Chapter A

Stratigraphic Framework of the Alaska Peninsula

By ROBERT L. DETTERMAN, JAMES E. CASE,
JOHN W. MILLER, FREDERIC H. WILSON,
and M. ELIZABETH YOUNT

Sedimentary, volcanic, metamorphic, and plutonic rocks of Permian to Quaternary age are named, described, and correlated using standard stratigraphic sections

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Stratigraphic Framework of the Alaska Peninsula

By Robert L. Detterman, James E. Case, John W. Miller, Frederic H. Wilson, *and* M. Elizabeth Yount

Abstract

This paper describes the sedimentary rocks exposed on the Alaska Peninsula, as well as some interlayered volcanic and intrusive rocks. This sequence of rocks has a cumulative thickness of about 14,000 m, but most localities contain no more than 7,000–8,000 m. Locally the section is much thinner where units are missing through erosion or nondeposition. The sedimentary and volcanic rocks of Tertiary age and older are divided into 23 formations, several of which are further subdivided into mappable members. Some of the stratigraphic units are newly named, and several others have been geographically extended from adjoining areas. Many formations are revised either in age or with regard to the positions of their contacts.

Paleozoic rocks are known definitely from only one locality, a small islet at the entrance to Puale Bay. About 40 m of mid-Permian limestone are exposed on this islet. Isolated outcrops of metamorphic rocks are preserved as roof pendants in the Alaska-Aleutian Range batholith northeast of Becharof Lake, and their protoliths may have been, in part, of Permian age, but the lithology indicates that their protoliths were more likely of Triassic or Early Jurassic age.

The Mesozoic sequence ranges in age from Late Triassic to Late Cretaceous and has a maximum thickness of about 8,500 m. In ascending stratigraphic order, the units consist of the Kamishak Formation (Upper Triassic), Talkeetna Formation (Lower Jurassic), Kialagvik Formation (Lower and Middle Jurassic), Shelikof Formation (Middle Jurassic), Naknek Formation (Upper Jurassic), herein-revised Staniukovich Formation (Lower Cretaceous), herein-redefined Herendeen Formation (Lower Cretaceous), Pedmar Formation (new) (Lower Cretaceous), herein-redescribed Chignik Formation (Upper Cretaceous), Hoodoo Formation (Upper Cretaceous), Shumagin Formation (Upper Cretaceous), and Kaguyak Formation (Upper Cretaceous). Additionally, the Naknek Formation is subdivided into five members. In ascending order, they are the Chisik Conglomerate Member, Northeast Creek Sandstone Member (new), Snug Harbor Siltstone Member, Indecision Creek Sandstone Member (new), and Katolinat Conglomerate Member (new).

The Mesozoic sedimentary rocks are predominantly marine in origin and are feldspathic to arkosic in the upper part of the section and volcanogenic in the lower part. The provenance for the clastic sediments was initially an early Mesozoic volcanic arc; it shifted with time to the Alaska-Aleutian Range batholith (Middle Jurassic) and included some recycled older sediments. Clasts from this early Mesozoic volcanic arc are included within the Talkeetna Formation.

The Tertiary sequence is somewhat thinner than the Mesozoic one; it has a maximum thickness of about 5,400 m, but it is considerably thinner at most localities due to nondeposition or postdepositional erosion. The rocks are mainly continental in origin, and the sequence contains a considerable amount of volcanic detritus and interbedded volcanic units. These rocks are divided into 11 formations, 1 of which is further subdivided into 2 informal members. In ascending order, they are the Tolstoi Formation (upper Paleocene to middle Eocene), Copper Lake Formation (Paleocene? and lower Eocene), Stepovak Formation and herein-redefined Meshik Volcanics (upper Eocene and lower Oligocene), Belkofski Formation (upper Oligocene? and lower and middle Miocene?), Hemlock Conglomerate (upper Oligocene), herein-revised Unga Formation (upper Oligocene to middle Miocene), Bear Lake Formation (middle and upper Miocene), Tachilni Formation (upper Miocene), Milky River Formation (Pliocene), and Morzhovoi Volcanics (upper Miocene? to lower Quaternary?). Additionally, the Stepovak Formation is divided into informal (lower) siltstone and (upper) sandstone members.

The provenance for sediments of the Tertiary formations was contemporaneous volcanic deposits and Mesozoic sedimentary and plutonic rocks of the Alaska Peninsula. The Mesozoic rocks were the main source for the Tolstoi and Bear Lake Formations, and the volcanic rocks were the main source for the other formations.

Tertiary volcanic and intrusive igneous rocks form a considerable part of the stratigraphic sequence on the Alaska Peninsula. The volcanic rocks were formed mainly during two major pulses of activity. The first began during the Eocene (48 Ma) and continued into the early Miocene (22 Ma); these materials are termed the Meshik arc. Most of the rocks from this episode of volcanic activity are included within the Meshik Volcanics. Volcanic rocks of this age from the Shumagin Islands are called the (informal) Popof volcanic rocks. The second pulse of volcanic activity started during the late Miocene and is continuing at present.

Intrusive bodies ranging in size from small stocks and plugs to large batholiths were emplaced throughout the Tertiary. The large batholithic intrusions clustered near the beginning and end

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of the Tertiary: The Semidi and Shumagin Islands batholiths and Sanak pluton were emplaced at 58 to 65.6 Ma; the Devils, Agripina Bay, and other batholiths at 2 to 10 Ma.

Quaternary volcanic rocks and surficial deposits cover much of the Alaska Peninsula. Large stratovolcanoes are spaced along the entire peninsula and form the highest peaks; 37 major volcanic centers and numerous small vents have been identified. Surficial deposits, primarily resulting from Pleistocene glaciation, cover most of the lowland along Bristol Bay. Deposits from four major glaciations are preserved on the peninsula.

INTRODUCTION

The Alaska Peninsula is a 775-km-long southwestward extension of mainland Alaska (fig. 1). The peninsula is about 225 km wide at the northeast end and narrows to less than 10 km near the southwest end. The southeast side is bordered by rugged mountains that rise sharply out of the Pacific Ocean. Many large bays and fiords cut the southeast shoreline. The northwest side, bordering Bristol Bay, is level and rarely more than 100 m above sea level; the coastline is nearly smooth and is broken by only a few large bays. At least 37 principal volcanic centers dot the length of the peninsula, and at least 30 have erupted during the Holocene (Miller and Richter, 1994). The present Aleutian volcanic arc overlies an early Mesozoic magmatic arc and a middle Tertiary volcanic arc.

A considerable amount of new stratigraphic and paleontologic data has become available as the result of recent work on the Alaska Peninsula during investigations for the Alaska Mineral Resource Assessment Program (AMRAP). This work includes detailed studies of lithostratigraphic units and the collection of nearly 1,000 megafauna and megaflora samples and more than 200 new K-Ar ages. As a result, we can more precisely date many of the units. The new stratigraphic data indicate that some named units should be subdivided and others combined.

Geologic investigations on the Alaska Peninsula started more than 200 years ago when G.W. Steller accompanied Vitus Bering in 1741 on the voyage that discovered Alaska. After Alaska was purchased from Russia in 1867, Dall (1870, 1882, 1896, 1898) and Dall and Harris (1892) explored many parts of the peninsula and established a stratigraphic nomenclature. A second wave of exploration started in 1903 and continued until about 1930, during which time Atwood (1911), Capps (1923, 1934), Knappen (1929), Martin (1905, 1916, 1921, 1925, and 1926), Mather (1925), Paige (1906), Smith (1925a, 1925b), Smith and Baker (1924), and Stone (1905) made reconnaissance surveys of parts of the peninsula and added to the stratigraphic nomenclature. The most recent and detailed investigation of the Alaska Peninsula southwest of Wide Bay (see fig. 2) was by Burk (1965). Most of the nomenclature in common use at the present time was established by Burk (1965). (For an extensive list of reports published through 1985 on the geology of the Alaska Peninsula, see the bibliography by Wilson and others, 1986.)

As a result of the numerous investigations, the stratigraphic nomenclature of the Alaska Peninsula has undergone considerable change. Now additional changes are indicated, and undoubtedly other changes will be made as more detailed investigations are accomplished. The Unga Conglomerate Member (of the Bear Lake Formation) is herein revised as the Unga Formation; the Herendeen Limestone is herein redefined as the Herendeen Formation, and its age is clarified; and the Staniukovich Formation is herein revised, and its age is clarified. Additionally, we herein divide the Naknek Formation into five members, from oldest to youngest, the Chisik Conglomerate Member, Northeast Creek Sandstone Member (new), Snug Harbor Siltstone Member, Indecision Creek Sandstone Member (new), and Katolinat Conglomerate Member (new). Some of the other units contain age changes and (or) changes in position of their contacts, and several previously defined units in southern Alaska (Kamishak Formation and Talkeetna Formation) are herein geographically extended to include strata on the Alaska Peninsula.

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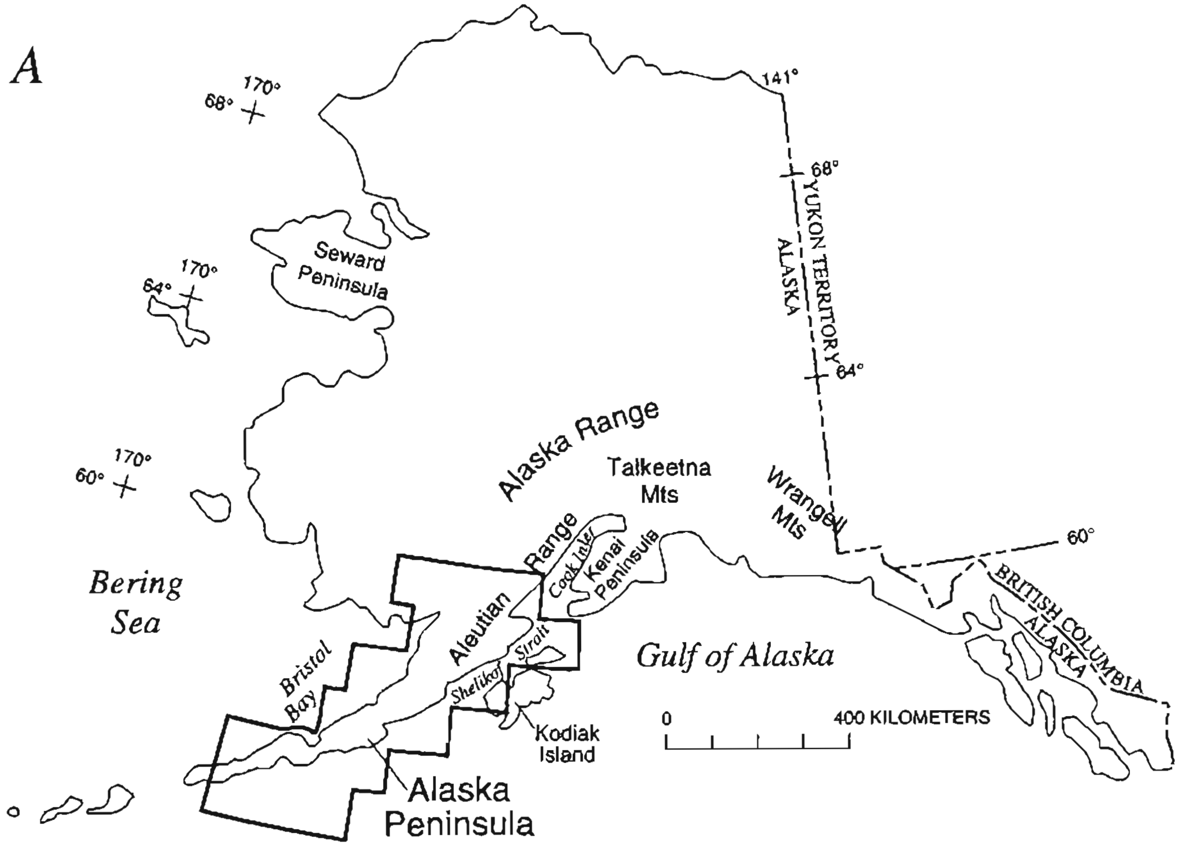
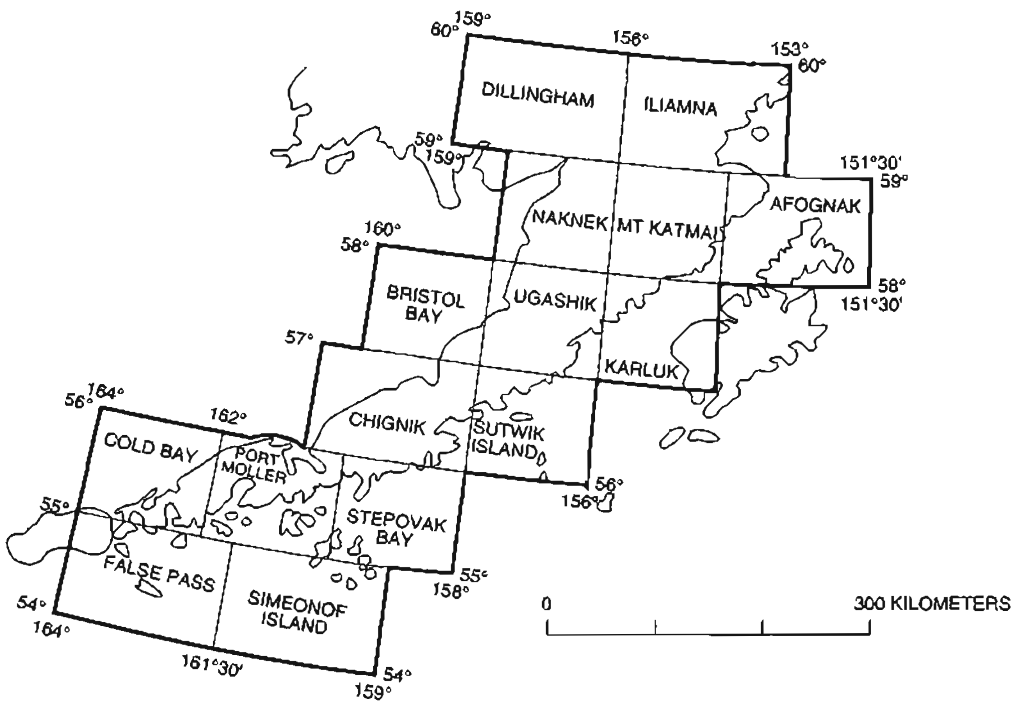
This report was made possible through the cooperation and assistance, both technical and nontechnical, of many individuals in the field and in the office; it would be impossible to acknowledge all of them, and we apologize for any major omissions.

Many individuals within the U.S. Geological Survey aided in the collection of field data or gave technical assistance in some of the more specialized aspects of the program. Some of the major contributors to the field investigations include W.H. Allaway, Jr., Nairn Albert, L.M. Angeloni, C.D. Blome, D.P. Cox, R.M. Egbert, L.B. Magoon, T.P. Miller, D.H. Richter, J.R. Riehle, Nora Shew, and Florence Weber. Identification of the many megafauna, microfauna, and megaflora specimens was provided by C.D. Blome, R.W. Imlay, D.L. Jones, Louie Marincovich, Jr., N.J. Silberling, R.A. Spicer, and J.A. Wolfe. Identification of rocks in thin section and initial drafting of figures for this report were accomplished by Michael Mullen.

We appreciate the efforts of many persons at Sand Point, Chignik Lagoon, Port Heiden, and Port Moller who provided logistical support without which the field work would have been impossible. A special thanks is due to the crew of the U.S. Geological Survey Research Vessel *Don J. Miller II*, especially "Frosty" Frothingham and Ed Magalhaes, and to helicopter pilots Bruce Reiche, Glenn Bell, Tom Robbins, Edward Svec, Lucky Wilson, and Ross Rossiter, who often worked under adverse weather conditions. Re-

Figure 1. Location of study area. *A*, Generalized map of Alaska showing location of Alaska Peninsula and outline of quadrangles shown in figure 1*B*. *B*, 1:250,000-scale quadrangles that encompass study area. ➤


A
Seward Peninsula
Alaska Range
Talkeetna Mts
Wrangell Mts
YUKON TERRITORY
ALASKA
BRITISH COLUMBIA
ALASKA
Bering Sea
Bristol Bay
Aleutian Range
Cook Inlet
Kenai Peninsula
Shelikof Strait
Gulf of Alaska
Kodiak Island
Alaska Peninsula
0
400 KILOMETERS
141°
68°
64°
60°
170°


B
DILLINGHAM
ILIAMNA
NAKNEK
MT KATMAI
AFOGNAK
BRISTOL BAY
UGASHIK
KARLUK
CHIGNIK
SUTWIK ISLAND
COLD BAY
PORT MOLLER
STEPOVAK BAY
FALSE PASS
SIMEONOF ISLAND
0
300 KILOMETERS
60°
159°
156°
153°
59°
151°30'
58°
160°
57°
56°
164°
162°
55°
158°
54°
161°30'

views by C.M. Molenaar and Louie Marincovich, Jr., of the U.S. Geological Survey greatly improved the manuscript.

GEOLOGIC SETTING

The Alaska Peninsula is part of an active continental margin that may have been accreted to North America during the Jurassic (Jones and others, 1978; Stone and others, 1982). The Alaska Peninsula constitutes the main part of what has been called the Peninsular terrane (Jones and others, 1981) and, more recently, the Alaska Peninsula terrane (Wilson and others, 1985). The lithology and faunal content of its Triassic and Lower Jurassic rocks indicate a depositional source at low paleolatitudes, and paleomagnetic studies suggest the site was at about 15° N. (Hillhouse, 1977). Faunal remains, mainly ammonites, indicate the Alaska Peninsula was near its present latitude by Middle Jurassic time (Taylor and others, 1984).

Paleozoic rocks are known from only one locality on the peninsula. A few 10's of meters of mid-Permian limestone are exposed on one small islet at the entrance to Puale Bay (fig. 2; outcrop too small to show on maps in this report).

Lower Mesozoic (Upper Triassic and Lower Jurassic) sedimentary rocks are mainly limestone and volcaniclastic sedimentary rocks that are interpreted to have been deposited along an island arc. Magmatic activity was associated with movement of the Alaska Peninsula to near its present position in Middle Jurassic time. This activity resulted in the emplacement of the Alaska-Aleutian Range batholith. Locally, the magma chamber vented to the surface and formed a thick volcanic sequence. These volcanic rocks were reworked into the sedimentary regime and constitute most of the Middle Jurassic sedimentary rocks on the Alaska Peninsula. The provenance for sediments of the Upper Jurassic and for the remainder of the Mesozoic section was mainly the Alaska-Aleutian Range batholith; additional components were contributed by minor reworking of older volcaniclastic rocks.

Lower Tertiary sedimentary rocks were derived mainly from erosion of Mesozoic sedimentary rocks and the batholith, but by late Eocene time, contemporaneous volcanic rocks were becoming a major source for the sedimentary sequence. The Meshik volcanic arc (Wilson, 1985) was active from late Eocene to early Miocene time, and was followed after a brief hiatus by the Aleutian volcanic arc, which began its history during the late Miocene and has been active to the present. Most post-Eocene sedimentary rocks, with the exception of the Bear Lake Formation, were formed from detritus derived from these volcanic deposits.

Rocks at the northeast end of the Alaska Peninsula are bisected by a major high-angle fault, the Bruin Bay fault (fig. 2). From the northeast edge of the field area, the Bruin Bay fault continues northeastward for about 325 km before intersecting the Castle Mountain fault, which strikes east-northeast north of Cook Inlet (fig. 3). The Alaska-Aleutian Range batholith, associated Lower Jurassic volcanic rocks, and meta-

Figure 2. Generalized geologic map of the Alaska Peninsula.

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

Tertiary intrusive rocks

Til Late Tertiary

Tim Middle Tertiary

Tie Early Tertiary

Tv Tertiary volcanic rocks

Mesozoic sedimentary rocks

Kl Late Cretaceous

Ke Early Cretaceous

Jl Late Jurassic

Jm Middle Jurassic

Je Early Jurassic

℞ Triassic

Ji Jurassic intrusive rocks of the Alaska-Aleutian Range batholith

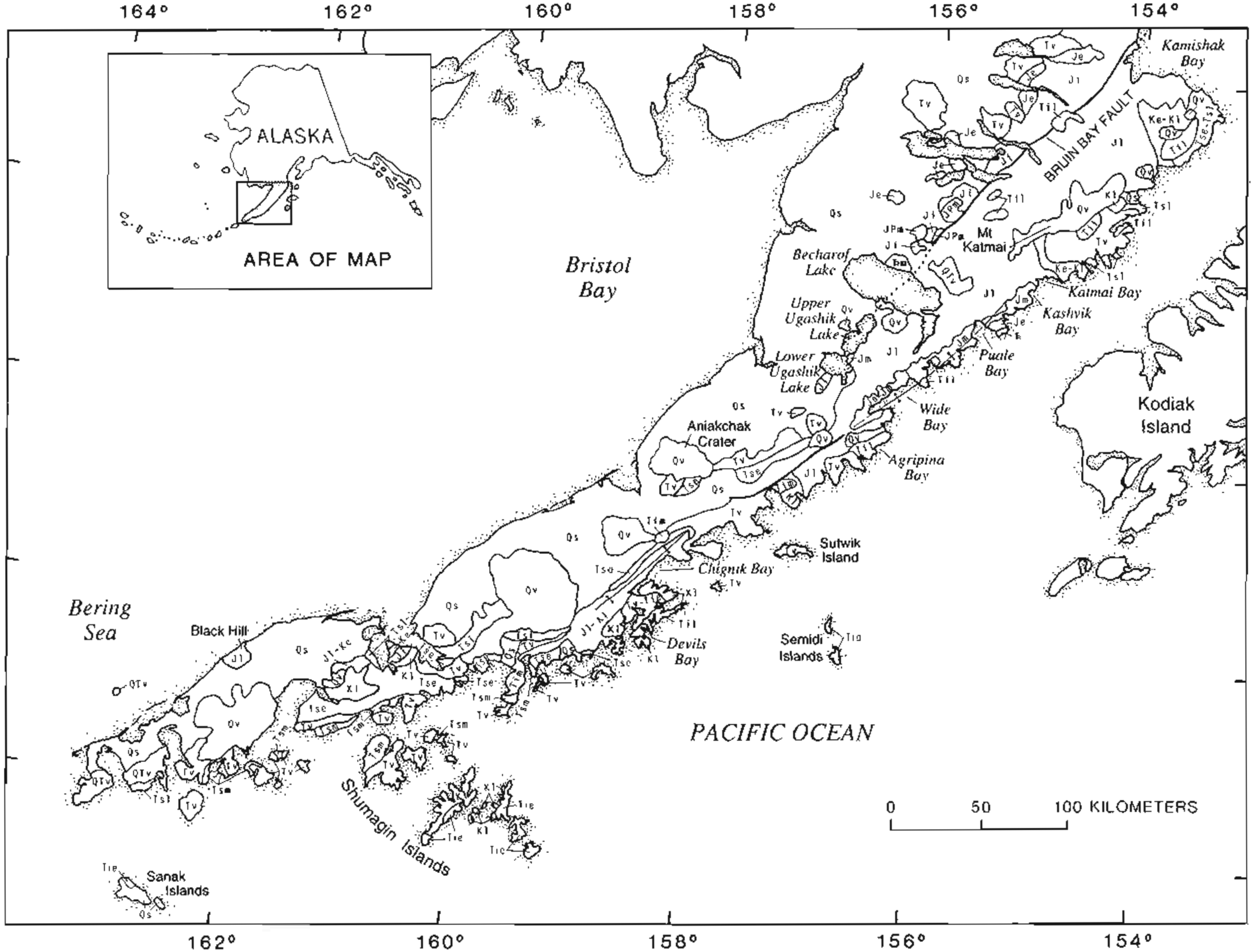
JPm Jurassic to Permian metamorphic rocks

℞m Triassic metamorphic rocks

Contact

Fault—Dotted where concealed

Anticline—Dashed where inferred


ALASKA
AREA OF MAP
Bristol Bay
Bering Sea
PACIFIC OCEAN
Kamishak Bay
BRUIN BAY FAULT
Mt Katmai
Becharof Lake
Upper Ugashik Lake
Lower Ugashik Lake
Katmai Bay
Kashvik Bay
Puale Bay
Wide Bay
Kodiak Island
Aniakchak Crater
Agripina Bay
Sutwik Island
Chignik Bay
Devils Bay
Semidi Islands
Black Hill
Shumagin Islands
Sanak Islands
0 50 100 KILOMETERS
164°
162°
160°
158°
156°
154°
59°
58°
57°
56°
55°

morphic rocks lie west of the fault (fig. 2). Slightly deformed Mesozoic strata are mainly marine and were deposited in a shelf to lower-slope environment. Tertiary strata are largely nonmarine to inner neritic.

PALEOZOIC ROCKS

Paleozoic rocks were first reported on the Alaska Peninsula by Hanson (1957), when he described limestone of mid-Permian age from a small islet at the entrance to Puale Bay. Additionally, a Silurian or Devonian age was reported for two small areas of limestone north of Becharof Lake (fig. 2; Detterman and others, 1979). After subsequent reevaluation of the poorly preserved fossils (W.A. Oliver, written commun., 1985) and reexamination of the outcrops north of Becharof Lake in 1985, we have concluded that the age of this limestone is Triassic rather than middle Paleozoic. Consequently, the only definite Paleozoic rocks on the Alaska Peninsula are on the small islet at Puale Bay.

Permian System

A section about 40 m thick of thin- to thick-bedded, medium-grained, crystalline, tan to gray limestone with thin interbeds of chert is exposed on a 100-by-200-m islet at the entrance to Puale Bay (Karluk C-4 and C-5 1:63,360 quadrangles). The islet is located about 1 km from nearby islets that consist of only Triassic strata. The highly contorted beds dip about 40° NW., which would place them structurally under the nearby Triassic sequence, but the actual contact relations are unknown.

The limestone contains a poorly preserved and silicified megafauna consisting of the horn coral *Lophophyllidium* sp. and the brachiopod *Spiriferella* aff. *S. sarance* (de Verneiul). Several genera of foraminifers were obtained also from these rocks including *Bradyina*? sp., *Endothyra* sp., *Globivalvulina* sp., *Langella* aff. *L. conica*, *Langella* sp., *Monotaxinoides*? sp., and *Protonodosaria* sp. Hanson (1957) reported the age of these fossils as late mid-Permian (early Guadalupian).

Neither the upper nor the lower contact of this unit is exposed, so its relations to other stratigraphic units on the Alaska Peninsula are unknown.

PALEOZOIC(?) AND MESOZOIC ROCKS

Permian(?), Triassic, and Jurassic Systems

Metamorphic Rocks

Metamorphic rocks of uncertain age are exposed west of the Bruin Bay fault northeast of Becharof Lake (fig. 2, unit JPm). The rocks are mainly preserved as roof pendants in the Alaska-Aleutian Range batholith, but some outcrops are surrounded by surficial deposits, and contacts with other bedrock lithologic units are unknown.

The rocks include metalimestone, quartzite, greenstone and other metavolcanic rocks, and schist. Most are weakly metamorphosed greenschist facies rocks in which relic bedding is still discernible. A few fragments of a silicified megafauna are present in the metalimestone and quartzite but are unidentifiable. The minimum age of the batholith enclosing the metamorphic rocks is 156 Ma (Reed and Lanphere, 1972). This batholith age places an upper age limit of early Late Jurassic on the metamorphic rocks. Lithologically, the rocks indicate that their precursors were limestone, sandstone, and volcanic rocks similar to those in the Upper Triassic and Lower Jurassic sections at Puale Bay, east of the fault. The metalimestone could also be derived from the Permian limestone sequence. These rocks probably are a part of the Kakhonak Complex as mapped in the Cook Inlet area northeast of the Alaska Peninsula (Detterman and Reed, 1980).

Cottonwood Bay Greenstone

The Cottonwood Bay Greenstone was named for a sequence of dark-green to gray metavolcanic rocks exposed along the south shore near the head of Cottonwood Bay on the west side of lower Cook Inlet (fig. 3; see Detterman and Reed, 1980). A similar sequence of metavolcanic rocks is exposed near the northeast end of the Alaska Peninsula. Whale Mountain on the north shore of Becharof Lake consists almost entirely of greenstone (fig. 2, unit R̶m). A second small area of greenstone (not shown on map) is exposed about 18 km to the northeast, just north of the King Salmon River.

The rocks at both these Alaska Peninsula localities are weakly metamorphosed to epidote-albite-actinolite assemblages suggestive of the greenschist facies. Original flow structure is locally discernible, and the rocks' precursors were probably porphyritic basalt. Similar-appearing rocks are locally included within the Kakhonak(?) Complex.

The Cottonwood Bay Greenstone is a part of the sequence of rocks preserved as roof pendants in the Alaska-Aleutian Range batholith just west of the Bruin Bay fault. The thickness of the unit is unknown, but probably 400 to 500 m of it is present at Whale Mountain. Contact relations with other stratigraphic units are obscure, although at the locality north of the King Salmon River, the Cottonwood Bay lies between rocks of the Kakhonak(?) Complex and Kamishak Formation. The greenstone has not been dated, but its close association with the Kamishak Formation, the basal part of which contains clasts of similar-appearing rocks, suggests that the age of the Cottonwood Bay Greenstone is Late Triassic, probably Norian.

MESOZOIC ROCKS

Mesozoic sedimentary rocks form the backbone of the Alaska Peninsula as well as the adjacent Kodiak, Shumagin, and Sanak Islands (fig. 2). The stratigraphic units of the Alaska Peninsula sequence are shown in figure 4, which also includes an unnamed Permian limestone exposed on one small island at the mouth of Puale Bay (Hanson, 1957; Detterman and others, 1987a). Stratigraphic sections and locality maps are shown for most units (figs. 6–11, 13–16). The locality maps also contain many geographic names mentioned in the text. The locations of all sections described herein are shown on figure 5.

Triassic System

Kamishak Formation

The oldest Mesozoic unit on the Alaska Peninsula is an Upper Triassic (Norian) limestone and volcanic rocks unit about 800 m thick called the Kamishak Formation (fig. 6) by Kellum (1945). The Kamishak Formation was originally called the Kamishak Chert by Martin and Katz (1912, p. 47) for highly contorted chert and limestone exposed at Bruin Bay and Ursus Cove in the Cook Inlet area (fig. 3). Recent investigations of the Upper Triassic rocks between Bruin Bay and Ursus Cove (Detterman and Reed, 1980) have determined that chert is only a minor part of the sequence, and consequently, the name "Kamishak Formation" was applied to those rocks by Detterman and Reed (1980, p. B13). Initially in this study, we had concluded that the rocks at Puale and Alinchak Bays were not part of the Kamishak Formation, but additional thin-section investigations and a reevaluation of the fauna now indicate that they are part of the formation. The Kamishak Formation was divided into three members in the Cook Inlet area by Detterman and Reed (1980). In ascending order, they are the Bruin Limestone Member, middle member, and Ursus Member. The strata in the Puale Bay area are here assigned to the Bruin(?) Limestone Member of the Kamishak Formation. The strata in both areas are shallow-water shelf deposits containing reef and biohermal buildups.

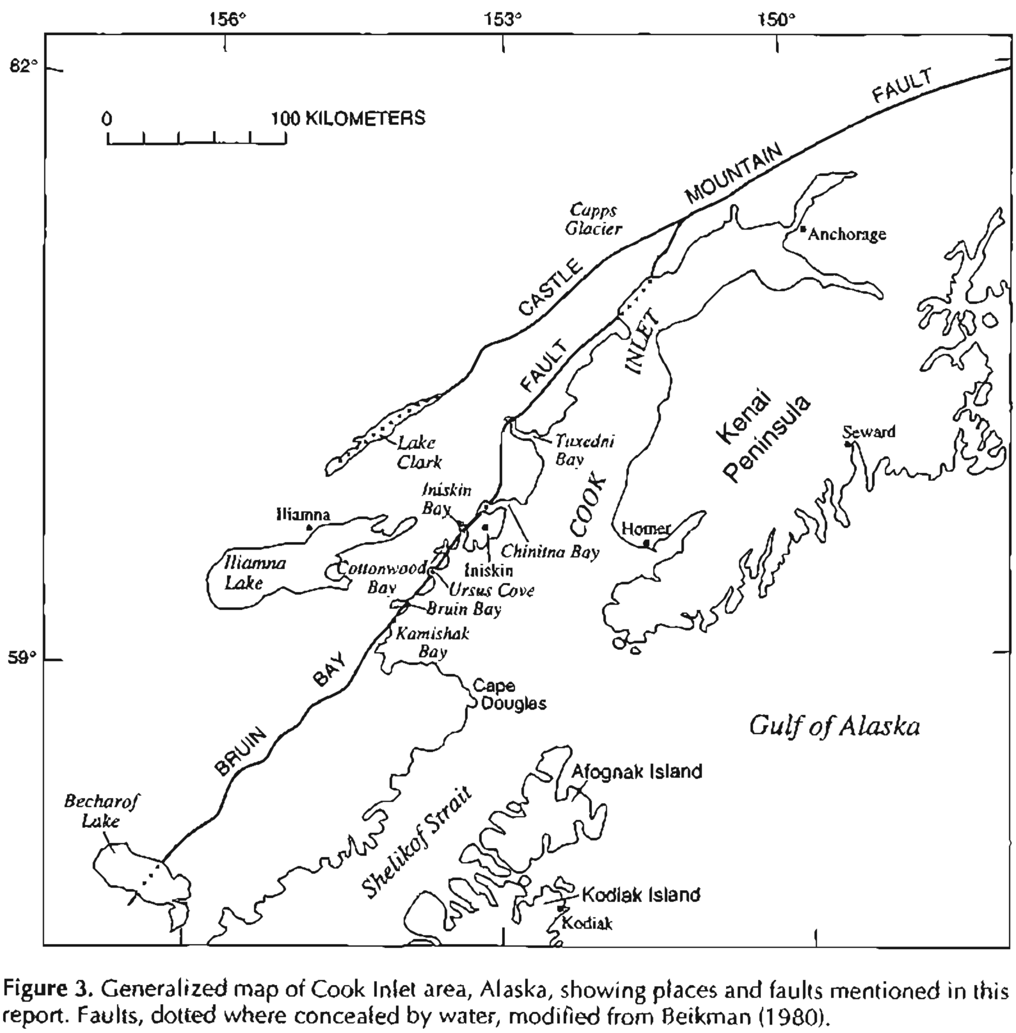


Figure 3. Generalized map of Cook Inlet area, Alaska, showing places and faults mentioned in this report. Faults, dotted where concealed by water, modified from Beikman (1980).

