 and 119–122), has had a lengthy and involved history since Paleozoic time. Stone and Packer (1977) reported results of paleomagnetic investigations which suggested that since Jurassic time the Alaska Peninsula has migrated thousands of kilometers northward from a position south of the equator. Somewhat tongue-in-cheek, Stone and Packer (1977) called this allochthonous terrane "Baja Alaska" and left its geologic definition to others. Jones and Silberling (1979) designated a Peninsular terrane and gave a brief definition based on its Mesozoic stratigraphy. Wilson, Case, and Detterman (1985) redefined the Peninsular terrane and proposed the terrane be called the Alaska Peninsula terrane; here we summarize and update that definition of the Alaska Peninsula terrane (fig. 1, 2). Moore (1974c, p. 813) suggested the rocks of the Alaska Peninsula represent two “regional tecto-stratigraphic terrains”; however using the concept of subterranes, as introduced by Berg and others (1978), Wilson, Case, and Detterman (1985) suggested that Baja Alaska or the Peninsular terrane composes two distinct but tectonically related subterranes. In this particular case, the two subterranes, the Chignik and Iliamna subterranes, share a limited common geologic history. The Iliamna subterrane has served at most times as a source area for the Chignik subterrane; however, some rock units are in common across the subterranes. The two subterranes have probably always been in close proximity.

Paleomagnetic studies after Stone and Packer (1977) in southern Alaska were summarized by Hillhouse (1987); these later studies in part reinforced Stone and Packer’s (1977) original conclusions and in part showed that variability in the data was large, indicating a range of Jurassic paleolatitudes for the Alaska Peninsula terrane from 4° to 40°. Detterman (1988) presented a somewhat different view of the timing for the migration history of the Alaska Peninsula based on paleobiogeographic interpretation of Mesozoic fossil data. He suggested that by Middle Jurassic time, the Alaska Peninsula was well into the northern Pacific based on the presence of faunal elements of the Boreal Realm and specifically the Boreal and Bering Provinces (Detterman, 1988, p. 12).

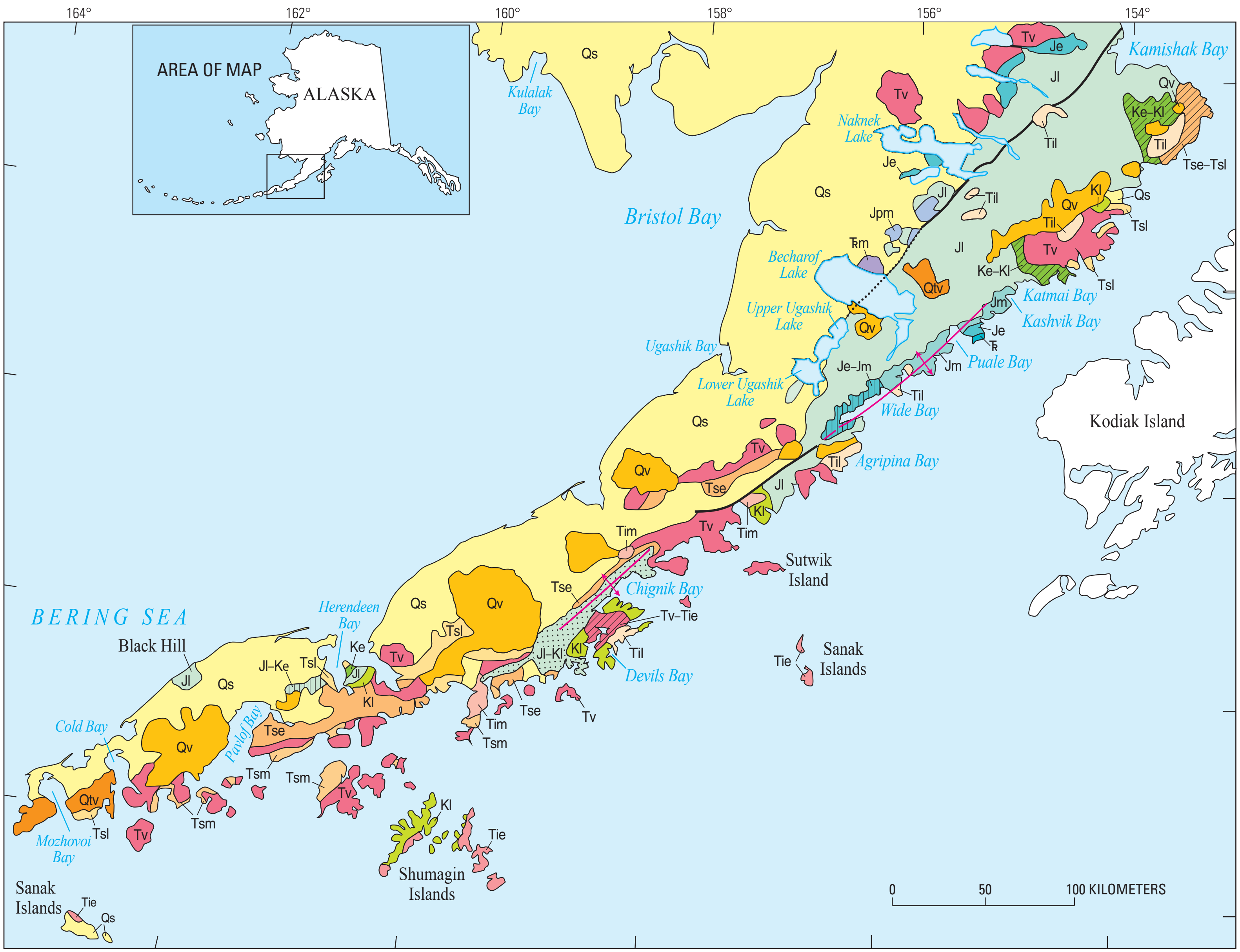
The subterranes of the Alaska Peninsula terrane (fig. 1, 2) are (1) the Iliamna subterrane, Paleozoic(?) and early Mesozoic rocks intruded by and including the Mesozoic part the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973), and (2) the Chignik subterrane, Permian to latest Cretaceous little-deformed fossiliferous sedimentary rocks of the Alaska Peninsula and areas of southern Alaska including Cook Inlet and the Matanuska Valley north of the map area.

The Iliamna and Chignik subterranes are separated by the Bruin Bay Fault System north of Becharof Lake. The boundary between the subterranes southwest of Becharof Lake is not defined. Many authors have continued the Bruin Bay Fault System south of Becharof Lake (see Jones and Silberling, 1979; von Huene and others, 1985; and Lewis and others, 1988); however, no actual data conclusively demonstrates its continuation. At Becharof Lake, a structural high trends across the Alaska Peninsula. South of the structural high the Iliamna terrane is not exposed in outcrop; however, aeromagnetic (Case and others, 1988) and drillhole data suggest the continuation of the Iliamna subterrane in the subsurface. Small normal faults of short length occur along the east shore of Ugashik Lakes, these faults are roughly aligned along the trend of the Bruin Bay Fault; however, the sense of motion of these faults is opposite that of the Bruin Bay system. Similar faulting has not been mapped farther southwest along the Alaska Peninsula, but if the Bruin Bay Fault System continues south of Becharof Lake, it must undergo a significant change in character. In the Iliamna quadrangle, north of the map area, it is a high-angle fault system (northwest up) that has a possible sinistral strike-slip component and as much as 3 km of stratigraphic throw (Detterman and Reed, 1980, p. B69). If the fault system occurs south of Becharof Lake, drillhole data suggest the sense of motion is apparently down on the north. North of Becharof Lake, the Naknek Formation is not known to occur west of the fault system. Southwest of Becharof Lake, rocks of the Naknek Formation were reached by drilling in the General Petroleum Great Basins No. 1 drillhole at a depth of 10,500 ft (3,360 m), west of the extension of the Bruin Bay Fault System (Detterman, 1990). Based on the available constraints, a small rotational tilt (3° to 4°) along the axis of the Alaska Peninsula can explain the depth to the Naknek as an alternative to reliance on the Bruin Bay Fault System. Case and others (1988) interpretation of aeromagnetic data from the Ugashik 1:250,000-scale quadrangle postulated that, “If the geologic projection of the fault is correct, it seems likely that the fault splays into several strands southwest of Becharof Lake***” The aeromagnetic data do not require or clearly define that the fault system is present; rather it is permissive data that if, on the basis of other data, the fault system must occur southwest of Becharof Lake, the aeromagnetic data can be interpreted to explain where it does occur.

Iliamna Subterrane

The Iliamna subterrane, named after exposures in the Iliamna 1:250,000-scale quadrangle located north of the map area, is composed of moderately deformed marine sedimentary and volcanic rocks of early Mesozoic age; schist, gneiss, and marble of Paleozoic(?) and Mesozoic age; and plutonic rocks of the Alaska-Aleutian Range batholith. In the map area, the batholith, which has been well described by Reed and Lanphere (1969, 1972, 1973, 1974), intrudes rocks of the Kakhonak(?) Complex, Cottonwood Bay Greenstone, Kamishak Formation, and the partially coeval Talkeetna Formation (Detterman and Reed, 1980). Each of these units is correlative with parts of the Chignik subterrane or in the case of the Kamishak and Talkeetna Formations, is actually part of both subterranes. The southernmost exposure of rocks of the Iliamna subterrane occurs in the vicinity of Becharof Lake. Here, quartz diorite of Jurassic age (Reed and Lanphere, 1972) is exposed on a small island on the south side of the lake and in the hills north of the lake in the Naknek 1:250,000-scale quadrangle.

The Kamishak Formation is one of the few units that occur in both the Iliamna and Chignik subterranes; lithologically and faunally equivalent units, the Nizina Limestone and the McCarthy Formation (Detterman and Reed, 1980), occur in the McCarthy 1:250,000-scale quadrangle 700 km northeast of the Alaska Peninsula in the Wrangellia terrane (Jones and others, 1977) and the Port Graham sequence occurs in the Seldovia area (Kelley, 1985). The Cottonwood Bay Greenstone has been correlated(?) with the Nikolai Greenstone of the McCarthy 1:250,000-scale quadrangle



164°
162°
160°
158°
156°
154°
58°
57°
56°
55°
AREA OF MAP
ALASKA
Kulalak Bay
Qs
Kamishak Bay
Naknek Lake
Bristol Bay
Becharof Lake
Upper Ugashik Lake
Ugashik Bay
Lower Ugashik Lake
Katmai Bay
Kashvik Bay
Puale Bay
Wide Bay
Agripina Bay
Kodiak Island
Sutwik Island
Chignik Bay
Devils Bay
Sanak Islands
Herendeen Bay
BERING SEA
Black Hill
Cold Bay
Pavlof Bay
Mozhovoi Bay
Shumagin Islands
Sanak Islands
Tv
Je
Jl
Qv
Ke–Kl
Til
Tse–Tsl
Jpm
Ʀm
Kl
Tsl
Qtv
Jm
Ʀ
Je–Jm
Tse
Tim
Tv–Tie
Jl–Kl
Tie
Jl–Ke
Ke
Tsm
0
50
100 KILOMETERS

EXPLANATION

- Qs — Quaternary surficial deposits
- Qv — Quaternary volcanic rocks
- QTv — Quaternary and Tertiary volcanic rocks

Tertiary sedimentary rocks

- Tsl — Late Tertiary
- Tsm — Middle Tertiary
- Tse — Early Tertiary
- Tse–Tsl — Early to late Tertiary

Tertiary intrusive rocks

- Til — Late Tertiary
- Tim — Middle Tertiary
- Tie — Early Tertiary
- Tv — Tertiary volcanic rocks
- Tv–Tie — Tertiary volcanic rock (early Tertiary)

Mesozoic sedimentary rocks

- Kl — Late Cretaceous
- Ke — Early Cretaceous
- Ke–Kl — Early to Late Cretaceous
- Jl–Kl — Late Jurassic to Late Cretaceous
- Jl–Ke — Late Jurassic to Early Cretaceous
- Jl — Late Jurassic
- Jm — Middle Jurassic
- Je — Early Jurassic
- Je–Jm — Middle to Early Jurassic
- ₮ — Triassic
- Ji — Jurassic intrusive rocks of the Alaskan-Aleutian Range batholith
- Jpm — Jurassic to Permian metamorphic rocks
- ₮m — Triassic metamorphic rocks
- Contact
- Fault—Dotted where location is concealed
- Anticline—Dashed where location is inferred

Figure 1: Generalized geology of the Alaska Peninsula. The Iliamna subterrane of the Alaska Peninsula terrane consists of Paleozoic(?) and early Mesozoic rocks (Je and Jpm) intruded by and including the Mesozoic part the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973, unit Ji here); the Chignik subterrane consists of Permian (not shown) to latest Cretaceous little-deformed fossiliferous sedimentary rocks (not including Kl in the Shumagin Islands).

(Detterman and Reed, 1980). The Nikolai Greenstone and Nizina Limestone are fundamental units of the Wrangellia terrane (Jones and others, 1977). Originally the Cottonwood Bay Greenstone and Kamishak Formation were not considered part of a Wrangellian sequence (Jones and others, 1977, p. 2572); however, the correlation of these units with typical Wrangellian units on lithologic, faunal, and structural grounds suggests otherwise. The Cottonwood Bay Greenstone of the Iliamna subterrane may also be coeval with the Triassic volcanic rocks at Puale Bay. However, the Cottonwood Bay Greenstone has been interpreted as of oceanic affinity, possibly ocean island basalt (Riehle and others, 1993; J.R. Riehle, oral commun., 1991) in contrast to the possible island arc derivation of the rocks at Puale Bay (Moore and Connelly, 1977; Hill, 1979; Wang and others, 1988). No chemical data presently exists to conclusively categorize the Cottonwood Bay Greenstone.

Southwest of Becharof Lake the extent of the Iliamna subterrane is masked by younger rocks, although its presence may be inferred from geophysical and drilling data. Brockway and others (1975) showed in a cross section that the batholith had been reached by drilling south of Becharof Lake on the Alaska Peninsula; however, a sample of the drill core (supplied by Randy Billingsley, AMOCO, 1990) is a sheared greenstone more likely part of either the Kakhonak(?) Complex or the Cottonwood Bay Greenstone (B.L. Reed, oral commun., 1991). Interpretation of aeromagnetic data (Case and others, 1981) suggested that the subterrane may continue at least as far south as Port Heiden. Pratt and others (1972) suggested continuation of the batholith into southern Bristol Bay based on interpretation of shipborne magnetic data.