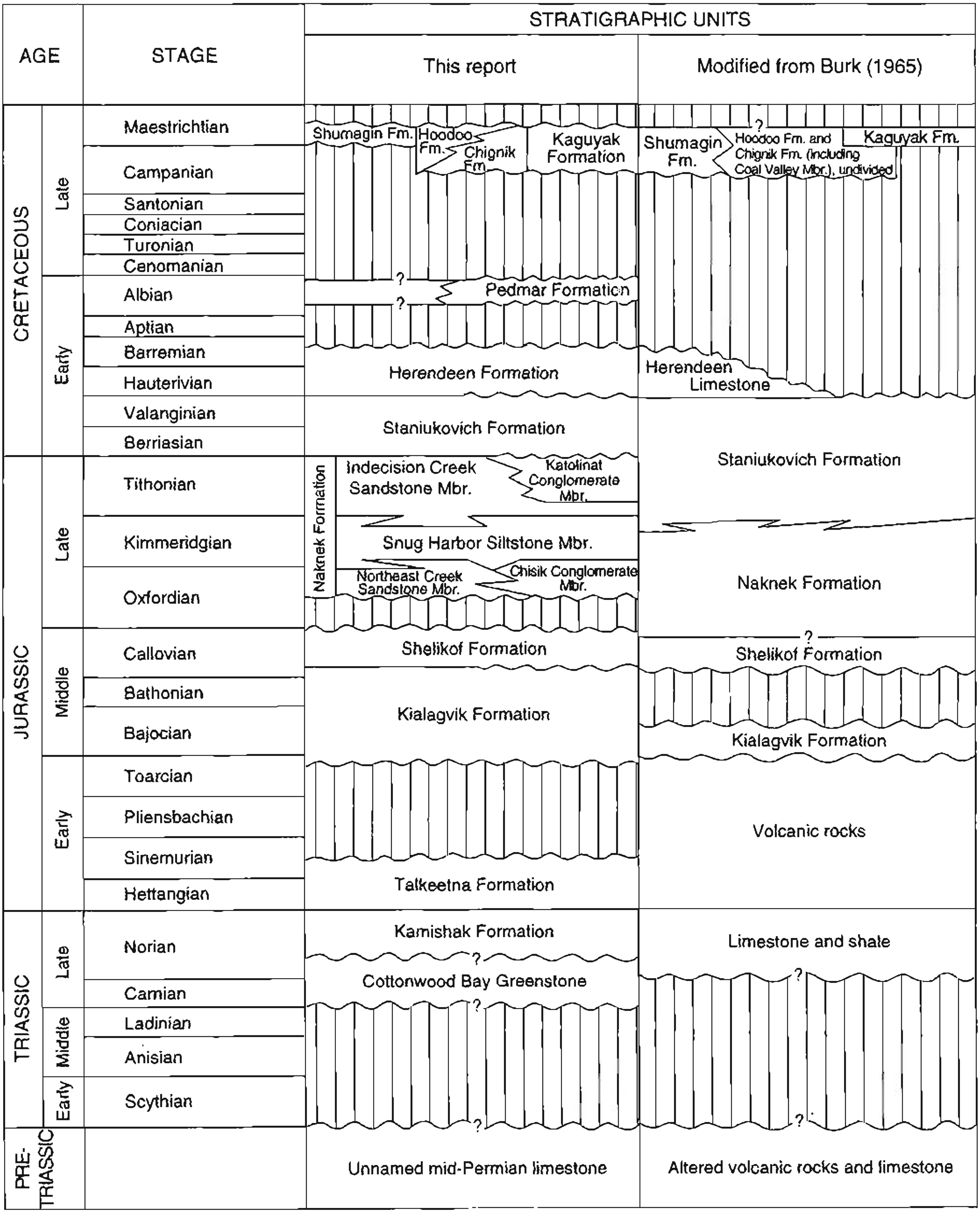


Figure 4. Correlation chart of Mesozoic stratigraphic units, Alaska Peninsula.

The only other exposures on the Alaska Peninsula that may be assignable to the Kamishak Formation are several small areas of recrystallized limestone and greenstone preserved as roof pendants in the Alaska-Aleutian Range batholith west of the Bruin Bay fault, north of Becharof Lake (fig. 2). The limestone and greenstone north of Becharof Lake were originally believed to be Silurian or Devonian in age (Detterman and others, 1979), but as described previously (see section "Paleozoic Rocks"), these rocks are now considered (Late) Triassic in age and thus part of the Kamishak Formation. Triassic rocks have been reported in the subsurface near the southwest end of the Alaska Peninsula, in the AMOCO Cathedral River #1 borehole (McLean, 1977).

A reference section (section 1) for the Kamishak Formation was measured by R.M. Egbert (U.S. Geological Survey) in 1979 (fig. 6). The section starts at Cape Kekurnoi (Karluk C-4 and C-5 1:63,360 quadrangles), continues 4.8 km southwest along the shore to the entrance to Puale Bay, then runs about 600 m northwest along the shore of Puale Bay to the contact with the overlying Talkeetna Formation. The strata are cut by numerous small faults and locally are highly contorted. Consequently, the thickness of the reference section described below can best be considered as only approximate.

Section 1. Reference section of the Kamishak Formation, Puale Bay (fig. 6)

	Thickness (meters)
Talkeetna Formation	
Gradational contact	
Kamishak Formation:	
14. Limestone, thin- to thick-bedded, medium-gray; contains few *Monotis subcircularis* (D11288)	13.7
Fault, displacement unknown	
13. Limestone, thin- to medium-bedded, light-gray, highly contorted	33.5
Fault, displacement unknown	
12. Limestone, thin- to medium-bedded, yellowish-gray; thin interbeds of siltstone, sandstone, and shale; contains few *Monotis salinaria*	103.6
11. Limestone, similar to unit 13	22.2
10. Basalt, brecciated and recemented with calcite	38.7
9. Limestone, similar to unit 13; contains *Monotis*	60.9
Fault, displacement unknown	
8. Basalt, columnar-jointed; dated at 197±12.0 Ma (Wilson and Shew, 1992)	45.7
7. Limestone, thin-bedded, gray	6.0
6. Siltstone and mudstone, thin-bedded, brownish-gray, calcareous; contains few *Monotis*	37.1
5. Covered interval	98.1
4. Limestone, thin-bedded, tuffaceous; few trace fossils	38.1
3. Volcanic breccia, green to red, vesicular; includes blocks of limestone	91.4
2. Limestone, thin- to medium-bedded, light-gray, bioclastic; reef and bioherms; contains *Monotis subcircularis*, hydrozoans, and ammonites (79AEg5-4G, 79AEg5-4D)	180.8

Section 1. Reference section of the Kamishak Formation, Puale Bay (fig. 6)—Continued

1. Limestone conglomerate, massive to thick-bedded, gray; clasts mainly limestone and limy mudstone, minor chert; contains bivalves, coral, gastropods, and ammonites (79AEg5-3, 79AEg5-2A, 79AEg5-1)	29.7
Total exposed section	799.5
Base of exposed section	

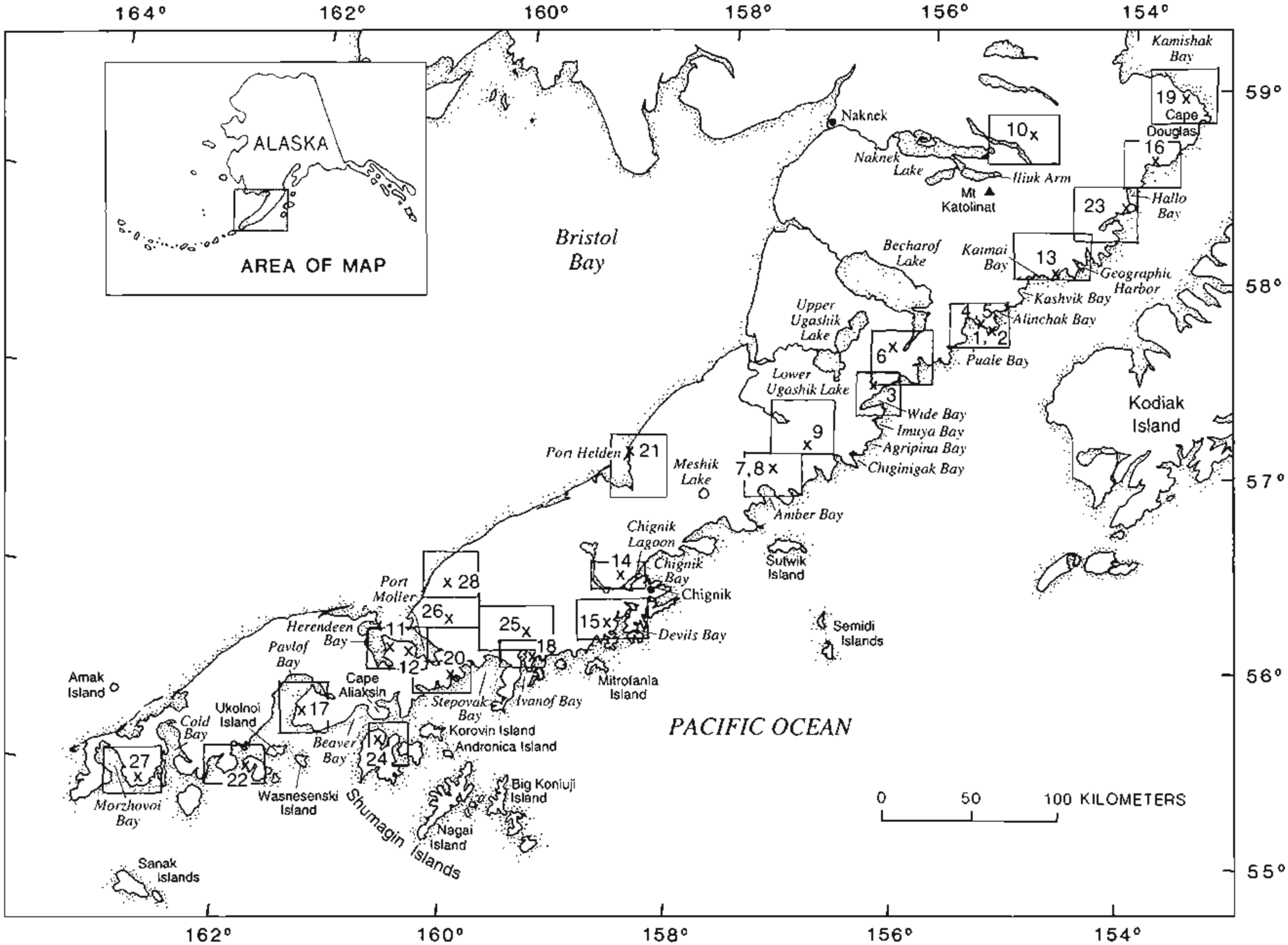
The nature of the contact between the Kamishak Formation and the mid-Permian limestone is unknown. The mid-Permian rocks are exposed only on one small island, which is located about 3.5 km from the Triassic section. The northwest dip of these Permian rocks suggests that they underlie the Triassic section. The contact with the overlying Lower Jurassic Talkeetna Formation is conformable and gradational. The contact is arbitrarily placed at the point where clastic sediments—siltstone and sandstone—replace limestone as the major constituents of the rock sequence (fig. 6).

The columnar basalt (unit 8) shown in section 1 and dated at 197±12 Ma (Wilson and Shew, 1992) may not actually be a part of the Kamishak Formation. The exact age of the Triassic-Jurassic boundary is not well constrained. There are many published ages that vary by as much as 13 m.y. A recently published age of 200 Ma (Olsen and others, 1987) based on vertebrate and invertebrate megafauna, pollen, and K-Ar ages on associated volcanic rocks is probably close to the true boundary age. If 200 Ma is the age of the boundary, then the basalt of unit 8, and probably unit 10, may be sills generated during the volcanic episode that produced the Talkeetna Formation; as such they would not be part of the Kamishak Formation.

Jurassic System

Talkeetna Formation

Detterman and others (1983, 1987a) geographically extended the Talkeetna Formation from the Iliamna quadrangle, along the west side of Cook Inlet adjoining the Alaska Peninsula (see Detterman and Reed, 1980), to include 405 m of clastic sedimentary and volcanic rocks exposed on the northeast shore of Puale Bay. The section at Puale Bay (fig. 6), and in the mountains between the bay and Alinchak Bay, contains considerably more clastic debris than that in the Iliamna quadrangle, but it is similar to rocks of the Talkeetna Formation in the Talkeetna Mountains (fig. 1; Martin, 1926). The name "Talkeetna Formation" was introduced by Martin (1926) for a sequence of greenstone and tuff first described in the Talkeetna Mountains by Paige and Knopf (1907). The formation in the Talkeetna Mountains consists of lava, agglomerate, breccia, tuff, and interbedded sandstone and shale. This sequence of volcanic and sedimentary rocks has been recognized as an important marker horizon in southern Alaska,



164°
162°
160°
158°
156°
154°
59°
58°
57°
56°
55°
ALASKA
AREA OF MAP
Bristol Bay
PACIFIC OCEAN
Kodiak Island
Naknek
Naknek Lake
Iliuk Arm
Mt Katolinat
Kamishak Bay
Cape Douglas
Hallo Bay
Becharof Lake
Katmai Bay
Geographic Harbor
Kashvik Bay
Alinchak Bay
Puale Bay
Upper Ugashik Lake
Lower Ugashik Lake
Wide Bay
Imuya Bay
Agripina Bay
Chiginagak Bay
Port Heiden
Meshik Lake
Amber Bay
Chignik Lagoon
Chignik Bay
Chignik
Sutwik Island
Semidi Islands
Devils Bay
Mitrofania Island
Ivanof Bay
Stepovak Bay
Korovin Island
Andronica Island
Big Koniuji Island
Nagai Island
Shumagin Islands
Port Moller
Herendeen Bay
Pavlof Bay
Cape Aliaksin
Beaver Bay
Ukolnoi Island
Cold Bay
Wasnesenski Island
Amak Island
Morzhovoi Bay
Sanak Islands
0 50 100 KILOMETERS

EXPLANATION

Mesozoic units				Tertiary units	
1	Kamishak Fm.		Naknek Fm.—Divided into:	17	Tolstoi Fm.
2	Talkeetna Fm.	6	Chisik Conglomerate Mbr.	18	Tolstoi Fm.
3	Kialagvik Fm.	7	Northeast Creek Sandstone Mbr.	19	Copper Lake Fm.
4	Kialagvik Fm.	8	Snug Harbor Siltstone Mbr.	20	Stepovak Fm.
5	Shelikof Fm.	9	Indecision Creek Sandstone Mbr.	21	Meshik Volc.
		10	Katolinat Conglomerate Mbr.	22	Belkofski Fm.
		11	Staniukovich Fm.	23	Hemlock Cgl.
		12	Herendeen Fm.	24	Unga Fm.
		13	Pedmar Fm.	25	Bear Lake Fm.
		14	Chignik Fm.	26	Bear Lake Fm.
		15	Hoodoo Fm.	27	Tachilni Fm.
		16	Kaguyak Fm.	28	Milky River Fm.

Figure 5. Index map of Alaska Peninsula, showing location of sections of Mesozoic and Tertiary formations described in this report. X's mark locations of sections; rectangles show areas of index maps in figures 6 through 11 and 13 through 16. Numbers refer to section descriptions in text.

and the unit was geographically extended into the Cook Inlet area by Detterman and Hartsock (1966) when they mapped the Talkeetna Formation in the Iniskin-Tuxedni Bay area (fig. 3). The stratigraphic sequence in the Iniskin-Tuxedni area was divided into three members whose type sections were described by Detterman and Hartsock (1966, p. 12–20). In ascending order the members are the Marsh Creek Breccia Member, Portage Creek Agglomerate Member, and Horn Mountain Tuff Member. The name "Talkeetna Formation" was later applied to the volcanic sequence in the remainder of the Iliamna quadrangle (see Detterman and Reed, 1980), which borders the Alaska Peninsula.

The tuffaceous sandstone and tuff exposed between Puale and Alinchak Bays (Karluk C-4 and C-5 1:63,360 quadrangles; fig. 6) closely resembles the Horn Mountain Tuff Member in the Iniskin-Tuxedni area as well as the Talkeetna Formation in the Talkeetna Mountains. Because the same prolific marine megafauna occurs in the rocks at Puale Bay and in the Talkeetna Mountains, the Talkeetna Formation was geographically extended to include the rocks at Puale Bay by Detterman and others (1983, 1987a).

The Talkeetna Formation mapped west of the Bruin Bay fault, northeast of Becharof Lake (fig. 2, unit Je, in part) is more like the formation as it is mapped in the Iliamna area (see Detterman and Reed, 1980) in that it is mainly a volcanic unit that includes local deposits of volcanic conglomerate and sandstone. The area west of the Bruin Bay fault and the area near Puale Bay evidently were farther apart when the strata were deposited than they are at present, and the Puale Bay locality received mainly deposits of volcanic ash and thin sills and flows.

Lower Jurassic volcaniclastic sedimentary rocks, lithologically equivalent to the Talkeetna Formation, have been penetrated in several boreholes on the Alaska Peninsula southwest of the outcrop area of the unit. The southwesternmost borehole is the AMOCO Cathedral River #1, near the end of the Alaska Peninsula, where a sequence of tuffaceous siltstone, sandstone, and limestone was penetrated. This section is similar to the rocks exposed at Puale Bay and indicates that the Talkeetna Formation may underlie the entire Alaska Peninsula.

A megafauna—consisting mainly of ammonites—similar to that found in the Talkeetna Formation in the Talkeetna

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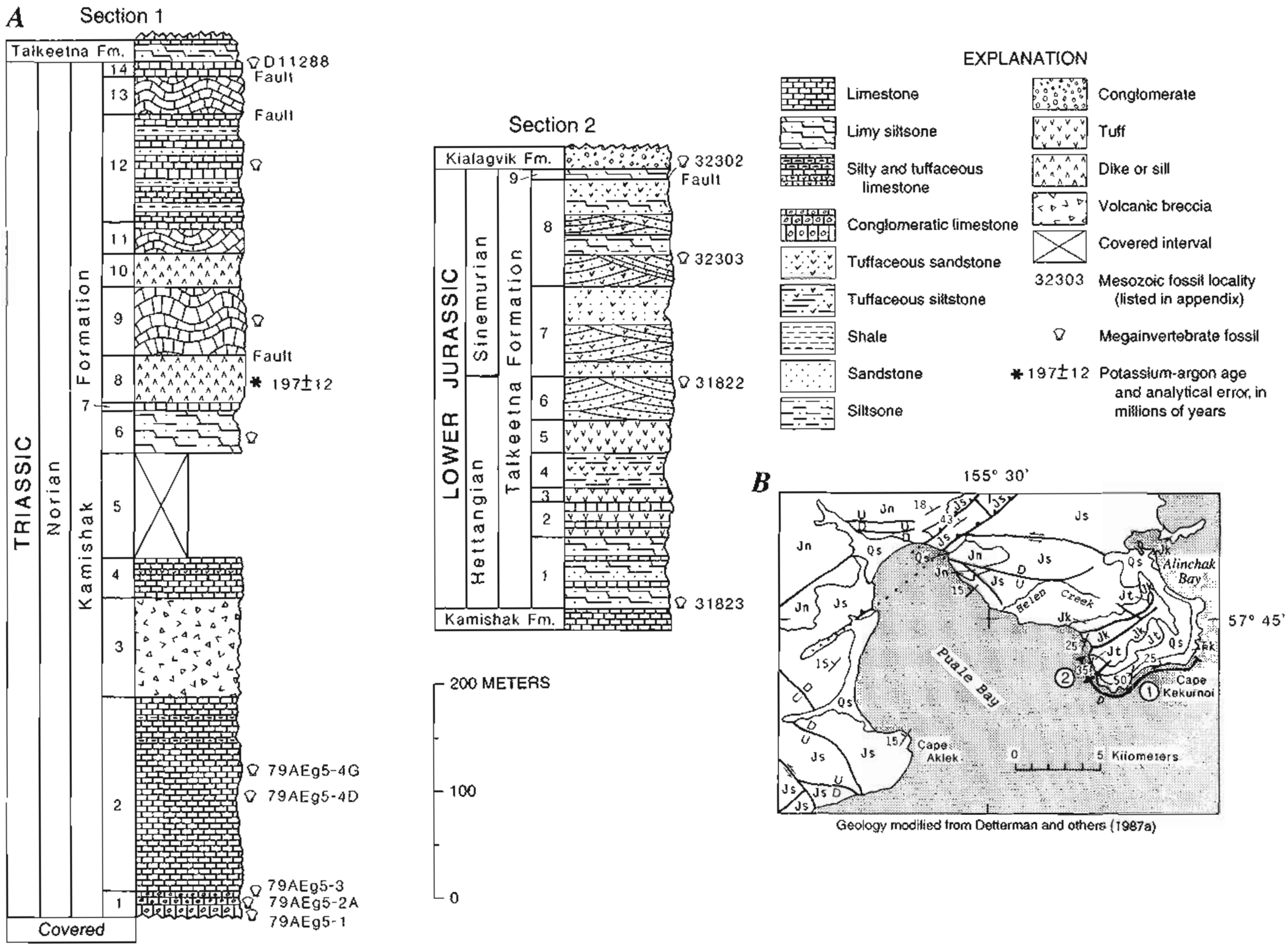
Figure 6 (next page). Triassic and Lower Jurassic formations, Puale Bay, Alaska Peninsula. *A*, Reference section of Kamishak Formation and section of Talkeetna Formation. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index map. Circled numbers label location of sections on index map and figure 5. Explanation applies to index maps in figures 6 through 11 and 13 through 16. It lists all the Mesozoic and Cenozoic sedimentary units discussed in this report except for the Shumagin Formation (Upper Cretaceous), which does not appear on any of the index maps. ➤



A
Section 1
Talkeetna Fm.
TRIASSIC
Norian
Kamishak Formation
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Covered
D11288
Fault
Fault
Fault
✱ 197±12
79AEg5-4G
79AEg5-4D
79AEg5-3
79AEg5-2A
79AEg5-1
Section 2
Kialagvik Fm.
LOWER JURASSIC
Sinemurian
Hettangian
Talkeetna Formation
Kamishak Fm.
32302
Fault
32303
31822
31823
200 METERS
100
0
EXPLANATION
Limestone
Limy siltstone
Silty and tuffaceous limestone
Conglomeratic limestone
Tuffaceous sandstone
Tuffaceous siltstone
Shale
Sandstone
Siltsone
Conglomerate
Tuff
Dike or sill
Volcanic breccia
Covered interval
32303 Mesozoic fossil locality (listed in appendix)
Megainvertebrate fossil
✱197±12 Potassium-argon age and analytical error, in millions of years
B
155° 30'
57° 45'
Alinchak Bay
Puale Bay
Cape Kekurnoi
Cape Aklek
Creek
0 5 Kilometers
Jn
Js
Qs
Jk
Jt
Geology modified from Detterman and others (1987a)

EXPLANATION OF INDEX MAPS FOR FIGURES 6 THROUGH 11 AND 13 THROUGH 16

SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

Qs	Surficial deposits (Holocene and Pleistocene)
Tmr	Milky River Formation (Pliocene)
Tta	Tachilni Formation (Miocene)
Tbl	Bear Lake Formation (Miocene)
Tu	Unga Formation (Miocene and Oligocene)
Tb	Belkofski Formation (Miocene? and Oligocene?)
Th	Hemlock Conglomerate (Oligocene)
Ts	Stepovak Formation (Oligocene and Eocene)
Tt	Tolstoi Formation (Eocene and Paleocene)
Tc	Copper Lake Formation (Eocene and Paleocene?)
Kk	Kaguyak Formation (Upper Cretaceous)
Kh	Hoodoo Formation (Upper Cretaceous)
Kc	Chignik Formation (Upper Cretaceous)
Kp	Pedmar Formation (Lower Cretaceous)
Khe	Herendeen Formation (Lower Cretaceous)
Ks	Staniukovich Formation (Lower Cretaceous)
Jn	Naknek Formation (Upper Jurassic)—Divided into:
Jnk	Katolinat Conglomerate Member
Jni	Indecision Creek Sandstone Member
Jns	Snug Harbor Siltstone Member
Jnn	Northeast Creek Sandstone Member
Jnc	Chisik Conglomerate Member
Js	Shelikof Formation (Middle Jurassic)
Jk	Kialagvik Formation (Middle and Lower Jurassic)
Jt	Talkeetna Formation (Lower Jurassic)
R̄k	Kamishak Formation (Upper Triassic)

VOLCANIC ROCKS

Qv	Volcanic rocks (Holocene and Pleistocene)
QTv	Volcanic rocks (Quaternary and Tertiary)
Tm	Meshik Volcanics (Oligocene and Eocene)
Tp	Popof volcanic rocks (Oligocene and Eocene)
Tv	Volcanic rocks (Pliocene to Eocene)

INTRUSIVE ROCKS

Ti	Intrusive rocks (Pliocene to Eocene)
Jqd	Quartz diorite (Jurassic)
Jgd	Granodiorite (Jurassic)
Tgd	Granodiorite (Tertiary)

Contact

U D Fault—Dashed where inferred; dotted where concealed. U, upthrown side; D, downthrown side; arrows indicate direction of relative movement

Thrust or high-angle fault—Dotted where concealed. Sawteeth on upper plate

Anticline—Dashed where inferred; dotted where concealed

Syncline—Arrow indicates direction of plunge. Dotted where concealed

16 Strike and dip of bedding

9 Measured section

Exploratory well

Mountain peak

Spring

Settlement

Mountains indicates a Hettangian and early Sinemurian (Early Jurassic) age for the Talkeetna Formation in the Puale Bay area. The unit's contact with the overlying Kialagvik Formation is structurally conformable, but it is considered to be a disconformity because the late Sinemurian, Pliensbachian, and most of the Toarcian Stages are apparently missing, owing to either nondeposition or erosion. A small fault occurs at the contact on the shore of Puale Bay but is not present elsewhere. The lower contact with the Kamishak Formation is gradational.

A section measured along the northeast shore of Puale Bay (fig. 6) by L.B. Magoon and R.M. Egbert in 1979 begins at the contact with the underlying Kamishak Formation and continues northwest about 1.5 km (section 2).

The Talkeetna Formation at Puale Bay is entirely marine and was deposited in a neritic environment. The megafauna is present in great abundance at a few horizons and may represent mass kills as a result of volcanic eruptions.

Section 2. Section of the Talkeetna Formation, Puale Bay (fig. 6)

Kialagvik Formation

	Thickness (meters)
Disconformable contact	
Talkeetna Formation:	
9. Siltstone, thin-bedded, brownish-gray, calcareous; contains few bivalves (32302)	9.1
Fault, displacement minor	
8. Sandstone, thick-bedded to massive, coarse-grained, light-brown; tuffaceous and crossbedded; thin interbeds of calcareous and tuffaceous siltstone; contains ammonite *Arnioceras* (32303)	99.0
7. Sandstone, thin-bedded at base becoming thicker bedded upward; tuffaceous and crossbedded	86.8
6. Sandstone, thick-bedded, coarse-grained, greenish-gray; poorly sorted; crossbedded; carbonaceous debris on bedding plane; contains ammonites *Psiloceras* and *Discamphiceras* (31822)	40.2
5. Tuff, massive, coarse-grained, green to red	27.4
4. Siltstone, thin-bedded, gray; tuffaceous; thin interbeds of tuff	35.0
3. Tuff, similar to unit 5	15.2
2. Limestone and tuff interbedded, thick-bedded; limestone grayish brown; tuff gray to green; tuff beds become thicker in lower part	30.5
1. Limestone, sandstone, and siltstone interbedded, mostly thin-bedded; predominantly gray; laminations; contains ammonites *Discamphiceras* and *Waehneroceras* (31823)	61.0
Total section	404.2

Gradational contact

Kamishak Formation

Kialagvik Formation

The Kialagvik Formation was defined by Capps (1923, p. 94–97) for a few hundred feet of sandstone, shale, and conglomerate exposed along the northwest shore of Wide Bay (then known as Kialagvik Bay), between Pass Creek and the southwest end of the bay. Capps did not designate a "type" or publish specific stratigraphic details about the formation along the northwest side of Wide Bay. The outcrops there are discontinuous, and there is heavy brush cover. A fairly complete section along the south side of Short Creek, about 5 km southwest of Pass Creek, was investigated by L.N. Kellum in 1944 and measured by R.W. Imlay and D.J. Miller in 1948. Imlay published a generalized version of this section (Imlay, 1984). The present authors obtained more details on this section in 1980, during field work in the Ugashik and Karluk 1:250,000 quadrangles. Combining our data with the data published by Imlay (1984), we here designate this section as the principal reference section for the Kialagvik Formation (section 3; fig. 7). The section lies along the south side of Short Creek, starting at VABM Creek (Sec. 34, T. 32 S., R. 44 W., Ugashik B-2 1:63,360 quadrangle), continuing westward about 2 km to the east side of sec. 32, and then running northeastward up a ridge into sec. 28. A minor fault cuts the section a short distance below its contact with the Shelikof Formation, but strata can be correlated across the fault. The upper contact of the section with the Shelikof Formation is an unconformity. The lower contact is not exposed in the Wide Bay area.

Section 3. Principal reference section of the Kialagvik Formation along Short Creek (fig. 7)

Shelikof Formation

	Thickness (meters)
Unconformable contact	
Kialagvik Formation:	
23. Mudstone, thin-bedded, brown; thin interbeds of fine-grained brown sandstone; contains *Inoceramus lucifer* (31974)	22.8
22. Limestone, light-brown; contains *Holcophylloceras*, *Inoceramus lucifer*, and *Grammatodon* (31975)	6.0
21. Siltstone and sandstone, thin-bedded, brown; few limestone concretions	33.5
20. Sandstone, medium-bedded, fine-grained, light-brown; contains *Parabigotites crassicostatus*, *Inoceramus lucifer*, and *Camptonectes* (31976)	6.0
19. Siltstone, thin-bedded, fault through section	28.9
18. Sandstone, thin-bedded, fine-grained; few pebbles; contains *Bradfordia* cf. *B. costidensa*, and *Parabigotites* cf. *P. crassicostatus* (21256)	7.6
17. Siltstone and shale interbedded; few limestone concretions; contains *Arkelloceras*, *Pelekodites*?, *Lytoceras*, and *Macrophylloceras* (21255)	45.7
16. Sandstone, similar to unit 18	6.0
15. Shale, gray, blocky	36.3
14. Sandstone, medium- to thick-bedded, fine-grained, few pebbles; contains *Pseudolioceras whiteavesi*, *Tmetoceras kirki*, *T. kirki flexicostatum*, *Erycitoides howelli*, and *E. spinatus* (21254 and 31978)	25.9
13. Sandy siltstone and shale	10.6

Section 3. Principal reference section of the Kialagvik Formation along Short Creek (fig. 7)—Continued

12. Interbedded sandstone, conglomerate, and sandy siltstone; contains *Erycitoides howelli*, *E. kialagvikensis*, *E. spinatus*, *E. levis*, and *Pseudolioceras whiteavesi* (21245 and 19748) 32.0
11. Sandy shale 12.2
10. Covered 65.5
9. Sandy siltstone and shale, brown 12.2
8. Covered 67.0
7. Sandstone, thick-bedded to massive, crossbedded; conglomerate lenses; muddy; abundant wood fragments; contains *Trigonia* 15.2
6. Covered 50.2
5. Sandy siltstone and shale 12.2
4. Covered 35.0
3. Sandy siltstone and shale, brown; contains *Tmetoceras scissum* and *Pseudolioceras* (21248) 22.8

2. Covered 44.2
1. Siltstone, brownish-gray; contains *Tmetoceras scissum* (21247) 28.9

Total exposed section 626.7

Base of exposed section

The strata in the Kialagvik Formation at Wide Bay indicate that the lower part of the section was deposited in a nearshore, shallow-water environment. The sandstone is crossbedded and contains lenses of conglomerate and abundant wood and carbonaceous debris. Additionally, it contains the thick-shelled bivalve *Trigonia* sp. indicative of a nearshore high-energy environment. The upper part of the formation includes rhythmically bedded thin siltstone and sandstone

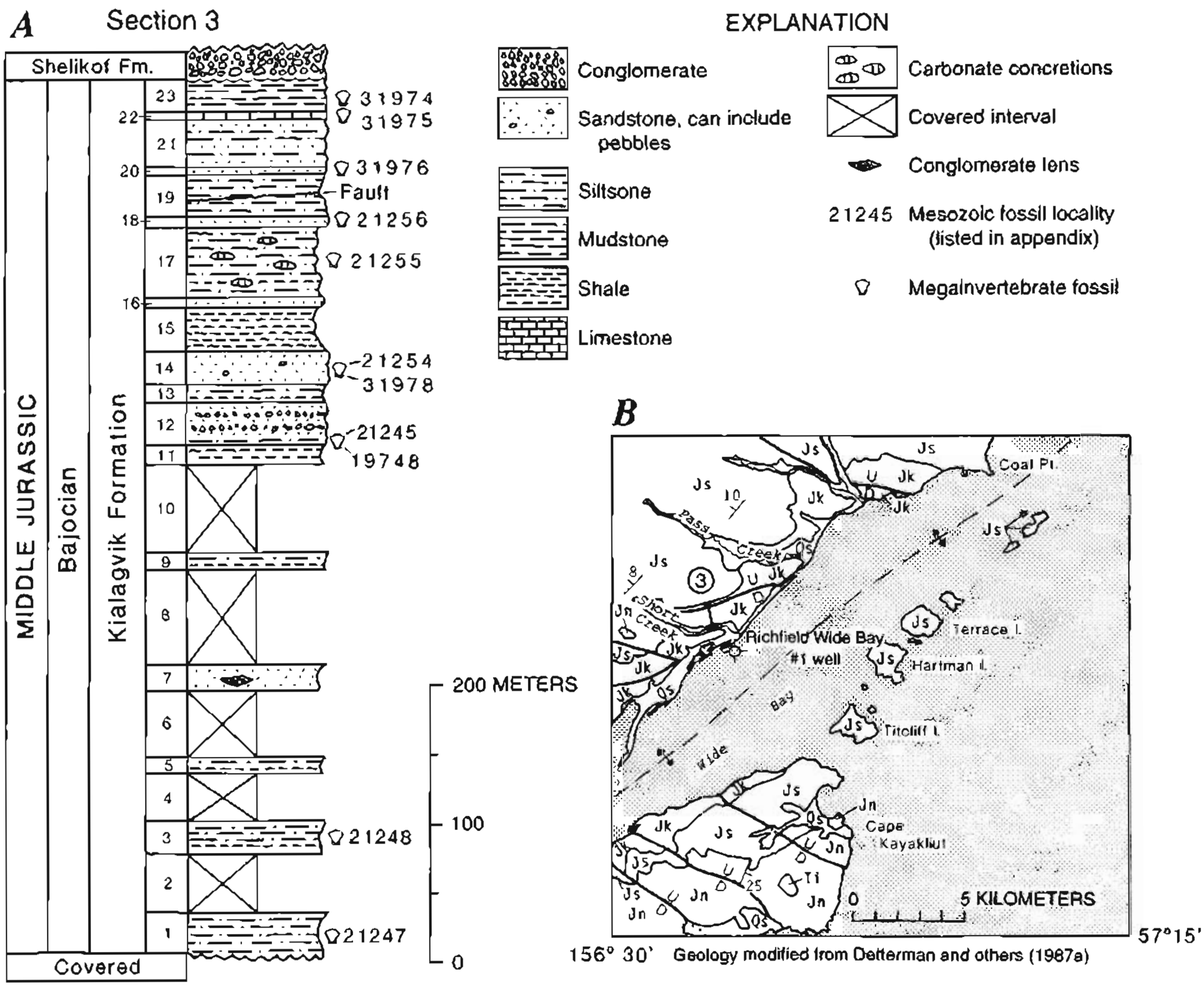


Figure 7. Middle Jurassic Kialagvik Formation, Wide Bay, Alaska Peninsula. *A*, Principal reference section. Age, formation name, and lithic intervals (numbered to correspond to text) are shown for section. *B*, Index map. Circled number labels location of section on index map and figure 5. See figure 6 for explanation of other symbols.

units, limestone nodules and lenses, and other features characteristic of deeper water deposition. These features suggest that the area subsided rapidly.