Chignik Subterrane

Little deformed, shallow-marine to continental clastic sedimentary rocks are characteristic of the Chignik subterrane. However, deep-marine, volcaniclastic, and calcareous rocks are present as important components of the older rocks in the subterrane. The rocks range in age from Permian to latest Cretaceous, and are found south or east of the Iliamna subterrane.

The rocks of the Chignik subterrane in the map area record Permian to Holocene sedimentary and igneous activity along an episodically active convergent plate margin. The oldest rocks known in the Chignik subterrane are found at Puale Bay and are fossiliferous late middle Permian limestone (Pls) and Permian(?) volcanic agglomerates and flows (Pv) (see inset A, pl. 1). These Permian and Permian(?) units are structurally overlain by Late Triassic carbonate and volcanic rocks of the Kamishak Formation (Trk). Triassic limestone deposition and volcanism, possibly in an island arc setting (Moore and Connelly, 1977; Hill, 1979; Wang and others, 1988), occurred at low latitude (Detterman, 1988). Lithologically similar Triassic rocks are also known in the subsurface in the Cathedral River area (McLean, 1977) at the southwest end of the Alaska Peninsula. Moore and Connelly (1977) suggested that rocks of the Shuyak Formation (Connelly, 1978) on western Kodiak Island are possible correlatives of the Triassic volcanic and volcaniclastic rocks at Puale Bay. Finally, the Cottonwood Bay Greenstone of the Iliamna subterrane may be coeval with the Triassic (Norian?) volcanic rocks at Puale Bay, although the age control that does exist suggests that the Cottonwood Bay Greenstone may be older than Norian.

Jurassic-age strata record the development and subsequent erosion of an island arc; this may be the same island arc as suggested by interpretation of the character of the Late Triassic strata at Puale Bay. Early Jurassic volcaniclastic sedimentary rocks (Talkeetna Formation) are derived from the volcanic part of the arc. The Talkeetna Formation or laterally equivalent rocks crop out discontinuously from the Matanuska Valley and the Talkeetna Mountains to Puale Bay; stratigraphically and lithologically equivalent rocks were reported from a drillhole in the Cathedral River area (McLean, 1977) and from the Seldovia area (Kelley, 1985). The Talkeetna, within the Chignik subterrane, undergoes a gradual lithologic transition from northeast to southwest as sedimentary rocks come to dominate the unit; this suggests the rocks of the unit become more distal from the arc volcanism to the southwest. The Talkeetna Formation is succeeded by Early and Middle Jurassic sandstone and conglomerate (Kialagvik Formation), indicating a gradually subsiding depositional basin. The Kialagvik Formation is exposed only in a limited area between Wide and Puale Bays; however, correlative rocks of the Tuxedni Group are exposed on the west side of Cook Inlet. The Kialagvik records the continued erosion of the volcanic part of the island arc; however, a few granitic rock cobbles in some conglomerate beds suggest the initial unroofing of the Alaska-Aleutian Range batholith, the plutonic root of the island arc (Reed and others, 1983). Yet, not until the deposition of the Late Jurassic Naknek Formation do granitic lithic fragments become an important component of the sedimentary rocks. Northeast of the map area, the lower part of the Tuxedni Group (Detterman and Hartsock, 1966; Imlay, 1984) is a lithologic and stratigraphic correlative of the Kialagvik Formation. The Tuxedni Group is a much thicker (as much as 3,000 m) and more complete sequence than the Kialagvik (Detterman and others, 1996) and is a thick sequence of graywacke, sandstone, conglomerate, siltstone, and shale. The conglomerate of the Tuxedni is mainly composed of volcanic rocks in a graywacke matrix. The Tuxedni Group crops out entirely north of the map area from Iniskin Bay to the Talkeetna Mountains (Imlay, 1984). Stratigraphically and lithologically equivalent rocks to both the Talkeetna and Kialagvik Formations were reported from a drillhole in the Cathedral River area (McLean, 1977).

Callovian rocks (Shelikof Formation) on the Alaska Peninsula mainly reflect the continued erosion of the volcanic part of the arc and the eventual shallowing of the depositional basin. Initially deposited in deep water, the sedimentary rocks of the Shelikof record a shallow-water environment at the close of deposition. The lithologic- and age-equivalent

Chinitna Formation north of the map area is divided into the Paveloff Siltstone and Tonnie Siltstone Members, and is fossiliferous dark-gray siltstone with abundant calcareous concretions (Detterman and Hartsock, 1966). The Chinitna ranges in areal extent from the Talkeetna Mountains to the Iniskin Peninsula. The Shelikof and Chinitna Formations represent the same or similar depositional environments. The source area supplied volcanic debris and lay to the present northwest of the Chignik subterrane.

Late Jurassic deposition of arkosic sandstone, conglomerate, and siltstone (Naknek Formation) occurred in a shallow-water shelf and nonmarine environment. The Naknek Formation contains the first significant influx of granitic debris in the stratigraphic column and records the initial unroofing of the Jurassic part of the Alaska-Aleutian Range batholith. Abrupt lateral facies changes are present in the Naknek. The facies changes within the Naknek Formation occur both along, and transverse to, the Alaska Peninsula and result from rapid uplift and erosion of the Alaska-Aleutian Range batholith and older sedimentary rocks that flank it. The eroded sediments were carried to the east by short, high-energy streams that debauched onto the continental shelf and deposited their loads partly in subaerial and partly in marine environments. The facies changes in the Naknek Formation, as well as those in some of the other late Mesozoic stratigraphic units, can best be seen in a fence diagram of the late Mesozoic stratigraphic units, on the Alaska Peninsula (Detterman and Miller, 1987). Several small, starved basins are preserved on the east side of the peninsula—for example, near Hallo Bay and Amber Bay—in which the entire Naknek sequence (normally 1,700 to 2,000 m thick) is compressed into a section of siltstone less than 500 m thick (Detterman and Miller, 1986). The Naknek Formation is exposed from Black Hill in the southwestern part of the map area to the Talkeetna Mountains (Csejtey and others, 1978), 500 km northwest of the map area. Vallier and others (1980) described Late Jurassic sandstone and siltstone dredged from near the Pribilof Islands in the southern Bering Sea. They correlated these rocks with the Naknek Formation and suggested that these rocks "underlie a large part of the continental margin on the St. George Basin region of the southern Bering Sea." However, the Naknek is not known to be exposed west or north of rocks that form the Iliamna subterrane. The Naknek Formation has also been correlated with the Root Glacier Formation of the southern Wrangell Mountains (E.M. MacKevett, Jr., oral commun., 1977; cited in Csejtey and others, 1978).

Early Cretaceous deposition of fine-grained siltstone, shale, and calc-arenaceous sandstone (Staniukovich and Herendeen Formations) followed the deposition of the Naknek Formation. Deposition into Early Cretaceous time was continuous as the Staniukovich Formation conformably overlies the Naknek. The depositional environment remained shallow marine and nonmarine; however, the generally finer grain size of the Staniukovich suggests a lower energy environment. Detterman and others (1996) suggested that the three sandstone units in the Staniukovich Formation in the Mount Katmai area probably represent stacked offshore or barrier bars. The Staniukovich, like the Naknek Formation, was derived from a gradually eroding source terrane composed in part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973; Reed and others, 1983). Apparently, relief relative to the source area was decreasing with time as witnessed by the absence of coarse clastic rocks. Also, the more altered character of mineral fragments in the Staniukovich and typically better rounding compared to the Naknek (Detterman, 1990) suggests that reworking of older sedimentary units may have occurred. The record of the Late Triassic to Early Cretaceous sedimentary regime culminates with deposition of a thin, well-sorted, calc-arenaceous sandstone unit (Herendeen Formation) composed of as much as 40 percent *Inoceramus* prisms (Detterman, 1990) and angular to subrounded quartz and feldspar grains (Burk, 1965, p. 45), suggesting the contribution of new lithic clastic debris from the source terrane was virtually eliminated. North of the Mount Katmai area, rocks of Early Cretaceous age are generally not known in the Chignik subterrane (J. Bolm, U.S. Geological Survey, personal commun., 1981), although a thin (100 m thick) Early Cretaceous clastic unit which includes, in part, the Nelchina Limestone has been mapped by Csejtey and others (1978) and Grantz (1960a,b) in the Talkeetna Mountains 1:250,000-scale quadrangle. The Nelchina Limestone is a lithologic and stratigraphic equivalent of the Herendeen Formation.

Middle Cretaceous (Aptian to Santonian) rocks are missing over much of the Alaska Peninsula, presumably eroded. The widespread absence of rocks of this age suggests uplift and erosion of the entire terrane during a part of Aptian to Santonian time. Uplift through middle Cretaceous time resulted in removal of much of the Herendeen, the Staniukovich, and parts of the Naknek Formation. The uplift appears to have been most pronounced in the Puale Bay to Lake Iliamna area. However, in the Mount Katmai area, small fault-bounded patches of Albian rocks (Pedmar Formation) have been found which indicate some deposition, possibly local, occurred during Aptian to Santonian time.

The stratigraphically uppermost part of the Chignik subterrane consists of the Chignik, Hoodoo, Kaguyak, and Matanuska Formations. A short-lived but vigorous marine transgression in Late Cretaceous time resulted in the deposition of fluvial to deep-marine clastic rocks (Chignik, Hoodoo, and Kaguyak Formations) on the Alaska Peninsula and deep-sea fan and abyssal-plain turbidites (Shumagin Formation) in the Outer Shumagin and Sanak Islands and presumably the Semidi Islands vicinity. The Shumagin Formation and the lithologic- and age-equivalent Kodiak Formation and Valdez Group (Moore, 1974c; Plafker and others, 1977) underlie much of the continental margin along the Alaska Peninsula and in southern Alaska, and record an extensive Late Cretaceous trench system. The Chignik and Hoodoo Formations are Campanian and Maestrichtian in age, and exposed southwest of Puale Bay and Becharof Lake. They are apparently in large part derived from reworking of earlier strata although a volcanic-rock component may have been added. In the Matanuska Valley of south-central Alaska, the stratigraphically highest part of the Chignik subterrane is the Matanuska Formation. The Matanuska Formation, named by Martin (1926) is composed predominantly of dark-gray marine siltstone, shale, and minor conglomerate (Grantz and Jones, 1960; Grantz, 1964); its type area is defined as the Matanuska Valley. It ranges in age from Albian to Maestrichtian, although several faunal gaps and unconformities divide the formation. The much longer depositional history of the predominantly Late Cretaceous Matanuska Formation, compared to the other Late Cretaceous formations in the subterrane, indicates a return to a marine depositional basin sooner in the northeastern part of the subterrane than in more southwestern parts. However, the faunal gaps and unconformities within the Matanuska Formation indicate the basin was not stable. The Chignik Formation shows extensive evidence of a nearshore to nonmarine environment, whereas conglomerate and coal seams are known only locally in the Matanuska Formation. The Aptian to Santonian geologic history of the Alaska Peninsula and Cook Inlet region parts of the subterrane is unclear due to the virtual absence of Aptian to Santonian age rocks. Although erosion was apparently deep, as evidenced by removal in some areas of rocks as old as Late Jurassic, structural deformation was minimal. The cyclical marine to nonmarine depositional history documented by Fairchild (1977) and Detterman (1978) in the Chignik Formation may indicate lesser stability in the Chignik region in Campanian and Maestrichtian time.

Structure of the Alaska Peninsula

The two subterranes of the Alaska Peninsula terrane are characterized by radically different structural and metamorphic styles. The rocks of the Iliamna subterrane, which lie west of the Bruin Bay Fault, are characterized by metamorphism up to amphibolite-facies grade and intense folding. The severity of these effects is variable and is most intense nearest the Alaska-Aleutian Range batholith. Both of these effects are attributed to forcible intrusion of the batholith (B.L. Reed, personal commun., 1981).

In much of the central part of the map area, which is largely composed of the Chignik subterrane, the structural style of the Alaska Peninsula is dominated by en echelon anticlines, normal faulting, and thrust and high-angle reverse faults that have minor displacement in a northwest to southeast direction. Folds in the northern and southern parts of the map area are dominantly related to faulting, in contrast to the well-developed, northeastwardly aligned, large en echelon anticlines and synclines of the central Alaska Peninsula. In the northeast part of the map area, these faults are dominantly normal faults, whereas in the southwest, low-angle thrust and high-angle reverse faults are more common. Structures on the Alaska Peninsula are typically aligned subparallel to the approximately northeast-to-southwest trend of the Alaska Peninsula. In general, as shown below, compressional features become a relatively more important component of the structural style of the Alaska Peninsula as one travels southwest.

North of the Wide Bay (Detterman, Case, and others, 1987) and Bear Creek anticlines, in the northern part of the Ugashik and western part of the Karluk 1:250,000 quadrangles, large en echelon anticlines and minor thrusts and reverse faults tend to disappear, to be replaced by closely spaced normal faults of small displacement aligned perpendicular to the general trend of the Alaska Peninsula. The dip of bedding tends to be low in this area and, in general, rocks of Tertiary age are not present. Farther north and northeast in the Katmai area, the structures can be characterized as “jostled” homoclinally dipping blocks with no clear regional structures developed southeast of the Bruin Bay Fault (J.R. Riehle, oral commun., 1989). Tertiary and younger rocks again become important in the Katmai area, where the Meshik arc volcanic rocks lie northwest of the Bruin Bay Fault and Paleocene(?), Eocene, and Oligocene sedimentary and Miocene and younger igneous rocks of the Aleutian arc lie along the coast, southeast of the Bruin Bay Fault. Compressional structures are particularly absent except for the Bruin Bay Fault which is a high-angle reverse fault.

In the Port Moller area at the southwestern end of the Alaska Peninsula, the regional structures are dominated by a zone of northeast-to-southwest-trending high-angle reverse faults (Wilson, Case, and Detterman, 1985). This zone extends from the vicinity of Tolstoi Peak in the southwest to Mitrofania Bay in the northeast. Northwest of this zone, the major structures are a series of ramped, northwestward-directed low-angle thrust faults that carry the Mesozoic rocks of the Chignik subterrane of the Alaska Peninsula terrane and early Cenozoic rocks over the middle and late Miocene rocks of the Bear Lake Formation. Southeast of the zone of high-angle reverse faults, the only exposed Mesozoic rocks (Shumagin Formation) lie in the Outer Shumagin and Sanak Islands and are part of the Chugach terrane (Plafker and others, 1977). Early Cenozoic rocks southeast of the fault zone are the same lithologically as early Cenozoic rocks northwest of it; however, the Bear Lake Formation is not known to occur southeast of the fault zone. Wilson, Case, and Detterman (1985) suggested that this fault zone may represent a projection of the buried boundary between the Chugach and Alaska Peninsula terranes through the overlying younger rocks.

In the Outer Shumagin and Sanak Islands, the Shumagin Formation is characterized structurally by tight, generally northeast-trending folds. Dips in these rocks tend to be steep, rarely less than 35°, and overturned beds are locally common, for example, on the north end of Nagai Island. This is in marked contrast to the Mesozoic rocks of the mainland part of the map area. Moore (1974a,b) indicated that the rocks of the Shumagin Formation are pervasively faulted; however, he was only able to trace individual faults for limited distances in most cases.

History and Character of Alaska Peninsula Terrane Overlap Sequences

Division of southern Alaska into tectonostratigraphic terranes (see Jones and Siberling, 1979) emphasizes Mesozoic stratigraphy in the definition of terranes. Certainly, post-Mesozoic terranes have been defined, for example the Prince William terrane, yet in general, Cenozoic rocks in southern Alaska are terrane overlap sequences. This discussion of Cenozoic terrane overlap sequences is limited to those on the Alaska Peninsula; the reader is referred elsewhere for discussion of Cenozoic rocks of the Matanuska Valley (see Winkler, 1990).

On the Alaska Peninsula, a brief regression in early Tertiary time and granodiorite plutonism in the Outer Shumagin, Semidi, and Sanak Islands was followed by deposition of fluvial and marine clastic strata on the mainland (Tolstoi and Copper Lake Formations) and in the Inner Shumagin Islands. This was followed by deposition of transgressive marine clastic strata (Stepovak Formation) and an areally extensive outpouring of andesitic, dacitic, and basaltic volcanic and volcaniclastic materials (Meshik Volcanics) between late Eocene and earliest Miocene time on the southwestern part of the Alaska Peninsula. These volcanic and volcaniclastic rocks have been included in the Meshik arc as defined by Wilson (1985). In the Mount Katmai region of the map area, the only sedimentary rocks between late Eocene and earliest Miocene time are fluvial clastic strata (Hemlock Conglomerate) that were deposited during the later stages (late Oligocene) of the Meshik arc. The Hemlock contains clasts of varying lithologies and probably was not derived from direct erosion of the volcanic rocks of the Meshik arc.

A major gap in the Meshik arc occurs between the southern end of Ugashik Lakes and the north side of Naknek Lake. Exposures of early Cenozoic volcanic rocks in the Naknek 1:250,000-scale quadrangle, shown as the Meshik Volcanics on this map, are on trend with exposures of the Meshik arc southwest of Ugashik Lakes. However, both surface exposures (see map) and drillhole data (Detterman, 1990) provide no evidence of the magmatic arc in the gap between. Erosion is not a good explanation for this gap, as no plutonic root or alteration of the presumably underlying Mesozoic rocks is apparent. It appears that during late Eocene to earliest Miocene time, magmatic activity and sedimentary deposition did not occur across this gap. It is in this gap that the oldest rocks known on the Alaska Peninsula, middle Permian limestone, are exposed. Finally, the last known exposure of the Bruin Bay fault system occurs in the northern part of this gap. Could the southern limit of the known Alaska-Aleutian Range batholith have served as a “plug” around which magmatic activity was displaced or contained below? Does the batholith and the “plug-contained” Cenozoic igneous rocks then provide the extra buoyancy to uplift the Paleozoic and older part of the Mesozoic section? Alternatively, does the marine record contain evidence that the subducted seafloor had some irregularity that resulted in uplift of the continental margin and elimination of subduction related magmatism? Interestingly, the modern Aleutian volcanic arc is offset in a left-lateral sense roughly 50 km at the southern end of this gap. Does the postulated batholithic plug or seafloor irregularity still affect the convergent margin at this location?

Late Miocene time was marked by another brief transgression and northwest- to southeast-directed compression, followed by renewed volcanism and plutonism which initiated the modern Aleutian magmatic arc. Engelbretson and others (1985, p. 27) suggest that the extinct Kula-Pacific ridge arrived at the Aleutian trench at roughly 10 Ma and postulated that given its relatively young age it might have been sufficiently buoyant to have produced compressive tectonics in the Aleutian arc. Burk (1965) ascribed most of the tectonic features, that is folding and faulting, seen on the Alaska Peninsula to a Pliocene deformational event. Low-angle thrust faults, not recognized by Burk (1965), in the Port Moller-Herendeen Bay area emplaced Mesozoic and early Tertiary rocks over the deformed middle and late Miocene Bear Lake Formation. In some areas, Quaternary volcanic centers are apparently emplaced into the upper plate rocks, constraining thrusting to no older than the late Miocene and no younger than the Quaternary. However, at most exposures, the Bear Lake Formation is little deformed. The local angular unconformities seen between the Bear Lake and Stepovak Formations suggest that most of the deformation in Cenozoic time occurred in the Miocene, prior to deposition of the Bear Lake; however, as the Bear Lake is only known northwest of the Alaska Peninsula ridge crest, distinction between post-middle Miocene and Pliocene or later deformation is difficult. At the southwest end of the Alaska Peninsula the late Miocene Tachilni Formation is mildly deformed, having dips usually less than 20° (Marincovich, 1983). Subsequent rapid uplift and erosion has exposed the roots of late Miocene and Pliocene and older volcanic centers.

Outcrop patterns of the late Miocene to Holocene volcanic and intrusive rocks indicate that the Aleutian magmatic arc has migrated in a northwestward direction from the Pacific coast. This is shown by a number of exposures of late Miocene or Pliocene plutons and coeval volcanic rocks at the Pacific coast, and by emplacement of progressively younger hypabyssal or volcanic rocks inland toward the modern volcanic front. Among the numerous examples of this pattern are the trends from the Agripina Bay batholith and associated volcanic rocks to Chiginagak and Kialagvik Volcanoes, southwest of Wide Bay; and from Weasel Mountain, through the Bee Creek prospect (Wilson and Cox, 1983), to Black Peak, northwest of Chignik Bay.

Finally the youngest overlap sequences include the many Holocene volcanic edifices that occur in the map area. These include the well-known volcanoes of Katmai National Park, Aniakchak Caldera, Mount Veniaminof, and the volcanoes of the Pavlof group, which is the most active volcanic center in the continental United States. Complex interaction between glacial advances and retreats, volcanic activity, and sea level variation has resulted in a rich Quaternary geologic history (see Detterman and others, 1981b; Detterman, Wilson, and others, 1987; Riehle and Detterman, 1996).

Terrane Boundaries

The boundaries separating the Alaska Peninsula terrane from other terranes are commonly indistinct or poorly defined. A few of these boundaries have been defined at major faults, yet even in the best cases, the extensions of these faults are speculative through some areas. The most clearly defined boundary of the Alaska Peninsula terrane is the Border Ranges Fault (MacKevett and Plafker, 1974; BRFS herein), which separates the Alaska Peninsula terrane from the Chugach terrane (Plafker and others, 1977). However, implicit in our interpretation is that the BRFS is a fault system and not a simple thrust as described by MacKevett and Plafker (1974). The BRFS is considered the southern and southeastern boundary of the Alaska Peninsula (Peninsular) terrane in the Matanuska Valley; however, the rocks bounded on the north of the Chugach terrane within the BRFS cannot be unequivocally related to the Alaska Peninsula terrane (see Pavlis, 1986; Roeske and others, 1989). The BRFS extends from the Matanuska Valley southwesterly, to a point southwest of Kodiak Island near longitude 156° west (Fisher, 1981). In the Kodiak Islands and on the Kenai Peninsula, rocks of the Shuyak Formation, the Raspberry Schist of Roeske (1986), and the Seldovia Schist of Roeske (1986) (D.C. Bradley, oral commun., 1991) are sufficiently different from the known Alaska Peninsula terrane stratigraphy as to possibly constitute another, probably exotic, block, here called the “hidden block” (pl. 2) and probably equivalent to the Knik River terrane of Pavlis (1986). A major fault is shown just offshore of the Alaska Peninsula in Shelikof Strait by von Huene and others (1985); this may well constitute the true terrane boundary of the Alaska Peninsula terrane in this area.

The BRFS has been projected southwest through the Shumagin Islands from its last known position (Fisher, 1981), where it forms the southern boundary of the Alaska Peninsula terrane, out to its western edge. Recent work on the mainland adjacent to Sand Point in the Shumagin Islands (Wilson, Detterman, and Case, 1985) suggests that, if the BRFS exists at all in the area, it lies inland of the Shumagin Islands on the Alaska Peninsula mainland. Wilson, Detterman, and Case (1985) defined a zone of structurally disrupted Oligocene to Miocene rocks that may overlie the extension of the fault system.

The position of the BRFS in the vicinity of the Sanak Islands, 160 km to the southwest of Sand Point, cannot be determined by available data but may lie as far north as Cold Bay, as the last known exposure of Alaska Peninsula terrane rocks occurs in the Black Hill area northeast of Cold Bay. Although this boundary may be clearly defined in a structural sense, the probable facies relations between the Chignik, Hoodoo, and Shumagin Formations lead to the conclusion that the Alaska Peninsula and Chugach terranes on the southwestern Alaska Peninsula may be part of a larger, as yet undefined, Late Cretaceous terrane. The stratigraphic relationship between the geologic units of the Alaska Peninsula and Chugach terranes indicates that the hidden block or Knik River terrane was probably in place before deposition of the Chugach terrane flysch.

The northwestern boundary of the Alaska Peninsula terrane is largely speculative. Northwest of the terrane, a sequence of Late Jurassic and Cretaceous flyschoid rocks overlie the Iliamna subterrane (for example, in the Lake Clark quadrangle, Nelson and others, 1983). This flysch sequence is not well mapped and often is not separated from lithologically similar rocks of the Kuskokwim Group (Cady and others, 1955; Nelson and others, 1983). The Lake Clark-Castle Mountain Fault System, traversing this area, does not represent a terrane-bounding fault because zenolithic blocks of rocks which are lithologically similar to rocks of the Talkeetna and Kamishak Formations are present in Cretaceous and Tertiary plutonic rocks of the Alaska-Aleutian Range batholith north of the fault system (B.L. Reed, oral commun., 1991). Likewise the apparent continuity of the informally named Tlikakila complex of Wallace and others (1989) (here considered equivalent to the Kakhonak Complex) on both sides of the fault system suggests that displacement is small. The southern Kahiltna terrane as defined by Wallace and others (1989) lies between the Late Jurassic and Cretaceous flysch sequence and the Alaska Peninsula (Peninsular) terrane. The lithologic similarity and general age equivalency of the Chilikadrotna Greenstone of Wallace and others (1989) of the southern Kahiltna terrane and the combined Cottonwood Bay Greenstone, Kamishak Formation, and Talkeetna Formation, and the absence of any mapped terrane-bounding fault indicates the southern Kahiltna terrane is actually part of the Iliamna subterrane of the Alaska Peninsula terrane. Wallace and others (1989) define the southern Kahiltna terrane boundary as the contact with the Alaska-Aleutian Range batholith; however, the batholith and its contact rocks are an integral part of the Iliamna subterrane. The Koksetna River sequence of Wallace and others (1989, p. 1392) could, in part, represent forearc sediments derived from the Jurassic magmatic arc, as suggested by Wallace and others (1989, p. 1397–1398) and therefore would not be part of a different terrane. Wallace and others (1989, p. 1392) show a discontinuously exposed Chilchitna Fault; this may be the northwest boundary of the Alaska Peninsula terrane. However, in light of the reinterpretation by Reed and others (1983) of the polarity of the Jurassic magmatic arc and the mapping and interpretation of the Late Jurassic and Cretaceous flyschoid rocks by John Decker (oral commun., 1984); the Late Jurassic and Cretaceous flysch northwest of the terrane may also represent, in part, forearc sediments derived from the Jurassic magmatic arc and not a distinct terrane.

In the Talkeetna Mountains, the boundary of the Alaska Peninsula terrane is a zone of intense shearing and possible thrusting (Csejtey and St. Aubin, 1981; Csejtey and others, 1978; called the West Fork fault by W.L. Nokleberg, written commun., 1991) where the Alaska Peninsula terrane is juxtaposed against the Wrangellia terrane. Stratigraphic ties dating from Middle Jurassic time between the Wrangellia and the Alaska Peninsula (Peninsular) terranes lead to definition of the Talkeetna superterrane by Csejtey and St. Aubin (1981). We have shown in this report that those stratigraphic ties can be reasonably extended to Triassic time and that the Alaska Peninsula and Wrangellia terranes may be more closely related than previously thought (Jones and others, 1979; Csejtey and St. Aubin, 1981). Csejtey and St. Aubin (1981) and Csejtey and others (1978; 1982) briefly described the Talkeetna thrust as the terrane boundary that separates the Talkeetna superterrane from the flysch basins to the northwest. Southwest of the Talkeetna Mountains 1:250,000-scale quadrangle in the Talkeetna (Reed and Nelson, 1977), Lime Hills (B.L. Reed, oral commun., 1991) and Lake Clark (Nelson and others, 1983) quadrangles, the Talkeetna thrust is not mapped or is not recognized; however, it may be represented by the Chilchitna Fault.

On the Alaska Peninsula, the west side of the Alaska Peninsula terrane is overlapped by Tertiary sedimentary and volcanic rocks and Quaternary deposits of the Nushagak-Bristol Bay Lowland physiographic province of Wahrhaftig (1965). Although it is not now possible to define the northwest boundary of this part of the Alaska Peninsula terrane, extrapolation of structural trends and limited aeromagnetic data (U.S. Geological Survey, 1978) suggests that it is subparallel to the Alaska Peninsula.