The formation at Wide Bay has been investigated numerous times since 1923, for example, by Smith and Baker (1924), Smith (1926), Martin (1926), Kellum and others (1945), Imlay (1961, 1984), Imlay and Detterman (1977), and Westermann (1964, 1969). Smith (1926) was the first to recognize the formation at Puale Bay, and he geographically extended the unit to include the rocks there. The formation is abundantly fossiliferous, and most of these authors located the contact between the Kialagvik and Shelikof Formations on the basis of faunal evidence rather than lithologic characteristics. Allaway and others (1984) revised the contact between the Kialagvik and Shelikof Formations on lithologic evidence and, as a consequence, revised (that is, stratigraphically extended) the upper boundary of the Kialagvik Formation. To illustrate this boundary in the Puale Bay area, we here designate a reference section (section 4) of the Kialagvik Formation that runs along the northeast shore of Puale Bay and incorporates this contact. This section begins about 2 km northwest of the entrance point to the bay and continues northwest along the shore for approximately 1.75 km (secs. 29 and 19, T. 28 S., R. 37 W., Karluk C-4 and C-5 1:63,360 quadrangles).

Section 4. Reference section of the Kialagvik Formation at Puale Bay (fig. 8)

	Thickness (meters)
Shelikof Formation	
Conformable contact	
Kialagvik Formation:	
9. Siltstone, thin-bedded, gray; contains few ammonites, *Cadoceras tenuicostatum* (31818)	15.2
8. Sandstone, thick-bedded, fine- to medium-grained; graded and laminated, gray	12.1
7. Siltstone, thin- to thick-bedded, gray, micaceous; somewhat sandy; contains bivalve *Inoceramus lucifer* and ammonites *Pseudolioceras maclintocki* and *Eudmetoceras* cf. *E. amplectens* (31819 and 32301)	271.2
6. Sandstone, thick-bedded, fine- to medium-grained, grayish-green; laminated and graded; few rip-up clasts; minor siltstone	47.7
5. Conglomerate, massive, disorganized; clasts mainly volcanic rocks, minor intrusive rocks; clasts range from pebbles to boulders; channeled into underlying siltstone	30.5
4. Siltstone and sandstone, thin- to thick-bedded, rhythmically interbedded; siltstone dark gray; sandstone yellowish gray; lenticular limestone concretions throughout	213.4
3. Sandstone, thick-bedded, coarse-grained, tan	19.2
2. Siltstone and sandstone, rhythmically interbedded; similar to unit 4; few limestone concretions	172.6
1. Conglomerate, massive, pebble to cobble; minor sandstone; contains *Haugia* (19804)	7.6
Total section	789.5
Unconformable contact	
Talkeetna Formation	

The reference section at Puale Bay is about 790 m thick (fig. 8). The lowermost 420 m consists of rhythmically interbedded gray siltstone and tan sandstone deposited in deep water and overlain by a massive, disorganized, and channeled conglomerate (unit 5). Limestone concretions occur throughout much of this part. The upper part of this reference section is gray siltstone and minor sandstone. The Kialagvik Formation at Puale Bay is similar to the upper part of the formation at Wide Bay. The nearshore beds in the basal part of the Wide Bay section are missing at Puale Bay. The two areas are about 60 km apart, and the lithic differences between them may represent simply facies changes; additionally, they may mean that neither section is complete and that each represents a somewhat different time interval. The sequences at Wide Bay and Puale Bay are the only outcrops of the Kialagvik Formation on the Alaska Peninsula, but the unit has been encountered in the subsurface. The Humble Oil-Shell Oil Company Bear Creek well (see location in Detterman and others, 1983), about midway between Wide Bay and Puale Bay, encountered about 1,000 m of siltstone and shale correlated with the Kialagvik Formation (R.L. Detterman, unpub. data, 1987). AMOCO Production Company drilled through about 530 m of the Kialagvik Formation in the Cathedral River #1 borehole at the southwest end of the Alaska Peninsula (see McLean, 1977). There the formation consists of siltstone, sandstone, and shale similar to the rocks of the Wide Bay section.

Rocks in part lithologically equivalent to the Kialagvik Formation are well exposed along the west side of Cook Inlet (see Detterman and Hartsock, 1966), where they are called the Tuxedni Group. The Tuxedni Group is divided into six formations (see Detterman and Hartsock, 1966) and is a much thicker (3,000 m) and more complete sequence than the Kialagvik Formation. The Kialagvik is similar to the lower part of the Tuxedni. The Tuxedni Group is also present in the Talkeetna Mountains (Imlay, 1984), 500 km northeast of the Alaska Peninsula.

The contact of the Kialagvik with the overlying Shelikof Formation is conformable at Puale Bay where the Kialagvik is as young as Callovian (Middle Jurassic) and unconformable at Wide Bay where the Kialagvik is entirely Bajocian (Middle Jurassic); the contact is placed at the base of a thick volcanic sandstone and conglomerate sequence. The contact of the Kialagvik with the underlying Talkeetna Formation at Puale Bay is an unconformity.

Only sparse fossils are present in the deep-water deposits at Puale Bay in contrast to the abundant megafauna in the shallow-marine sedimentary rocks at Wide Bay. The megafauna at Wide Bay indicates a depositional event starting in the late Toarcian (Early Jurassic) and continuing until the Callovian (Middle Jurassic). Most of the megafauna is correlated with the lower and middle parts of the Bajocian Stage of the Middle Jurassic (Imlay, 1984). The age-diagnostic ammonites are *Tmetoceras*, *Erycitoides*, *Eudmetoceras*, and *Pseudolioceras* (Taylor and others, 1984; Westermann, 1964, 1969).

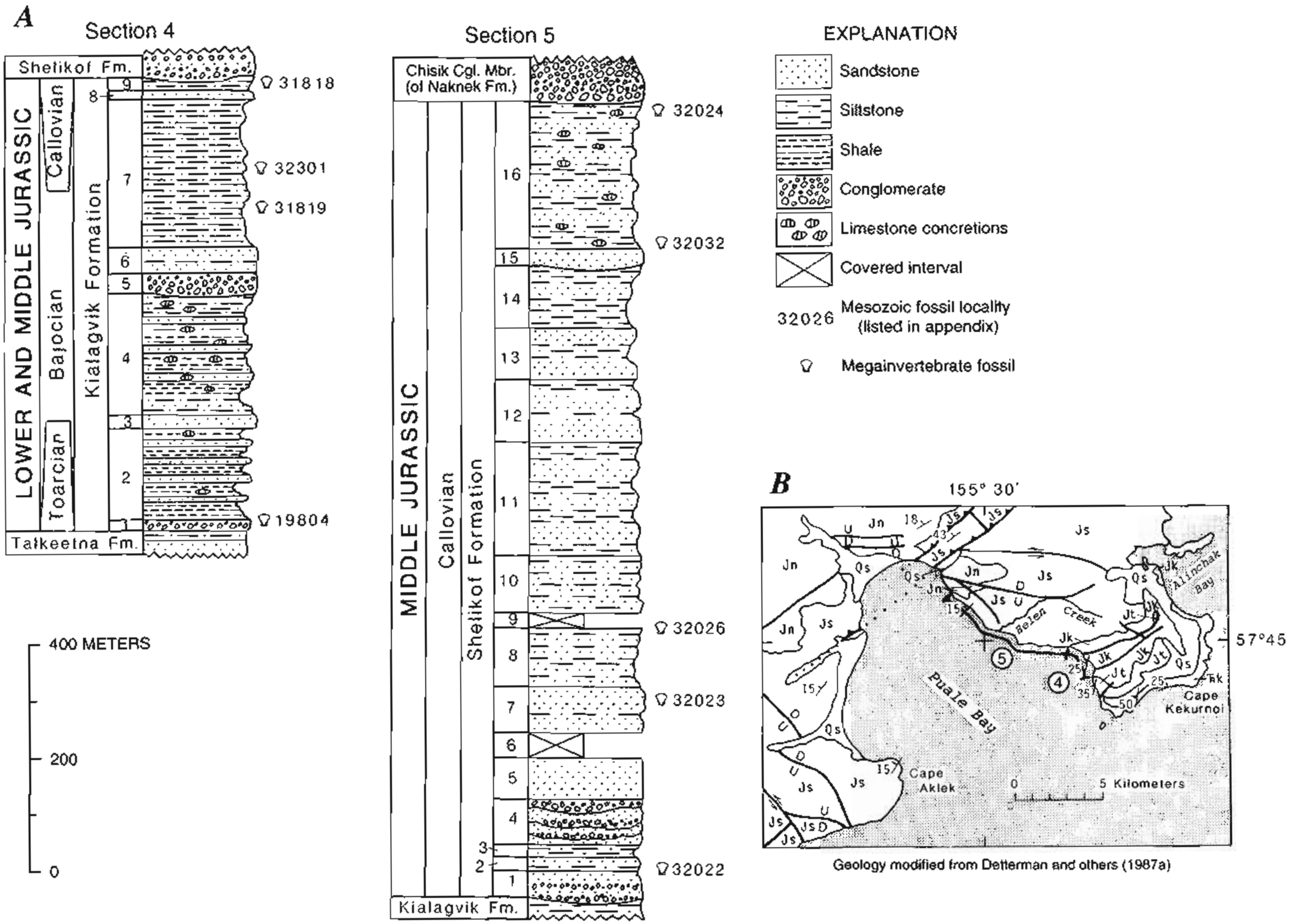


Figure 8. Lower and Middle Jurassic formations, Puale Bay, Alaska Peninsula. *A*, Reference section of Kialagvik Formation and type section of Shelikof Formation. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index map. Circled numbers label location of sections on index map and figure 5. See figure 6 for explanation of other symbols.

Shelikof Formation

The Shelikof Formation was named by Capps (1923, p. 97–101) for exposures along the northwest shore of Shelikof Strait. He did not specify a "type," but Allaway and others (1984, p. 21–27) designated the section along the northeast shore of Puale Bay as the type section and established two reference sections at Alai and Big Creeks, near the southwest and northeast ends, respectively, of Wide Bay. The type section at Puale Bay begins at the contact with the Kialagvik Formation in sec. 19, T. 28 S., R. 37 W., Karluk C-4 and C-5 1:63,360 quadrangle, and continues along the northeast shore to sec. 9, T. 28 S., R. 38 W., Karluk D-5 1:63,360 quadrangle (fig. 8).

The Shelikof Formation is the major stratigraphic unit forming the mountains along the west side of Shelikof Strait from Kashvik Bay to Wide Bay (fig. 2). The only other known exposures of the unit are along faults on the east shore of Upper and Lower Ugashik Lakes and in the Chignik area (fig. 5; Detterman and others, 1981a, 1983, 1987a). The formation has been identified in several boreholes including the AMOCO Cathedral River #1 near the southwest end of the Alaska Peninsula. Consequently, we presume that the Shelikof Formation underlies the entire Alaska Peninsula. Northeastward from the Alaska Peninsula, rocks of similar age are mapped as part of the Chinitna Formation, a major stratigraphic unit along the west side of Cook Inlet (Detterman and Hartsock, 1966) and in the Talkeetna Mountains (Grantz, 1960). The Shelikof Formation contains much more coarse volcanic debris than does the Chinitna Formation, which consists mainly of shale and siltstone; and the Shelikof is correlative, lithologically and faunally, with the Paveloff Siltstone Member in the uppermost part of the Chinitna Formation.

The Shelikof Formation is a deep- to shallow-water volcaniclastic unit 1,402 m thick in its type locality. The lower part of the unit is mainly thick-bedded to massive, dusky-yellowish-green graywacke and conglomerate. Clasts in the conglomerate are volcanic. The upper part of the formation is mainly brownish-gray siltstone containing limestone nodules. Capps (1923) divided the Shelikof into three informal members, called the siltstone, sandstone, and conglomerate members. These are useful for mapping locally, but owing to abrupt lateral facies changes, they are impractical for most mapping.

The type section of the Shelikof Formation (section 5; fig. 8) was measured in part by L.B. Magoon and J.W. Miller in 1979 and in part by W.H. Allaway, Jr., and C.D. Blome in 1981.

Megafauna are locally very abundant in strata of the Shelikof Formation, but most of the unit is unfossiliferous. Where present, the fauna consists mainly of the ammonites *Cadoceras*, *Pseudocadoceras*, and *Stenocadoceras*, of early to middle Callovian (Middle Jurassic) age. A few specimens of *Iniskinites* at Wide Bay (Detterman and others, 1985) and a few species of the genus *Cadoceras* suggest a late Bathonian(?) age for some of the rocks. A few pelecypods are also present, but most are long-ranging forms. It may be that deposition was continuous from the Kialagvik through the Shelikof Formation; this appears likely as no erosional break between the Kialagvik and the unfossiliferous strata in the basal part of the Shelikof Formation is apparent at the type section at Puale Bay. Lacking positive stratigraphic evidence and from available faunal evidence we consider the contact between these units to be conformable at Puale Bay; however, there may be a diastem between the Kialagvik and

Section 5. Type section of the Shelikof Formation (fig. 8)

Naknek Formation
Unconformable contact

	Thickness (meters)
Shelikof Formation:	
16. Siltstone and sandstone rhythmically interbedded; siltstone, thin-bedded, dark-gray; sandstone, medium-bedded, medium-grained, dark-green; volcanogenic; lenticular limestone concretions in siltstone; contains ammonite *Cadoceras* (*Stenocadoceras*) *striatum* and bivalve *Meleagrinella* (32024, 32032)	260
15. Sandstone, thick-bedded, fine- to medium-grained, yellowish-gray; mainly volcanic sand	31
14. Siltstone and sandstone interbedded; similar to unit 16	100
13. Siltstone and sandstone; thick-bedded sandstone with thin siltstone interbeds; sandstone, olive-green	95
12. Sandstone, massive, coarse-grained, olive-green; thin interbeds of siltstone; sandstone composed mainly of volcanic fragments	110
11. Sandstone and siltstone interbedded, similar to unit 16	205
10. Siltstone, olive-gray; thin sandstone interbeds	100
9. Covered interval	30
8. Siltstone and sandstone interbedded; contains ammonite *Cadoceras* (*Stenocadoceras*) *striatum* (32026)	100
7. Sandstone, thick-bedded to massive, medium- to coarse-grained, moderate olive-brown; graded and amalgamated; graywacke-type; contains ammonite *Cadoceras* (*Stenocadoceras*) (32023)	85
6. Covered interval	40
5. Volcanic graywacke, thick-bedded to massive, dusky-yellow-green, medium-grained; contains abundant plant debris	75
4. Conglomerate and sandstone, thick-bedded, channeled, greenish-black; poorly sorted; mainly volcanic clasts	80
3. Siltstone, thin-bedded, dark-gray	15
2. Siltstone and sandstone, light-olive-gray; contains ammonite *Cadoceras* (*Stenocadoceras*) cf. *C.* (*S.*) *stenoloboide* (32022)	25
1. Sandstone and conglomerate, medium- to thick-bedded; mainly volcanic debris	51
Total section	1,402

Conformable contact
Kialagvik Formation

Shelikof Formations. The upper contact of the Shelikof Formation with the Naknek Formation is an unconformity.

Naknek Formation

The Upper Jurassic Naknek Formation is the most persistent and widespread Mesozoic formation on the Alaska Peninsula, extending 650 km southwest from Kamishak Bay to Black Hill, and another 500 km to the northeast from Kamishak Bay. The formation was originally named the Naknek Series by Spurr (1900, p. 169–171). Martin (1905) first used the name "Naknek Formation" for the rocks in the Cook Inlet area. Early work (Kirschner and Minard, 1949), mainly in the Cook Inlet area, showed that the formation was divisible into four members; from oldest to youngest these are the Chisik Conglomerate Member (Martin and Katz, 1912), lower sandstone member, Snug Harbor Siltstone Member, and Pomeroy Arkose Member (Detterman and Hartsock, 1966). The Chisik Conglomerate Member was originally considered a formational rank unit (= Chisik Conglomerate) by Martin and Katz (1912), but it was subsequently revised as a member of the Naknek Formation by Moffit (1927).

A similar subdivision of its strata is appropriate for the Naknek Formation on the Alaska Peninsula (fig. 9). Additionally, two members younger than those listed above have been mapped on the peninsula; the older of the two was called the "upper sandstone member" by Detterman and Reed (1980, p. B37). We herein geographically extend the Chisik Conglomerate Member and Snug Harbor Siltstone Member to include the equivalent strata on the Alaska Peninsula. Additionally, we herein introduce the name "Northeast Creek Sandstone Member" for rocks on the peninsula equivalent to the lower sandstone member of the Cook Inlet area, and the name "Indecision Creek Sandstone Member" for the upper sandstone member in the Kamishak Bay area (Detterman and Reed, 1980, p. B37). The name "Katolinat Conglomerate Member" is herein proposed for the lithic unit that is younger than the upper sandstone member in the Kamishak Bay area. The Pomeroy Arkose Member is not recognized on the Alaska Peninsula, probably owing to facies change or a change in source terrain.

The division of the Naknek Formation into mappable members serves several purposes: (1) It indicates major shelf areas, depositional basins, source terranes, and the overall direction of sediment transport, and (2) it can be used to delineate the areas most likely to have clean sandstone intervals that may be potential oil-producing horizons. Three of the members, the Indecision Creek Sandstone, Snug Harbor Siltstone, and Northeast Creek Sandstone Members, are mappable throughout the length of the Alaska Peninsula. The Chisik Conglomerate Member is present as far south as the Chignik area, and the Katolinat Conglomerate Member is preserved for about 80 km in the Mount Katmai area, as well as in a small area near Wide Bay.

The aggregate thickness of the members of the Naknek Formation on the Alaska Peninsula is approximately 3,205 m (fig. 9*B*). This is a maximum thickness as it incorporates the thicknesses from the various type or reference sections that show the maximum development of each member. The average thickness of the formation is approximately 1,700 to 2,000 m. Abrupt lateral facies changes are present, so that only one or two members are of considerable thickness at any one locality, and the Katolinat Conglomerate Member is present only at the northeast end of the peninsula. Several small starved basins are preserved—for example, near Hallo Bay and Amber Bay—in which the entire Naknek sequence is compressed into a section of siltstone less than 500 m thick. The facies changes within the Naknek Formation occur both parallel and transverse to the Alaska Peninsula. The starved basin sequences at Hallo and Amber Bays lie on the southeast side of the peninsula. The abrupt changes are the results of rapid uplift and erosion of the Alaska-Aleutian Range batholith and older sedimentary rocks that flank it. The eroded sediments were carried to the southeast 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 upper Mesozoic stratigraphic units, can best be seen in a fence diagram of the upper Mesozoic stratigraphic units on the Alaska Peninsula (see Detterman and Miller, 1987).

The age of most of the Naknek Formation is well constrained by a biozonation of the bivalve *Buchia* (Imlay, 1959; Jeletsky, 1965; Miller and Detterman, 1985). *Buchia concentrica*, the oldest form of *Buchia* in Alaska, occurs within the Snug Harbor Siltstone Member of the Cook Inlet area and is associated with the ammonite *Cardioceras* (Detterman and Hartsock, 1966). *Cardioceras* in association with other ammonites in the Cook Inlet area indicates an age of late Oxfordian (Imlay, 1981) for the basal part of the Snug Harbor Siltstone Member. On the Alaska Peninsula, *Buchia concentrica* occurs sparsely in the upper part of the Northeast Creek Sandstone Member and in the lower part of the Snug Harbor Siltstone Member; its presence suggests that these beds are no younger than late Oxfordian. The thick sequence comprising the Chisik Conglomerate Member and the lower part of the Northeast Creek Sandstone Member could be as old as earliest Oxfordian. The succession of *Buchia* species on the Alaska Peninsula (Miller and Detterman, 1985) indicates that deposition of the Naknek was continuous from at least middle Oxfordian to latest Tithonian time. Ammonites in the Naknek Formation on the Alaska Peninsula are restricted to long-ranging forms, *Phylloceras* and *Lytoceras*, that are of minimal value for age determinations.

Chisik Conglomerate Member

A reference section (section 6) of the Chisik Conglomerate Member, which is here geographically extended into the area of this report, is designated in the Ugashik C-1 1:63,360 quadrangle, located on an unnamed mountain in secs. 26 and

27, T. 30 S., R. 43 W., just west of two small lakes 3 km west of Ruth Lake (fig. 9*B*). The section, located 6.5 km southwest of the southernmost arm of Becharof Lake, begins at the top of the mountain and continues down its east-facing slope to near lake level. The 614 m of the member exposed at this locality (fig. 9*A*) consists mainly of massive to thick-bedded conglomerate with interbeds and lenses of clean, quartzose sandstone that is commonly crossbedded. Clast size in the conglomerate decreases upward in the section from a maximum of 120 cm at its base to about 15 cm at its top. Average composition of the polymictic clasts is about 30 percent granitic rocks, 30 percent quartzite, 20 percent metavolcanic rocks, 10 percent schist, and 10 percent chert and quartz. Clasts are generally well rounded and commonly decrease in size upward within each unit. Pebbles of similar composition are found in many of the sandstone beds. The contact between the Chisik Conglomerate Member and the underlying Shelikof Formation is not exposed at this locality, but it is exposed at several localities nearby where the Chisik unconformably overlies the Shelikof Formation. Consequently, the thickness of the member may be as much as 100 to 150 m more than measured in the section just described. The rocks at nearby localities are conglomerate similar to the lowest measured unit. At some localities near Wide Bay and Chignik Bay the basal conglomerate bed is channeled into the underlying Shelikof Formation, and that contact is obviously unconform-

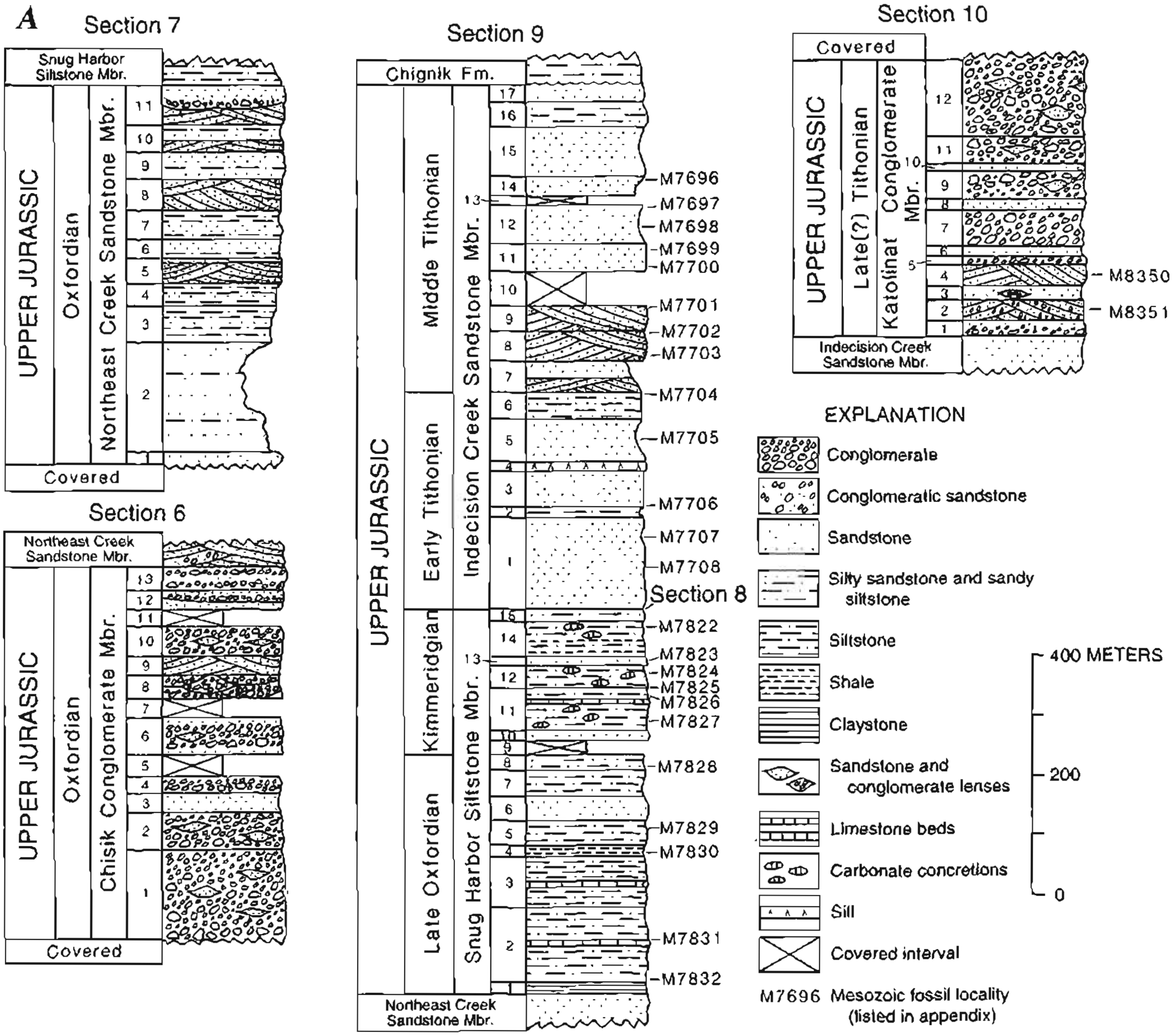


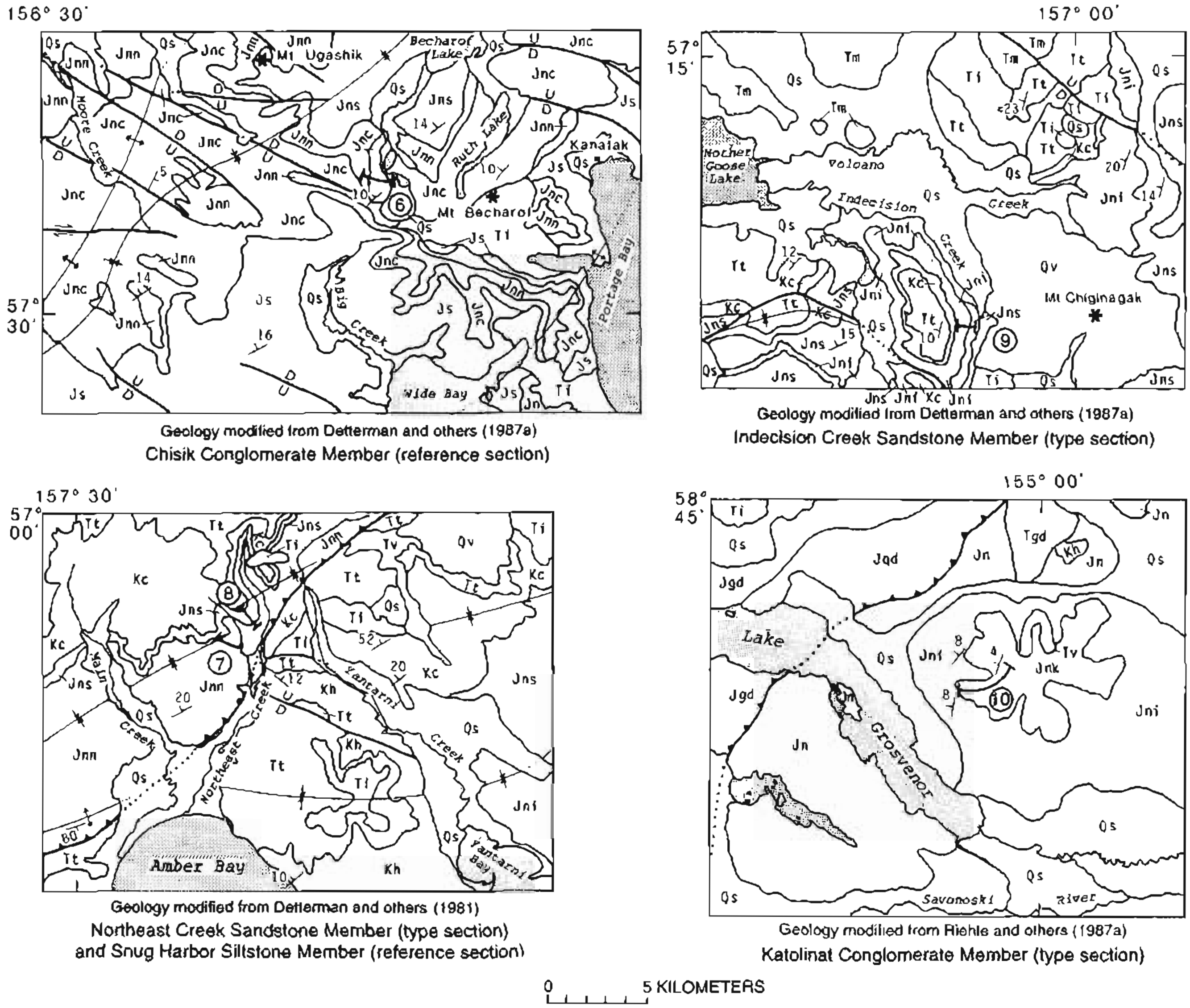
Figure 9. Members of Upper Jurassic Naknek Formation, Alaska Peninsula. *A*, Type sections of Northeast Creek Sandstone, Indecision Creek Sandstone, and Katolinat Conglomerate Members, and reference sections of Chisik Conglomerate and Snug Harbor Siltstone Members. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols.

Section 6. Reference section of the Chisik Conglomerate Member of the Naknek Formation (fig. 9)

Northeast Creek Sandstone Member
Conformable contact

	Thickness (meters)
Chisik Conglomerate Member:	
13. Conglomerate, massive, pebble-cobble; maximum clast size 26 cm; clasts 30 percent quartzite, 15 percent metavolcanic rocks, 15 percent chert, 10 percent quartz, and 10 percent schist and metalimestone; clasts well rounded; a coarse-grained, light-brownish-gray sandstone interval in middle part of conglomerate unit	38.0
12. Sandstone and conglomerate, thick-bedded to massive; sandstone is medium grained, light brown; conglomerate clasts are 60 percent quartzite, 20 percent metavolcanic rocks, 15 percent chert (gray, green, red), 5 percent quartz; maximum clast size 20 cm	30.3
11. Covered interval	23.6
10. Conglomerate, massive, 60 percent metavolcanic rocks, 20 percent quartzite, 10 percent schist, 10 percent chert and quartz; few coarse sandstone lenses	53.3
9. Sandstone, medium-bedded, fine-grained, olive-gray; high-angle crossbeds; frosted grains	30.4
8. Conglomerate, massive, channeled; clasts are 60 percent schist and quartzite, 20 percent metavolcanic rocks, 10 percent granitic rocks, 10 percent chert and quartz; maximum clast size 120 cm	42.6
7. Covered interval	30.4

B



Geology modified from Detterman and others (1987a)
Chisik Conglomerate Member (reference section)

Geology modified from Detterman and others (1987a)
Indecision Creek Sandstone Member (type section)

Geology modified from Detterman and others (1981)
Northeast Creek Sandstone Member (type section) and Snug Harbor Siltstone Member (reference section)

Geology modified from Riehle and others (1987a)
Katolinat Conglomerate Member (type section)

Figure 9.—Continued.