The Border Ranges Ultramafic and Mafic Complex Problem

The informally named Border Ranges ultramafic and mafic complex of Burns (1985) (approximate age range 163–194 Ma) has, on the basis of chemistry and proximity, been considered the root of the Talkeetna volcanic arc (Burns, 1985), a role also ascribed to the apparently younger (approximate age range 155–175 Ma) Alaska-Aleutian Range batholith of Reed and Lanphere (1969, 1972, 1973, 1974; Reed and others, 1983). The Border Ranges ultramafic and mafic complex, considered by some to be an integral part of the Alaska Peninsula terrane (W.J. Nokleberg, oral commun., 1991), is consistently found within or seaward of the BRFS. For example, in the Seldovia region, the Border Ranges ultramafic and mafic complex is found as klippen east of the Seldovia Schist, separated from the Alaska Peninsula terrane rocks by the Port Graham and Seldovia Faults. Direct age control on rocks of the Border Ranges ultramafic and mafic complex is suggestive of correlation with the rocks of the Talkeetna Formation; however, given the expected great depth of emplacement and slow cooling of the mafic rocks (Burns, 1985, p. 1034–1035), it is unlikely that the reported ages represent emplacement ages. In addition the increasing spatial separation of the Border Ranges ultramafic and mafic complex and the Talkeetna Formation southwest of the Kenai Peninsula argues against a close genetic association. Finally, inclusion of the Border Ranges ultramafic and mafic complex in the Alaska Peninsula terrane requires that its rocks be preferentially emplaced seaward of the main Alaska Peninsula terrane. This suggests that faulting and uplift along the BRFS operated to dismember the terrane rather than to override the Chugach terrane.

Rocks of the Talkeetna Formation have been found as outcrops on both sides and as roof pendants of the Alaska-Aleutian Range batholith. Potassium-argon age determinations on the batholith are generally younger than fossil or apparent ages from the Talkeetna Formation, which may be ascribed to cooling. The reasonably close age and close spatial relationships between the batholith and the Talkeetna Formation provide good evidence for a close genetic association. If so, the Border Ranges ultramafic and mafic complex, Shuyak Formation, Raspberry Schist, Seldovia Schist, and other rocks may constitute a newly recognized “hidden” block or terrane, extending northeastward parallel to the BRFS from Shelikof Strait to the Matanuska Valley. This hidden terrane may also extend in the offshore southwestward of Shelikof Strait; however, it is not known in and probably does not extend much farther than the Sutwik Island area. Rocks of this hidden terrane appear to consist of an early Mesozoic island arc and a juxtaposed, coeval subduction complex. The Knik River terrane of Pavlis (1986) may well represent this terrane in the Matanuska Valley; its spatial relationship to the Chugach and Alaska Peninsula terranes and the character of the rocks that constitute it are sufficiently similar to the hidden block to suggest they may be the same terrane.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

Surficial deposits—Typically unconsolidated, poorly sorted to well sorted, poorly to moderately well-stratified sand, gravel, and silt. Includes alluvial, colluvial, glacial, marine, lacustrine, and eolian deposits, as well as locally reworked volcanic-ash and debris-flow deposits. Consist of:

Qa **Alluvial deposits (Holocene and Pleistocene)**—Ranges from coarse, subangular rock fragments to fine sand and silt in grain-size; locally includes considerable amounts of pumice near volcanic centers. As mapped, unit locally incorporates deposits of fluvial, colluvial, glacial outwash, lacustrine, estuarine, swamp, and eolian origin, in addition to minor areas of other Quaternary surficial units. Large areas are covered by organic-rich silt deposits. Unit includes much volcanic ash and volcanic debris in vicinity of Katmai, Aniakchak, Kametolook, and Joshua Green Rivers, Knife Creek, and unnamed river west of Kametolook River, as well as in vicinity of most volcanoes, particularly those of Pavlof group and on Unimak Island. Eolian deposits form dunes 10 to 20 m high that are composed largely of sand and pumice

Qaf **Alluvial fan and landslide deposits (Holocene and Pleistocene)**—Locally mapped; grain-size in this unit ranges from coarse, subangular rock fragments to fine sand and silt. Alluvial fans either typically have a well-developed cone shape, or multiple cones coalescing into aprons. Landslide deposits have poorly developed to well-developed lobate morphology

Qb **Marine beach and estuarine deposits (Holocene and Pleistocene)**—Moderately well stratified and sorted sand and gravel on beaches; mud and silt in estuaries

Qm **Moraines and other glacial deposits (Holocene and Pleistocene)**—Poorly sorted, nonstratified, glacial drift that forms end, lateral, and ground moraines. Locally includes moderately well sorted and stratified ice-contact and outwash deposits. Morphologically distinct drift units indicated by dash-dot internal contacts shown within unit

Qmt **Marine terrace deposits (Holocene and Pleistocene)**—Stratified and moderately well sorted sand and gravel deposits that form nearly level plains that end locally at prominent wave-cut scarps. Terraces occur at 15 to 18 m elevation along Bristol Bay and between 40 and 45 m elevation along Pacific Ocean

Tmr **Milky River Formation (Pliocene)**—Named by Galloway (1974, p. 381, 384) and defined by Detterman and others (1981a), who designated type locality as northeast spur of unnamed mountain 12 km east of Bear Lake (see sec. 14, 15, and 22, T. 48 S., R. 69 W. of Chignik A–7 1:63,360-scale quadrangle). Formation is of variable thickness (as much as 600 m) and consists of volcanogenic, nonmarine sedimentary rocks and interlayered flows and sills; volcanic rocks are thicker and more abundant stratigraphically upward in unit. Lower part of unit consists nearly entirely of coarse, highly crossbedded and channeled, fluvial volcaniclastic sandstone and cobble-boulder conglomerate. Rocks are poorly indurated, are dark brown to gray, and have clasts composed almost entirely of volcanic lithologies. Upper part of unit contains numerous porphyritic andesite flows, lahar deposits, and tuff beds interlayered with sedimentary rocks. Volcanic rock clasts in lahar deposits are as large as 2 m. A flow unit near top of stratigraphic section in type locality was dated at 3.53±0.27 Ma (Wilson and others, 1981). Another flow unit in lower part of the section exposed in the Port Moller D–1 1:63,360-scale quadrangle has been dated at 3.87±0.06 Ma (F.H. Wilson and Nora Shew, unpub. data, 1987). Unit unconformably overlies Bear Lake Formation (Tbl) and conformably underlies Pliocene(?) and Quaternary volcanic flows (QTv) and surficial deposits. Included in unit in area northwest of Pavlof group of volcanoes are rocks mapped as agglomerate of Cathedral Valley by Kennedy and Waldron (1955), described as a thick sequence of agglomerate beds and subordinate tuff beds and lava flows that are well exposed in Cathedral Valley. These volcanic rocks crop out north of line of volcanoes from Mount Dutton to Pavlof volcanoes. According to Kennedy and Waldron (1955), rocks are predominantly basalt and basaltic andesite and dip north toward Bering Sea. Kennedy and Waldron (1955) suggested that they are probably comparable in age to Belkofski Tuff, later renamed the Belkofski Formation by Burk (1965); we suggest here that a better lithologic and stratigraphic correlation is with Milky River Formation and map rocks as such

Tbl **Bear Lake Formation (late and middle Miocene)**—Named by Burk (1965, p. 89–92; see also, Allison and Addicott, 1973) for exposures on ridges along and running eastward from Bear Lake. Type locality was clarified by Detterman and others (1981a) to be located on southeast slope of unnamed mountain 10 km east of Bear Lake (see secs. 27 and 28, T. 48 S., R. 69 W. of Chignik A–7 and Port Moller D–1 1:63,360-scale quadrangles). Unit locally reaches thickness of 300 to 500 m and consists of inner-neritic marine and nonmarine (Wisehart, 1971; Nilsen, 1984) sandstone, conglomerate, siltstone, and shale. Rocks are dark brown to pale yellowish brown. Bear Lake unit is distinguished from other local Tertiary units by its greater abundance of nonvolcanic debris and its better degree of sorting. Sandstone is moderately well sorted and grains are moderately well rounded. Conglomerate beds are made up of well-rounded clasts, 40 to 55 percent of which are quartz and chert, 20 to 30 percent are volcanic fragments, 10 to 15 percent are felsic plutonic clasts, and remainder are lithic sedimentary clasts. Formation is abundantly fossiliferous; fossils are mainly pelecypods, gastropods, and echinoids of late Miocene age (Louie Marincovich, Jr. and C.W. Allison, written commun., 1978, in Detterman and others, 1981a). Most of these fossils lived in shallow, nearshore environments in water less than 100 m deep (Marincovich, 1983, and written commun., 1985, in Detterman and others, 1996). Contact between Bear Lake Formation and locally underlying Meshik Volcanics (Tm) and Stepovak and Tolstoi Formations (units Ts and Tt, respectively) varies from disconformity to angular unconformity. Contact between Bear Lake and overlying Milky River Formation (Tmr) generally is disconformable; however, contact locally is an angular unconformity. Marincovich (1983) noted partial age correlation of Bear Lake with late Miocene Tachilni Formation (Tta)

Tta **Tachilni Formation (late Miocene)**—Named by Waldron (1961) for marine sedimentary rocks roughly 100 m thick at Morzhovoi Bay at southwest end of Alaska Peninsula. Unit composed of gray to brown, poorly consolidated, crossbedded subgraywacke sandstone commonly interbedded with volcanic-pebble conglomerate and siltstone (Detterman and others, 1996). Sandstone is composed of 30 to 35 percent angular quartz, 30 percent volcanic rock fragments, 10 to 15 percent feldspar, 5 percent pyroxene and amphibole, and 20 percent clay matrix. Measured reference section 130-m-thick was designated by McLean (1979b) at South Walrus Peak in False Pass 1:250,000-scale quadrangle; however, section is incomplete, as basal part was not examined. McLean (1979b) reported thickness of about 460 m for Tachilni; however, Detterman and others (1996) suggested that structural complications and poor exposures preclude measurement of complete section. Unit is richly fossiliferous, containing 36 genera of bivalves and 11 genera of gastropods (Detterman and others, 1996). Marincovich (1983) showed that these fossils have close correlation with Wishkahan Stage of late Miocene, resulting in late Miocene age assignment for unit, in contrast to late Miocene and early Pliocene age reported by McLean (1979a,b). Tachilni is unconformably overlain by late Tertiary and Quaternary volcanic and volcaniclastic rocks that are presumably partially correlative with Milky River Formation. Contact of Tachilni and Morzhovoi Volcanics generally is structurally conformable although locally unconformable where volcanic flows fill former stream valleys cut into Tachilni. No lower contact of formation is known although it may overlie Belkofski Formation

Tu **Unga Formation (middle Miocene to late Oligocene)**—Originally named Unga Conglomerate by Dall (1882, 1896) for exposures west of Zachary Bay on Unga Island (see Port Moller B–2 and B–3 1:63,360-scale quadrangles); later redefined by Burk (1965; see also, Allison and Addicott, 1973) as lower member (Unga Conglomerate Member) of Bear Lake Formation; and subsequently excluded from Bear Lake Formation and returned to formational rank by Detterman and others (1996). Atwood (1911, p. 66) designated type section of unit as sequence of rocks located along west shore of Zachary Bay; Burk (1965) later included in unit coal-bearing rocks exposed below Atwood's section on Unga Island. Detterman and others (1996) stratigraphically and geographically extended

Burk's Unga to include rocks westward from Zachary Bay to Unga Spit; extended section is 275-m-thick, 25 percent or more of which is volcanic rocks (lahar deposits, debris-flow deposits, and tuff). Volcanic rocks are dominant in upper part of extended section, whereas carbonaceous shale and coal are restricted to lower part; sandstone and conglomerate throughout unit are composed of poorly sorted and typically loosely consolidated volcanic debris. Unit is geographically restricted to Unga Island, Deer Island, Pavlof Islands, and along Pacific coast of Alaska Peninsula adjacent to Unga Island. Fossils are locally abundant but are restricted to thin zones that contain numerous specimens of a few genera. Petrified wood, including logs and stumps in growth position, is common and is typically associated with debris-flow deposits that engulfed then-existent forests of *Metasequoia sp*. (Eakins, 1970). A well-known petrified forest is found within unit on Unga Island (Eakins, 1970), and another is found on Wosnesenski Island. Neither top nor base of formation is exposed, and, therefore, its relation to other units is not well defined; however, because formation has similar structural attitudes as underlying and overlying units, we infer that it disconformably overlies Stepovak Formation (Ts) and is disconformably overlain by late Miocene volcanic rocks (Tv)

Tbe **Belkofski Formation (middle Miocene? to late Oligocene?)**—Originally named Belkofski Tuff by Kennedy and Waldron (1955); later renamed Belkofski Formation by Burk (1965; see also, McLean, 1979a). McLean (1979a,b) gave generalized description of section about 1,830-m-thick along northwest shore of Belkofski Bay in the Cold Bay 1:250,000-scale quadrangle; it consists of tuffaceous, volcaniclastic sandstone, siltstone, and conglomerate, and contains interbeds of tuff and volcanic breccia. Along Belkofski Bay, unit is mainly gray or greenish gray to gray brown; however, on Pavlof Islands, rocks are dominantly red, pink, and purple, and are very well indurated. Stratigraphic relations of this unit with other units on Alaska Peninsula are not known with certainty; however, most likely correlative unit, on the basis of lithologic similarity and apparent stratigraphic position, is Unga Formation (unit Tu; Detterman and others, 1996). Lower contact of Belkofski Formation is nowhere exposed; upper part of unit is overlain unconformably by volcanic flows of late Miocene age. Potassium-argon age determination on clast from volcanic agglomerate, tentatively mapped as Belkofski Formation on Dolgoi Island, is 11.79±0.41 Ma (Nora Shew, oral commun., 1988)