Section 6. Reference section of the Chisik Conglomerate Member of the Naknek Formation (fig. 9)—Continued

6. Conglomerate, massive, well-rounded clasts; clasts are 30 percent quartzite, 30 percent granitic rocks, 20 percent metavolcanic rocks, 15 percent schist, 10 percent chert and quartz; thick sandstone at top and bottom	60.8
5. Covered interval	38.1
4. Conglomerate, same as unit 8	38.1
3. Sandstone, thin-bedded, fine-grained, dusky-yellow	21.3
2. Conglomerate, thick-bedded to massive, pebble to cobble; clasts are 30 percent granitic rocks, 20 percent metavolcanic rocks, 30 percent quartzite, 10 percent chert and quartz; sandstone lenses	64.0
1. Conglomerate, massive, cobble-pebble; contains sandstone lenses; forms vertical cliff; not measured in detail	143.0
Total exposed section	613.9

Base of exposed section

able. The upper contact of the Chisik with the Northeast Creek Sandstone Member is conformable and gradational.

Northeast Creek Sandstone Member

The Northeast Creek Sandstone Member is here named for exposures along Northeast Creek, Sutwik Island D-5 1:63,360 quadrangle. The Northeast Creek Sandstone Member is the lateral equivalent of the lower sandstone member of the Naknek Formation in the Cook Inlet area (see Detterman and Hartsock, 1966). The Northeast Creek Sandstone Member occupies the same stratigraphic position on the Alaska Peninsula with respect to the underlying Chisik Conglomerate Member and the overlying Snug Harbor Siltstone Member as does the lower sandstone member in the Cook Inlet area. The Northeast Creek Sandstone Member is present throughout the entire length of the Alaska Peninsula.

The contact of the Northeast Creek with the underlying Chisik Conglomerate Member is conformable and is placed where thick sandstone replaces conglomerate in the section. Laterally, the contact may range either upward or downward due to facies changes. The upper contact of the Northeast Creek Sandstone Member with the Snug Harbor Siltstone Member is conformable and sharp. This contact may range upward or downward also, but to a lesser extent than does the lower contact. The upper contact represents a major shift in depositional environment from mainly nonmarine to marine conditions, and it varies both temporally and spatially depending on conditions at the local depositional site.

The here-designated type section (section 7; fig. 9) of the Northeast Creek Sandstone Member is on an east-facing ridge in sec. 34, T. 37 S., R. 51 W., Seward Meridian, Sutwik Island D-5 1:63,360 quadrangle. It begins on a ridge top and extends down to a tributary of Northeast Creek. The 624-m-thick section is, in part, a lateral facies equivalent of the Chisik Conglomerate Member and, in part, a younger unit overlying that member. This relation is readily apparent in exposures of the two members along strike. Sandstone constitutes the main part of the Northeast Creek Sandstone Member, which is a nonmarine to shallow-marine deposit. The sandstone is mainly fine to medium grained, crossbedded, and laminated. Dark laminae in the rocks are commonly composed of magnetite. Some of the sand beds contain channels with lag gravel at their bases. The crossbeds are mostly high-angle aeolian crossbeds with variable flow directions; some are small-scale, tabular crossbeds with clay drapes characteristic of point-bar deposits. Siltstone intervals are locally bioturbated. The composition of the Northeast Creek Sandstone Member is remarkably consistent throughout the length of the Alaska Peninsula. The lower contact of the member is not exposed at the type section.

Section 7. Type section of the Northeast Creek Sandstone Member of the Naknek Formation (fig. 9)

Snug Harbor Siltstone Member
Conformable contact

Northeast Creek Sandstone Member:	*Thickness (meters)*
11. Sandstone, thick-bedded, fine- to medium-grained; yellowish- to brownish-gray; contains channels with lag gravel; abundant carbonaceous debris; laminae formed by magnetite grains	62.5
10. Sandstone and siltstone, thin- to medium-bedded; brownish- to olive-gray; crossbedded; siltstone is carbonaceous	50.2
9. Sandstone, thick-bedded, fine-grained, pale-olive; laminated; minor siltstone	38.1
8. Sandstone, thick-bedded to massive, medium- to coarse-grained, dusky-yellow; few pebbles; large-scale, high-angle crossbeds	.60.9
7. Siltstone and sandstone, thin- to thick-bedded, fine-grained, brownish-gray to yellow-green; laminated and bioturbated	45.7
6. Sandstone, massive, medium-grained, light-gray; minor carbonaceous siltstone at base	32.0
5. Sandstone, thick-bedded, fine-grained, yellow-green; laminated and crossbedded	44.2
4. Siltstone with thin sandstone lenses, thin-bedded, olive-gray	31.9
3. Siltstone, thin-bedded, medium-dark gray; abundant plant debris; bioturbated; sandstone interbeds	54.8
2. Sandstone and siltstone rubble traces	189.0
1. Sandstone, thick-bedded, fine-grained, yellowish-gray; abundant plant debris	15.2
Total exposed section	624.5

Base of exposed section

Snug Harbor Siltstone Member

A reference section (section 8; fig. 9) for the Snug Harbor Siltstone Member, which is here geographically extended into the area of this report, is designated on Northeast

Creek about 1 km north of the type section of the Northeast Creek Sandstone Member in the Sutwik D-5 1:63,360 quadrangle; it is located along the top and down the southeast face of a flat-topped ridge in sec. 27, T. 37 S., R. 51 W. The 637-m-thick section consists mainly of dark-gray siltstone that contains numerous limestone concretions in its upper part and a few limestone beds at intervals throughout the section. Sandstone constitutes a minor part of the section but increases upward to a gradational contact with the overlying Indecision Creek Sandstone Member. Both the upper contact of the Snug Harbor with the Indecision Creek Sandstone Member and the lower contact with the Northeast Creek Sandstone Member are conformable but gradational. The lower contact is generally more sharply defined than the upper contact. Laterally, the contacts range upward or downward owing to facies changes. Sandstone is a minor part of the Snug Harbor Siltstone Member; it is most abundant in the northwesternmost exposures of the member and decreases southeasterly across the peninsula. The source area for this member, as well as for all the other members of the Naknek Formation, was located northwest of the present outcrop area.

Section 8. Reference section of the Snug Harbor Siltstone Member of the Naknek Formation (fig. 9)

	Thickness (meters)
Uppermost part of section missing	
Snug Harbor Siltstone Member:	
15. Silty sandstone, thin-bedded, fine-grained, dark-yellowish-brown; rusty weathering	18.2
14. Siltstone and silty shale, thin-bedded, dark-yellowish-brown; limestone nodules in upper part; contains *Buchia mosquensis* and *B. rugosa* (M7822)	62.4
13. Sandstone, thick-bedded, fine-grained, dark-yellowish-brown; silty; few limestone nodules; contains bivalves *Buchia mosquensis* and *B. rugosa* and ammonite *Lytoceras* (M7823)	12.1
12. Siltstone, thin-bedded, olive-gray; abundant limestone concretions; contains *Buchia rugosa* and *B. mosquensis* (M7824 and M7825)	41.1
11. Siltstone, similar to unit 12; contains a few limestone beds in addition to concretions; contains *Buchia rugosa* and *B. concentrica* (M7826 and M7827)	68.5
10. Sandstone, medium-bedded, medium-grained, moderate-yellowish-brown; contains fossils as in unit 11	4.5
9. Covered interval	24.7
8. Sandstone, thin- to medium-bedded, fine-grained, olive-gray; silty; contains few bivalves and gastropods (M7828)	25.8
7. Siltstone, thin-bedded, olive-gray	30.5
6. Sandstone, medium- to thick-bedded, fine-grained, light-olive-brown	39.6
5. Siltstone, thin-bedded, medium-gray; contains few bivalves (M7829)	44.1
4. Shale, dark-gray; contains *Buchia concentrica* (M7830)	19.8
3. Siltstone, thin-bedded, sandy, olive-gray; few limestone layers	95.9

Section 8. Reference section of the Snug Harbor Siltstone Member of the Naknek Formation (fig. 9)—Continued

2. Siltstone, similar to unit 13; contains *Buchia concentrica* (M7831 and M7832)	128.0
1. Claystone, olive-gray	22.8
Total exposed section	638.0
Conformable contact	
Northeast Creek Sandstone Member	

The Snug Harbor Siltstone Member is stratigraphically the lowest abundantly fossiliferous unit in the Naknek Formation. The main elements of the fauna are bivalves of the genus *Buchia*. A few brackish- and fresh-water bivalves occur in the older Naknek strata on the Alaska Peninsula, but *Buchia* is the oldest age-diagnostic marine fossil found in the formation on the peninsula. The species of *Buchia* present on the Alaska Peninsula can be divided into definite biozones (Miller and Detterman, 1985) that range in age from middle Oxfordian (Late Jurassic) to Valanginian (Early Cretaceous). Of note in the Snug Harbor reference section is the barren zone, units 7 and 6, overlying rocks that contain *Buchia concentrica* in unit 4. This 70-m interval is the same barren zone as that seen at Hallo Bay and described by Detterman and Miller (1986, p. 27–29).

The Snug Harbor Siltstone Member was deposited in moderately deep water, not below the carbonate compensation depth but well below wave base, in a basin with restricted circulation. The depositional site could have been in a deep fiord-like setting similar to many of the bays along the Pacific coast of the Alaska Peninsula at present. The sandstone (unit 8) overlying the barren zone contains only a small amount of volcanic detritus, but the sand grains are cemented by montmorillonite clay (identified by scanning electron microscope and microprobe analysis), indicating nearby volcanic activity (Mullen, 1987).

Indecision Creek Sandstone Member

The uppermost part of the Naknek Formation throughout most of the Alaska Peninsula is sandstone, which is here named the Indecision Creek Sandstone Member after a thick section measured on Indecision Creek in the Ugashik A-4 1:63,360 quadrangle. The Indecision Creek Sandstone Member is equivalent to the upper sandstone member mapped and described by Detterman and Reed (1980, p. B37) in the Kamishak Bay area. The sandstone was first recognized in the Mount Katmai area at the northeast end of the Alaska Peninsula by Keller and Reiser (1959), and it was made an informal member of the Naknek Formation by Detterman and Reed (1980). Recent work has shown that the Indecision Creek Sandstone Member is the most widespread unit of the Naknek Formation on the Alaska Peninsula; it is present along the entire 650-km length of Mesozoic exposures on the peninsula. The type section (section 9; fig. 9) of the Indecision Creek is here designated in secs. 35 and 36, T. 35 S., R. 49 W., Seward Meridian, Ugashik A-4 1:63,360 quadrangle; it is located on the east-facing slope of an unnamed mountain opposite Mount Chiginagak, beginning at the top of the ridge and continuing down to stream level. The predominantly sandstone sequence is fine grained, thin bedded to massive, locally crossbedded, and abundantly fossiliferous. The depositional environment for this member is interpreted to be shallow-water shelf to inner neritic. The lithology and depositional environment of the member are the same throughout the Alaska Peninsula, and there are only very minor differences in its sand-shale ratio throughout its outcrop area. Changes in the thickness of the member along the peninsula are due almost entirely to post-depositional erosion. The lower contact of the Indecision Creek with the Snug Harbor Siltstone Member is conformable and slightly gradational. The upper contact is in most places an unconformity overlain by Upper Cretaceous or Tertiary strata. In a few places, mainly in the Mount Katmai area and near Wide Bay, the Katolinat Conglomerate Member conformably overlies the Indecision Creek Sandstone Member. The abundant megafauna of the Indecision Creek is restricted almost exclusively to bivalves of the genus *Buchia*. Ammonites are extremely rare, which suggests that the unit does not represent an open-marine environment. Ammonites were free-swimmers and their presence normally indicates access to open-marine conditions.

Section 9. Type section of the Indecision Creek Sandstone Member of the Naknek Formation (fig. 9)

Chignik Formation
Unconformable contact
Indecision Creek Sandstone Member:

	Thickness (meters)
17. Sandstone, thin-bedded, fine-grained, yellowish-brown; yellowish-orange weathered zone at upper contact with Chignik Formation	27.4
16. Sandstone, thin-bedded, very fine grained, silty	39.6
15. Sandstone, medium-bedded, fine-grained, yellow-brown, micaceous; mottled	83.8
14. Sandstone, thick-bedded, fine-grained, greenish-gray; in part rubble; contains *Buchia blanfordiana* (M7696)	27.4
13. Covered interval	19.8
12. Sandstone, thin-bedded, fine-grained, grayish-green; plant debris common; contains *Buchia blanfordiana* and other bivalves (M7697 and M7698)	67.0
11. Sandstone, thick-bedded to massive, fine-grained, light- to dark-gray; laminated; contains *Buchia blanfordiana* (M7699 and M7700)	46.2
10. Covered interval	60.9
9. Sandstone, thin- to thick-bedded, very fine grained, light-green; low-angle crossbedding; contains fossils as in unit 11 (M7701)	39.6
8. Sandstone, medium-bedded, fine-grained, pale-yellow; herringbone current crossbeds; contains fossils as in unit 11 (M7702 and M7703)	45.7

Section 9. Type section of the Indecision Creek Sandstone Member of the Naknek Formation (fig. 9)—Continued

7. Sandstone, thin-bedded, very fine grained, pale-yellowish-brown; current crossbeds; mostly rubble	60.9
6. Sandstone, thin-bedded, very fine grained, silty; contains *Buchia blanfordiana*, *B. mosquensis*, and other bivalves (M7704)	39.6
5. Sandstone, thin-bedded, fine-grained, pale-greenish-yellow; contains *Buchia mosquensis* (M7705)	67.0
4. Porphyritic andesite sill	9.1
3. Sandstone, medium-bedded, fine-grained, greenish-yellow; plant debris; contains *Buchia mosquensis* (M7706)	67.0
2. Siltstone, thin-bedded, dark-gray	13.7
1. Sandstone, medium-bedded, medium-grained, medium-green; contains *Buchia mosquensis* (M7707 and M7708)	157.0
Total section	871.7

Conformable contact
Snug Harbor Siltstone Member

Katolinat Conglomerate Member

A thick conglomerate sequence is present in part as a lateral facies equivalent of the upper part of the Indecision Creek Sandstone Member in the northeastern part of the Alaska Peninsula. This sequence of conglomerate in the uppermost part of the Naknek Formation was recognized on Mount Katolinat by Keller and Reiser (1959, p. 270), but it was not investigated in detail or mapped separately by them. Recent studies have shown it to be a thick mappable unit in the northeastern part of the Alaska Peninsula. It also crops out over an area of a few square kilometers between Wide Bay and Imuya Bay. This conglomerate is a distinctive mappable unit that is exposed for about 100 km in the Mount Katmai 1:250,000 quadrangle, and we here name it the Katolinat Conglomerate Member after Mount Katolinat on the south shore of Iliuk Arm of Naknek Lake in the Mount Katmai B-5 1:63,360 quadrangle. The member forms the upper part of Mount Katolinat, as well as other mountains along its outcrop belt. A section, here designated as the type section of the Katolinat, was measured on an unnamed mountain on the northeast shore of Lake Grosvenor, Mount Katmai C-4 1:63,360 quadrangle (section 10; fig. 9). The section begins at peak 4470 in sec. 34, and continues southwest down the ridge into sec. 33, T. 17 S., R. 35 W. The upper part of the member at the type section forms vertical cliffs and was not measured, but because the rocks are nearly flat-lying the thickness estimate is believed to be reasonably accurate. At the type section the lower contact of the Katolinat is gradational with the Indecision Creek Sandstone Member. The

Section 10. Type section of the Katolinat Conglomerate Member of the Naknek Formation (fig. 9)

Top of exposed section	*Thickness*
Katolinat Conglomerate Member:	*(meters)*
12. Conglomerate, massive; contains sandstone lenses; not investigated but probably similar to underlying units	approximately 120
11. Conglomerate, massive, pebble-boulder, reverse-graded; maximum clast size 32 cm; clasts are 25 percent quartz and quartzite, 25 percent red chert, 20 percent granitic rocks, 10 percent schist and metalimestone, 5 percent gray chert; few coarse sandstone lenses	48.7
10. Sandstone, thin-bedded, medium- to coarse-grained, greenish-gray; crossbedded	3.6
9. Conglomerate, similar to unit 11	48.7
8. Sandstone, thin-bedded, medium- to coarse-grained, greenish-gray; thin conglomerate lens	12.1
7. Conglomerate, massive, cobble-pebble; well-rounded clasts; clasts are 25 percent quartz and quartzite, 25 percent granitic rocks, 20 percent metamorphic rocks, 10 percent volcanic rocks, 10 percent red chert, 10 percent gray chert; one schist boulder 4 m long	76.2
6. Sandstone, medium-bedded, coarse-grained, greenish-gray	9.1
5. Conglomerate, massive pebble-cobble	15.2
4. Sandstone, medium-bedded, coarse-grained with scattered pebbles, moderate yellowish-green; small-scale tabular crossbeds; contains *Buchia mosquensis* and *Corbicula* (M8350)	32.0
3. Sandstone, thin-bedded, medium-grained, light-olive-gray; lenses of pebbles	32.0
2. Conglomeratic sandstone, thin- to medium-bedded, medium-grained, light-olive-gray; crossbedded; contains *Buchia mosquensis* (M8351)	35.0
1. Sandstone and conglomerate, thin-bedded to massive, coarse-grained; fining upward; clasts are 60 percent chert, quartz, and quartzite, 20 percent granitic rocks, 10 percent metamorphic rocks, 10 percent volcanic rocks	22.8
Total exposed section	approximately 455.4
Conformable contact	
Indecision Creek Sandstone Member	

upper contact is not exposed here, but about 12 km north, the Herendeen Formation disconformably overlies the Katolinat Conglomerate Member.

The contacts between members of the Naknek Formation are gradational, and the formation probably represents nearly continuous deposition from the late Oxfordian through the Tithonian (Late Jurassic). This conclusion is based primarily on the *Buchia* zones of the Alaska Peninsula (Miller and Detterman, 1985). Lateral facies changes are common, so that the thickness of individual members may vary considerably within short distances. The contact between the Naknek Formation and the overlying Lower Cretaceous Staniukovich Formation is gradational. At Staniukovich Mountain (see fig. 10), strata containing *Buchia piochii* (late Tithonian, Late Jurassic) directly underlie strata containing *Buchia uncitoides* (Berriasian, Early Cretaceous). At many localities, however, Upper Cretaceous or Tertiary strata rest unconformably on the Naknek Formation.

Intrusive Rocks

Jurassic intrusive rocks are exposed west of the Bruin Bay fault and northeast of Becharof Lake (fig. 2). They form the major part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1969, 1972, 1973a, 1973b) that continues northeastward from the Alaska Peninsula, along the west side of Cook Inlet. The batholith is not exposed southwest of Becharof Lake, but it is present in the subsurface where several boreholes on the lowlands bordering Bristol Bay have penetrated Jurassic intrusive rocks (Brockway and others, 1975). Additionally, interpretation of aeromagnetic surveys (Case and others, 1981, 1988) indicates that the batholith is probably present in the subsurface throughout the lowlands southwest of Becharof Lake beneath a cover of surficial deposits and sedimentary rocks.

The Alaska-Aleutian Range batholith was formed by multiple intrusive events. The main part of the batholith was emplaced during the Jurassic and has been radiometrically dated between 155 and 176 Ma (Reed and Lanphere, 1969, 1972). Tertiary intrusive rocks, dated at between 25 and 36 Ma (Reed and Lanphere, 1969, 1972), are present within the batholith near the northeast end of the Alaska Peninsula, and Late Cretaceous intrusive rocks are present farther north.

Hornblende-biotite granodiorite constitutes most of the batholith on the Alaska Peninsula. Lesser amounts of quartz diorite and granite are present locally. Most of the rock is coarsely crystalline and weakly foliated to nonfoliated on the Alaska Peninsula. Metamorphosed roof pendants, whose precursors were presumably Upper Triassic and Lower Jurassic sedimentary and volcanic rocks, are fairly common near the northeast end of the peninsula.

We infer that the batholith was uplifted and subjected to erosion shortly after it solidified because it was the main source of sediments for the Naknek Formation, which is dated on faunal evidence at about 155 to 145 Ma. The batholith continued to be a major sediment source throughout the remainder of the Mesozoic and into the Tertiary.

Cretaceous System

Staniukovich Formation

The Staniukovich Formation was originally named the Staniukovich Shale by Atwood (1911, p. 38) for rocks exposed on Staniukovich Mountain, located on the peninsula between Herendeen Bay and Port Moller (Port Moller D-2, D-3 1:63,360 quadrangles). Atwood considered these rocks to be Early Cretaceous in age, although some of the fossils he listed from this area are now known to be Late Jurassic and may actually have been collected from the upper part of the Naknek Formation. Burk (1965) changed the name to Staniukovich "Formation," and included within this unit many more of the rocks exposed on the peninsula than had Atwood. A considerable part of the section included by Burk in his Staniukovich is here considered to be part of the Naknek Formation. During recent mapping on the Alaska Peninsula that followed Burk's lead (Detterman and others, 1981a, 1983), we experienced considerable difficulty in trying to separate the Naknek and Staniukovich Formations. In 1985, we sampled and measured Atwood's section on Staniukovich Mountain, and the source of the mapping problem immediately became apparent. The formation as defined by Atwood is a mappable unit, but as changed by Burk, it is not a mappable unit. Consequently, we here stratigraphically restrict the Staniukovich Formation to that part of the section composed of siltstone and shale with a few sandstone beds at the base (fig. 10); as so restricted, its age is Early Cretaceous. Thus, the formation conforms to the lithology as originally defined by Atwood (1911, p. 38). Some revisions of recently published maps are required as a result of returning to the original definition of the Staniukovich Formation. For example, in the Ugashik and Karluk 1:250,000 quadrangles (see Detterman and others, 1983, 1987a) all rocks mapped as the Staniukovich Formation are here reassigned to the Indecision Creek Sandstone Member of the Naknek Formation. This same reassignment holds for most of the Chignik-Sutwik Island area (see Detterman and others, 1981a). The only rocks that remain assigned to the Staniukovich Formation in the Chignik-Sutwik Island area are those occurring along the northwest side of the mountains bordering Chignik Bay, where a thin sequence of dark siltstone conformably overlies the Indecision Creek Sandstone Member and underlies the Herendeen Formation.

The section on Staniukovich Mountain (section 11; fig. 10), which Atwood (1911) designated as the type section of the Staniukovich Formation, is located in sec. 30, T. 50 S., R. 73 W., Port Moller D-2 1:63,360 quadrangle. It begins about 400 m northwest of the peak and continues northwest along the ridge for about 1,000 m. The lower part of this 246-m-thick section consists of light-olive-gray siltstone with two light-olive-brown sandstone intervals. The upper part of the section is composed of thin-bedded to shaly olive-gray siltstone containing numerous limestone nodules and concretions. The concretions commonly formed around belemnite and bivalve fossil fragments, including, in rare cases, *Inoceramus* prisms. The rocks of the upper part of the section are very soft and typically form saddles along ridge lines rather than good exposures. An abundant megafauna, consisting mainly of the bivalve *Buchia*, is present in the sandy intervals in the lower part of the formation. *Buchia uncitoides* of Berriasian (Early Cretaceous) age occurs throughout the lower part as high as

Section 11. Type section of the Staniukovich Formation at Staniukovich Mountain (fig. 10)

Herendeen Formation
Conformable contact

	Thickness (meters)
Staniukovich Formation:	
5. Siltstone and shale, shaly to thin-bedded, light-olive-gray; numerous irregularly shaped limestone concretions containing belemnite and bivalve fragments, including rare *Inoceramus* prisms (M8214)	120.0
4. Sandstone, medium- to thick-bedded, medium- to coarse-grained, light-olive-brown; quartz rich; layer of pebbles at top; contains abundant *Buchia crassicollis solida* (M8213)	32.0
3. Siltstone with thin sandstone interbeds, light-olive-gray, contains *Buchia uncitoides*	30.4
2. Sandstone, medium- to thick-bedded, medium-grained, light-olive-brown; contains *Buchia uncitoides* (M8212)	9.1
1. Siltstone, thin-bedded, light-olive-gray; contains *Buchia uncitoides* (M8211)	54.8
Total section	246.3

Conformable contact
Naknek Formation

the base of the second sandstone unit. The second sandstone unit is about 30 m thick, medium to coarse grained, and rich in quartz. Large, thick-shelled *Buchia crassicollis solida* of Valanginian (Early Cretaceous) age occurs throughout this sandstone. The only identifiable megafossil from the siltstone of the upper part of the section is the bivalve *Pleuromya*, which is of little value for age determinations as it is a long-ranging genus.

The Staniukovich Formation is well exposed near the northeast end of the Alaska Peninsula in the Mount Katmai B-2, B-3, and B-4 1:63,360 quadrangles. The formation in the Mount Katmai area is comparable in thickness to the type section at Staniukovich Mountain, but it contains three thick sandstone units rather than the two present in the type section. The three sandstone units contain low-angle crossbeds that are considered to represent stacked offshore or barrier bars. The units are abundantly fossiliferous, but contain only the bivalve *Buchia uncitoides*. Siltstone with thin interbeds of sandstone is present between the thick offshore sandstone units.

The contacts of the Staniukovich Formation with both the underlying Naknek Formation and the overlying Herendeen Formation are conformable at the type section. A minor diastem may be represented within the Staniukovich by a thin layer of pebble conglomerate that occurs at the top of the upper sandy unit underlying the thick siltstone part of the section. In the Mount Katmai area, the Staniukovich Formation unconformably overlies the Naknek Formation and is in turn unconformably overlain by the Herendeen Formation. Locally in the Mount Katmai area, the Herendeen Formation lies directly on the Naknek Formation.

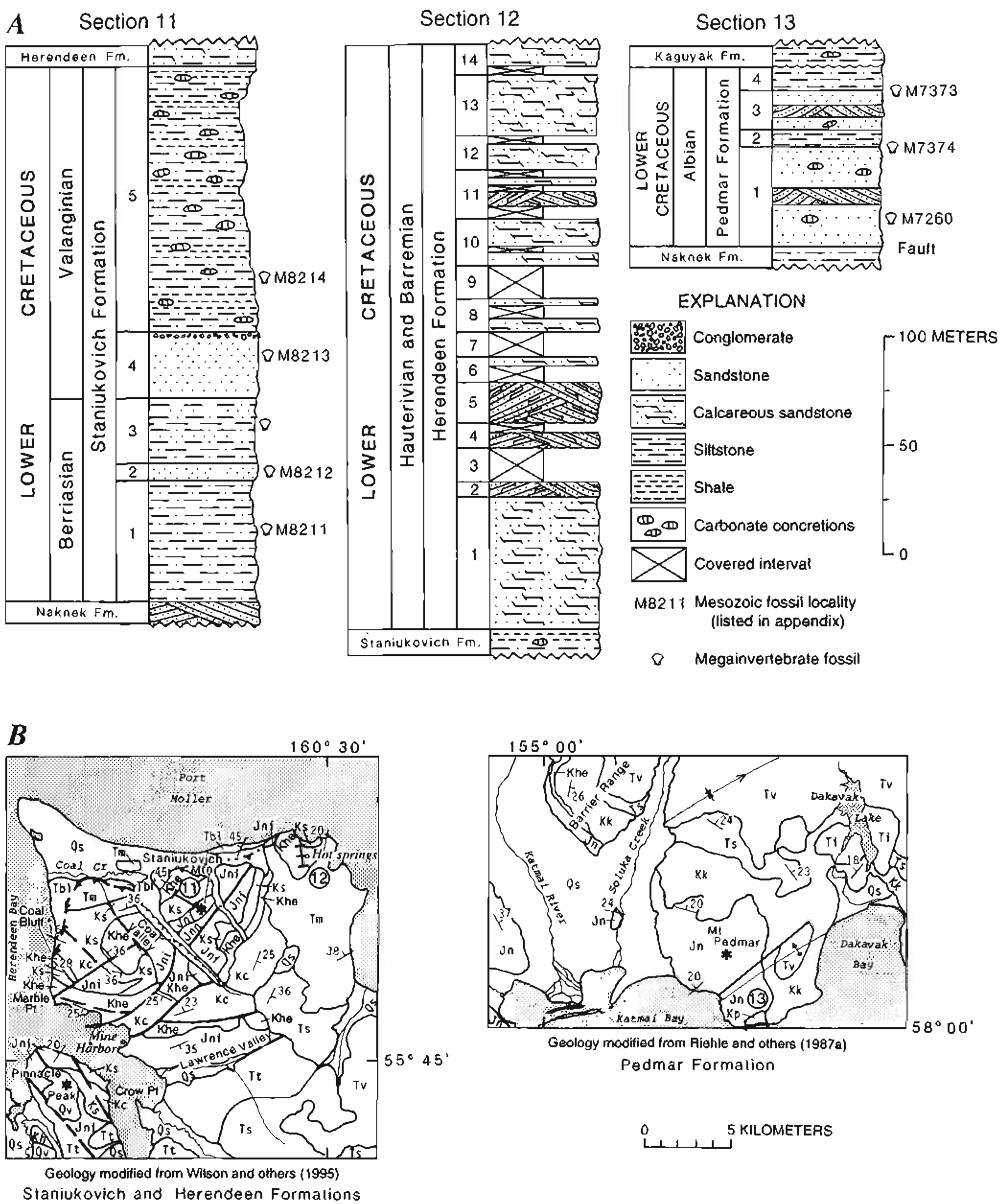


Figure 10. Lower Cretaceous formations, Alaska Peninsula. *A*, Type sections of Staniukovich and Pedmar Formations and reference section of Herendeen Formation. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols.

Herendeen Formation

Atwood (1911, p. 39) proposed the name "Herendeen Limestone" for about 800 ft of what he described as light-gray arenaceous limestone exposed along the east shore of Herendeen Bay, north of Coal Harbor (Mine Harbor) and near Marble Point in the Port Moller D-2 and D-3 1:63,360 quadrangles. However, these rocks are not limestone, but rather calcareous sandstone. We, therefore, here redefine this unit as the Herendeen "Formation" and designate a reference section (section 12) for the Herendeen in the low hills directly southwest of the hot springs in sec. 14, T. 50 S., R. 73 W., Port Moller D-2 1:63,360 quadrangle. The reference section begins about 1,000 m southwest of the hot springs and continues across the low ridges for about 1 km (fig. 10). The conspicuous light-gray color of the rocks makes the section readily apparent.

The reference section at the hot springs is 270 m thick. The strata are uniform in composition and are mainly thin-bedded, medium-grained calcareous sandstone, dusky yellow to pale yellowish brown on fresh surfaces, and light gray and yellowish gray on weathered surfaces. The rocks have a distinct platy fracture. Tabular crossbedding is common throughout the section, but is developed best in the lower part of the section. Nearly all of the rocks have a strong petroliferous odor when freshly broken. The yellowish cast of the rocks suggests oil staining, but this has not been checked.

In thin section, rocks from throughout the Herendeen Formation are remarkably uniform in composition. Fifteen thin sections were examined. The average composition is as follows: quartz, 25 percent; feldspar, mainly plagioclase, 13 percent; lithic fragments, mainly volcanic rocks, 4 percent; biotite, 7 percent; bioclastic grains, mainly *Inoceramus* prisms and shell fragments, 35 percent. The remaining 16 percent is composed of accessory minerals and cement. The grains are angular to subangular and in the fine to medium (0.125–0.264 mm) range. The biotite is fresh; its presence gives the light-colored rocks a speckled appearance. The sandstones are moderately clean, and the possible oil staining suggests good porosity; however, the porosity of the unit has not been measured.

Prisms and shell fragments of *Inoceramus* form a major part of the rocks, but complete specimens have not been found in the Herendeen Bay-Port Moller area. The Herendeen Formation in the Mount Katmai area, near the northeast end of the Alaska Peninsula, has yielded numerous complete specimens of *Inoceramus ovatoides* as well as prisms and shell debris; it also contains the ammonites *Acrioceras* and *Hoplocrioceras* and the belemnite *Acroteuthis* (Jones and Detterman, 1966). These fossils permit an age determination of Hauterivian and Barremian (Early Cretaceous) for the Herendeen Formation.

The Herendeen Formation in the Mount Katmai area is composed of nearly 50 percent siltstone and shale that are interbedded with the calcareous sandstone. This composition suggests that these rocks were deposited in somewhat deeper water than the high-energy deposits in the Port Moller area. The occurrence of numerous complete *Inoceramus* shells, rather than only shell fragments, and the association with ammonites also suggest a deeper water depositional environment for the formation in the Mount Katmai area than in the Port Moller area.

The contact of the Herendeen with the underlying Staniukovich Formation is conformable in the type section and is placed at the base of the lowest resistant calcarenaceous sandstone bed. However, in the Mount Katmai area the Herendeen unconformably overlies both the Naknek Forma-

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Section 12. Reference section of the Herendeen Formation (fig. 10)

	Thickness (meters)
Top of exposed section	
Herendeen Formation:	
14. Calcareous sandstone, thin-bedded, medium-grained, yellowish-gray; contains abundant *Inoceramus* prisms; covered interval at base	12.8
13. Calcareous sandstone, thick-bedded, medium-grained, yellowish-gray; few chert pebbles at base; contains *Inoceramus* prisms; strong petroliferous odor	30.5
12. Calcareous sandstone, thick-bedded, fine-grained, dusky-yellow; contains *Inoceramus* prisms; strong petroliferous odor; covered interval at top	15.1
11. Calcareous sandstone; thin-bedded, fine-grained, moderate-olive-brown; low-angle tabular cross-beds; contains *Inoceramus* prisms; partly covered	21.3
10. Calcareous sandstone, thin- to thick-bedded, moderate-olive-brown; tabular crossbeds; contains *Inoceramus* prisms; petroliferous odor	22.8
9. Covered interval	5.2
8. Calcareous sandstone, thin-bedded, fine-grained; contains few *Inoceramus* prisms	15.2
7. Covered interval	12.2
6. Calcareous sandstone, thin-bedded, fine-grained; poorly exposed and partly covered	11.4
5. Calcareous sandstone, thin- to thick-bedded, fine-grained, pale-yellowish-brown; high-angle cross-beds; contains *Inoceramus* prisms; strong petroliferous odor	18.2
4. Calcareous sandstone, shaly to thin-bedded, fine-grained, light-olive-brown; crossbedded; contains *Inoceramus* prisms	12.2
3. Covered interval	15.2
2. Calcareous sandstone, thin-bedded, fine-grained, pale-yellowish-brown; wavy crossbedding; contains *Inoceramus* prisms; petroliferous odor	7.6
1. Calcareous sandstone, shaly to thin-bedded, fine-grained; layer of chert grit in middle; contains *Inoceramus* prisms	60.9
Total exposed section	270.6
Conformable contact	
Staniukovich Formation	

tion and the Staniukovich Formation. The upper contact of the Herendeen is a major unconformity throughout the Alaska Peninsula. The formation has been completely stripped away along most of the peninsula. Where still present, it is generally overlain by Upper Cretaceous (Campanian and Maestrichtian) rocks. Albian (Lower Cretaceous) rocks are present locally in the Mount Katmai area, where they disconformably overlie the Herendeen Formation.

Pedmar Formation

A thin sequence of Lower Cretaceous (Albian) rocks was discovered in 1979 in seacliffs along Katmai Bay (Petering and Smith, 1981; Miller and others, 1982). We here name this unit the Pedmar Formation after Mount Pedmar, which dominates this part of the coastline in the Mount Katmai A-3 1:63,360 quadrangle. The type section of the unit (section 13) is designated as the exposures in the seacliff along the north edge of sec. 24, T. 25 S., R. 34 W., Mount Katmai A-3 1:63,360 quadrangle, beginning at the northeast corner of the section and continuing west along the cliff for about 760 m (fig. 10).

Section 13. Type section of the Pedmar Formation (fig. 10)

Kaguyak Formation
Disconformable contact

	Thickness (meters)
Pedmar Formation:	
4. Siltstone, thin-bedded, olive-gray	10
3. Sandstone, thick-bedded, fine- to medium-grained, light-olive-gray to greenish-gray; few limy concretions; in part crossbedded; contains *Marshallites cumshewaensis* (M7373)	18
2. Siltstone, thin-bedded, olive-gray	7
1. Sandstone, medium- to thick-bedded, fine- to medium-grained, olive-gray; middle part cross-bedded; few large limy concretions; plant debris common; few chert pebbles; contains *Desmoceras (Pseudoughligella) dawsoni*, *Turrilites*(?), and *Mesopuzosia* (M7374 and M7260)	47
Total section	82

Fault
Naknek Formation

The type section of the Pedmar Formation is about 82 m thick (fig. 10) and consists mainly of thick-bedded, fine- to medium-grained, gray to olive-gray sandstone. Abundant carbonaceous debris is present throughout, and a few pebbles as large as 4 cm are found in its middle part, which also contains tabular crossbeds. A few large calcareous sandstone concretions occur near the base. Two poorly exposed siltstone and shale units are present in the upper part of the formation. The contact of the Pedmar with the overlying Kaguyak Formation is a disconformity. The lower contact in the type section is a fault contact with the Naknek Formation. Another section of the Pedmar Formation, 88 m thick, was measured 42 km north of the type section on an unnamed mountain peak above an unnamed lake east of Ikagluik Creek (Mount Katmai B-3 1:63,360 quadrangle). This section, composed of mainly siltstone with sandstone interbeds, disconformably overlies the Herendeen Formation.

Ammonites are found throughout the type section of the Pedmar Formation, including *Desmoceras* (*Pseudoughligella*), *Marshallites*, *Calliphylloceras*, and *Turrilites*. These ammonites indicate a correlation with strata of late Albian age in the Chitina Valley of the southern Wrangell Mountains (Jones, 1967, p. 4) and in British Columbia (McLearn, 1972). The section near Ikagluik Creek did not produce ammonites, but does contain abundant *Aucellina* sp., also indicating an Albian age for the rocks. A single specimen of the ammonite *Grantziceras* sp. (Albian) was obtained in the Port Moller area from a sequence of sandstone and siltstone. Unfortunately, the same field locality number was given to two sandstone and siltstone sequences 25 km apart. Both localities were revisited, but no more fossils were found. Consequently, we know that rocks equivalent in age to the Pedmar are present in the Port Moller quadrangle, but we are not currently able to map the formation there as we do not know which locality the fossil came from. One of the localities is on the south shore of Port Moller 2.75 km west of the hot springs. The other is on a ridgetop south of Buck Valley and 5.6 km west of the head of Herendeen Bay.

Chignik Formation

The Chignik Formation was named by Atwood (1911, p. 41–48), who designated a type section on Whalers Creek (see fig. 11), secs. 9 and 10, T. 45 S., R. 60 W., Chignik B-2 1:63,360 quadrangle. Atwood included within the unit the coal-bearing rocks along Herendeen Bay that had been described as Late Cretaceous in age by Paige (1906). Burk (1965, p. 50) referred the lower nonmarine coal-bearing part of the Chignik, exposed at Herendeen Bay, to his Coal Valley Member of the Chignik Formation. The type locality of the member was given as the hills above Coal Valley, southeast of Staniukovich Mountain (fig. 10*B*; Burk, 1965, p. 50). Recent detailed studies of the Chignik Formation have shown that the formation is a cyclic nearshore marine, tidal flat, and nonmarine floodplain and fluvial deposit (Fairchild, 1977; Detterman, 1978) in which the nonmarine sequence is present at different positions within the formation. Consequently, we believe that the designation of the Coal Valley Member as the basal part of the Chignik Formation is not correct, and we do not use it herein. The Coal Valley Member is a useful mapping unit only on the peninsula between Port Moller and Herendeen Bay, where it forms the basal part of the Chignik Formation. Elsewhere, nonmarine coal-bearing rocks are found at different stratigraphic levels within the Chignik Formation, and therefore the Coal Valley Member should not be considered the basal part of the Chignik Formation everywhere the Chignik occurs.

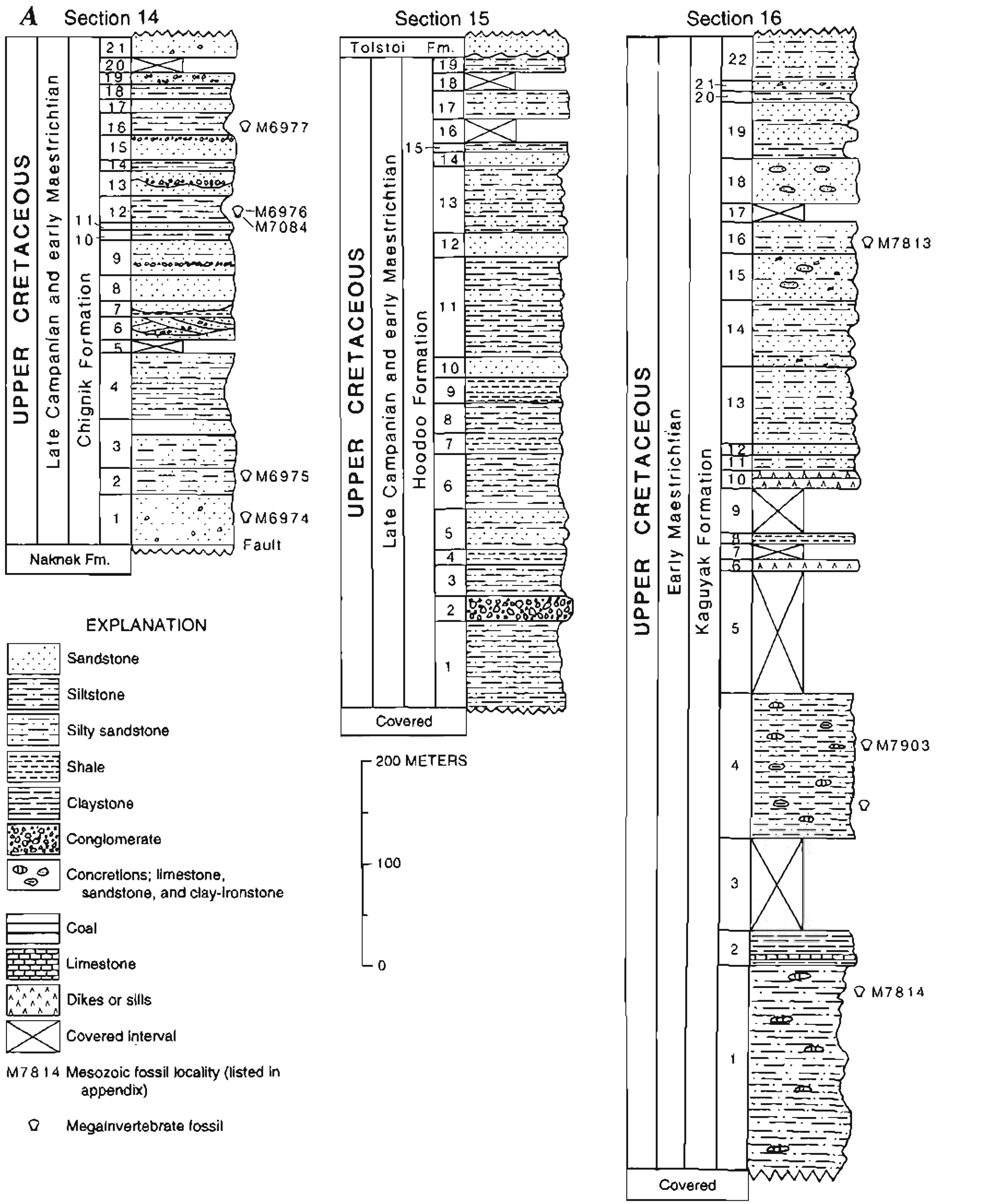
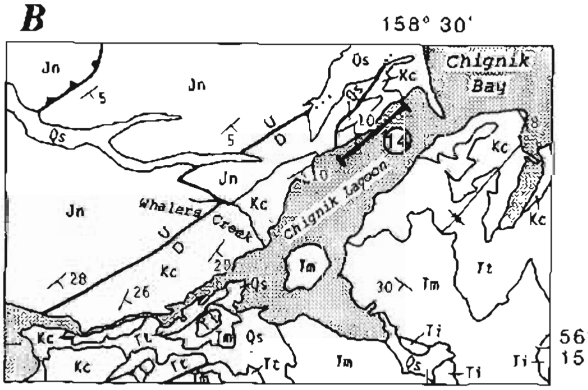


Figure 11. Upper Cretaceous formations, Alaska Peninsula. *A*, Type section of Kaguyak Formation and reference sections of Hoodoo and Chignik Formations. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols.

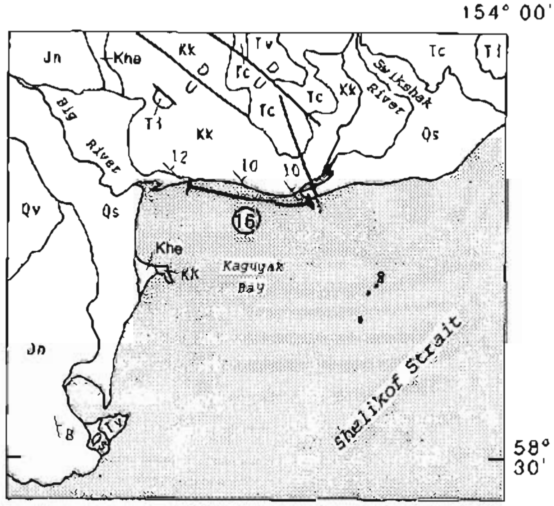
The Chignik Formation has its greatest thickness (500 to 600 m) in the area between Port Moller and Chignik Bay. This is the area that contains tongues of nonmarine coal-bearing strata mapped by Burk (1965) as his Coal Valley Member. The formation thins rapidly both northeast and southwest from this area and becomes entirely marine. The massive units of pebble-cobble conglomerate and coarse-grained sandstone interbedded with carbonaceous shale, coal, and siltstone on the peninsula between Port Moller and Herendeen Bay indicate that the area was part of a fluvial deltaic system adjacent to a source area northwest of the peninsula. It should be mentioned that we here consider the volcaniclastic sequence exposed at Coal Bluff, on the east shore of Herendeen Bay, to be unassigned Tertiary strata rather than the Coal Valley Member of the Chignik Formation as mapped by Burk (1965). This is an important exposure that, owing to its ready accessibility on the shore of the bay, is often investigated by persons studying the geology of the Alaska Peninsula. Much of the shoreline of the Port Moller-Herendeen Bay peninsula, as well as the west shore of Herendeen Bay, consists of deformed Tertiary sedimentary rocks. The mountains west of Herendeen Bay, and those on the peninsula along the east side of the bay, are underlain mainly by Mesozoic sedimentary rocks. We consider the Mesozoic rocks to be part of the upper plate of a low-angle thrust fault that has placed them over the deformed Tertiary sequence on the shore of the bay (Wilson and others, 1995). An inspection of the Coal Bluff section (Fairchild, 1977) shows that it is richer in volcaniclastic rocks than exposures of the Chignik Formation a few kilometers distant, whereas it is similar to nearby volcanic-rich sedimentary rocks of Tertiary age.

The type section of the Chignik Formation was established on Whalers Creek, one-half mile from the shore of Chignik Lagoon, by Atwood (1911, p. 41). A slightly thicker and more accessible section along the shore of Chignik Lagoon is here designated as a reference section (section 14) for the unit. The reference section, which is located along the northwest shore of Chignik Lagoon in secs. 24, 26, and 34, T. 44 S., R. 59 W., Chignik B-2 1:63,360 quadrangle, begins at Boomer Cove and continues northeast along the shore for 3.7 km (fig. 11). This section is 490 m thick; it consists of nearshore sandstone and siltstone and two intervals of flood-plain and fluvial deposits. Coal and carbonaceous shale are present in the nonmarine parts of the section, and some of the sandstone is oil stained (Keller and Cass, 1956). Marine fossils, mainly the bivalves *Inoceramus balticus* var. *kunimiensis* and *I. schmidti* and the ammonite *Canadoceras newberryanum*, indicate a late Campanian to early Maestrichtian (Late Cretaceous) age for the Chignik Formation.

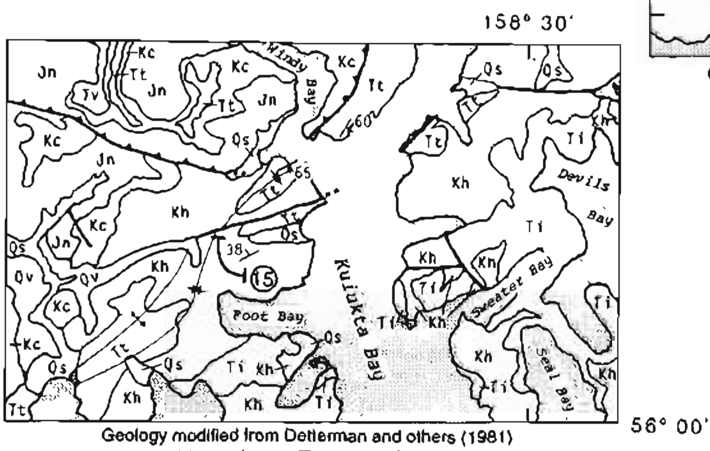
B



Geology modified from Detterman and others (1981)
Chignik Formation



Geology modified from Riehle and others (1987a)
Kaguyak Formation



Geology modified from Detterman and others (1981)
Hoodoo Formation

0 5 KILOMETERS

Section 14. Reference section of the Chignik Formation (fig. 11)

Top of exposed section	*Thickness*
Chignik Formation:	*(meters)*
21. Sandstone, massive, fine-grained, light-olive-gray; few scattered pebbles; micaceous	19.8
20. Covered interval	15.2
19. Sandstone, massive, fine-grained, light-olive-gray; conglomeratic	13.7
18. Siltstone, thin-bedded, olive-black; bioturbated	12.2
17. Sandstone, thick-bedded, light-olive-gray	10.8
16. Siltstone, thin-bedded, olive-black; contains *Inoceramus* (M6977)	24.4
15. Sandstone, medium-bedded, fine-grained, dark-greenish-gray; ripple marks; conglomerate bed at top	21.3
14. Siltstone, thin-bedded, olive-gray	9.1
13. Sandstone and conglomerate, medium-bedded, greenish-gray; channeled and crossbedded	24.4
12. Siltstone, thin-bedded, medium-dark-gray; micaceous; contains *Canadoceras newberryanum* and *Inoceramus schmidti* (M6976 and M7084)	24.4
11. Sandstone and conglomerate, massive	4.5
10. Siltstone, thin-bedded, medium-dark-gray	18.3
9. Sandstone, silty, and conglomerate, medium-bedded, greenish-gray; micaceous; oil stained	33.4
8. Sandstone, thin-bedded, medium-grained, medium-gray	27.4
7. Sandstone, thin-bedded; channeled into black carbonaceous shale	14.7
6. Sandstone, conglomeratic, medium-bedded, medium- to coarse-grained olive-gray; tabular crossbeds; oil-stained	21.3
5. Covered interval	12.1
4. Siltstone, thin-bedded, dark-yellowish-brown	62.5
3. Sandstone, thin-bedded, fine-grained, moderate-yellowish-brown; silty; carbonaceous, thin coal seams	42.6
2. Sandstone, medium-bedded, fine-grained; contains *Inoceramus balticus* and *I. schmidti* (M6975)	21.3
1. Sandstone, medium- to thick-bedded, fine-grained, light-gray; few pebbles; contains *Anomia* and *Calva* (M6974)	57.3
Total exposed section	490.7
Fault	
Naknek Formation	

The 490-m-thick reference section of the Chignik Formation is incomplete; it is in fault contact with the underlying Naknek Formation, and its top is an erosional surface. The lower contact of the Chignik Formation is a major unconformity that represents a considerable part of Cretaceous time. The Chignik commonly overlies the Naknek Formation, but it may locally overlie either the Herendeen or Staniukovich Formation. There is only a minor structural discordance between the Chignik and underlying rocks; bedding attitudes generally differ by no more than a few degrees. The Alaska Peninsula must have been fairly stable tectonically during the 45 to 75 m.y. represented by the missing strata. The upper contact of the Chignik is also an unconformity in most localities, where the Tolstoi Formation of late Paleocene to early middle Eocene age overlies the Chignik Formation with only minor discordance. Locally the Chignik is in contact with the Hoodoo Formation, which is, in part, the age equivalent of the Chignik and is generally considered to be a deep-water lateral facies equivalent of the Chignik rather than an overlying unit.

Hoodoo Formation

The Hoodoo Formation was named by Burk (1965, p. 59) for the black-siltstone and shale flysch unit at the top of the Cretaceous sequence on the Alaska Peninsula. The type section of the unit is located north of Beaver Bay (fig. 5), along the southeast side of Hoodoo Mountain and the west side of the upper Beaver River valley (Port Moller C-3 1:63,360 quadrangle), where Burk reported 2,000 to 3,000 ft of section (1965, p. 59). A structurally uncomplicated section of the Hoodoo has not been located; its strata are commonly folded and probably repeated by faulting. A partial section, 630 m thick, was measured on a ridge north of Foot Bay (Chignik A-3 1:63,360 quadrangle) and is here designated as a reference section (section 15). The section begins at the southwest corner of sec. 30 and continues south along the west border of sec. 31, T. 47 S., R. 60 W. (fig. 11).

Section 15. Reference section of the Hoodoo Formation (fig. 11)

Tolstoi Formation	
Unconformable contact	*Thickness*
Hoodoo Formation:	*(meters)*
19. Siltstone and sandstone, thin-bedded, olive-black; sandstone laminated; convolute bedding common	15.2
18. Covered interval	15.2
17. Siltstone and sandstone, thin-bedded, olive-gray; pencil fracture in siltstone	30.4
16. Covered interval	25.9
15. Siltstone, thin-bedded	7.6
14. Sandstone, medium- to thick-bedded, fine-grained, medium-gray; laminated, graded	12.2
13. Siltstone and sandstone, thin- to thick-bedded, fine-grained, olive-gray; laminated, graded; convolute bedding common	64.0
12. Sandstone, thick-bedded, fine-grained, brownish-gray; laminated	24.3
11. Siltstone and shale, shaly to thin-bedded, olive-gray; pencil fracture	97.5
10. Sandstone, massive, fine-grained, light-brownish-gray	16.7
9. Shale, olive-gray	27.4
8. Siltstone, thin-bedded, olive-gray	25.9
7. Shale, olive-black; pencil fracture	22.8
6. Siltstone, thin-bedded; convolute lamination	53.3
5. Sandstone and siltstone, thin- to thick-bedded, olive-gray to olive-black; laminated and graded	36.5
4. Shale, olive-black	15.2

Section 15. Reference section of the Hoodoo Formation (fig. 11)—Continued

3. Siltstone, thin-bedded, olive-gray; plant debris	30.4
2. Conglomerate, massive, pale-brown; chaotic; clasts of chert, quartz, siltstone, and shale	24.4
1. Siltstone, thin-bedded, olive-gray; laminated; well-developed cleavage	85.3
Total exposed section	630.2

Base of exposed section

The Hoodoo Formation may be considerably thicker than the 630 m measured at the reference section, but complex folding and faulting and the absence of good marker beds make it impossible to ascertain the formation's true thickness. A bore-hole (Pure Oil Company #1 Canoe Bay) at Canoe Bay (Port Moller C-4 1:63,360 quadrangle, sec. 8, T. 54 S., R. 78 W.) drilled 2,024 m (6,640 ft) entirely within the Hoodoo Formation. The section in this borehole was probably repeated several times by faulting, but the exact positions of the faults are difficult to ascertain.

The Hoodoo Formation is thicker and more continuously exposed between Pavlof Bay and Chignik Bay than elsewhere on the Alaska Peninsula. The northernmost good exposures are at Amber Bay (fig. 5). Nearly all exposures border or are within a few kilometers of the Pacific Ocean coast of the Alaska Peninsula. The thickest part of the Hoodoo Formation, and the part containing the most sandstone and conglomerate, is located between Pavlof Bay and Herendeen Bay. This part of the Hoodoo is southwest of the thickest part of the partially coeval Chignik Formation, and its location is evidence that the source for the two formations was to the northwest and that a deep basin lay adjacent to the fluvial plain on which the Chignik Formation was deposited.

The lower contact of the Hoodoo Formation is not exposed at the reference section, nor is it exposed at the type section. In the Chignik Bay area the Hoodoo Formation is seen to overlie the Chignik Formation with apparent conformity. Some investigators (Mancini and others, 1978; Molenaar, 1980) consider the Hoodoo Formation to be a deep-water lateral facies equivalent of the Chignik Formation. On the basis of our investigation of the two formations, we conclude that they were formed during a major Late Cretaceous marine transgression and that they represent two distinct facies of the same time-stratigraphic interval. The contact between the Hoodoo and Chignik Formations should be considered gradational. Continued deposition during subsidence of the basin suggests that the uppermost part of the Hoodoo Formation may be slightly younger than the upper part of the Chignik Formation.

The lower part of the Hoodoo Formation consists mainly of dark-gray to black, thin-bedded siltstone that fractures in pencil-shaped splinters. Subordinate, thin interbeds of fine-grained sandstone are present at regular intervals. The sequence becomes more sandy upward, and the upper part of the formation contains medium-bedded, fine-grained sandstone units as much as 60 m thick. Chert-pebble lag gravel is present near the tops of some beds. Siltstone and shale rip-up clasts are common in most sandstone beds. Clasts in the conglomeratic units become larger and more numerous upward in the section. Most are well rounded and less than 15 cm in diameter, but a few reach 0.5 m in diameter. Clasts include volcanic and plutonic rocks as well as chert and quartz.

Deposition of the Hoodoo Formation is attributed to submarine slumps and turbidity currents. The predominantly thin-bedded siltstone and thin, regularly spaced sandstone intervals in the lower part of the unit were probably deposited on the lower slope of a submarine fan. Both siltstone and sandstone are finely laminated locally, and rip-up clasts are common in the sandstone beds, but other sedimentary structures characteristic of turbidites are missing. The splintery fracture of the siltstone possibly has obliterated other features. The thick sandstone and conglomerate units in the upper part of the formation are interpreted as submarine fan build-ups, locally including upper-fan deposits. The sand beds are broadly lenticular and graded, and they contain flute and load casts; the lag gravels are interpreted as inner-fan channel deposits.

Marine megafossils are present, but sparse, throughout the formation; they are somewhat more abundant in the upper part. *Inoceramus schmidti*, *I. balticus*, and *I. vancouverensis* are found throughout the formation. Ammonites including *Diplomoceras notabile*, *Neophylloceras hetonaise*, and *Canadoceras newberryanum* are found mainly in the upper part of the formation. These megafossils indicate a late Campanian to early Maestrichtian (Late Cretaceous) age for the Hoodoo Formation, which is approximately the age of the Chignik Formation. However, the two formations have different faunal assemblages and therefore may not be exact age equivalents. *Canadoceras*, *Inoceramus schmidti*, and *I. balticus* are found mainly in the Chignik, whereas *Diplomoceras* and the other *Inoceramus* species are restricted to the Hoodoo and correlative rocks. Additional evidence that the Hoodoo is in part younger than the Chignik Formation is seen at several localities in the Chignik area where the Hoodoo Formation conformably overlies the Chignik Formation. Of course, another possible interpretation is that the different faunal assemblages were coeval and their distribution patterns were governed by depositional environments.

In structurally complex areas, the dark siltstone of the Hoodoo Formation is extremely difficult to differentiate from similar-appearing dark siltstone in the overlying Tolstoi Formation (upper Paleocene to middle Eocene) or in the lower part of the herein-adopted Stepovak Formation of Burk (1965) (upper Eocene and lower Oligocene). There are a few distinguishing features, however, in each of these units. The Hoodoo tends to fracture into pencil-shaped splinters or small chips more commonly than either of the other units; siltstone in the Tolstoi commonly contains abundant plant debris and complete leaves; small concretions in the siltstone of the Stepovak generally contain small glendonite crystals and are typically brownish black.

The upper contact of the Hoodoo with the Tolstoi Formation in the Port Moller area is structurally conformable. The oldest flora (Paleocene) in the lowermost part of the Tolstoi is found only where the Tolstoi overlies the Hoodoo in the Pavlof Bay-Port Moller area. Likewise, the Hoodoo Formation contains its youngest (early Maestrichtian) megafauna in this same area. The contact between the formations in this area is probably a disconformity. From Chignik northeastward, the contact between these same units is unconformable.

The Hoodoo Formation is, at least in part, the age equivalent of other Late Cretaceous flysch deposits on or near the Alaska Peninsula; these deposits are the Kaguyak, Kodiak, and Shumagin Formations. Faunal remains are sparse in all these formations owing to the deep-water depositional environment that they represent; the few fossils collected from them indicate a Late Cretaceous (Campanian to Maestrichtian) age for each of the units.

Shumagin Formation

The Shumagin Formation was named by Burk (1965) for the Cretaceous flysch deposits on the outer Shumagin Islands, particularly Nagai and Big Koniuji Islands, and the small islands between them (fig. 5). The least disturbed sequence occurs at Falmouth Harbor on the west side of Nagai Island, and these rocks were termed "typical exposures" of the unit by Burk (1965, p. 64); Moore (1974a) designated this area as the type area of the formation. The highly contorted deep-water turbidites are intruded by a granodiorite batholith dated at 57.4 to 65.6 Ma (Burk, 1965; Moore, 1974a; Kienle and Turner, 1976, recalculated using constants of Steiger and Jäger, 1977). A considerable amount of detailed stratigraphic and structural information about these rocks was obtained by Moore (1973, 1974a, 1974b). During the course of our investigations on the Alaska Peninsula and offshore islands, we have not added much new data on the Shumagin Formation. However, we have obtained additional megafauna collections, samples for K-Ar determinations, and samples for thin-section analysis.

The Shumagin Formation consists of interbedded graywacke, siltstone, mudstone, and shale at least 3,000 m thick (Burk, 1965). The dark-gray sandstone, mostly lithic graywacke, ranges from beds 2 cm thick to massive units 20 m thick. Most beds are graded and contain abundant shale and siltstone chips. Their contacts with underlying siltstone and shale units are sharp, but their upper contacts with overlying fine clastic units are gradational. Convolute bedding is common, and the bases of many beds contain abundant flute and load casts as well as drag and prod marks. These features are all commonly associated with turbidite deposition. The thick to massive sandstone units pinch and swell abruptly along strike, and were probably deposited as deep-sea fans. The thin-bedded, very fine to fine-grained sandstone units are rhythmically interbedded with the siltstone, and both their upper and lower contacts are sharp. Bed thickness is uniform. These sandstone and siltstone interbeds are characteristic of abyssal plain deposits.

In many cases it is extremely difficult to identify tops and bottoms of beds. However, on a large scale the rhythmically bedded abyssal plain sequence is the lowest part of the Shumagin Formation and is overlain by the submarine fan sequence composed of more massive sandstone units. There are no exposed contacts with other sedimentary units. The only exposed contact is with the Shumagin batholith, which has altered the sedimentary rocks to hornfels near its contacts.

Megafaunal remains are extremely rare in the Shumagin Formation, and most were probably deposited by the turbidity currents. *Inoceramus kusiroensis* is the most common bivalve; many were found along bedding planes with both valves attached and in an open position. Jones and Clark (1973, p. 134) suggested that this species of *Inoceramus* may have had a pseudoplanktonic habit in nearshore water. Upon the death of the animal, its shell would open and sink to the bottom. One collection also contains *Inoceramus* cf. *I. shikotanensis* and *Terebellina palachii*, a marine worm. These fossils indicate an early Maestrichtian age; thus the Shumagin Formation is age equivalent to the upper parts of the Hoodoo and Kaguyak Formations. The Shumagin Formation was deposited farther offshore than either of those formations; it was deposited at or near the paleo-Aleutian trench. Thin-section analysis of sandstone samples from the Shumagin suggests that it has a major lithic component similar to the Kodiak Formation on Kodiak Island and a minor lithic component similar to the Hoodoo Formation. This composition suggests that most of the sediments that make up the Shumagin were transported from the northeast along the axis of the paleo-Aleutian trench (John Decker, oral commun., 1985). The source areas for the Hoodoo and Kaguyak Formations were located on the Alaska Peninsula.

Kaguyak Formation

The Kaguyak Formation was named by Keller and Reiser (1959) for the sequence of rocks of Late Cretaceous age exposed in seacliffs along the shore of Kaguyak Bay between the Swikshak and Big Rivers (Afognak C-6 1:63,360 quadrangle) (fig. 11). These rocks had been described earlier by Martin (1926) and Hazzard and others (1950) but had not been named. This sequence of rocks was remeasured and described by Detterman and Miller (1985) as part of the Upper Cretaceous flysch sequence in southern Alaska. The formation is mapped only in the northeastern part of the Alaska Peninsula, from Katmai Bay northeastward to Kamishak Bay.

The type section in the seacliffs (section 16) begins at the mouth of the Swikshak River and continues westward along the cliffs for about 5 km in secs. 19 and 20, T. 18 S., R. 27 W., and secs. 13 and 14, T. 18 S., R. 28 W., Afognak C-6 1:63,360 quadrangle. Additionally, beds at the base of the formation on a narrow cape about 2 km southwest (sec. 34, T. 18 S., R. 28 W.) are projected into the section; these basal beds were measured by Keller and Reiser (1959) and listed as their unit 15 (p. 276). We also investigated these beds and sampled the abundant megafauna in them but did not measure the section. We have added these beds measured by Keller and Reiser to the section presented below (unit 2). Neither the upper nor the lower contact of the Kaguyak Formation is exposed at the type section, but both are exposed nearby.