Th **Hemlock Conglomerate (late Oligocene)**—Originally described by Calderwood and Fackler (1972) and Adkison (1975) for exposures in Cook Inlet area. Magoon and others (1976a,b) applied this name to rocks in northern part of Mount Katmai 1:250,000-scale quadrangle and correlated thicker section there with type Hemlock Conglomerate. Detterman and others (1996) described reference section about 560-m-thick of Hemlock Conglomerate in Mount Katmai 1:250,000-scale quadrangle that is composed primarily of fluvial sandstone and conglomerate that contain interbeds of siltstone, shale, and coal. Chert, quartz, and granitic and metasedimentary rocks form most of clasts in conglomerate; volcanic rocks are small but significant proportion of clasts. Minor tuff is present; however, erosion of underlying Mesozoic rocks is probably main source for Hemlock Conglomerate. In most areas, unit unconformably overlies Kaguyak Formation; in a few localities, it unconformably overlies Naknek Formation. At Cape Douglas, it disconformably overlies Copper Lake Formation. Megaflora fossils of broadleaf deciduous plants and evergreen needles suggest late Oligocene age (J.A. Wolfe, written commun., 1988, in Detterman and others, 1996)

Ts **Stepovak Formation (early Oligocene and late Eocene)**—Originally called Stepovak Series by Palache (1904) for rocks exposed on east side of Chichagof Bay; later renamed as Stepovak Formation by Burk (1965; see also, Detterman and others, 1996); and divided into two informal members by Detterman and others (1996). Unit is age equivalent of volcanic rocks mapped to north as Meshik Volcanics (Tm) and of rocks informally called Popof volcanic rocks on Inner Shumagin Islands (Wilson and others, 1995). Popof volcanic rocks are included in the Meshik Volcanics (Tm) on this map. Reference section described by Detterman and others (1996) begins on ridge top in sec. 12, T. 52 S., R. 71 W., continues southwesterly into sec. 13, and then southerly into sec. 24 and on to Pacific coast (Port Moller C–1 1:63,360-scale quadrangle). Reference section has 2,030 m exposed, approximately evenly divided into an (informal) lower siltstone member and an (informal) upper sandstone member (Detterman and others, 1996). This reference section is not complete section of formation, as neither upper nor lower contacts are exposed. Lower member is deep-water turbidite deposit that is composed of dark-brown laminated siltstone and shale, as well as interbedded sandstone that commonly shows graded bedding and rip-up clasts. Upper member, rich in unaltered volcanic debris, was deposited in shallow-water shelf environment; megafauna distributed throughout upper member are characteristic of water depths no greater than 30 to 50 m (Louie Marincovich, Jr., written commun., 1983 to 1986). Upper and lower contacts of formation are structurally conformable with Unga and Tolstoi Formations (units Tu and Tt, respectively) but are considered disconformities because considerable time gaps exist between younger and older units

Tt **Tolstoi Formation (middle Eocene to late Paleocene)**—Named and defined by Burk (1965; see also, Detterman and others, 1981a), who designated type locality along east shore of Pavlof Bay north of Tolstoi Peak. Detterman and others (1996) have designated stratigraphic section exposed at type locality between Tolstoi Peak and Cone Peak (Port Moller B–5 and C–5 1:63,360-scale quadrangles) as type section. They have also designated reference section that is more representative of unit's lithology, located along east shore of Ivanof Bay that begins at northeast corner of sec. 3 and continues south along east shore of Ivanof Bay to southeast corner of sec. 10, T. 50 S., R. 66 W., in Stepovak Bay D–5 1:63,360-scale quadrangle. In approximately 640-m-thick type section, lithology is characteristic of shallow marine environment that is succeeded northward (stratigraphically upward) by rocks characteristic of nonmarine delta-plain and fluvial deposits, mainly of braided-stream character. Much thicker (1,319 m) reference section has lithology that is typical of nonmarine fluvial flood-plain, delta sequence, which is common in main part of Tolstoi Formation. Marine rocks are not known in Tolstoi north of Ivanof Bay (C.M. Molenaar, written commun., 1991). In type section, sandstone is dominant lithology of formation; sandstone intervals grade upward from light gray to olive gray and tend to become more thin bedded. Siltstone intervals in section are consistently thin bedded and are usually light olive gray. Plant debris is present throughout type section, whereas megafauna is only reported from lower 280 to 290 m. In reference section, proportion of sandstone and siltstone thickness is subequal; additionally, conglomerate and conglomeratic sandstone intervals make up roughly 15 percent of section. Sandstone intervals tend to be massive or thick bedded, medium grained, and various shades of gray and brown. Siltstone intervals in reference section are usually thin bedded and consistently dark gray. Conglomerate and conglomeratic sandstone intervals are typically pale yellowish brown and massive. Lithic clasts in conglomerate and conglomeratic sandstone are dominantly granitic and arkosic detritus but also include as much as 30 percent volcanic clasts. Most volcanic clasts are altered or weathered, which is in sharp contrast to most overlying units (Detterman and others, 1996); additionally, presence of granitic and arkosic detritus suggests a Mesozoic source rather than derivation from contemporaneous magmatic activity. Plant debris, including well-preserved leaves, are common throughout reference section; however, no megafauna has been reported. In southern part of map area, Tolstoi Formation disconformably overlies Late Cretaceous Hoodoo Formation (Kh); in central part of map area, Tolstoi overlies Late Cretaceous Chignik Formation (Kc) with slight unconformity. Tolstoi is disconformably overlain by both Stepovak and Bear Lake Formations (units Ts and Tbl, respectively). In its northeastern exposures Tolstoi overlies Hoodoo Formation with angular unconformity and is overlain by Meshik Volcanics with angular unconformity (C.M. Molenaar, written commun., 1991)

Tc **Copper Lake Formation (early Eocene and Paleocene?)**—Named by Detterman and Reed (1980) for exposures in Iliamna 1:250,000-scale quadrangle directly north of map area, name "Copper Lake Formation" also was applied to rocks in Mount Katmai area by Riehle and others (1987; see also Riehle and others, 1993). Detterman and others (1996) described 1,025-m-thick section in Mount Katmai area (see secs. 16 and 21, T. 14 S., R. 25 W., Afognak D–5 1:63,360-scale quadrangle); formation there consists of thick pebble-cobble conglomerate in its uppermost and lowermost parts and contains sandstone and siltstone in its middle part. In measured section, conglomerate intervals are massive and have clasts that are mixture of volcanic, granitic, and metamorphic rocks in subequal proportions. Sandstone and siltstone intervals of measured section vary from thin bedded to massive and are typically dark to medium gray; they are fine to medium grained lower in section and become medium to coarse grained toward top. More fine grained clastic parts of formation contain considerable carbonaceous debris and minor coaly material. In map area, Copper Lake Formation, like Tolstoi Formation, was derived from erosion of Mesozoic source area and is nonmarine. In Mount Katmai and Iliamna areas (north of map area), this source area was underlain by Alaska-Aleutian Range batholith (Reed and Lanphere, 1973) and associated Mesozoic sedimentary and metamorphic rocks. North of map area, Copper Lake undergoes transition from rocks of Mesozoic provenance to fresh volcanic clasts of probably Tertiary age (Detterman and Reed, 1980, p. B47). Age of Copper Lake is not well constrained; sparse megaflora in type section in Iliamna area and abundant megaflora in map area are restricted to sandstone and siltstone intervals that are present in middle part of unit (Detterman and others, 1996). Detterman and others (1996) consider age of Copper Lake to be Paleocene(?) and early Eocene. Upper and lower contacts of Copper Lake Formation are disconformities with Hemlock Conglomerate and Kaguyak Formation, respectively. Unit also includes, only for map display purposes, rocks mapped by Riehle and others (1987) as their unit Ts, Sedimentary rocks, undifferentiated and unit Ts, Sedimentary rocks of Riehle and others (1993)

Kh **Hoodoo Formation (Late Cretaceous; Maestrichtian and Campanian)**—Named by Burk (1965, p. 59–63, 182; see also, Detterman and others, 1981a) for exposures southeast of Hoodoo Mountain between Herendeen and Pavlof Bays; type section of unit is located on southeast side of Hoodoo Mountain and along west side of upper Beaver River valley in Port Moller C–3 1:63,360-scale quadrangle. Reference section, 630-m-thick, was designated by Detterman and others (1996) in Chignik A–3 1:63,360-scale quadrangle. Detterman and others (1996) indicate Hoodoo may be considerably thicker than measured at reference section, but complex folding and faulting, including well-developed olistostromes, and absence of good marker beds make it difficult, if not impossible, to determine true thickness of formation. Unit is typically dark-gray to black, thin-layered and rhythmically bedded, splintery to pencil-fracturing shale, siltstone, and fine sandstone, becoming more sandy stratigraphically upwards. At Hoodoo Mountain, section contains ammonite-bearing channel conglomerate composed of clasts of plutonic and volcanic rocks, chert, and quartz. Sandstone beds are 0.3- to 1-m-thick and siltstone and shale beds are 1- to 2-m-thick, although individual layers are as thin as 1 cm (Detterman and others, 1981a). Depositional environment for most of unit is characteristic of lower slope of a submarine fan; structures imply submarine slumping and turbidity current flow. Locally, thick sandstone and conglomerate in upper part of unit imply upper fan-regime environment. Hoodoo can be easily mistaken for similar-appearing dark-green or brown siltstone of overlying Tolstoi Formation (Tt) or lower part of the Stepovak Formation (Ts), although color, style of fracturing, and fossils can help to distinguish units. Hoodoo is, in part, age equivalent to Chignik Formation (Kc), which can be considered shallow-water-facies equivalent of Hoodoo (Mancini and others, 1978; Molenaar, 1980; Detterman and others, 1996). However, where two units are in contact, Hoodoo conformably overlies Chignik Formation, which indicates a generally transgressive sequence. Hoodoo is in turn unconformably overlain by Tolstoi Formation, although locally the contact can be structurally conformable (Detterman and others, 1996). Sparse megafauna indicates an age of late Campanian and early Maestrichtian for Hoodoo (J.W. Miller, written commun., 1983–85)

Kc **Chignik Formation (Late Cretaceous; Maestrichtian and Campanian)**—Named by Atwood (1911, p. 41–48) for exposures at Chignik Lagoon and Chignik Bay; unit has type section located on Whalers Creek (all locations in Chignik B–2 1:63,360-scale quadrangle). Burk (1965, p. 50) subdivided lower, nonmarine part of formation as his Coal Valley Member; however, Detterman and others (1996) consider Coal Valley Member to be useful mapping unit only between Port Moller and Herendeen Bay, and state that exposures along east shore of Herendeen Bay at Coal Bluff are not Coal Valley Member but refer them, rather, to unnamed Tertiary strata. Chignik is cyclic, nearshore-marine, tidal-flat, and nonmarine flood-plain and fluvial deposit (Fairchild, 1977; Detterman, 1978); its thickness is as much as 600 m in area between Port Moller and Chignik Bay. Unit consists dominantly of light-olive-gray to olive-gray sandstone containing interbedded olive-gray to olive-black siltstone and conglomerate. Conglomerate intervals are composed of multicolored chert, white quartz, felsic plutonic, and minor volcanic clasts. Nonmarine part locally contains coal beds as much as 2-m-thick, that were mined at Mine Harbor on Herendeen Bay around turn of twentieth century. As mapped, includes rocks mapped as undivided Chignik and Hoodoo Formations in Ugashik 1:250,000-scale quadrangle by Detterman, Case, and others (1987). Marine fossils, mainly pelecypods, indicate late Campanian and early Maastrichtian age (J.W. Miller, written commun., 1983–85) for Chignik. Formation unconformably overlies Herendeen, Staniukovich, and Naknek Formations (units Khe, Kst, and Jn, respectively) and conformably interfingers and underlies Hoodoo Formation (Kh) at Chignik Bay; Hoodoo Formation is both a deep-water-facies equivalent and an overlying unit of Chignik (Mancini and others, 1978; Molenaar, 1980; Detterman and others, 1996). Tolstoi Formation (Tt) unconformably overlies Chignik

Kk **Kaguyak Formation (Late Cretaceous; Maastrichtian and Campanian)**—Named by Keller and Reiser (1959) for rocks exposed near abandoned village of Kaguyak in Afognak C–6 1:63,360-scale quadrangle. Detterman and Miller (1985) remeasured and described type section that begins at mouth of Swikshak River and continues westward in cliffs for approximately 5 km. Measured thickness is more than 1,200 m of dark-gray to pale-brown, typically thin bedded shale, siltstone, and fine grained sandstone. Proportion of sandstone in unit increases up-section. Load and flute casts are common; in upper part of unit, graywacke is graded with numerous rip-up clasts. Overall depositional environment of formation is near mid-fan within multi-channeled system; however, uppermost part of unit may have been deposited in upper-fan regime (Detterman and others, 1996). In general, fossils are sparse; however, in lower part of unit they are locally abundant. Ammonites are most common and may range in size to as much as 1-m-across. Fossils allow age assignment of latest Campanian and early Maastrichtian for Kaguyak. Kaguyak unconformably overlies rocks as young as Early Cretaceous; upper contact is unconformity with Copper Lake Formation

Ks **Shumagin Formation (Late Cretaceous; Maastrichtian)**—Named and defined by Burk (1965; see also, Moore, 1974a) for typical exposures at Falmouth Harbor on Nagai Island, which was later designated as type area of unit by Moore (1974a). Shumagin Formation consists of interbedded sandstone, siltstone, mudstone, and shale at least 3,000-m-thick (Burk, 1965). Sandstone is dominantly very fine- to medium-grained, medium-light-gray to medium-dark-gray, highly indurated, lithic graywacke (Moore, 1974a). Sandstone beds in unit vary in thickness from 2 cm to 20 m, are graded, and contain abundant shale and siltstone chips (Moore, 1974a; Detterman and others, 1996). Thin (less than 10 cm) grayish-black mudstone layers are interbedded with sandstone; however, in some areas, mudstone forms dominant lithology. Areas of outcrops containing 80 percent or more mudstone were mapped separately by Moore (1974a); that distinction is also made on this map (unit Ksm). Thin-bedded siltstone, mudstone, and sandstone sequences are rhythmically bedded and have sharp upper and lower contacts that are indicative of turbidity-current deposition in deep-sea-fan and abyssal-plain environments. Only observed contact of Shumagin with a younger unit is where early Tertiary Sanak Island and Shumagin Islands batholiths intrude (Kienle and Turner, 1976; Detterman and others, 1996); at these contacts, Shumagin has been contact-metamorphosed. In Sanak Islands, Shumagin depositionally overlies structurally conformable sequence of chert and volcanic rock (unit KJcv). Fossils are uncommon in Shumagin, but existing collections indicate early Maastrichtian age for formation (J.W. Miller, written commun., 1983–88; oral commun., 1991), which is equivalent to upper parts of Hoodoo, Kaguyak, and Chignik Formations (units Kh, Kk, and Kc, respectively). Shumagin is trench- and abyssal-plain-facies equivalent of Hoodoo Formation (Mancini and others, 1978); Plafker and others (1977) also correlated Shumagin Formation with Kodiak Formation of Kodiak