Section 16. Type section of the Kaguyak Formation (fig. 11)

Top of exposed section	*Thickness*
Kaguyak Formation:	*(meters)*
22. Sandstone and siltstone, thin-bedded to massive, medium-dark-gray to pale-brown; rip-up clasts	44.2
21. Sandstone, thick-bedded, fine-grained, pale-brown; rip-up clasts; load clasts	10.6
20. Siltstone, thin-bedded, medium-gray; crossbedded	12.2
19. Sandstone and siltstone, thin-bedded to massive, olive-gray; rip-up clasts and graded bedding	56.3
18. Sandstone and siltstone, thin-bedded to massive, fine-grained, medium-dark-gray; bedding graded, laminated to convolute; load and flute casts along amalgamation surfaces; limy sandstone concretions	42.6
17. Covered interval	15.2
16. Siltstone and sandstone, thin-bedded, dark-gray; convolute; contains *Inoceramus subundatus* (M7813)	30.5
15. Sandstone, massive, fine-grained, medium-dark-gray; rip-up and load clasts along amalgamation surfaces; limy sandstone concretions	45.7
14. Siltstone and sandstone, thin-bedded to massive, fine-grained, dark-gray; rhythmically bedded; rip-up and load clasts in sandstone; flame structures in siltstone	67.0
13. Siltstone and sandstone, thin-bedded, fine-grained, medium-gray; flame structures, sole and drag marks	74.6
12. Sandstone, massive, fine-grained, medium-gray; amalgamated; ball and pillow structures	11.5
11. Siltstone and sandstone, thin-bedded to massive, fine-grained, medium- to dark-gray	15.2
10. Andesite porphyry sill	16.7
9. Covered interval	44.2
8. Shale, dark-gray	9.1
7. Covered interval	18.2
6. Andesite porphyry sill	12.1
5. Covered interval	112.7
4. Siltstone, thin-bedded, medium-dark-gray; limestone and clay-ironstone concretions; contains *Diplomoceras notabile*, *Didymoceras*, and *Inoceramus balticus* var. *kunimiensis* (M7903)	137.0
3. Covered interval	91.4
2. Claystone and limestone, shaly to thin-bedded, dark-gray	30.4
1. Siltstone, massive, medium-gray; siliceous; very dense; breaks down into hackly fracturing shale; abundant large spheroidal limy concretions; abundant ammonites and bivalves aligned on bedding planes, including *Didymoceras* aff. *D. hornbeyense*, *Diplomoceras notabile*, *Gaudryceras tenuiliratum*, *Neophylloceras ramosum*, *Pachydiscus* (*Pachydiscus*) *hazzardi*, *Inoceramus balticus* var. *kunimiensis*, and *Glycymeris* (M7814)	219.4
Total exposed section	1,116.8
Base of exposed section	

The thickness of the Kaguyak Formation as given here is somewhat less than that published by Keller and Reiser (1959, p. 275). The discrepancy is apparently within the uppermost part of the formation. We did not observe the upper contact at the type section, but have seen it in other exposures very nearby where Tertiary sedimentary and volcanic rocks unconformably overlie the Kaguyak Formation. We suggest that unit 1 of the Keller and Reiser section (1959, p. 275) may actually be part of the Tertiary sequence. This suggestion is supported by their report of carbonaceous partings in this unit. Carbonaceous material is very common in the Tertiary sequence, but is uncommon in the Kaguyak Formation.

Like the upper contact, the lower contact of the Kaguyak Formation is not exposed at the type section but can be seen at outcrops nearby. We estimate that this contact lies 91 m below the base of the exposed section at the type section. At this contact, the Kaguyak Formation unconformably overlies the Herendeen Formation, and not the Naknek Formation as reported by Keller and Reiser (1959, p. 277). The 30-ft-thick sandstone bed that they considered to be the Naknek Formation actually contains *Inoceramus ovatoides*, which is characteristic of the Herendeen Formation. Prisms from this *Inoceramus* compose most of the sandstone bed. The 30-ft-thick sandstone bed in turn unconformably overlies the Naknek Formation.

The Kaguyak Formation is a turbidite deposit representing a submarine fan prograding into a deep-water environment. The lower part of the unit consists of thin-bedded to massive dark-gray siltstone with numerous silty limestone concretions and a few thin limestone beds. A few of the siltstone beds are laminated, load and flute casts are common, and drag marks and flame structures are present. Thin, graded sandstone beds become more numerous upward.

The upper part of the Kaguyak is an interbedded sequence of siltstone and graywacke in units 10 to 20 m thick. The graywacke is graded and contains numerous rip-up clasts; load and flute casts up to 1 m long indicate a current direction from about N. 30° E. Some of the sandstone beds are channeled into the underlying siltstone. Siltstone overbank and levee deposits are commonly interbedded with the sandy units. These rocks were deposited in a submarine fan complex and have been assigned to the middle-fan facies association of Mutti and Ricci-Lucchi (1972).

Megafossils are locally abundant in the lower part of the Kaguyak at the type section. Elsewhere they occur randomly throughout the formation. Most represent forms that were probably carried in by turbidity currents. Ammonites are common and include *Diplomoceras notabile*, *Neophylloceras ramosum*, *Pachydiscus kamishakensis*, *P. hazzardi*, and *Didymoceras* aff. *D. hornbeyense*. Some of the pachydiscids are 1 m or more across. *Inoceramus balticus* var. *kunimiensis*, *I. subundatus*, and *I. kusiroensis* also are common. These fossils have been assigned to the *Pachydiscus kamishakensis* zone of latest Campanian to early Maestrichtian age (Jones, 1963).

The lower contact of the Kaguyak Formation is an unconformity, and the formation overlies strata ranging in age from Kimmeridgian (Late Jurassic) to Albian (Early Cretaceous). The upper contact also is unconformable; beds of early Tertiary age (Copper Lake Formation) locally overlie the Kaguyak Formation. In the Katmai Bay-Geographic Harbor area, nonmarine upper Oligocene strata overlie the formation; elsewhere it is overlain by Tertiary and Quaternary volcanic rocks.

CENOZOIC ROCKS

Tertiary System

Rocks of all the Tertiary epochs are present on the Alaska Peninsula. They are mainly volcaniclastic sedimentary rocks, both marine and continental, interlayered with volcanic rocks and unconformably overlying Mesozoic rocks. As much as 5,000 to 6,000 m of Tertiary sedimentary rocks mantle the southwest end of the Alaska Peninsula. The Tertiary strata become thinner northeastward, and only about 2,000 m are exposed at the northeast end of the peninsula. Most of the Tertiary sedimentary rocks are rich in contemporaneous volcanic debris. Exceptions are the Tolstoi and Bear Lake Formations, which are made up largely of nonvolcanic sediments. Mesozoic strata, in contrast to the Tertiary rocks, contain much less volcanic debris and considerably more intrusive and metamorphic rock fragments.

The Tertiary sequence on the Alaska Peninsula is divided into 11 formations, 1 of which is subdivided into 2 informal members (fig. 12). In ascending order these units are the Tolstoi Formation (upper Paleocene to middle Eocene), Copper Lake Formation (Paleocene? and lower Eocene), Stepovak Formation and Meshik Volcanics (upper Eocene and lower Oligocene), Belkofski Formation (upper Oligocene? and lower and middle Miocene?), Hemlock Conglomerate (upper Oligocene), Unga Formation (upper Oligocene to middle Miocene), Bear Lake Formation (middle and upper Miocene), Tachilni Formation (upper Miocene), Milky River Formation (Pliocene), and Morzhovoi Volcanics (upper Miocene? to lower Quaternary?). The Stepovak Formation is divided into informal (lower) siltstone and (upper) sandstone members. In some cases the distinction between these formations is rather subtle, but we consider them all to be mappable units and therefore separate formations.

Intrusive and volcanic rocks form a considerable part of the Tertiary sequence on the Alaska Peninsula. The large intrusive bodies are mapped as the Shumagin Islands batholith (Paleocene), Devils Bay batholith (Miocene and Pliocene), and Agripina Bay batholith (Miocene and Pliocene). Smaller plutons of similar ages are located in the Sanak and Semidi Islands, and at American Bay, Moss Cape, and Mount Becharof. Additionally, numerous small plugs, domes, and stocks of hypabyssal intrusive rocks associated with volcanism are present and range in age from Oligocene to Pliocene. The outpouring of basalt and andesite of the Meshik arc (see Wilson, 1985) began in the late Eocene and continued into the early Miocene. The present Aleutian volcanic arc began its development in late Miocene time and is still active today.

Early Tertiary Intrusive Rocks

Granitic rocks were first reported on the outer Shumagin Islands by Dall and Harris (1892) and Dall (1896), but no map or description of these rocks was provided. Grantz (1963) was the first to report biotite granodiorite, on the basis of samples obtained during a brief visit to the islands. Burk (1965) was the first to conduct an extensive mapping program on the outer Shumagin Islands, and he determined that the granitic rocks had intruded the Upper Cretaceous flysch deposits (Shumagin Formation) on Nagai and Big Koniuji Islands. Burk also obtained samples of granitic rocks for age determinations. Moore (1974a) did detailed mapping of the islands and obtained megafossils and intrusive rock samples for age determinations. Samples of intrusive rocks were also obtained from the Shumagin Islands by Kienle and Turner (1976). The present investigators visited the islands only briefly, but we did obtain more megafossils and samples for K-Ar age determinations.

The Shumagin Islands batholith (Shumagin-Kodiak batholith of Kienle and Turner, 1976) consists mainly of medium-grained biotite granodiorite and quartz monzonite; it has hypidiomorphic granular texture. Potassium feldspar phenocrysts are locally as much as 1 cm across, and minor muscovite is present. A hornfels zone a few meters to as much as 500 m wide is present where the batholith intrudes the Upper Cretaceous flysch.

The Shumagin Islands batholith is one in a line of northeast-trending hybrid granodiorite batholiths (Hill and others, 1981) that begin on Sanak Island, 50 km southeast of the tip of the Alaska Peninsula. The line of batholiths continues northeast of the Shumagin Islands to the Semidi and Kodiak Island groups. The batholiths parallel the southeast side of the Alaska Peninsula and also roughly parallel the edge of the continental shelf.

The age of the Shumagin Islands batholith is well constrained by numerous K-Ar age determinations and ranges between 65.6±3.3 and 57.4±2.9 Ma (Burk, 1965; Moore, 1974a; Kienle and Turner, 1976). Corresponding ages have been obtained from other batholiths in this northeast-trending line, and all intrude an Upper Cretaceous flysch sequence that is dated by its megafauna as early Maestrichtian.

Beaver Bay Group

The name "Beaver Bay Group" was proposed by Burk (1965, p. 88–89) for a thick sequence of volcanic sandstone and conglomerate, breccia, and black siltstone exposed along the west shore of Beaver Bay (fig. 5) and in the mountains bordering the lower part of the Beaver River, which flows south into Beaver Bay. Burk's Beaver Bay Group consists of the Tolstoi and Stepovak Formations. Burk felt that it was impossible to tell the difference between these two formations when viewing them in isolated outcrops. However, there are major differences between the Tolstoi and Stepovak Formations that we will discuss below.

In Burk's report (1965, p. 88–89), he designated a type locality for the Beaver Bay Group in which he did not separate the Tolstoi and Stepovak Formations. However, on Burk's geologic map (1965, part 2, sheets 1 and 2), he did not map the Beaver Bay Group in its type locality; instead he mapped the

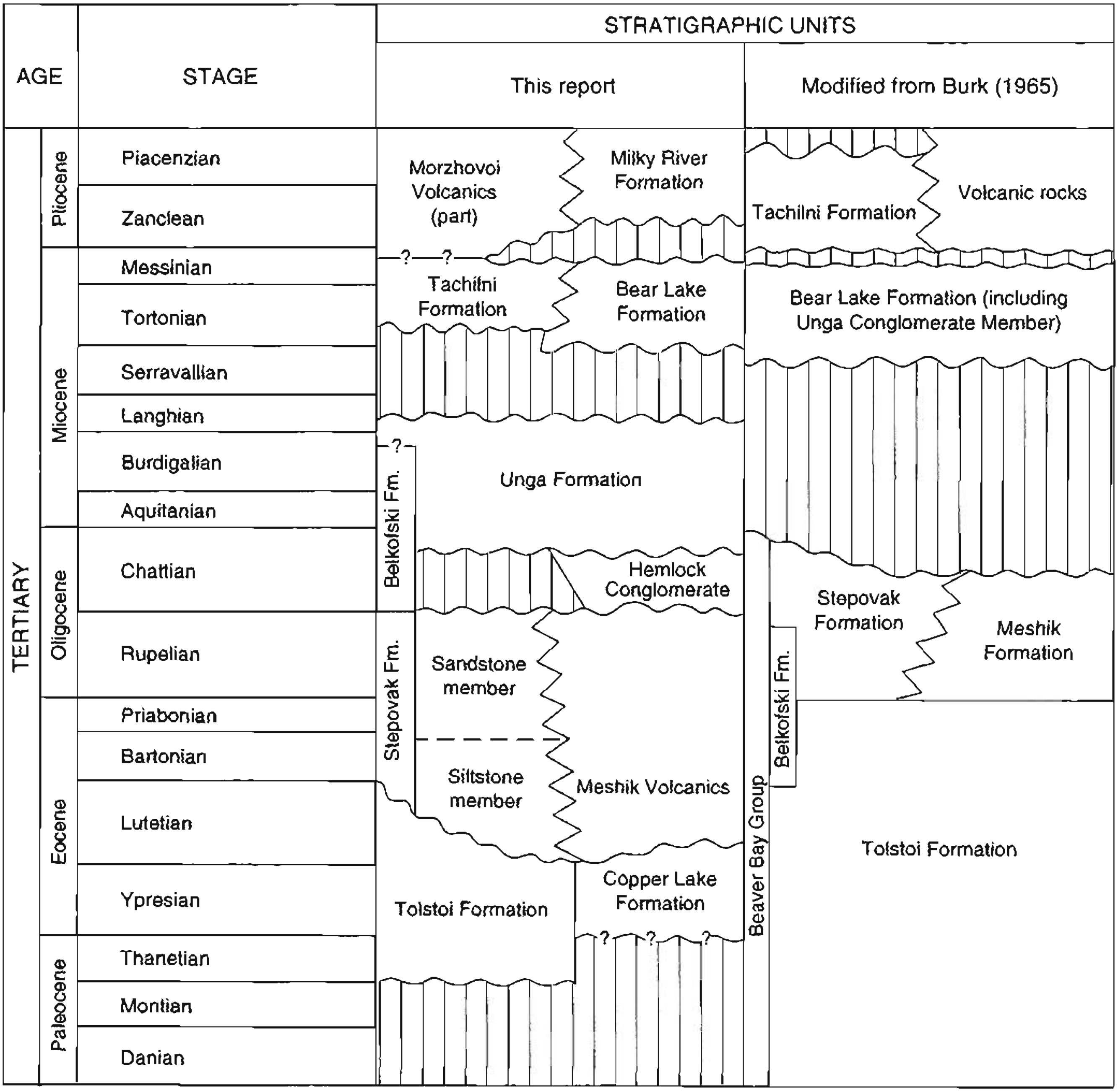


Figure 12. Correlation chart of Tertiary stratigraphic units, Alaska Peninsula.

Tolstoi and Stepovak Formations as separate units there. Burk mapped the Beaver Bay Group only between Stepovak Bay and Chignik Bay, and even in that area, he mapped the Beaver Bay Group as two subunits corresponding, respectively, to the Tolstoi and Stepovak Formations. Thus Burk assigned rocks to either the Stepovak or the Tolstoi Formation, even when using the Beaver Bay Group designation, apparently using the subunits of the Beaver Bay Group to indicate uncertainty about his assignments in the area between Stepovak Bay and Chignik Bay.

We believe that during Burk's broad reconnaissance-scale mapping he did not recognize that the volcaniclastic sedimentary rocks of the Stepovak Formation and the mainly volcanic sequence of the Meshik Volcanics constitute intertonguing facies of a time-stratigraphic unit. The presence of this additional unit, the Meshik Volcanics, may have contributed to Burk's confusion about the distinction between the Stepovak and Tolstoi Formations. The area between Stepovak Bay and Chignik Bay, where he mapped the Beaver Bay Group, is the same area where the Stepovak Formation and the Meshik Volcanics intertongue. The abundant volcanic rocks that he noted as belonging to the Tolstoi Formation in that area are herein considered to be the Meshik Volcanics. Stratigraphically below these rocks are sedimentary rocks which we have assigned to the Tolstoi Formation (Wilson and others, 1995).

Although the Beaver Bay Group has been used and might be useful for generalized mapping on the Alaska Peninsula, there are major differences between the Tolstoi and Stepovak Formations that can be used for detailed mapping. Sedimentary rocks of the Stepovak Formation are almost entirely derived from a volcanic source terrain. Clasts in its conglomerate beds are mostly unaltered volcanic rocks. Its fine-grained siltstone and shale contain montmorillonite clay as a major component, and its sandstones are commonly tuffaceous. The Tolstoi Formation, in contrast, generally contains more than 50 percent nonvolcanic materials. Clasts in its conglomerate beds are composed mainly of chert (black, gray, and red), quartz, quartzite, and metalimestone; these conglomerates generally contain no more than 25 to 35 percent volcanic rocks. Many of the volcanic clasts are highly altered and silicified. Sandstones from each formation are of the same general composition, but some of those of the Stepovak contain a higher percentage of volcanic fragments. Carbonaceous debris and plant remains are abundant in the Tolstoi Formation, as are coal and carbonaceous shale. On the basis of the above, we don't consider the name "Beaver Bay Group" to be a useful stratigraphic term and suggest that its usage be discontinued on the Alaska Peninsula.

Tolstoi Formation

The oldest Tertiary deposits overlying Mesozoic strata were named the Tolstoi Formation by Burk (1965). He designated a type locality along the east shore of Pavlof Bay, between Tolstoi Peak and Cone Peak (Port Moller B-5 and C-5 1:63,360 quadrangles). These rocks, which are here regarded as the type section of the Tolstoi (section 17), are not typical of the rest of the formation as mapped by either Burk or us to the northeast of the type locality. The Tolstoi Formation at Pavlof Bay is in part a shallow-water marine deposit, whereas northeastward along the peninsula the formation is a nonmarine fluvial deposit containing abundant conglomerate, crossbedded sandstone, coal, and carbonaceous shale. For this reason, we here designate a reference section (section 18) along the east shore of Ivanof Bay, in the Stepovak Bay D-5 1:63,360 quadrangle, beginning at the northeast corner of sec. 3 and continuing south along the shore to the southeast corner of sec. 10, T. 50 S., R. 66 W. (fig. 13). Both the type and reference sections were measured during the course of the present investigation. Dikes and sills are noted in the descriptions of the measured sections but are not included in the sections' total thicknesses. The 659 m measured here as the thickness of the type section of the Tolstoi Formation at Pavlof Bay is about 20 percent less than that given by Burk (1965, p. 189). The discrepancy may result from difficulties in correlating beds across the several small anticlinal and synclinal folds in the section, and at present the actual thickness is unknown. The reference section measured at Ivanof Bay (fig. 13) is characteristic of the fluvial flood-plain and delta sequence that is common in the Tolstoi Formation northeast of its type locality.

Volcaniclastic debris forms a conspicuous but not major part of the sedimentary rocks of the Tolstoi Formation. A few thin tuff beds are present in all sections, and some of the sandstones are tuffaceous. Clasts in the conglomerate beds consist of 25 to 35 percent volcanic rocks. Most of the volcanic clasts are not fresh-appearing, suggesting that they have been reworked from a Mesozoic source rather than derived from contemporaneous Tertiary volcanic deposits. The sandstones contain much arkosic and granitic detritus, likewise indicating a Mesozoic source terrane. This is in sharp contrast to the overlying Stepovak Formation and the Meshik Volcanics, whose sandstones are composed almost entirely of fresh volcanic debris.

The Tolstoi was deposited by onlap onto the underlying Mesozoic rocks. Deposition of shallow-marine sediments at Pavlof Bay and the inner Shumagin Islands was, in part, contemporaneous with deposition of delta-plain and fluvial (mainly braided-stream) deposits elsewhere on the peninsula. Mollusks at Pavlof Bay and Korovin Island indicate a late middle Eocene age for the Tolstoi Formation according to Marincovich (1988b). Marine mollusks are restricted almost entirely to the Pavlof Bay and Korovin Island localities where the marine beds are interlayered with nonmarine strata. The main elements of the fauna are *Turritella uvasana stewarti* Merriam and *Microcallista* (*Costacallista*) *conradiana* (Gabb). The fauna also includes *Nuculana* sp., *Tellina* sp., *Ostrea* sp., *Solena* sp., *Corbicula* sp., *Volsella* sp., and *Glycymeris* sp. This fauna represents an extremely shallow-water, warmtemperate to subtropical marine environment (Marincovich, 1988b).

Dinoflagellates obtained from the same bed on Korovin Island that yielded the *Turritella uvasana stewarti* indicate an early to middle Eocene age (Nairn Albert, written commun., 1985). The dinoflagellates include *Impagidinium californiense, Adnatosphaeridium multispinosom, Turbiosphaera filosa, Glaphyrocysta retiintexta,* and *Rhombodinium* sp.

An abundant fossil megaflora was obtained from the reference section at Ivanof Bay. The main elements of this flora include *Acer arcticum* Heer, *Alnus* sp., *Cocculus flobella* (Newberry) Wolfe, *Grewiopsis curiculaecrodatus* (Hollick) Wolfe, *Liquidambar* sp., *Metasequoia occidentalis* (Newberry) Channey, *Protophyllum semotum* Hickey, and *Thuites interruptus* (Newberry) Bell. The flora was identified by J.A. Wolfe (1981) as late Paleocene to middle Eocene in age. Wolfe (1981) stated that the flora indicates a paratropical rain-forest environment with a mean annual temperature of about 22°C. Thus, both the megaflora and megafauna indicate a warm temperature for the area at the time of deposition of the

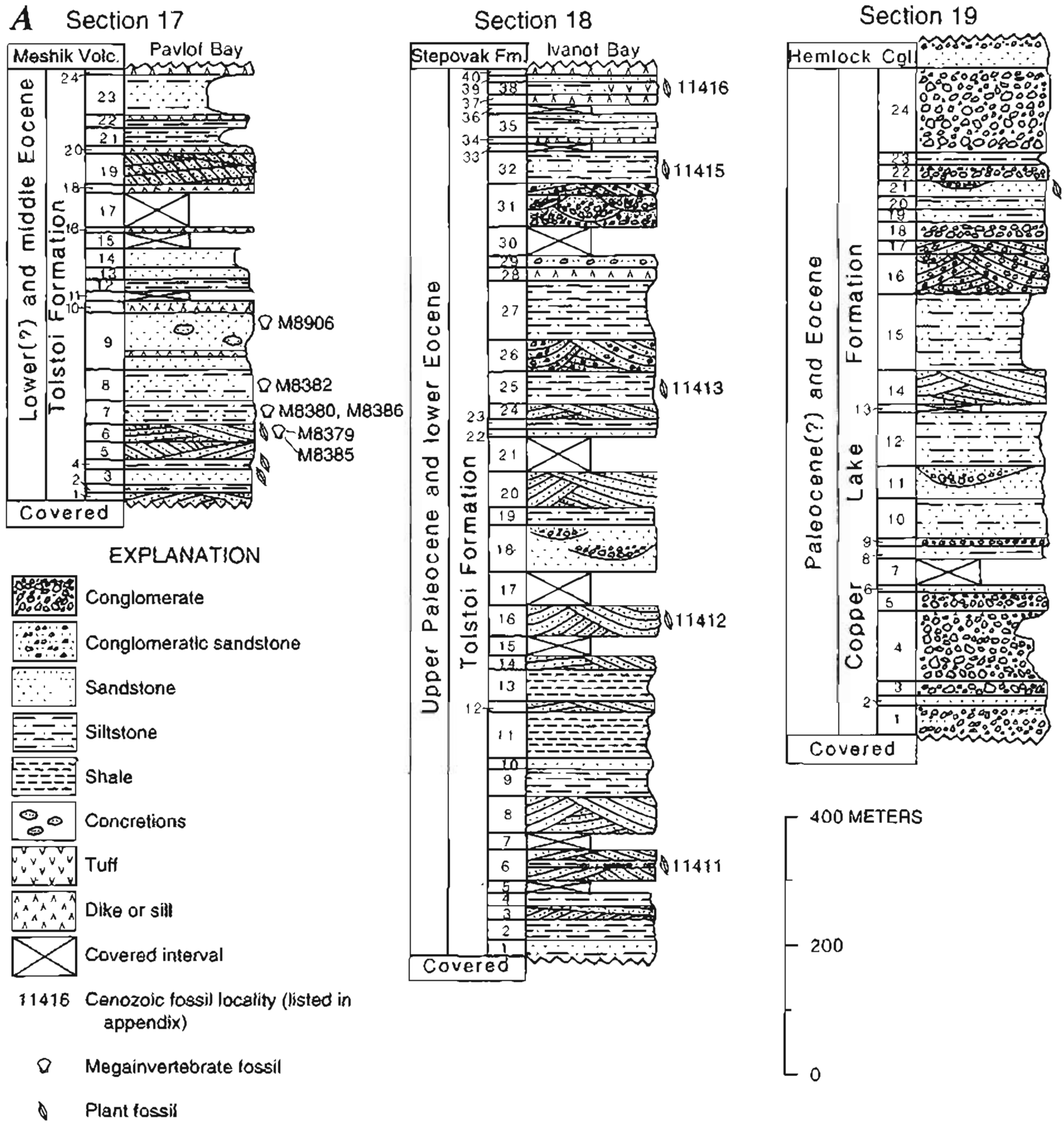
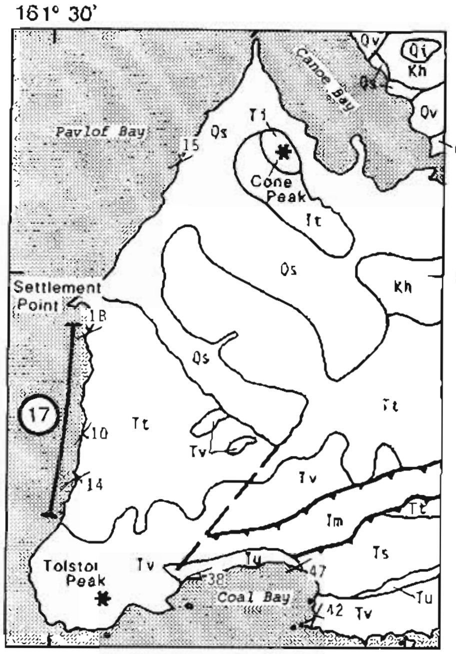
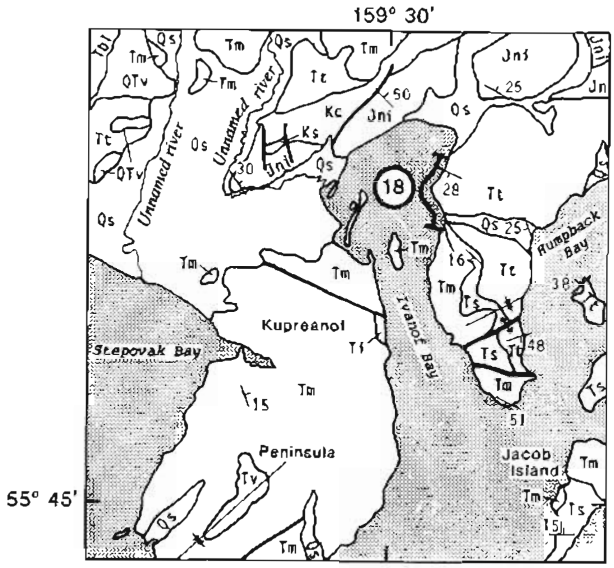


Figure 13. Paleocene and Eocene formations, Alaska Peninsula. *A*, Type section (17) of Tolstoi Formation at Pavlof Bay, reference section (18) of Tolstoi Formation at Ivanof Bay, and section (19) of Copper Lake Formation. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols.

B

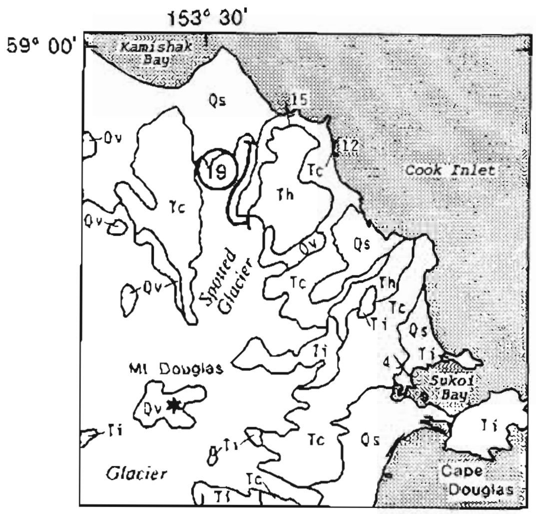


Geology modified from Wilson and others (1995)
Tolstoi Formation



Geology modified from Wilson and others (1995)
Tolstoi Formation

0 5 KILOMETERS



Geology modified from Riehle and others (1987a)
Copper Lake Formation

Section 17. Type section of the Tolstoi Formation (fig. 13)

Meshik Volcanics
Unconformable contact
Tolstoi Formation:

	Thickness (meters)
24. Andesite porphyry dike	5.4
23. Sandstone and siltstone; rubble; mostly covered	67.6
22. Siltstone, thin-bedded, olive-gray; andesite porphyry sill at top	18.2
21. Siltstone; rubble, mostly covered	30.4
20. Andesite porphyry dike	6.7
19. Sandstone, thin-bedded, olive-gray to massive, pale-yellowish-brown; small-scale crossbedding and ripple marks; plant debris	53.3
18. Andesite porphyry sill	5.4
17. Covered interval	60.9

Section 17. Type section of the Tolstoi Formation (fig. 13)—Continued

16. Andesite porphyry sill	3.6
15. Covered interval	28.9
14. Sandstone; rubble	30.4
13. Sandstone, thin-bedded, fine-grained, light-olive-gray; thin tuff bed at base	13.7
12. Siltstone, thin-bedded, light-olive-gray; plant debris	16.7
11. Covered interval	16.7
10. Sandstone, massive, fine-grained, olive-gray; clay ironstone nodules; plant debris; sill at base	15.2

9. Sandstone, thin-bedded to massive, fine-grained, pale-olive; sandstone concretions; current-ripple marks; plant debris; andesite dike in middle part; bivalves and gastropods in upper part, include

Section 17. Type section of the Tolstoi Formation (fig. 13)—Continued

Ostrea, *Microcallista* (*Costacallista*) *conradiana*, and *Turritella uvasana stewarti* (M8906) 91.4
8. Sandstone and siltstone, thin- to medium-bedded, pale-olive to light-gray; plant debris; bivalves and gastropods, *Turritella uvasana stewarti* (M8382) ... 48.7
7. Siltstone with thin sandstone interbeds and two thin andesite dikes; ripple marks; bivalves *Solena* cf. *S. clarki* and *Corbicula* (M8380 and M8386) 39.6
6. Sandstone, thin- to medium-bedded, fine-grained, light-olive-gray; crossbedded; plant leaves; bivalves *Nuculana* and *Microcallista* (*Costacallista*) *conradiana* (M8379 and M8385) . 24.4
5. Sandstone, thick-bedded, medium-grained, light-gray; large-scale tabular crossbeds 25.9
4. Siltstone, thin-bedded, irregular; plant leaves 15.2
3. Sandstone, medium-bedded, medium-grained, olive-gray; carbonaceous; plant leaves; thin dike .. 19.8
2. Siltstone, thin-bedded; sandstone concretions 8.5
1. Sandstone, massive, olive-gray; crossbedded 12.2

Total exposed section 658.8

Base of exposed section

Section 18. Reference section of the Tolstoi Formation (fig. 13)

Stepovak Formation

Unconformable contact — *Thickness (meters)*

Tolstoi Formation:

40. Andesite porphyry sill 13.7
39. Sandstone, massive, medium-grained, greenish-gray; plant debris 7.6
38. Siltstone, sandstone, and tuff, thin-bedded; sandstone channeled into siltstone; leaves common, *Acer*, *Alnus*, *Cocculus*, *Liquidambar*, *Metasequoia* (11416) 17.4
37. Andesite sill 18.2
36. Covered interval 18.2
35. Sandstone and siltstone, massive to thin-bedded, fine- to coarse-grained, medium-light-gray; wood and plant debris; sandstone channeled into siltstone 33.5
34. Andesite sill 6.0
33. Covered interval 15.2
32. Siltstone and sandstone, thin- to medium-bedded, medium- to greenish-gray; coal and carbonaceous shale; abundant *Acer* and *Alnus* (11415) 45.7
31. Conglomeratic sandstone and conglomerate, massive, pale-yellowish-brown; numerous channels containing pebble lag gravel; carbonaceous 92.0
30. Covered interval 51.8
29. Conglomeratic sandstone, massive, pebble, greenish-gray; carbonaceous 15.2
28. Andesite sill 18.2
27. Siltstone, thin-bedded, dark-gray; plant debris 74.6
26. Conglomeratic sandstone, massive, pebble, pale-yellowish-brown; crossbedded and channeled 48.7
25. Siltstone, thin-bedded, dark-gray; leaves, *Cocculus* (11413) 42.6
24. Sandstone, massive, fine-grained, pale-yellowish-

Section 18. Reference section of the Tolstoi Formation (fig. 13)—Continued

brown; large tabular crossbeds; carbonaceous 21.3
23. Siltstone, thin-bedded, dark-gray; carbonaceous 9.0
22. Sandstone, thin-bedded, fine-grained; crossbedded . 17.6
21. Covered interval 65.5
20. Sandstone, thin- to thick-bedded, fine-grained, light-olive-gray; crossbedded; carbonaceous 53.3
19. Siltstone, thin-bedded, medium-gray; carbonaceous .. 19.8
18. Sandstone, massive, medium-grained, olive-gray; lag gravel in channels; coal; carbonaceous; plant debris 83.8
17. Covered interval 51.8
16. Sandstone, massive, medium-grained, pale-yellowish-brown; crossbedded, channeled; plant fossils *Metasequoia* and *Thuites* (11412) 38.1
15. Covered interval 36.6
14. Sandstone, massive, medium-grained, light-brownish-gray; large tabular crossbeds; plant debris 19.8
13. Shale, fissile to thin-bedded, dark-gray; carbonaceous 33.5
12. Sandstone, thick-bedded, medium-grained, medium-gray; crossbedded; carbonaceous 12.2
11. Shale, fissile to thin-bedded, dark-gray; carbonaceous 71.6
10. Sandstone, massive, fine-grained, medium-gray; carbonaceous 7.6
9. Siltstone, massive, fine-grained, medium-gray; carbonaceous 39.6
8. Sandstone, massive, medium-grained, pale-yellowish-brown; crossbedded 76.1
7. Covered interval 22.8
6. Sandstone, massive, medium-grained, brownish-gray; crossbedded; plant debris; contains *Chaetoptelea*, *Dicotylophyllum*, *Grewiopsis*, *Protophyllum*, and *Metasequoia* (11411) 51.8
5. Covered interval 13.7
4. Siltstone, thin-bedded, dark-gray; sandstone concretions; laminated 19.8
3. Sandstone, thick-bedded, fine-grained, brownish-gray; crossbedded 19.8
2. Siltstone, dark-gray; laminated; carbonaceous 41.1
1. Sandstone and siltstone, brownish-gray; laminated and crossbedded 10.6

Total exposed section 1,355.4

Base of exposed section

Tolstoi Formation. The flora suggests an older and longer age range (late Paleocene to middle Eocene) than does the fauna (middle Eocene) for Tolstoi deposition. We believe that there is a logical explanation for this apparent discrepancy in age. The sequence of the Tolstoi Formation at Ivanof Bay is twice as thick as at the type section at Pavlof Bay (fig. 13*A*), and we believe the Ivanof Bay section is more complete. The floristic elements of late Paleocene age came from the lower part of the Ivanof Bay sequence and are, therefore, older than any of the strata exposed at Pavlof Bay. Thus, the overall age of the Tolstoi Formation is regarded in this report as late Paleocene to middle Eocene.