Islands and Valdez Group of south-central Alaska. Thin-section analysis of unit samples by John Decker (oral commun., 1985) also suggests close lithologic relation with Kodiak Formation on Kodiak Island. According to Decker, protolith for Shumagin was derived from north and transported along paleo-Aleutian trench, although a protolith component of apparently local derivation has same provenance as Hoodoo Formation. Locally, divided into:

Ksm **Mudstone**—Thin-bedded (less than 10 cm) grayish-black mudstone layers; mapped in areas where outcrops contain 80 percent or more mudstone (Moore, 1974a)

Kp **Pedmar Formation (Early Cretaceous; Albian)**—Named by Detterman and others (1996) for thin (82 m) sequence of thick-bedded, fine- to medium-grained, gray to olive-gray sandstone exposed along coast of Katmai Bay near Mount Pedmar in Mount Katmai A–3 1:63,360-scale quadrangle. Carbonaceous debris is present throughout, and pebbles as large as 4 cm in diameter are found in tabular crossbedded sandstone in middle part of formation. Clasts are typically quartz; volcanic clasts are conspicuously absent. Two poorly exposed siltstone and shale intervals are present in upper part of formation; siltstone is much more common in a measured section east of Ikagluik Creek, 42 km north of type section in Mount Katmai B–3 1:63,360-scale quadrangle. Abundant ammonite and *Aucellina sp*. fossils help to establish well-controlled Albian age for formation. Upper contact of formation is disconformity with overlying by Kaguyak Formation. In type section, lower contact is fault that juxtaposes Pedmar and Naknek Formations. At Ikagluik Creek section, formation disconformably overlies Herendeen Formation

KJcv **Chert and volcanic sequence (Early Cretaceous or Jurassic)**—Unit was originally described by Moore (1974b) for rocks found on northeast coast of Long and Clifford Islands in the Sanak Islands (False Pass B–3 1:63,360-scale quadrangle). Moore's (1974b) description of these rocks is as follows: "Reddish-brown, light-gray, and grayish-green bedded chert; dark-greenish-gray pillow lava and tuffs, thin (5–10 cm) medium-gray, medium- to fine-grained sandstone interbedded with dark-gray mudstone." Maximum exposed thickness reported by Moore (1974b) is 250 m; however, as no base of unit is exposed, total thickness of unit is unknown. Clasts of chert, presumably derived from this unit, are found in depositionally overlying massive sandstone of Shumagin Formation (Ks); hence, a Jurassic or Early Cretaceous age is assigned to these rocks (Moore, 1974b), because no fossil or radiometric-age control exists. No other locality on Alaska Peninsula or adjacent islands has similar lithologies, except for parts of Early Cretaceous Uyak Formation (Moore, 1969; Fisher, 1979) on Kodiak Island, with which Moore (1974b) made only lithologic correlation. Since publication of Moore (1974b), Uyak has been revised in age from Triassic to Early Cretaceous (Fisher, 1979), which further supports correlation of this chert and volcanic sequence with Uyak Formation (J.C. Moore, written commun., 1991). However, recent chemical analysis (F.H. Wilson, unpub. data, 1991) suggests that these volcanic rocks are significantly more siliceous than greenstone of the Uyak Formation (Hill, 1979)

Khe **Herendeen Formation (Early Cretaceous; Barremian and Hauterivian)**—Originally named Herendeen Limestone by Atwood (1911, p. 39) for exposures along east shore of Herendeen Bay, north of Mine Harbor; renamed Herendeen Formation by Detterman and others (1996), who designate a 270-m-thick reference section in hills southwest of Hot Spring on Port Moller (sec. 14, T. 50 S., R. 73 W., Port Moller D–2 1:63,360-scale quadrangle). Originally described as limestone, rocks of formation are actually an unusually uniform calc-arenaceous sandstone. Rocks are thin-bedded, medium-grained, and dusky yellow to pale yellowish brown on freshly broken surfaces and weather to conspicuous light gray. They have distinct platy fracture upon weathering and strong petroliferous odor when freshly broken. Inoceramus fragments form major component of formation, although complete specimens have only been found in the Mount Katmai area. A belemnite similar to *Acroteuthis sp. A* (Jones and Detterman, 1966) was found in rocks of formation just east of Staniukovich Mountain between Port Moller and Herendeen Bay. Ammonite fossils and other collections from Herendeen in Mount Katmai area allow an age assignment of Hauterivian and Barremian for formation (J.W. Miller, written commun., 1983–85; Detterman and others, 1996). Herendeen conformably overlies Staniukovich Formation (Kst) and is unconformably overlain by Chignik (Kc) and Pedmar (Kp) Formations

Kst **Staniukovich Formation (Early Cretaceous; Valanginian and Berriasian)**—Originally named Staniukovich Shale by Atwood (1911, p. 25, 38) for exposures on Staniukovich Mountain. Burk (1965; see also, Imlay and Detterman, 1973, and Detterman and others, 1981a) changed name to Staniukovich Formation and included within unit a variety of rocks of latest Jurassic and Early Cretaceous age; however, Detterman and others (1996) stratigraphically restrict formation to original usage of Atwood (1911), and, as so restricted, its age is Early Cretaceous. Type section (Atwood, 1911), in sec. 30, T. 50 S., R. 73 W., Port Moller D–2 1:63,360-scale quadrangle, is composed of 246 m of light-olive-gray siltstone containing two light-olive-brown sandstone intervals, overlain by shaly olive-gray siltstone containing numerous calcareous nodules and concretions (Detterman and others, 1996). Upper part of formation erodes readily and, therefore, is typically not well exposed; additionally, it contains few age-diagnostic fossils, whereas lower part has abundant megafauna fossils, particularly pelecypod *Buchia*, which indicates Berriasian and Valanginian age (J.W. Miller, written commun., 1982–88; Detterman and others, 1996). Upper and lower contacts of Staniukovich are conformable with Herendeen (Khe) and Naknek (Jn) Formations, respectively

Jn **Naknek Formation (Late Jurassic; Tithonian to Oxfordian)**—Originally named Naknek Series by Spurr (1900, p. 169–171, 179, 181) for exposures at Naknek Lake. Detterman and others (1996; see also, Detterman and Hartsock, 1966; Martin and Katz, 1912) have subdivided unit into five members on Alaska Peninsula. Megafossils, particularly pelecypod *Buchia* (Detterman and Reed, 1980, p. B38; J.W. Miller, written commun., 1982–88), are common, and fauna, which also includes ammonites, indicate age range of Oxfordian to late Tithonian (Late Jurassic). Naknek is conformable with overlying Staniukovich Formation (Kst) and unconformably overlies Middle Jurassic Shelikof Formation (Js). Alaska-Aleutian Range batholith was main source of sedimentary debris for Naknek Formation, that on faunal evidence ranges in age from about 138 to 155 Ma; hence, uplift and erosion of batholith occurred shortly after emplacement. Locally, divided into:

Jni **Indecision Creek Sandstone Member (Tithonian and Kimmeridgian)**—First recognized by Keller and Reiser (1959); designated as informal member of Naknek Formation by Detterman and Reed (1980); and formally named and described by Detterman and others (1996). Detterman and others (1996) designated an approximately 870-m-thick type section on east-facing slope of unnamed mountain near Mount Chiginagak (see secs. 35 and 36, T. 35 S., R. 49 W., Seward Meridian, Ugashik A–4 1:63,360-scale quadrangle). Consists of medium-gray, fine- to medium-grained arkosic sandstone and siltstone. It is thin bedded to massive; where bedded, it is locally crossbedded. Fresh biotite and hornblende are minor, but important, components of sandstone, as they are interpreted to indicate first-cycle erosion from Alaska-Aleutian Range batholith. Indecision Creek Sandstone Member is abundantly fossiliferous; however, fossils are restricted almost exclusively to pelecypods of genus *Buchia*. Depositional environment is shallow-water shelf to inner neritic (Detterman and others, 1996). Its lower contact is conformable and slightly gradational with Snug Harbor Siltstone Member. Upper contact is unconformity with overlying Late Cretaceous or Tertiary strata except where conformably and gradationally overlain by Staniukovich Formation or, in Mount Katmai region, Katolinat Conglomerate Member. Indecision Creek Sandstone Member is most widely exposed member of Naknek Formation and occurs throughout Alaska Peninsula

Jnk **Katolinat Conglomerate Member (Tithonian)**—Type section designated by Detterman and others (1996) is on unnamed mountain on northeast shore of Grosvenor Lake (secs. 33 and 34, T. 17 S., R. 35 W., Mount Katmai C–4 1:63,360-scale quadrangle). Thick (about 450 m) pebble-boulder conglomerate and minor amounts of greenish-gray to yellowish-green sandstone containing abundant quartz, chert, and granitic and metamorphic rock clasts. Restricted to northern part of Alaska Peninsula, it is, in part, lateral facies equivalent of upper part of Indecision Creek Sandstone Member. Lower contact is gradational with Indecision Creek Sandstone Member. Upper contact is unconformity with overlying Early Cretaceous Herendeen Formation

Jns **Snug Harbor Siltstone Member (Kimmeridgian and Oxfordian)**—Originally described by Kirschner and Minard (1949) and named by Detterman and Hartsock (1966) for exposures in Iniskin Peninsula area of Cook Inlet. Detterman and others (1996) established reference section on Northeast Creek in sec. 27, T. 37 S., R. 51 W., in Sutwik Island D–5 1:63,360-scale quadrangle. Reference section consists of more than 638 m of dark-yellowish-brown and dark-gray, thin-bedded siltstone and minor amounts of thin- to medium-bedded olive-gray sandstone. Limestone nodules are locally abundant, and limestone beds are present in some siltstone intervals. It is lowest abundantly fossiliferous member of Naknek; main fossils present are of genus *Buchia*. Depositional environment was interpreted by Detterman and others (1996) to have been moderately deep water, well below wave base and above carbonate compensation depth, in a basin that had restricted circulation. Both upper and lower contacts of unit are gradational with Indecision Creek Sandstone and Northeast Creek Sandstone Members, respectively

Jnn **Northeast Creek Sandstone Member (Oxfordian)**—Named and described by Detterman and others (1996) for exposures along Northeast Creek in Sutwik Island D–5 1:63,360-scale quadrangle (sec. 34, T. 37 S., R. 51 W., Seward Meridian). Type section consists of 624 m of fine- to coarse-grained, light-brownish-gray arkosic sandstone and minor amounts of olive-gray to dark-gray, thin-bedded siltstone in lower part of section. Sandstone is typically thick bedded and crossbedded and contains magnetite laminae and thin beds of conglomerate. Fossils are uncommon in unit although carbonaceous debris is common locally. Depositional environment is mainly nonmarine. Some sand beds are channeled with lag gravel at bases of channels. Crossbedding is mostly high-angle and variable directional eolian type, some is small-scale, tabular crossbedding with clay drapes characteristic of point bar deposits (Detterman and others, 1996). Lower contact is conformable on underlying Chisik Conglomerate Member and is placed where thick sandstone replaces conglomerate in section. Upper contact is sharp and conformable with overlying Snug Harbor Siltstone Member. At this contact, depositional environment shifts from mainly nonmarine to marine; position of contact varies temporally depending on local conditions

Jnc **Chisik Conglomerate Member (Oxfordian)**—Limited to northern half of map area, reference section is located 6.5 km south of Becharof Lake (secs. 26 and 27, T. 30 S., R. 43 W., Ugashik C–1 1:63,360-scale quadrangle) is composed of 614 m of massive to thick-bedded conglomerate and interbedded, crossbedded, clean quartzose sandstone. Clasts range in size from maximum of 120 cm at bottom to 15 cm at top. Clast composition is 30 percent granitic rocks, 30 percent quartzite, 20 percent metavolcanic rocks, 10 percent schist, and 10 percent chert and quartz. Clasts are well-rounded and commonly decrease in size stratigraphically upward within each lithic interval of member. Lower contact is unconformity with Shelikof Formation; upper contact is conformable and gradational with Northeast Creek Sandstone Member

Js **Shelikof Formation (Middle Jurassic; Callovian)**—Named by Capps (1923) for exposures at Cold (now named Puale) Bay along the northwest shore of Shelikof Strait. Type section designated by Allaway and others (1984) is 1,402 m of volcaniclastic sedimentary rocks along northeast shore of Puale Bay (see sec. 19 , T. 28 S., R. 37 W. to sec. 9, T. 28 S., R. 38 W., Karluk C–4, C–5, and D–5 1:63,360-scale quadrangles). Allaway and others (1984) also designated 1,524-m-thick principal reference section at Wide Bay along ridge southwest of Big Creek (see sec. 5, T. 31 S., R. 43 W., Ugashik C–1 to sec. 3, T. 32 S., R. 43 W., Ugashik B–1 1:63,360-scale quadrangles). Another reference section 823 m thick was designated by Allaway and others (1984) at Wide Bay along ridge southwest of Alai Creek, between sec. 13, T. 33 S., R. 46 W. and sec. 19, T. 33 S., R. 45 W., Ugashik B–2 1:63,360-scale quadrangle. Lower part of type section is mainly thick-bedded to massive, dusky-yellowish-green graywacke and conglomerate, and minor amounts of siltstone, whereas upper part is mainly volcanic sandstone interbedded with massive and laminated brownish-gray siltstone containing calcareous sandstone clasts. Many lithic intervals in upper part of section have a fining-upward sequence from conglomerate to sandstone or sandstone to siltstone (Allaway and others, 1984). Owing to rapid lateral facies changes, informal subdivisions of Capps (1923) have been found impractical for mapping and have been abandoned. Shelikof is interpreted to have been deposited in a deep- to shallow-water environment (Detterman and others, 1996). Megafauna are locally abundant in Shelikof, although, in general, formation is not fossil-bearing. Vast majority of fossils collected from formation are ammonites of Callovian age; however, a few specimens suggest a Bathonian(?) age for some rocks (Allaway and others, 1984, p. A23; Detterman and others, 1985, 1996). Contact with underlying Kialagvik Formation is considered conformable (see Detterman and others, 1996). Upper contact of Shelikof with Naknek Formation is an unconformity. Shelikof is lithologically and faunally correlative with Paveloff Siltstone Member of Chinitna Formation (Detterman and Hartsock, 1966) of Cook Inlet region (Detterman and others, 1996)

Jk **Kialagvik Formation (Middle and Early Jurassic; Callovian to late Toarcian)**—Originally defined by Capps (1923) for sandstone, shale, and conglomerate exposed on northwest shore of Kialagvik (now named Wide) Bay, between Pass Creek and southwest end of bay in Ugashik 1:250,000-scale quadrangle. Capps did not designate type section; however, Detterman and others (1996) designated principal reference section more than 620-m-thick on south side of Short Creek (see secs. 34 to 32 to 28, T. 32 S., R. 44 W., Ugashik B–2 1:63,360-scale quadrangle), and a second reference section 395-m-thick at Puale Bay (secs. 29 and 19, T. 28 S., R. 37 W., Karluk C–4 and C–5 1:63,360-scale quadrangles). Only well-known subaerial exposures of Kialagvik are found in vicinity of these two localities; however, it has been encountered in subsurface in a number of drillholes along Alaska Peninsula. Additionally, because of redefinition of Shelikof Formation on lithologic grounds, C.M. Molenaar (written commun., 1991) suggested that it may also crop out on crest of Bear Creek anticline east of Becharof Lake. Unit consists of brown, fossiliferous sandstone, siltstone, and minor conglomerate, grading upward into fossiliferous siltstone, mudstone, and rare limestone at Wide Bay. Lower part of unit was deposited in near-shore, shallow-water environment; sandstone is crossbedded and contains lenses of conglomerate and fossils indicative of high-energy environment. Upper part of unit has characteristics of deeper water deposition including thin, rhythmically bedded siltstone and sandstone packages and limestone nodules and lenses. At Puale Bay, Kialagvik consists dominantly of gray, thin-bedded siltstone but contains two thin conglomerate beds, thicker of which is submarine channel deposit. Nearshore beds of Wide Bay section do not crop out at Puale Bay, either because reference sections are not complete or because of facies change. Shallow-water deposits of Kialagvik Formation are abundantly fossiliferous; most megafauna indicate age of early and middle Bajocian, although overall age range of fossils collected from unit is late Toarcian to Callovian (Imlay, 1984; see also, Detterman and others, 1996). Contact of Kialagvik with overlying Shelikof Formation is conformable at Puale Bay, where Kialagvik is as young as Callovian (Middle Jurassic), but unconformable at Wide Bay where Kialagvik is entirely Bajocian (Middle Jurassic); contact is placed at base of thick volcanic sandstone and conglomerate sequence. Contact of Kialagvik with underlying Talkeetna Formation at Puale Bay is disconformity

Jt **Talkeetna Formation (Early Jurassic)**—Name introduced by Martin (1926) for series of greenstone and tuff deposits first described in Talkeetna Mountains of south-central Alaska by Paige and Knopf (1907). Detterman and Hartsock (1966) geographically extended unit into Cook Inlet area. Detterman and others (1983) further geographically extended unit to include 405 m of clastic sedimentary rocks and tuff exposed on northeast shore of Puale Bay. Stratigraphically and lithologically equivalent rocks have been encountered in drillholes as far southwest as vicinity of Cathedral River (AMOCO Cathedral River #1 drillhole) in southwest part of map area. In measured section at Puale Bay, described by Detterman and others (1996), Talkeetna Formation is composed of primarily of gray-green, coarse-grained tuffaceous sandstone, lesser amounts of green to red, massive coarse-grained tuff, and minor amounts of brownish-gray siltstone and gray to gray-brown limestone. At Puale Bay, formation records inner-neritic to sublittorial environment. Northeast of map area, formation has much higher proportion of volcanic rocks (Detterman and Hartsock, 1966). Age of unit, Early Jurassic (Hettangian and early Sinemurian), is based on abundant megafauna; however, this megafauna is present in great abundance in only a few horizons and may represent mass kills as a result of volcanic eruptions (Detterman and others, 1996). Contact of Talkeetna with underlying Kamishak Formation is conformable and gradational; it is arbitrarily placed where clastic sedimentary rocks replace limestone as major constituents of rock sequence. Contact of Talkeetna with overlying Kialagvik Formation is structurally conformable; however, it is considered a disconformity, as rocks of late Sinemurian, Pliensbachian, and most of Toarcian Stages are missing

Ɍk **Kamishak Formation (Late Triassic; Norian)**—Originally named Kamishak Chert by Martin and Katz (1912) for rocks in vicinity of Bruin Bay, in Cook Inlet area. Kellum (1945; see also, Kirschner and Minard, 1949) changed name to Kamishak Formation for similar rocks at Puale Bay. Detterman and Reed (1980) divided unit into three members, in descending order, Ursus Member, middle member, and Bruin Limestone Member. In map area (see inset A, pl. 1), Triassic limestone strata was assigned to Bruin(?) Limestone Member of Kamishak Formation by Detterman and others (1996). Reference section of Kamishak was measured near Puale Bay by R.M. Egbert (U.S. Geological Survey, 1979, cited in Detterman and others, 1996, section in Karluk C–4 and C–5 1:63,360-scale quadrangles). Section consists of approximately 800 m of light- to brownish-gray, thin- to medium-bedded limestone, minor amounts of brownish-gray, calcareous siltstone and mudstone, and limestone conglomerate. An interval of brecciated and calcite-recemented basalt occurs near top of section, as does a volcanic breccia interval in lower part of the section. A 46-m-thick columnar-jointed basalt flow or sill from upper part of section has yielded a potassium-argon age of 197±12 Ma (Wilson and Shew, 1992); however, it remains to be determined whether basalt is sill from overlying Early Jurassic Talkeetna Formation or, alternatively, a flow from Kamishak that yields an analytically “minimum” age. Depositional environment of unit was shallow water and high energy; intervals of unit include both reefs and biohermal buildups. Fossils that have been found yield Norian age (Detterman and Reed, 1980; C.D. Blome, U.S. Geological Survey, oral commun., 1981). In map area, no lower contact is exposed. Upper contact is conformable and gradational with overlying Talkeetna Formation; Detterman and others (1996) arbitrarily placed contact at point where clastic sedimentary rocks replace limestone as major constituent of rock sequence. As Bruin Limestone Member is lowest member of Kamishak Formation, this contact indicates Bruin Limestone Member is time-transgressive unit

Pls **Limestone (Permian; early Guadalupian)**—Only known exposure is 40 m of thin- to thick-bedded, medium-grained, crystalline tan to gray limestone containing thin interbeds of chert, located on a small islet (100 by 200 m) at entrance to Puale Bay (see inset A, pl. 1). Hanson (1957) reported age of late middle Permian (early Guadalupian) for these rocks on the basis of poorly preserved and silicified coral, brachiopod, and foraminifer fossils. No contacts are exposed, although highly contorted beds dip about 40° northwest, which places them structurally beneath Triassic rocks that are located on other islands about 1 km away

VOLCANIC ROCKS

Qv **Volcanic rocks (Holocene and Pleistocene)**—Andesite, dacite, and leucobasalt lava flows, volcanic breccia, lahar deposits, and debris-flow deposits. Lava flows and clasts in other volcanic deposits of unit are porphyritic, typically glassy, gray to black, and commonly vesicular. Andesite is overwhelmingly dominant composition and probably constitutes 60 percent or more of rocks. Includes basalt of Black Point, Arch Point Basalt, and Dushkin Basalt (Kennedy and Waldron, 1955), and Frosty Peak Volcanics (Waldron, 1961). Also includes lava flows, breccias, and older pyroclastic deposits of Yantarni Volcano (Riehle and others, 1987). Unit typically forms volcanic edifices; it also forms isolated outcrops that cap ridges, providing a good example of topography reversal caused by erosion. Individual flows are locally as thick as 30 m and are laterally continuous over large areas. Potassium-argon ages are as old as 1.78±0.034 Ma (Wilson and Shew, 1992). Morphologically distinct flows separated by internal long and short dash contacts. Unit also includes basaltic, basaltic andesite, and dacite parasitic cinder and spatter cones. Cones are commonly 30 to 300 m high, are steep sided, and have small crater at top. Rocks at Mount Veniaminof are mainly basaltic andesite, whereas those at Aniakchak Crater are mainly dacite (T.P. Miller, oral commun., 1990). Basaltic scoria cones occur at three separate locations in the Mount Katmai 1:250,000-scale quadrangle (Riehle and others, 1993). Rocks are highly scoriaceous to vitrophyric, ranging in size from cinder-size fragments to 1-m-long bombs (Detterman and others, 1981b; T.P. Miller, oral commun., 1991). Primarily located in vicinity of Mount Veniaminof, Aniakchak Crater, in Mount Katmai area, and on Unimak Island

Qpd **Pyroclastic and debris-flow deposits (Holocene and late Pleistocene?)**—Dacite and rhyolite ash-flow tuff and debris-flow, block-and-ash-flow, explosion debris, and air-fall deposits. Mapped near Pavlof Volcano, Mount Dana, Kupreanof Volcano and other nearby unnamed volcanoes (Wilson, 1989), Mount Veniaminof (Detterman and others, 1981b), Aniakchak Crater (Miller and Smith, 1977), Ugashik Caldera (Detterman, Wilson, and others, 1987), and Valley of Ten Thousand Smokes (Riehle and others, 1987 and 1993). Pyroclastic deposits "typically are composed of pumice and scoria bombs *** and subordinate lithic fragments in a matrix of fine to coarse ash, pumice, and lithic material" (Miller and Smith, 1977, p. 174). Miller and Smith (1977) reported that composition ranges from basaltic andesite to rhyolite, although most are dacite. Valley of Thousand Smokes is well known for its compositionally zoned rhyolite to andesite ash flows erupted in 1912 (see, for example, Hildreth, 1983). Hildreth (1987) estimated composition of lavas from 1912 Katmai eruption to have been roughly 54 to 59 percent rhyolite, 35 to 43 percent dacite, and 3 to 5 percent andesite. Map unit is interbedded with, and overlies, Quaternary glacial debris (Qm). Unit records multiple, late Pleistocene and (or) Holocene eruptions at each of following volcanic centers: Roundtop, Pavlof and Pavlof Sister volcanoes, Mount Dana, Mount Veniaminof, and Aniakchak Crater, as well as possibly other volcanic centers. Radiocarbon ages (Wilson and others, 1995; Miller and Smith, 1987) have been determined on peat, charcoal, and other organic material at numerous localities beneath air-fall and block-and-ash-flow deposits. Youngest deposits are clearly historic (Valley of Ten Thousand Smokes) or postglacial; older deposits may be coeval with latest glaciation and show reworking into shoreline deposits at low elevations, particularly west and southwest of Mount Dana and in vicinity of Aniakchak River. Where known, individual deposits are shown by long and short dash internal contacts

QTv **Volcanic rocks (Quaternary and Pliocene?)**—Andesite and basalt lava flows, sills, and plugs. These primarily extrusive rocks typically cap ridges and include massive lava flows, agglomerate, and lahar deposits. Includes basalt flows of Mount Simeon of Waldron (1961). Primarily located on southwest part of Alaska Peninsula and on Unimak Island

QTp **Pyroclastic deposits (Pleistocene? and Pliocene)**—Welded ash-flow tuff, block-and-ash-flow deposits, and air-fall deposits of dacitic(?) composition. Largest exposure is found southeast of Left Head in Port Moller D–1 1:63,360-scale quadrangle. Similar rocks, which are composed of variably indurated deposits of ash, vitrophyre blocks, and (or) pumiceous lapilli, are found in Mount Katmai 1:250,000-scale quadrangle near Devils Desk, Mount Griggs, and east of Blue (Whale) Mountain (see Riehle and others, 1993, unit QTap). In Port Moller area, pyroclastic rocks are pale green, propylitically altered, and form base of southernmost of unnamed Quaternary volcanic centers (Yount and others, 1985; Wilson, 1989) northwest of Clark Bay. Unit has very limited distribution but reaches thickness of at least 500 m (1,600 ft) in Port Moller area and 200 m (650 ft) in Mount Katmai area. Age of these deposits is poorly controlled; however, because in Port Moller area deposits are capped by Pliocene(?) and Quaternary volcanic rocks (QTv, Qv), and on the basis of outcrop patterns we think they overlie Tolstoi Formation (Tt), we infer partial age equivalence of these rocks with Milky River Formation (Tmr)

QTm **Morzhovoi Volcanics (early Quaternary?, Pliocene, and late Miocene?)**—Named by Waldron (1961) for sequence of lava flows, interbedded pyroclastic rocks, and minor amounts of volcanic sedimentary rocks that overlie Tachilni and Belkofski Formations. Unit composed of "the eroded remnants of an ancient large composite cone *** called Morzhovoi volcano, in the area south of Frosty Peak" (Waldron, 1961, p. 688). Waldron