The marine strata of the Tolstoi Formation constitute only a minor part of the formation as defined and mapped by Burk (1965) and by us. The dominant lithologies of the formation are sandstone and conglomerate with subordinate interbeds of siltstone, shale, carbonaceous shale, and coal. The sand-shale ratio in the unit at Pavlof Bay is 1:5; it increases to 2:6 near Chignik Bay and increases even more northeastward from Chignik. Volcanic debris is a conspicuous, but not a major, component of the unit's sandstones and conglomerates. Detritus derived from the Mesozoic sedimentary sequence and the Alaska-Aleutian Range batholith constitutes the major part of the Tolstoi Formation.

Carbonaceous shale and coal beds in the Tolstoi Formation are more numerous and thicker from Chignik Bay northeastward, as are conglomerate and sandstone units. The sandstone is generally crossbedded and channeled. A thin bed of blue pebble conglomerate occurs near the top of the Tolstoi in the northeastern part of its exposure area. The pebbles are black chert. We have been unable to confirm the composition of the blue coating, but we believe it is probably vivianite. This conglomerate underlies a lignite bed.

Throughout most of the Alaska Peninsula, the lower contact of the Tolstoi Formation is a major unconformity and the base of the formation rests locally on the Hoodoo, Chignik, Staniukovich, or Naknek Formation. A yellowish-orange weathered zone commonly occurs at the contact between the Tolstoi and the underlying formations and marks a definite erosional break. However, between Pavlof Bay and Port Moller, the Tolstoi Formation concordantly overlies the Hoodoo Formation and the contact is a disconformity. Orogenic activity, possibly associated with subduction along a paleo-Aleutian trench, was greatest in the Becharof Lake area of the peninsula. A structural high was centered in the Becharof Lake area (Fisher and others, 1981), and the Tolstoi Formation pinches out against the south flank of this structural high. The northeasternmost exposures of the Tolstoi form a thin sequence south of Lower Ugashik Lake (fig. 2), where the unit lies on the Naknek Formation. The upper contact of the Tolstoi is disconformable where it is overlain by the sedimentary rocks of the Stepovak Formation. Where the Tolstoi is overlain by the Meshik Volcanics, the contact is an unconformity.

Copper Lake Formation

Lower Tertiary rocks are missing for nearly 200 km across the Becharof Lake structural high, from southwest of Lower Ugashik Lake to the Swikshak River area near Cape Douglas on the northeast flank of the structural high. Tertiary sedimentary rocks along Shelikof Strait at the northeast end of the Alaska Peninsula were first described by Atwood (1911, p. 49). Atwood considered these rocks to be equivalent to the Kenai Formation and presumably of Eocene age. Smith (1939, p. 62) briefly mentioned the coal-bearing rocks in the Cape Douglas area and concluded also that they are part of the Kenai Formation. Keller and Reiser (1959, p. 278–281) described Tertiary sedimentary rocks in the Mount Katmai area as probably of Eocene age. Recent investigations at the northeast end of the Alaska Peninsula, first by Magoon and others (1976a, 1976b) and more recently by us, have shown that the Tertiary sedimentary sequence there consists of two separate rock units of different ages. The rocks are dissimilar in composition and are herein mapped as two formations, the Copper Lake Formation and Hemlock Conglomerate.

Continental lower Tertiary strata in the Cape Douglas area were mapped as part of the West Foreland Formation by Magoon and others (1976a, 1976b). However, the lower Tertiary strata in the Cape Douglas area are very different from the type West Foreland Formation (Calderwood and Fackler, 1972; Adkison, 1975; Adkison and others, 1975) in the upper Cook Inlet area. Consequently, we here reassign these strata to the Copper Lake Formation (see Detterman and Reed, 1980). The stratigraphic sequence exposed in the Cape Douglas area, particularly the section along Spotted Glacier (fig. 13), consists of thick pebble-cobble conglomerate in the uppermost and lowermost parts and sandstone and siltstone in the middle part. Considerable carbonaceous debris and minor coal are found in the finer clastic sediments. This sequence of strata is very similar to the type section of the Copper Lake Formation, located in the Iliamna 1:250,000-scale quadrangle south of Upper and Lower Copper Lakes (Detterman and Reed, 1980). The strata in the Cape Douglas area are unlike the white claystone and sandstone of the West Foreland Formation (Calderwood and Fackler, 1972).

The section along Spotted Glacier (section 19; fig. 13) was measured by Magoon and others (1976b) and examined several times by us during the present investigation. The section is along the east side of the glacier in secs. 16 and 21, T. 14 S., R. 25 W., Afognak D-5 1:63,360 quadrangle. Seacliff exposures of much of this section are present in secs. 14 and 23.

Section 19. Section of the Copper Lake Formation (fig. 13)

Hemlock Conglomerate

Disconformable contact

Copper Lake Formation:	*Thickness (meters)*
24. Conglomerate, massive, units to 15 m thick, pebble-cobble; clasts about 30–40 percent volcanic rocks, 20 percent granitic rocks, 0–20 percent chert and quartz, remainder quartzite, schist, and limestone	134.0
23. Siltstone, thin-bedded, dark-gray; carbonaceous	16.7
22. Conglomerate; similar to unit 24	21.3
21. Sandstone, thick-bedded, medium-gray; conglomerate lag gravel in channels; minor siltstone containing plant fossils	27.4
20. Siltstone and sandstone, thin-bedded, dark-gray	12.2
19. Sandstone and siltstone; similar to unit 20; thin sill at top	21.3
18. Conglomerate, massive, pebble; sandstone matrix	30.5

Section 19. Section of the Copper Lake Formation (fig. 13)—Continued

17. Conglomeratic sandstone, thick-bedded, medium- to coarse-grained; tabular crossbeds	21.3
16. Sandstone with few pebbles, thick-bedded; few channels; crossbedded	57.9
15. Sandstone and siltstone; mostly rubble	112.7
14. Sandstone, medium- to thick-bedded, medium-grained, medium-gray; crossbedded	54.8
13. Covered interval	10.6
12. Sandstone and siltstone, thin- to medium-bedded, fine-grained, dark-gray; carbonaceous	77.7
11. Sandstone, massive; contains conglomerate channel fills	50.3
10. Sandstone and siltstone; similar to unit 12	51.8
9. Conglomerate, massive, pebble	6.0
8. Sandstone and siltstone; similar to unit 12	18.2
7. Covered interval	57.9
6. Sandstone, medium-bedded, fine-grained	6.0
5. Conglomerate, thick-bedded to massive, pebble-cobble	33.5
4. Conglomerate, massive; poorly exposed	125.0
3. Conglomerate, massive, pebble-cobble	25.9
2. Sandstone, medium-bedded, medium-grained; silty; carbonaceous	15.2
1. Conglomerate, massive, pebble; minor sandstone lenses	36.5
Total exposed section	1,024.7

Base of exposed section

The fossil megaflora from seacliff exposures of the Copper Lake Formation, especially from Sukoi Bay at Cape Douglas, indicates correlation with the Franklinian Stage (Ypresian) of the early Eocene (Magoon and others, 1976a; J.A. Wolfe, written commun., 1984). Thus, the age of the Copper Lake Formation on the Alaska Peninsula is approximately the same as that of the Tolstoi Formation in the northeastern part of its outcrop area (Detterman and others, 1985, 1987a) and at its reference section (fig. 13*A*). (At the reference section of the Tolstoi, an early Eocene megaflora was collected from sandstone and siltstone strata that overlie beds containing a late Paleocene flora and underlie beds containing a middle Eocene flora.) The age of the Copper Lake Formation is poorly constrained at its type section (Detterman and Reed, 1980). The Paleocene(?) and early Eocene age favored here for the type section of the Copper Lake Formation is based on the early Eocene megaflora in the sandstone and siltstone member overlying the lower conglomerate member. In outcrops at the northeast end of the Alaska Peninsula, the abundant megaflora is also confined to siltstone and sandstone beds overlying a thick basal conglomerate. Therefore, we consider the age of the Copper Lake Formation in the Cape Douglas area to be the same as at the type section: Paleocene(?) and early Eocene. The provenance for the sediments, as determined from clast content, was the Alaska-Aleutian Range batholith and Mesozoic sedimentary and metamorphic rocks exposed in the Iliamna quadrangle north of the Cape Douglas area.

The contacts of the Copper Lake Formation with the underlying Kaguyak Formation and the overlying Hemlock Conglomerate are disconformable. A considerable amount of time elapsed between the deposition of each of the units, but apparently there was little orogenic activity as there is no structural discontinuity present between the formations.

Stepovak Formation

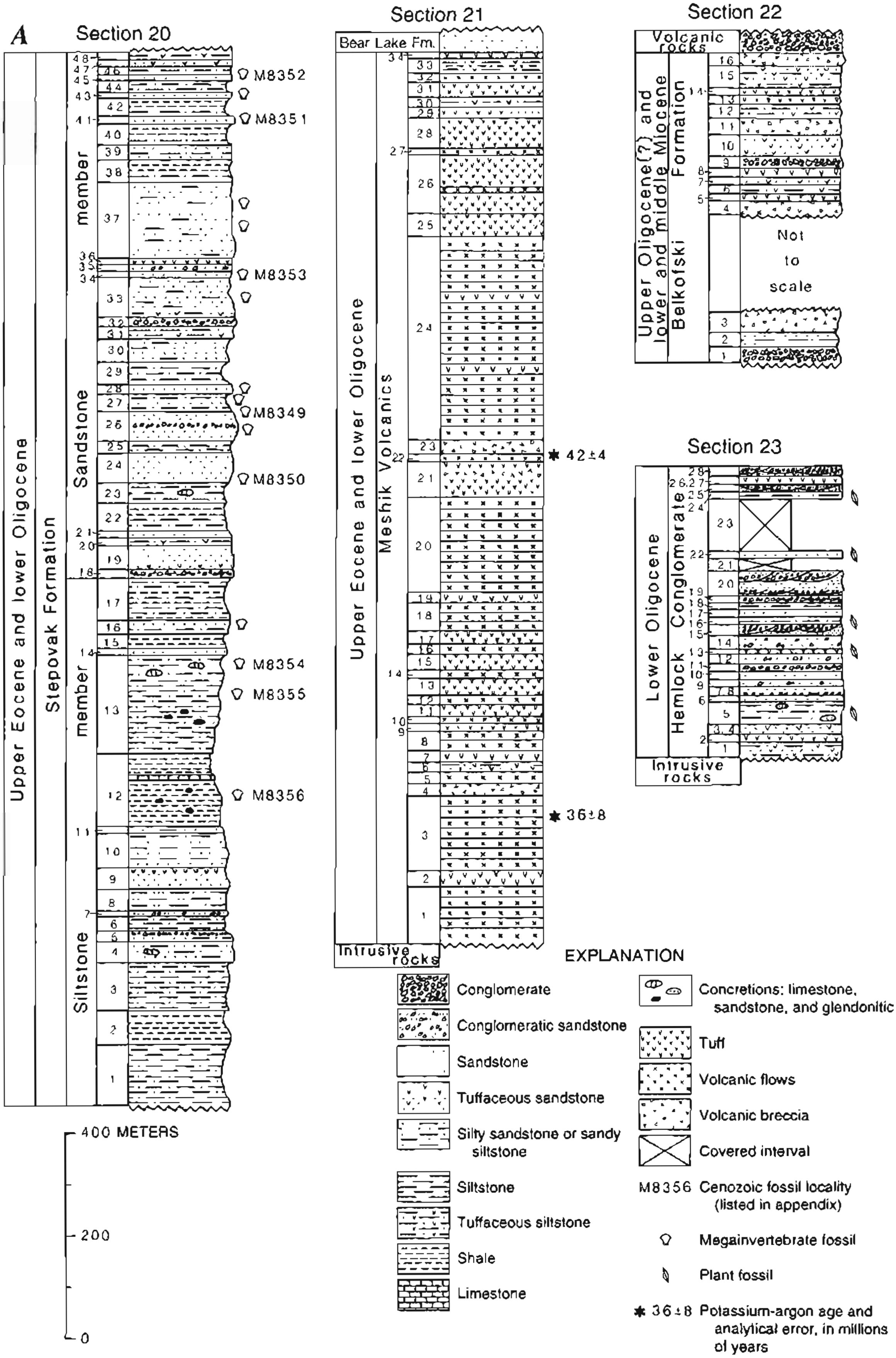
The name "Stepovak Formation" was used by Burk (1965) for rocks exposed along the east side of Chichagof Bay (see fig. 14*B*); we here agree with this usage. These rocks had originally been called the Stepovak Series by Palache (1904). Burk (1965) included the Stepovak Formation as the upper unit of his Beaver Bay Group. We here divide the Stepovak Formation into two informal members, a (lower) siltstone member and an (upper) sandstone member. We do not map the formation herein as part of Burk's Beaver Bay Group.

The volcaniclastic rocks of the Stepovak Formation are geographically restricted to the southwestern end of the Alaska Peninsula from Pavlof Bay to near Chignik (fig. 2). They are age equivalents of the sequence of volcanic rocks to the northeast mapped as the Meshik Volcanics (fig. 12) and of rocks to the south in the Shumagin Islands mapped as the informally named Popof volcanic rocks. The Meshik Volcanics and the Stepovak Formation intertongue between Stepovak Bay and Chignik, and the Popof volcanic rocks and the Stepovak Formation intertongue on Popof and Unga Islands. Northeast of Chignik, the rocks are almost entirely volcanic and are mapped as the Meshik Volcanics.

Burk (1965) designated a type locality for the Stepovak Formation along the east shore of Chichagof Bay. We here designate a reference section (section 20) for the Stepovak about 2.5 km east of the type locality, along ridge tops where the stratigraphic section is more completely exposed (fig. 14). The upper and lower contacts of the Stepovak were not observed at either locality. The reference section begins on a ridge top in the middle of sec. 12, T. 52 S., R. 71 W., Port Moller C-1 1:63,360 quadrangle, continues southwesterly along the ridge into sec. 13, and thence continues southerly across sec. 24 to the coast (fig. 14*B*).

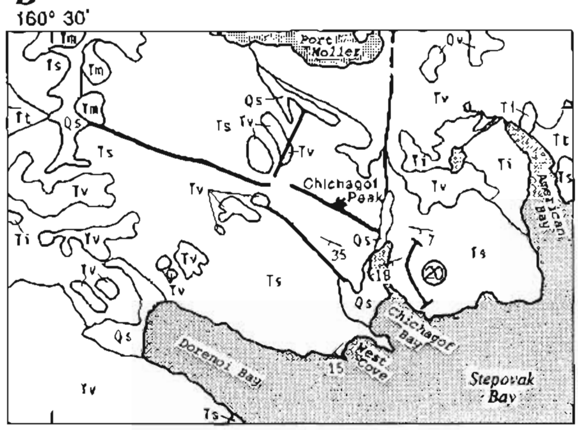
The Stepovak Formation is a thick volcaniclastic sedimentary unit. About 2,030 m of the unit are exposed at the reference section (fig. 14*A*) and are about evenly divided between its (lower) siltstone and (upper) sandstone members.

Figure 14. Eocene, Oligocene, and Miocene(?) formations, Alaska Peninsula. *A*, Reference section of Stepovak Formation, measured section of Meshik Formation, and partial sections of Belkofski Formation and Hemlock Conglomerate. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols. ➤

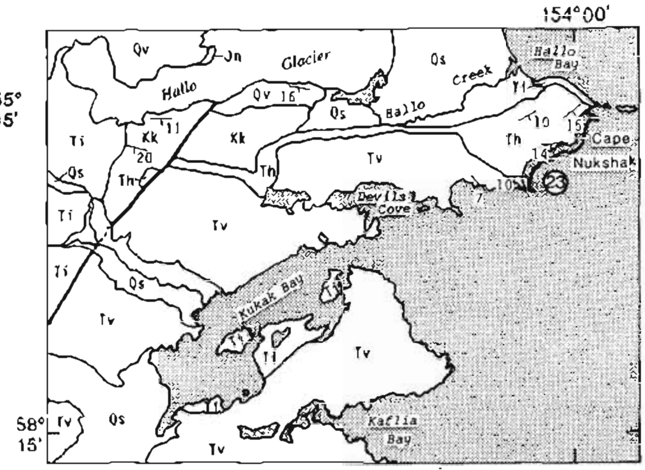


A
Section 20
Upper Eocene and lower Oligocene
Stepovak Formation
Siltstone member
Sandstone member
M8352
M8351
M8353
M8349
M8350
M8354
M8355
M8356
400 METERS
200
0
Section 21
Bear Lake Fm.
Upper Eocene and lower Oligocene
Meshik Volcanics
Intrusive rocks
42±4
36±8
Section 22
Volcanic rocks
Upper Oligocene(?) and lower and middle Miocene
Belkofski Formation
Not to scale
Section 23
Lower Oligocene
Hemlock Conglomerate
Intrusive rocks
EXPLANATION
Conglomerate
Conglomeratic sandstone
Sandstone
Tuffaceous sandstone
Silty sandstone or sandy siltstone
Siltstone
Tuffaceous siltstone
Shale
Limestone
Concretions: limestone, sandstone, and glendonitic
Tuff
Volcanic flows
Volcanic breccia
Covered interval
M8356 Cenozoic fossil locality (listed in appendix)
Megainvertebrate fossil
Plant fossil
36±8 Potassium-argon age and analytical error, in millions of years

B

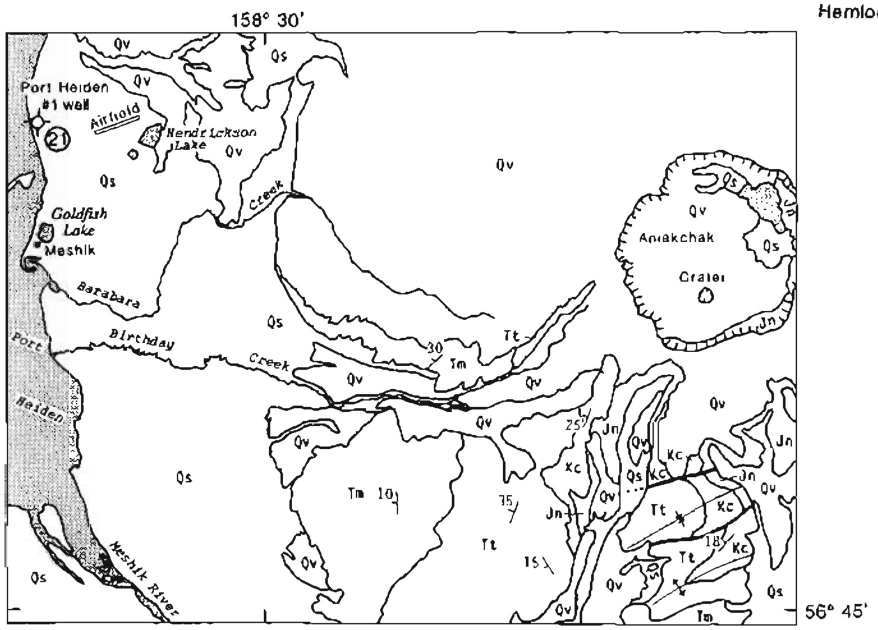


Geology from Wilson and others (1995)
Stepovak Formation

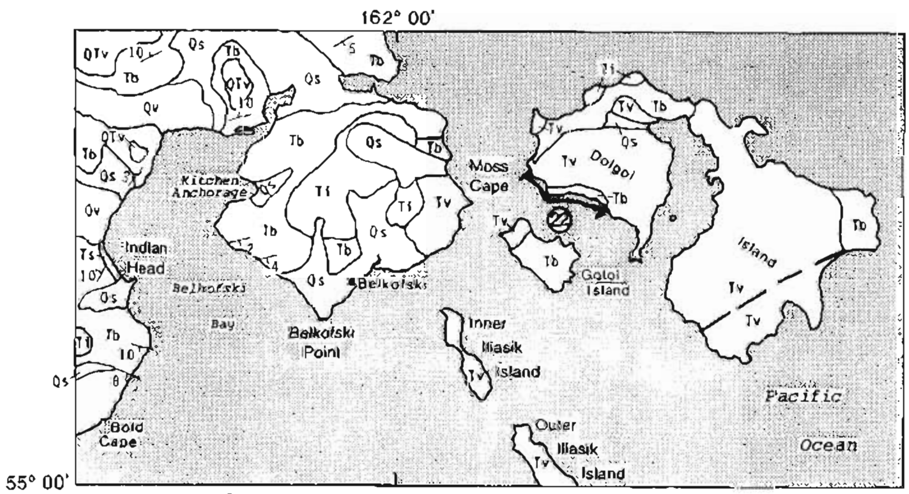


Geology modified from Riehle and others (1987a)
Hemlock Conglomerate

0 5 KILOMETERS



Geology from Detterman and others (1981)
Meshik Volcanics



Geology from Wilson and others (1992) and Wilson and others (1995)
Belkofski Formation

The two members of the Stepovak Formation represent very different depositional environments. The siltstone member, particularly units 1 through 10, is a deep-water turbidite deposit with dark laminated siltstone and shale beds and minor sandstone interbeds that contain numerous rip-up clasts and commonly show graded bedding. The sandstone member is particularly rich in volcanic debris and was deposited in a shallow-water shelf environment. Megafossils, mainly bivalves and gastropods, are found throughout the sandstone member and the upper part of the siltstone member. The lower part of the deep-water siltstone member is unfossiliferous. The megafossils were deposited in water depths no greater than 30 to 50 m and are correlated with Eocene or early Oligocene forms found elsewhere around the north Pacific Ocean (Louie Marincovich, Jr., written commun., 1985). The abrupt change from deep to shallow-water deposition may indicate the renewal of orogenic activity along the Alaska Peninsula, or it may represent an interval during the middle Oligocene worldwide lowering of sea level (Vail and others, 1977).

The volcaniclastic sedimentary rocks of the Stepovak Formation and the volcanic sequence of the coeval Meshik Volcanics record the beginning of a major magmatic episode on the Alaska Peninsula that produced the Meshik arc of Wilson (1985). The sandstone of the Stepovak Formation is composed almost completely of detritus from the volcanic part of this arc. The grains and clasts are fresh-appearing and unaltered. These clasts are in sharp contrast to the chloritized volcanic rock fragments that form a minor part of the underlying sedimentary sequence, and they indicate a change in provenance from the Alaska-Aleutian Range batholith and Mesozoic sedimentary rocks to the contemporaneous volcanic arc.

The contact of the Stepovak Formation with the underlying Tolstoi Formation is structurally conformable and is considered a disconformity. A major break in time between these two formations cannot be demonstrated by the enclosed megafauna, but the change in provenance and the change from the shallow-marine and nonmarine beds of the Tolstoi Formation to the deep-water siltstone of the overlying Stepovak Formation indicate a considerable interval of time. The upper contact of the Stepovak with the Unga Formation is a disconformity also. The lateral facies change from the sedimentary rocks of the Stepovak Formation to the coeval volcanic rocks of the Meshik Volcanics is gradual. Few outcrops exposing either formation are completely devoid of thin interbeds of the other rock unit. The depositional basin for the Stepovak Formation was centered in the area between the head of Port Moller and the northeast shore of Dorenoi Bay (fig 14*B*). This area contains only minor interbedded volcanic rocks of the Meshik Volcanics. It appears that volcanic centers surrounded this area because the marine volcaniclastic rocks abruptly pinch out in all directions and are replaced by volcanic rocks of the Meshik Volcanics or the coeval (informal) Popof volcanic rocks. The interbedded volcanic rocks have been dated by the K-Ar method numerous times, and their ages range from 32 to 36 Ma (Wilson, 1985; DuBois and others, 1987). The radiogenic ages obtained from volcanic rocks that were the source for the contemporaneous volcaniclastic sediments of the upper part of the Stepovak Formation provide a minimum age of early Oligocene for the Stepovak Formation. The K-Ar ages and the data provided by the megafossils indicate that the Stepovak Formation is late Eocene and early Oligocene in age.

Early to Middle Tertiary Volcanic Rocks

The Alaska Peninsula was the site of widespread volcanic and hypabyssal igneous activity during the Tertiary. Recent field and geochronologic investigations have shown that the igneous activity can be separated into two main episodes. One began during the Eocene and continued until the earliest Miocene. The second episode began in late Miocene time and is continuing now; it is represented by the present-day Aleutian volcanic arc. The older magmatic arc was termed the Meshik arc by Wilson (1985). The two arcs are subparallel to one another and roughly parallel to the northeastward trend of the Alaska Peninsula. The Aleutian arc lies along the west side of the Meshik arc in the southern part of the peninsula, but at the general latitude of Port Heiden the Aleutian arc shifts to the east side of the Meshik arc. The change in location of the arcs probably reflects a change in rate or direction of subduction along the Aleutian Trench.

The dacitic to basaltic flows, agglomerate, lahars, and coarse volcanic rubble produced by the Meshik arc in the central part of the peninsula were named the Meshik Formation by Knappen (1929, p. 198–200). Age-equivalent and lithologically equivalent rocks on the inner Shumagin islands were informally named the Popof volcanic rocks (Wilson and others, 1995) for exposures on Popof Island. The two units are described separately.

Meshik Volcanics

The name "Meshik Formation" was first used by Knappen (1929, p. 198) for volcanic and volcanogenic sedimentary rocks exposed along the Meshik River and near Meshik Lake. We here redefine this unit as the Meshik Volcanics to reflect its lithologic character. We have not measured any sections of the formation, but we do include herein a description of the section (section 21) encountered in the Gulf Port Heiden Unit No. 1 borehole (Brockway and others, 1975). The borehole is located in the Chignik D-3 1:63,360 quadrangle, sec. 20, T. 37 S., R. 59 W., approximately 3.2 km northwest of the Port Heiden airstrip. Approximately 1,716 m of section was drilled in this well beginning at –9,280 ft (–2,816 m) and continuing to the contact with Jurassic rocks; the section consists almost entirely of volcanic flows, tuffs, and breccia. A few thin intervals of sedimentary rocks (Stepovak Formation) were noted interfingering with the Meshik Volcanics.

Section 20. Reference section of the Stepovak Formation (fig. 14)

	Thickness (meters)
Top of exposed section	
Sandstone member:	
48. Siltstone, thin-bedded, medium-light-gray; tuffaceous	12.2
47. Sandstone, thin-bedded, fine-grained, light-olive-gray; tuffaceous	10.6
46. Siltstone, thin-bedded, dark-yellowish-brown	19.8
45. Sandstone, thin-bedded, fine-grained, light-olive-gray; contains bivalves (M8352) of indeterminate genus	9.1
44. Siltstone and shale, dark-yellowish-brown	24.3
43. Sandstone, conglomeratic, thin-bedded; thin limestone layer at base; contains bivalve and scaphopod fragments	4.6
42. Shale, dark-yellowish-brown; limestone concretions; siltstone at base	44.1
41. Sandstone, thin-bedded, fine-grained, olive-gray; volcanic; well-rounded grains; contains *Spisula callistaeformis*, *Unio*, and *Acila* (M8351)	9.1
40. Shale and siltstone, dark-yellowish-brown	42.7
39. Sandstone, thin-bedded, fine-grained, olive-gray; minor siltstone	32.0
38. Shale and siltstone, dark-yellowish-brown	41.1
37. Sandstone, thin- to medium-bedded, fine- to medium-grained, light-olive-gray to dark-yellowish-brown; volcanogenic; subangular grains; several thin tuff layers; few bivalve casts	149.3
36. Tuff, thin, olive-gray; water-laid	6.0
35. Conglomeratic sandstone, thick-bedded, grit to pebble; volcanic clasts	12.2
34. Sandstone, medium-bedded, medium-grained, olive-gray; contains *Spisula* (M8353)	12.2
33. Silty sandstone, very fine grained, grayish-orange; lower part tuffaceous; few bivalves	89.9
32. Conglomerate, sandy, medium-bedded, grit to pebble; volcanogenic; subangular clasts	13.7
31. Siltstone, sandy, thin-bedded; tuffaceous	24.4
30. Silty sandstone, thin-bedded, olive-gray; volcanogenic	45.7
29. Siltstone, thin-bedded, olive-gray	45.7
28. Sandstone, thin- to medium-bedded, olive-gray; volcanogenic; contains few bivalves	18.3
27. Siltstone and sandstone, rhythmically interbedded, moderate-yellowish-brown; contains few bivalves	48.7
26. Sandstone, thin-bedded to massive, fine- to medium-grained, light-olive-gray; grit beds formed of volcanic rocks in middle part of unit; abundant fossils throughout, *Acila*, ?*Yoldia palachei*, ?*Yoldia breweri*, *Spisula callistaeformis*, gastropod (M8349)	48.7
25. Siltstone, thin-bedded, dark-yellowish-brown	6.6
24. Sandstone, thin- to medium-bedded, fine- to medium-grained, dark-greenish-gray; volcanogenic; contains fossils similar to unit 26 (M8350)	27.4
23. Siltstone, thin-bedded, olive-gray; few limestone concretions	42.7
22. Siltstone and shale, dark-greenish-gray; pencil fracture	51.8

Section 20. Reference section of the Stepovak Formation (fig. 14)—Continued

	Thickness (meters)
21. Sandstone, thin-bedded, fine-grained, pale-yellowish-brown; clean	6.0
20. Siltstone, thin-bedded; tuffaceous	21.3
19. Sandstone, thin-bedded, medium-grained, pale-yellowish-brown; volcanogenic; subangular to angular grains	44.2
18. Conglomeratic sandstone; volcanogenic	10.6
Total exposed section, sandstone member	1,004.1
Contact	
Siltstone member:	
17. Siltstone and shale, thin-bedded, dark-gray	85.3
16. Sandstone and siltstone, thin-bedded, dark-gray; small-scale crossbeds; few bivalves	24.3
15. Shale, dark-gray	30.5
14. Sandstone, thin-bedded, fine-grained; few pumice fragments	6.1
13. Siltstone, thin-bedded, dark-gray; concretion with glendonites; fossils in upper part, ?*Spisula callistaeformis*, ?*Ostrea tigiliana*, *Crepidula* (M8354 and M8355)	198.1
12. Shale, dark-gray; concretions resistant to weathering; concretions containing glendonites; contains few fossils (M8356)	134.1
11. Sandstone, silty, thin-bedded, fine-grained, dark-gray; rhythmically bedded; rip-up clasts	6.1
10. Sandstone, silty, thin-bedded, fine-grained, dark-gray; rhythmically bedded; rip-up clasts	70.1
9. Sandstone, massive, medium- to fine-grained, graded, olive-gray; rip-up clasts; crossbedded	51.8
8. Siltstone, sandy, thin-bedded, dark-gray	48.7
7. Conglomeratic sandstone, medium-bedded; grit to small pebble; clasts mainly chert	3.0
6. Siltstone, thin-bedded, dark-gray	36.5
5. Sandstone, conglomerate, and minor siltstone	15.2
4. Sandstone, silty, thin-bedded to massive, olive-black; "floating" quartz grains; few limestone concretions	45.7
3. Siltstone, thin-bedded, grayish-black	88.4
2. Shale, grayish-black	65.5
1. Siltstone, thin-bedded, grayish-black	114.3
Total exposed section, siltstone member	1,023.7
Total exposed section, Stepovak Formation	2,027.8
Base of exposed section	

The measured section from the Gulf Port Heiden Unit No. 1 well contains considerably more tuff than do exposures of the Meshik Volcanics in the Meshik River valley and northward into the Ugashik 1:250,000 quadrangle. These exposures consist mainly of basalt and andesite flows, coarse volcanic rubble, breccia, and lahars. Apparently rocks in the exposures were deposited closer to vent areas than were rocks in the well section.