(1961, p. 688) designated type locality along Pacific coast south and east of Reynolds Head (see sec. 5, T. 59 S., R. 90 W., Cold Bay A–3 1:63, 360-scale quadrangle). At type locality, unit consists of poorly consolidated, dark sandy shale, sandstone, and fine- to coarse-grained conglomerate composed of subrounded to rounded fragments of volcanic debris, which are conformably overlain by interbedded lava flows, coarse agglomerates, and volcanic breccias of light- to pinkish-gray porphyritic basalt. Olivine is present in small amounts in nearly all rocks of Morzhovoi Volcanics that were examined (Waldron, 1961); however, olivine is not common in Alaska Peninsula volcanic rocks in general. Age of Morzhovoi Volcanics is not as yet well controlled. Waldron (1961) inferred an age of no older than latest Tertiary nor younger than middle Pleistocene. Detterman and others (1996) reported that upper part of the Tachilni Formation contains several ash beds that were possibly derived from Morzhovoi volcano. From this they inferred an earlier age limit of late Miocene for Morzhovoi Volcanics. Unit is probably correlative with parts of unit QTv elsewhere on Alaska Peninsula

Tvu **Volcanic rocks, undivided (Tertiary)**—Andesite, dacite, and basalt lava flows, tuffs, lahar deposits, volcanic breccia, and hypabyssal intrusions, all locally hydrothermally altered or hornfelsed. No potassium-argon ages are available and little stratigraphic control exists for these rocks, but outcrop and erosional patterns are similar to other Tertiary volcanic rocks. Includes volcanic rocks of Thinpoint Lagoon of Waldron (1961)

Tv **Volcanic rocks (late Miocene)**—Andesite and basalt flows, sills, and plugs. Extrusive rocks of unit typically cap ridges and consist of massive lava flows, agglomerate, and lahar deposits; unit also includes minor small intrusive bodies, for example, in San Diego Bay-Albatross Anchorage area of Port Moller C–2 1:63,360-scale quadrangle. Minor propylitic alteration is characteristic of these rocks, except in area around San Diego Bay, where sericitic and argillic alteration is pervasive. Potassium-argon ages range from 10.4±0.49 to 6.1±0.23 Ma (F.H. Wilson, unpub. data, 1987)

Tm **Meshik Volcanics (early Oligocene and late Eocene)**—Originally named Meshik Formation by Knappen (1929, p. 198–201) for exposures along Meshik River and near Meshik Lake in Chignik 1:250,000-scale quadrangle. Detterman and others (1996) have renamed unit Meshik Volcanics and have included measured section from Gulf Oil Co. Unit No. 1 drillhole, located near Port Heiden (see Chignik D–3 1:63,360-scale quadrangle). This drillhole penetrated almost 1,765 m of Meshik before reaching total depth, and remained within Meshik (Brockway and others, 1975). Drillhole section contains considerably more tuff than do outcrop exposures of Meshik Volcanics. In map area, formation is well exposed in mountains north of Ivanof and Chignik Bays; it consists of coarse andesitic and basaltic volcanic rubble, lahar deposits, andesite and basalt lava flows, tuff, hypabyssal basalt and andesite plugs, and minor amounts of volcaniclastic sedimentary rocks. Volcaniclastic sedimentary rocks are equivalent in age and in lithology to Stepovak Formation (Ts). In Stepovak Bay region, Meshik gradationally interfingers with Stepovak Formation; unit shown on map depends on which lithology dominates. On Unga Island, volcanic rocks of Meshik also include dacite and rare rhyolite flows and domes. Potassium-argon ages on multiple samples of Meshik Volcanics range from about 25 Ma to about 42 Ma (Wilson and others, 1981; DuBois and others, 1987; F.H. Wilson and Nora Shew, unpub. data, 1990; Wilson and Shew, 1992); vast majority of age determinations are between 30 and 40 Ma. Megafauna fossil collections from Meshik are rare; however, collections from Kupreanof Peninsula are Eocene and Oligocene in age. Contact of Meshik with underlying Tolstoi Formation (Tt) is considered a disconformity, although Meshik Volcanics unconformably overlie Tolstoi Formation in area northwest of Chignik Bay. Upper contact of Meshik Volcanics is unconformable with both Bear Lake Formation (Tbl) and late Miocene volcanic rocks (Tv). As mapped, unit includes informally defined Popof volcanic rocks of Wilson and others (1995), and also is herein geographically extended to include volcanic rocks of equivalent age, composition, and stratigraphic position mapped by Riehle and others (1987) as units Tvb and Tvm in Mount Katmai and Naknek 1:250,000-scale quadrangles

Ꞧv **Volcanic rocks (Late Triassic)**—Columnar-jointed basalt flows, volcanic breccia, and agglomerate (see inset A, pl. 1). Chemical data (Hill, 1979; Wilson and Shew, 1992) indicate these rocks are of tholeiitic affinity. Potassium-argon age determination on flow unit was 197±12 Ma (Wilson and Shew, 1992); age is thought to be minimum age, as it is younger than stratigraphic position suggests. Interbedded with Late Triassic Kamishak Formation (₸k)

Pv **Volcanic rocks (Permian?)**—Massive, dark-green to black volcanic breccia, agglomerate, and andesitic flows (Hanson, 1957; Hill, 1979). These rocks are only exposed on offshore islets east of Puale Bay and were not examined during this study (see inset A, pl. 1). Well-developed joint system has obscured original structure, and because of this, in part, thickness is unknown. No definite age control exists; however, these rocks appear to structurally underlie mid-Permian limestone (Pls). Hill (1979) briefly examined exposures and sampled rocks. Limited chemical data from Hill (1979) suggest these volcanic rocks are of calc-alkaline affinity, in contrast to Late Triassic tholeiitic volcanic rocks of nearby mainland (₸v)

INTRUSIVE ROCKS

Qi **Intrusive rocks (Holocene and Pleistocene)**—Hypabyssal dacite plugs and domes at Quaternary volcanic centers, particularly at Frosty Peak, Trader Mountain, Mount Dana, Ugashik Caldera, Blue Mountain (west of Ugashik Lakes), and The Gas Rocks. Porphyritic dacite at Trader Mountain has yielded potassium-argon age of 0.98±0.05 Ma (Wilson and Shew, 1992). Potassium-argon ages on other intrusive bodies range from about 1 Ma to about 165 ka (Wilson and others, 1981; Wilson and Shew, 1992). Pyroclastic deposits (Qpd) form an apron of ash around Mount Dana; radiocarbon ages (see table 1, Wilson and others, 1995) of samples from stratigraphic sections containing these deposits suggest Holocene age for dome at Mount Dana

Ti **Intrusive rocks (Pliocene and late Miocene)**—Medium- to coarse-grained, equigranular, granodiorite to quartz diorite plutons and stocks containing hornblende, biotite, and pyroxene as mafic minerals and typically are surrounded by well-developed hornfels zones and sporadic hydrothermal alteration in country rocks. Intrusive bodies are typically located along Pacific coast and include, but are not limited to, large plutons at Moss Cape, American Bay, Pyramid Mountain, Mitrofania Island, Devils Bay (Devils batholith, Detterman and others, 1981), Agripina Bay, Mount Becharof, Cape Igvak, and Cape Douglas. Potassium-argon ages range from 9.43±0.26 to 3.21±0.14 Ma (Wilson and others, 1981; F.H. Wilson and Nora Shew, unpub. data, 1990; Wilson and Shew, 1992)

Tiu **Intrusive rocks, undivided (Tertiary)**—Small, typically hypabyssal dikes, sills, and stocks of andesite, quartz diorite, or diorite containing phenocrysts of pyroxene or hornblende in fine-grained groundmass. No potassium-argon ages are available for these rocks; unit may include rocks of other Tertiary intrusive rock units

Tgd **Granodiorite (Oligocene)**—Riehle and others (1993) describe these rocks as "Light-gray to gray-green, medium-grained equigranular to marginally porphyritic rocks having subhedral plagioclase and (or) hornblende phenocrysts *** Biotite is subequal to clinopyroxene or hornblende and secondary epidote and chlorite are common *** Average color index *** is 18. Modal quartz rarely exceeds 25 percent, and unit includes samples that marginally classify as quartz monzodiorite, quartz diorite, or uncommonly, tonalite." Found in northern part of Mount Katmai 1:250,000-scale quadrangle

Tqd **Quartz diorite (Oligocene)**—Riehle and others (1993) describe these rocks as "Gray, medium-grained equigranular rocks consisting chiefly of plagioclase, pyroxene, and quartz and having accessory hornblende in excess of biotite. Average color index is 23 ***" Modal quartz content varies widely, and rocks composing unit include tonalite and monzonite (Riehle and others, 1987). Found in northern part of Mount Katmai 1:250,000-scale quadrangle

Tg **Granodiorite (Paleocene)**—Medium-grained biotite granodiorite, quartz monzonite, and granite(?) plutons of Sanak Island, outer Shumagin Islands, and Semidi Islands; exhibits hypidiomorphic-granular texture and locally contains potassium feldspar phenocrysts as long as 1 cm. Rare muscovite is found in limited areas near contacts with Shumagin

Formation (Ks). Minor hornfels zone as wide as 500 m is mapped at contact with Shumagin Formation (Moore, 1974a). Potassium-argon ages reported by Burk (1965), Moore (1974a), and Kienle and Turner (1976) range from 65.6±3.3 to 57.4±1.8 Ma when recalculated using currently accepted constants (Steiger and Jager, 1977)

Granitic rocks—Granitic rocks, typically hornblende-biotite granodiorite of Alaska-Aleutian Range batholith (Reed and Lanphere, 1969; 1972; 1973), although quartz diorite and granite are present locally. Most of batholith is composed of coarsely crystalline, weakly foliated to nonfoliated rocks. Metamorphosed roof pendants are most common at northern end of Alaska Peninsula. Potassium-argon age determinations yield ages that range from 153±4.6 to 174.7±8.8 Ma (Reed and Lanphere, 1969; 1972; Nora Shew and M.A. Lanphere, unpub. data, 1990; Wilson and Shew, 1992) in map area. Mapped separately as:

Jgd **Granodiorite (Late? and Middle Jurassic)**—Fine- to coarse-grained, gray, hornblende-biotite granodiorite. In Naknek Lake area, "Color index averages 16; either hornblende or biotite can be dominant mafic phase. Modal quartz comprises 22–44 percent of the rock, in excess of that found in unit Tgd" (Riehle and others, 1993). Generally is found in vicinity of Naknek Lake in Mount Katmai 1:250,000-scale quadrangle; however, southernmost outcrop of this unit of Alaska-Aleutian Range batholith is mapped on an unnamed island on south side of Becharof Lake in Ugashik 1:250,000-scale quadrangle

Jgr **Granite (Late? and Middle Jurassic)**—"Light-gray, medium-grained equigranular or fine-grained porphyritic rocks. Average color index is 8 and biotite equals or exceeds hornblende. Rounded quartz grains weather prominently from the rock and, where elliptical, define a foliation ***" (Riehle and others, 1993). Generally found between Becharof and Naknek Lakes in Mount Katmai and Naknek 1:250,000-scale quadrangles

Jqd **Tonalite and quartz diorite (Late? and Middle Jurassic)**—"Medium-grained, gray equigranular rocks. Average color index of tonalite is 28, of quartz diorite is 37. Either clinopyroxene or hornblende is the dominant mafic (mineral) and biotite is an accessory. Inclusions of fine-grained mafic rocks or of porphyroaphanitic volcanics (rocks) are common. Both a foliation and a layering commonly occur together ***" (Riehle and others, 1993). Generally found north of Naknek Lake in Mount Katmai 1:250,000-scale quadrangle

Jgb **Diorite and gabbro (Late? and Middle Jurassic)**—"Small bodies of dark gray, diabasic- and gabbroic-textured rocks having either or both of two pyroxenes and hornblende. In some, hornblende is secondary; others are hornfels in which biotite and muscovite have partly replaced hornblende and clinopyroxene ***" (Riehle and others, 1993). Generally found south of Naknek Lake in Mount Katmai 1:250,000-scale quadrangle

METAMORPHIC ROCKS

QTc **Contact-metamorphosed rocks (early Quaternary or late Tertiary)**—Contact-metamorphosed and hydrothermally altered rocks found in mountains east of Mount Dana in Port Moller C–4 1:63,360-scale quadrangle. Protoliths probably consist of, in order of importance, Late Cretaceous Hoodoo Formation (Kh), Tertiary volcanic rocks (Tvu), and Late Cretaceous Chignik Formation (Kc); may also include Tertiary intrusive rocks (Tiu) at lower elevations. Pervasive alteration prevents separation of altered rocks into their respective units. Rocks are hard, very fine grained, and intensely fractured; sulfide mineralization is common, and resultant iron staining is ubiquitous on weathered surfaces

JPk **Kakhonak(?) Complex (Late Jurassic? to Permian?)**—Name introduced by Detterman and Reed (1980) for heterogeneous assemblage of metamorphic rocks exposed in Iliamna 1:250,000-scale quadrangle north of map area. In map area, metamorphic rocks of unknown age exposed west of Bruin Bay fault north of Becharof Lake are tentatively correlated with Kakhonak Complex (Detterman and others, 1996). Rocks are mainly preserved as roof pendants in Alaska-Aleutian Range batholith, but some outcrops are found in areas surrounded by surficial deposits. Includes metalimestone, quartzite, greenstone and other metavolcanic rocks, and schist. Most are weakly metamorphosed, greenschist-facies rocks in which relict bedding is often discernable. Minimum age of enclosing batholith is about 155 Ma, which places upper age limit of early Late Jurassic on metamorphic rocks. Lithology of rocks indicates that protoliths were similar to Permian limestone and rocks of Kamishak and Talkeetna Formations exposed at Puale Bay and on nearby islands. Unit age is Permian(?) to early Late Jurassic(?)

Ɍc **Cottonwood Bay Greenstone (Late Triassic; Norian?)**—Named by Detterman and Reed (1980) for sequence of dark-green to gray metavolcanic rocks exposed on west side of Cook Inlet. In map area, unit mapped only as roof pendants in Alaska-Aleutian Range batholith north of Becharof Lake, where it consists of weakly metamorphosed epidote-albite-actinolite assemblages that are suggestive of greenschist-facies metamorphism. Thickness may exceed 400 m; however, contact relations with other stratigraphic units are not well understood. Some rocks locally included herein in Kakhonak(?) Complex (JPk) are Cottonwood Bay Greenstone. No isotopic age determinations exist for greenstone, but its close association with Kamishak Formation near Iliamna Bay northeast of map area suggests Late Triassic (Norian?) age.

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