Numerous samples from the Meshik Volcanics have been dated by the K-Ar method (Wilson, 1978, 1980, 1982,

Section 21. Measured section of the Meshik Volcanics from the Gulf Port Heiden No. 1 drillhole well log by Borst and Giddens Oilwell Logging Service (fig. 14)

Bear Lake Formation
Unconformable contact

Meshik Volcanics:	*Thickness (meters)*
34. Tuff, aphanitic, grayish-green; pyritic	9.1
33. Siltstone and shale, thin-bedded, dark-brown; tuffaceous	30.5
32. Andesite flow	15.2
31. Tuff, white to light-gray; minor siltstone	30.5
30. Siltstone and shale; tuffaceous	15.2
29. Tuff, greenish-gray; minor volcanic sandstone	24.4
28. Tuff, medium-gray to chalky-white; welded	61.0
27. Andesite flow	10.6
26. Tuff, porphyritic, rhyolitic; interbedded brown volcanic flow	114.3
25. Tuff, porphyritic, rhyolitic; locally lithic	57.9
24. Dacite and rhyolite (and probably andesite), gray-green to dark-gray and black; thick flow units; porphyritic; locally glassy	381.0
23. Volcanic breccia, medium-dark-green; tuffaceous	24.3
22. Andesite, dark-green; chloritic; K-Ar age 42±4 Ma (Brockway and others, 1975)	12.2
21. Tuff; pyroclastic flow and volcanic breccia	71.6
20. Silicic flow, dark-gray-green to brown; glassy; porphyritic	181.3
19. Tuff, white to light-gray; welded	13.7
18. Flow, medium-dark-green, porphyritic	53.3
17. Tuff and breccia, white to light-gray	22.8
16. Flow, medium-dark-green; glassy	13.7
15. Tuff, white; welded; pyritic	45.7
14. Flow, aphanitic, gray-green	12.2
13. Tuff, white; welded; pyritic	41.1
12. Flow, light-green	13.7
11. Tuff, white to light-gray; welded	35.0
10. Flow, dark-gray to black; glassy	6.0
9. Tuff, white to light-gray; welded	15.2
8. Flow, felsic, light-gray to green; fine-grained	41.1
7. Tuff; same as unit 9	15.2
6. Siltstone and sandstone, light-gray; tuffaceous	21.3
5. Flow; same as unit 8	19.8
4. Volcanic breccia, dark-green	23.1
3. Flow, dark-gray to brown; porphyritic; K-Ar age 36±8 Ma (Brockway and others, 1975)	143.2
2. Tuff; same as unit 9	30.4
1. Flow; same as unit 3	111.2
Total section	1,716.8

Unconformable contact
Jurassic intrusive rocks

1985; Wilson and others, 1981; Wilson and Shew, 1992; DuBois and others, 1987; F.H. Wilson and Nora Shew, unpub. data, 1991). The most reliable ages of the volcanic rock samples range from 24.9±0.49 to 43.1±1.3 Ma, and most of the ages range from about 28 to 38 Ma. An excellent collection of megaflora fossils from a tuff bed exposed on the south flank of Aniakchak Crater (fig. 2; Detterman and others, 1981c) was reported by Wolfe (J.A. Wolfe, written commun., 1980) as late Eocene to early Oligocene; this age range correlates closely with the K-Ar ages. Therefore, the overall age of the Meshik Volcanics is here considered to be late Eocene and early Oligocene.

The contact between the Meshik Volcanics and the underlying Tolstoi Formation is considered an unconformity. The upper contact of the Meshik is unconformable with either the overlying Bear Lake or Milky River Formation.

Popof volcanic rocks

The informal term "Popof volcanic rocks" is applied by Wilson and others (1995) to the volcanic rocks that form most of Popof, Unga, Korovin, and Andronica Islands of the inner Shumagin Islands (see figs. 5 and 15*B*). These rocks are best exposed on Popof Island. They are lithologically and temporally equivalent to the Meshik Volcanics and gradationally interfinger with the contemporaneous Stepovak Formation. The rocks are spatially separated from the Meshik Volcanics and had a local source on the islands.

The total thickness of the Popof volcanic rocks is unknown, but it may be at least 1,000 m on the basis of seacliff exposures. Volcanic flows, lahar deposits, debris flows, ashflow tuff, and tuff constitute the unit. The flows range from dacite to basalt in composition and include minor rhyolite on Unga Island. Andesite makes up most of the flow rocks and is interbedded with numerous volcanic rubble flows and lahar deposits. Many of these rocks are pervasively altered and mineralized. Propylitized andesite and dacite at the Apollo Mine on Unga Island contain gold, silver, galena, sphalerite, chalcopyrite, pyrite, and native copper (Berg and Cobb, 1967, p. 5). The mine produced about 2 million dollars in gold and silver between 1891 and 1904. The mine has been closed since World War I, but some exploration and assessment work is currently being done.

The Popof volcanic rocks locally interfinger with the Stepovak Formation along the north side of Unga Island and also on Korovin Island. Marine megafossils are very abundant locally in some of the sedimentary interbeds and include the bivalve *Ostrea tigiliana* and the gastropods *Whitneyella* cf. *W. sinuata aragoensis* and *Neverita* cf. *N. washingtonensis*. This megafauna, along with other species, indicates an Eocene and early Oligocene age according to Marincovich (Louie Marincovich, Jr., written commun., 1985). Potassium-argon ages on samples from several flows and an ash flow tuff range from 37.13±1.16 to 31.22±1.38 Ma (DuBois and others, 1987; F.H. Wilson and Nora Shew, unpub. data, 1991). Thus, the age of the Popof volcanic rocks corresponds to that of the Meshik Volcanics.

Belkofski Formation

Kennedy and Waldron (1955) first used the name "Belkofski Tuff" for volcaniclastic rocks found principally around Belkofski Bay and on Belkofski Point (fig. 14*B*).

McLean (1979b) renamed the unit the Belkofski "Formation," following Burk's (1965) usage, to better describe the varied lithologies occurring within the unit. The formation is present only near the southwest end of the Alaska Peninsula; it crops out between False Pass and Pavlof Bay and on the Pavlof Islands at the mouth of Pavlof Bay. The unit's type locality was considered by Burk (1965) to be between Cold and Pavlof Bays, and McLean (1979a) gave a generalized description of a section located on the northwest shore of Belkofski Bay, about 5 km north of Indian Head; this section (section 22) is here considered the unit's type section.

Section 22. Generalized section of the Belkofski Formation (fig. 14)

[Thicknesses are approximate]

Volcanic rocks

Unconformable contact

Belkofski Formation:	*Thickness (meters)*
16. Volcanic breccia, massive, gray; clasts mainly pale-green volcanic rocks	25
15. Sandstone and siltstone, medium-bedded, green to red; tuffaceous	45
14. Tuff, thin-bedded, pink	10
13. Volcanic breccia, massive, red; clasts of volcanic rocks mostly about 1 cm, angular	20
12. Siltstone, thin-bedded, pink to red; tuffaceous	30
11. Volcanic breccia, similar to unit 13	30
10. Sandstone, medium-bedded, red; tuffaceous	40
9. Conglomerate, pebble-cobble, thick-bedded, volcanic	25
8. Tuff, similar to unit 14	10
7. Sandstone, thin-bedded, pink to purple; tuffaceous	15
6. Siltstone, similar to unit 12	20
5. Tuff, lithic, pink	10
4. Volcanic breccia, massive, pink to red; clasts to 2 cm	30
Valley fill of unknown thickness consisting of younger volcanic rocks between units 3 and 4	
3. Volcanic breccia, massive, red	40
2. Sandstone and siltstone, thin-bedded, dark-gray	30
1. Conglomerate, thick-bedded, pebble	30
Total exposed section	410

Base of exposed section

The Belkofski Formation is a tuffaceous volcaniclastic sandstone, siltstone, and conglomerate with interbeds of tuff and volcanic breccia; it totals about 1,830 m in thickness (McLean, 1979b). The lower part of the unit is marine, and it grades upward into a nonmarine sequence. The rocks along Belkofski Bay are mainly gray and greenish-gray to gray-brown. On the Pavlof Islands the rocks are mainly red, pink, and purple. This difference in color may be due to thermal alteration of the rocks on the Pavlof Islands, which are near exposures of intrusive bodies. A green arkose mapped separately by Kennedy and Waldron (1955) was included in the Belkofski by Burk (1965). This green arkosic sandstone, considered to be the basal part of the Belkofski Formation by Burk (1965), McLean and others (1978), and McLean (1979b), probably should be considered a separate stratigraphic unit, as it was by Kennedy and Waldron (1955). However, we do not have enough data to justify such a reassignment at this time.

The green arkosic sandstone is tuffaceous and has blotchy green and white spots characteristic of a laumontite-rich rock. The sandstone is not massive as described by McLean and others (1978), but is instead composed of numerous low-angle tabular crossbed sets with pebbles between the bed sets. Some of the bed sets are bioturbated, and mudstone interbeds contain numerous plant remains and leaves. The dark-brown to black coaly mudstone associated with the sandstone indicates that the depositional site was a beach fronting a swamp. These lithologic features are in sharp contrast to those of the varicolored lithic tuff and volcanic breccia characteristic of the main part of the Belkofski Formation.

We investigated the Belkofski Formation only cursorily at its type locality and on the Pavlof Islands. The relations between the Belkofski Formation and the other stratigraphic units exposed near the southwest end of the Alaska Peninsula are not clear. Most likely, the Belkofski Formation can be correlated with the Unga Formation; this idea is based on several lines of evidence: (1) The one megafossil collection obtained from the type locality of the Belkofski includes *Anadara* sp., *Macoma* sp., and *Mya* sp. of probable Miocene age (Marincovich and McCoy, 1984); (2) plant fossils consisting of broad deciduous leaves, logs, and stumps indicate an Oligocene age (J.A. Wolfe, oral commun., 1978); and (3) volcaniclastic sandstone, siltstone, and conglomerate are interbedded with tuff and volcanic breccia, all of which are dark greenish-brown to red. All of these features are matched in the Unga Formation. Additionally, a thick sequence of the Unga Formation has been mapped on Ukolnoi Island about 10 km northeast of exposures of the Belkofski Formation on Dolgoi Island. We believe that these two formations may be, in part, correlative; however, correlation of part of the Belkofski (specifically the green arkose) with the Stepovak Formation is also possible.

The lower contact of the Belkofski Formation has not yet been found. The formation is overlain unconformably by volcanic flows and breccias as well as fluvial sedimentary rocks. Samples from some of the flows have been dated by K-Ar analysis as 11.82±0.50 and 11.79±0.40 Ma (late Miocene) (F.H. Wilson and Nora Shew, unpub. data, 1991). Because the Belkofski Formation is overlain by late Miocene lava flows and contains plant fossils of Oligocene age and a probable Miocene megafauna, we regard its age as late Oligocene(?) and early and middle Miocene(?).

Hemlock Conglomerate

Sedimentary rocks approximately equivalent in age to the Belkofski Formation are present in the Mount Katmai area at the northeast end of the Alaska Peninsula. Magoon and others (1976a, b) applied the name "Hemlock Conglomerate" to these rocks and correlated them with the type Hemlock Conglomerate noted at Capps Glacier in the Cook Inlet area by Calderwood and Fackler (1972) and Adkison (1975). The rocks at both localities are very similar in composition, but the rocks in the Mount Katmai area are considerably thicker than those measured at the type section in the Cook Inlet area.

The Hemlock Conglomerate in the Mount Katmai area consists mainly of fluvial sandstone and conglomerate; there are also minor interbeds of siltstone, shale, and coal. Minor tuff units are present in some exposures. The provenance for these sediments was different from that of the Belkofski Formation at the southwest end of the peninsula. In the Mount Katmai area, chert, quartz, and granitic and metasedimentary rocks form a major part of the conglomeratic clasts. Volcanic rocks compose a small percentage of these clasts, whereas volcanic rocks are the major constituents of the Belkofski Formation at the southwest end of the peninsula.

Tertiary fluvial sedimentary rocks that are here considered to be part of the Hemlock Conglomerate are exposed in the mountains bordering Shelikof Strait from Katmai Bay northeastward to Cape Douglas. In most exposures the Hemlock unconformably overlies the Kaguyak Formation (Upper Cretaceous). In a few localities, such as near Hallo Bay, the Hemlock lies unconformably on the Naknek Formation (Upper Jurassic). In the Cape Douglas area, the Hemlock Conglomerate disconformably overlies the Copper Lake Formation of early Tertiary age.

A reference section (section 23) of the Hemlock Conglomerate was measured on the northwest shore of Kukak Bay, in sec. 16, T. 21 S., R. 29 W., Mount Katmai B-1 1:63,360 quadrangle, beginning at VABM Yugnat and continuing northeastward to Cape Nukshak (fig. 14).

Section 23. Reference section of the Hemlock Conglomerate (fig. 14)

Tertiary volcanic rocks
Unconformable contact

Hemlock Conglomerate:	*Thickness (meters)*
28. Sandstone and conglomerate, thick-bedded, fine- to medium-grained, dark-yellowish-orange; tuffaceous; conglomerate as lag gravel in channels; clasts composed of chert, quartz, volcanic rocks; maximum clast size 20 cm; wood fragments	18.3
27. Covered interval	6.0
26. Lithic tuff, thick-bedded, pale-yellowish-brown	9.1
25. Conglomeratic sandstone, massive, coarse-grained, pale-yellowish-brown; channeled	15.2
24. Sandy siltstone, thin-bedded, pale-yellowish-brown; coaly seams; abundant deciduous leaves	12.2
23. Covered interval	100.0
22. Sandstone, thin- to thick-bedded, medium-grained, light-olive-gray; tuffaceous; deciduous leaves	12.2
21. Covered interval	22.8

Section 23. Reference section of the Hemlock Conglomerate (fig. 14)—Continued

20. Conglomeratic sandstone, thick-bedded to massive, fine- to coarse-grained, medium-dark-gray; conglomerate in channels; maximum clast size 60 cm; clasts composed of volcanic rocks, chert, quartz, granitic rocks	56.3
19. Conglomerate, massive, light-olive-gray; mainly volcanic rocks	9.1
18. Siltstone, thin-bedded, olive-gray; tree stump in growth position	12.2
17. Sandstone, thin-bedded to massive, brownish-gray; several coal seams	18.2
16. Siltstone, thin-bedded, medium-gray; fossil leaves	12.2
15. Conglomerate and sandstone, massive, olive-gray; channeled; clasts to 8 cm, mainly volcanic rocks	24.4
14. Conglomeratic sandstone, massive, medium-grained, light-olive-gray	24.4
13. Tuff, massive, dark-greenish-gray; laminated; fossil leaves	6.0
12. Conglomeratic sandstone, massive, coarse-grained, light-olive-gray; clasts mainly pebbles	24.4
11. Conglomerate, massive; clasts composed of chert, quartz, volcanic rocks; maximum clast size 15 cm; surface weathers orange	9.1
10. Sandstone, massive, fine-grained, silty, medium-dark-gray; crossbedded; carbonaceous	18.2
9. Conglomeratic sandstone, massive, medium-gray; carbonaceous; volcanic rock clasts	15.2
8. Sandstone, massive, fine-grained, medium-gray; carbonaceous	6.1
7. Conglomerate, massive, greenish-gray; volcanic rock clasts	10.6
6. Sandstone, thin- to thick-bedded, fine-grained	10.6
5. Siltstone, thin-bedded, olive-gray; laminated; sandstone concretions; coal seams; fossil leaves	42.6
4. Sandstone, massive, medium-grained, olive-gray; carbonaceous; numerous stumps; tuffaceous	9.1
3. Sandstone, thin-bedded; carbonaceous	10.6
2. Lithic tuff; volcanic rocks and pumice fragments	15.8
1. Siltstone and sandstone, thin-bedded, olive-gray; laminated; tuffaceous	27.4
Total section	558.3

Intrusive contact

Strata mapped as the Hemlock Conglomerate in the Mount Katmai area contain considerably more tuffaceous material than in the area of the type section (Calderwood and Fackler, 1972). The greater abundance of tuffaceous material is probably due to the greater proximity of the Mount Katmai area to centers of active volcanism on the Alaska Peninsula. Some volcanoes must have been fairly close, as pumice fragments are present in a number of Hemlock beds in the Mount Katmai area.

Megaflora fossils found in most outcrops of the Hemlock are mainly broadleaf deciduous plants; evergreen needles are also present. These fossils suggest a late Oligocene age

(J.A. Wolfe, written commun., 1988) though an earliest Miocene(?) age can not be ruled out (J.A. Wolfe, written commun., 1988). On the basis of Wolfe's interpretations, we consider the age of the Hemlock Conglomerate as late Oligocene.

Unga Formation

Volcaniclastic and volcanic rocks that are well exposed west of Zachary Bay on the north end of Unga Island were first investigated by Dall (1882, 1896) who applied the name "Unga Conglomerate" to the coarse clastic beds at White Bluff (see fig. 15*B*). Atwood (1911) renamed the unit the Unga "Formation." Burk (1965) reassigned these strata to the Unga Conglomerate Member, the basal member of the Bear Lake Formation; Allison and Addicott (1973) followed Burk's (1965) usage. We here return this unit to formational rank as the Unga "Formation" because it is a mappable unit lithologically distinct from the Bear Lake Formation.

The Unga Formation is geographically limited mainly to Unga Island and neighboring islands; it is also present along the southeast coast of the Alaska Peninsula facing Unga Island. The volcaniclastic rocks and interbedded volcanic rocks indicate a local volcanic provenance for the Unga. The Bear Lake Formation is found mainly on the northwest side of the Alaska Peninsula. Sedimentary rocks in the Bear Lake contain chert, quartz, and other nonvolcanic debris. Volcanic detritus constitutes only a minor part of the Bear Lake Formation, whereas volcanic clasts are the major part of the Unga Formation. The provenance for the Bear Lake Formation was different from that of the Unga Formation; the Bear Lake was derived mainly from the older Mesozoic formations and the Alaska-Aleutian Range batholith. Additionally, the two units are of different ages.

Atwood (1911, p. 66) established the type section of the Unga along the west shore of Zachary Bay, Unga Island. As thus defined, the type section is 200 ft (61 m) thick. Burk (1965) later included all of the rocks exposed along the west shore of Zachary Bay as part of his Unga Conglomerate Member. As part of the present investigation, we herein provide a more detailed description of the type section (section 24) than was published previously. Additionally, we have herein added about 30 m to the section measured by Burk (1965, p. 212). The breakdown of stratigraphic units described below and shown on figure 15 is not the same as that used by either Atwood (1911, p. 66) or Burk (1965, p. 212). The type section as defined by Atwood (1911, p. 66) consists of our stratigraphic units 14 through 18, which are equivalent to unit 5 of Burk (1965, p. 212). The section of the Unga Formation described here is the same as that described by Burk (1965), except that we define more units and have added about 30 m to the section's total thickness. Our measured section runs along the west shore of Zachary Bay from White Bluff northwestward along the coast to Unga Spit, Port Moller B-2 and B-3 1:63,360 quadrangles.

The volcaniclastic rocks composing the Unga Formation were derived locally from the (informal) Popof volcanic rocks that form the inner Shumagin Islands and adjacent islands, as well as from volcanic rocks dated as Miocene (F.H. Wilson and Nora Shew, unpub. data, 1991) that crop out on Unga and Wosnesenski Islands. The relatively small size of this source terrane may in large part explain the restricted areal extent of the Unga (Wilson and others, 1995), as well as the lack of major facies changes between its various exposures. The type section, being close to the source, contains more coarse volcanic debris than other exposures and is mainly a subaerial deposit. The more distal parts of the formation, such as the exposures forming Ukolnoi Island and Cape Aliaksin, are generally finer grained clastic rocks, some of which represent a shallow-marine environment. These thin marine sequences commonly contain a fairly abundant molluscan fauna that lived in the inner part of the inner shelf at approximately 25–35 m depths (Marincovich, 1988a).

Dall (1896), Dall and Harris (1892), and Atwood (1911) reported fossils, primarily *Crepidula* sp., from the type section. Both Burk (1965) and the present investigators failed to locate the so-called "*Crepidula* bed." We found only agatized burrows, probably Crustacean burrows, near the top of the extended type section (unit 23). The burrows are in a highly bioturbated sandstone (unit 23) that is exposed for about 1 km along the north shore of Unga Island, east of Unga Spit. The bioturbated sequence contains both agatized and sand-filled burrows 2 to 3 cm across and up to 45 cm long. The burrows are terminated at the top by a layer of grit and pebbles. Some of the agatized burrows are hollow, but most are solid. Unfortunately, no fossils were found associated with the burrows. *Crepidula ungana* is common at West Head on Unga Island, but at that locality the enclosing beds are part of the Stepovak Formation, not the Unga Formation. Fossils are locally very abundant elsewhere in the Unga Formation where thin marine sequences intertongue with thick nonmarine sequences. These thin marine layers contain numerous specimens of a few genera. Good examples of such layers are present on Ukolnoi Island and at Cape Aliaksin. The fauna at these localities include the bivalves *Mya* (*Mya*) *truncata*, *Acila* sp., *Yoldia* sp., *Macoma* sp., *Clinocardium* sp., and *Lucinoma acutilineata*, and the gastropods *Beringius crebricostatus*, *Natica* (*Cryptonatica*) *clausa*, and *Turritella* (*Hataiella*) *sagai*. *Turritella sagai* indicates an earliest middle Miocene age (15–16 Ma) for the Unga Formation on Ukolnoi Island according to Marincovich and Kase (1986) and Marincovich (1988a). The gastropod *Turritella sagai* was recently described by Marincovich and Kase (1986) as being from the oldest part of the Bear Lake Formation. However, we now consider the volcaniclastic beds from which *Turritella sagai* was obtained to be part of the Unga Formation rather than the Bear Lake Formation. The tuffaceous sandstone containing the *Turritella sagai* grades laterally into a thick tuff bed associated with lahars.

The remains of numerous petrified logs and smaller pieces of wood found in a debris flow (fig. 15, unit 14)

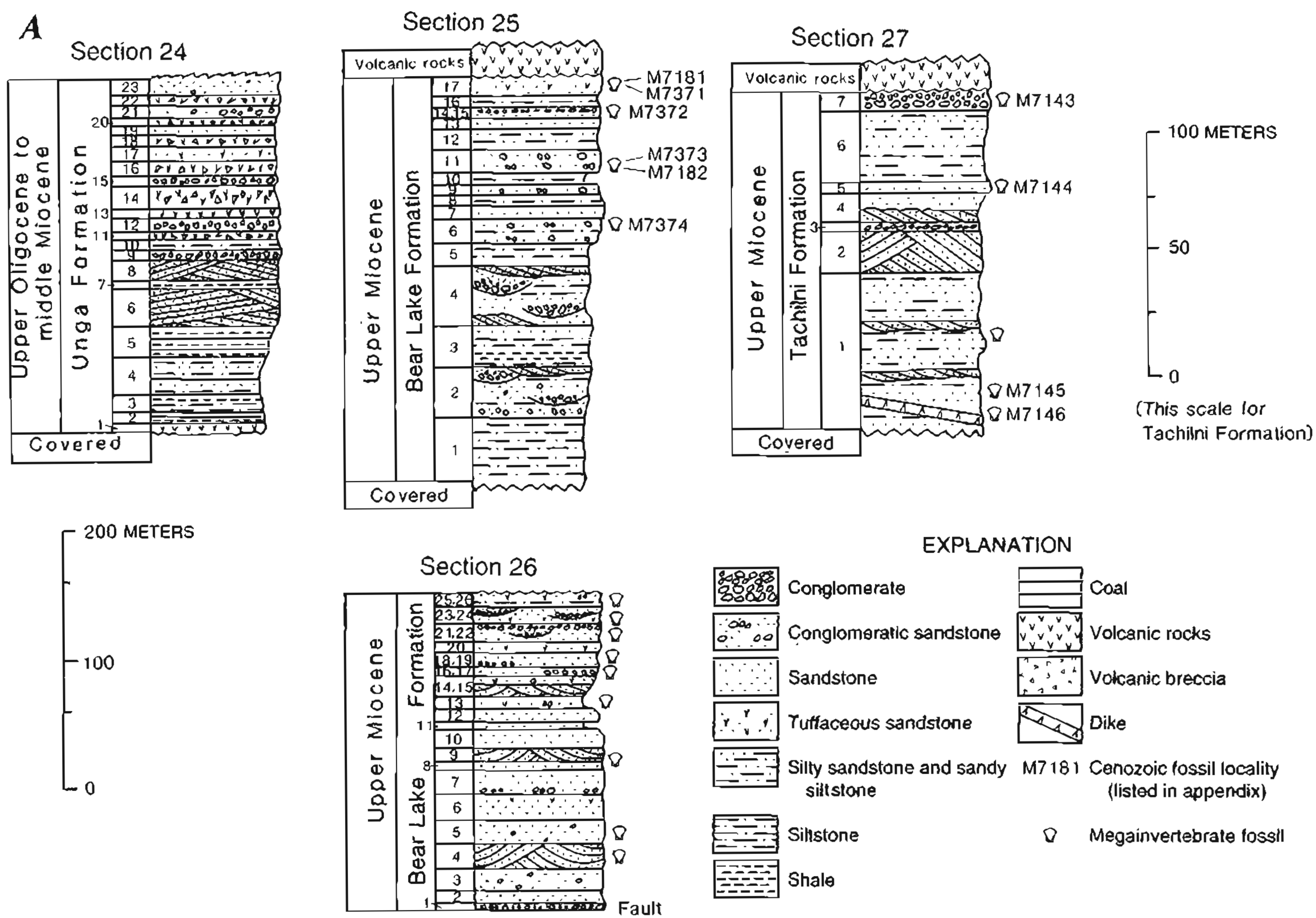
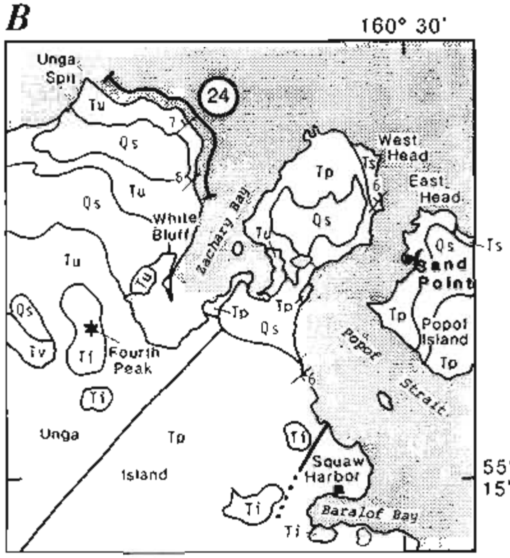
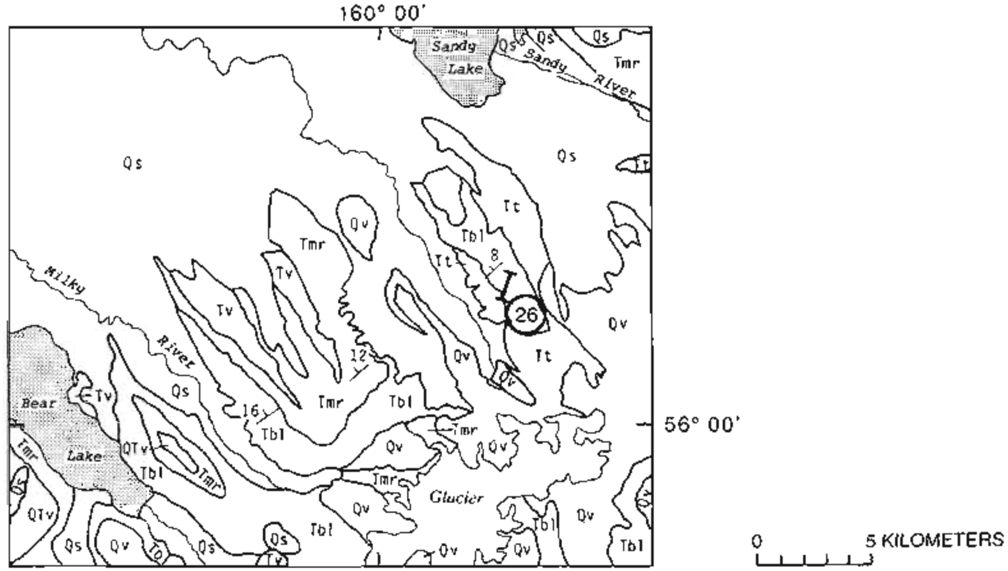


Figure 15. Oligocene and Miocene formations, Alaska Peninsula. *A*, Type section of Unga Formation and partial sections of Bear Lake and Tachilni Formations. Ages, formation names, and lithic units (numbered to correspond to text) are shown for each section. *B*, Index maps. Circled numbers label location of sections on index maps and figure 5. See figure 6 for explanation of other symbols.

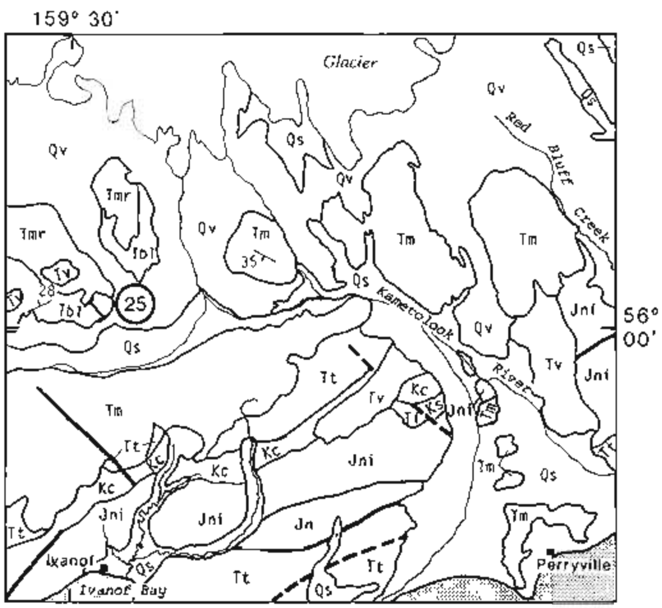
B



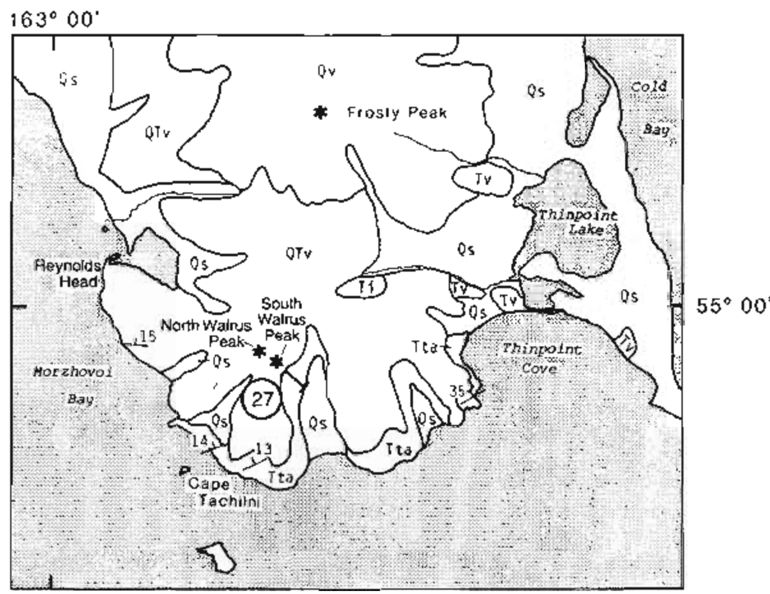
Geology modified from Wilson and others (1995)
Unga Formation
(type and measured sections)



Geology modified from Detterman and others (1981)
and Wilson and others (1995)
Bear Lake Formation



Geology modified from Detterman and others (1981)
and Wilson and others (1995)
Bear Lake Formation



Geology from Wilson and others (1992)
Tachilni Formation

Section 24. Type section of the Unga Formation (fig. 15)

Top of exposed section	*Thickness*
Unga Formation:	*(meters)*
23. Sandstone and grit, medium-bedded, fine- to coarse-grained, light-olive-brown; grit and small pebbles of volcanic rocks; limy concretionary lenses in sandstone; burrows filled with agate	12
22. Lahar or volcanic rubble flow, massive; angular clasts of wide size range in volcanic mud matrix	9
21. Sandstone and grit to small-pebble conglomerate, medium- to thick-bedded, light-olive-brown	9
20. Lahar, similar to unit 22	6
19. Sandstone, thick-bedded, medium- to coarse-grained, light-brownish-gray; interbedded yellowish-gray mudstone; wood fragments common	9
18. Lahar, similar to unit 22; clasts to 1.5 m	8
17. Sandstone, massive; volcanic and tuffaceous; few clasts; possibly a debris flow	12
16. Lahar, massive, brownish-gray; clast size to 2 m; angular	12
15. Conglomerate, massive, grit to cobble; all clasts are volcanic rocks	6
14. Debris flow, massive; contains logs and carbonized wood fragments	18
13. Tuff, massive, gray; partly welded	6
12. Conglomerate, thick-bedded; volcanic pebbles	12
11. Lahar, brown; angular clasts 1 cm to 1 m in size	6
10. Siltstone, mudstone, carbonaceous shale, and tuff, medium-brown	9
9. Conglomerate, massive, cobble-boulder; all clasts are volcanic rocks	5
8. Sandstone and siltstone, thin- to medium-bedded, light-olive-gray; low-angle crossbedding; few pebbles; carbonaceous	18
7. Carbonaceous shale and coal	6
6. Sandstone, siltstone, and carbonaceous shale; coaly debris in sandstone; low-angle crossbedding; poorly consolidated	30
5. Carbonaceous shale and coal; several coal seams to 0.5 m thick; shale weathers yellowish orange	25
4. Sandstone, siltstone, and coal, thin-bedded, medium-gray; poorly consolidated	30
3. Siltstone and shale, thin-bedded	18
2. Carbonaceous shale and coal	6
1. Tuff, massive, gray	3
Total exposed section	275

Base of exposed section

probably formed during the same event that produced the petrified forest on the northwest side of Unga Island (Eakins, 1970). Hundreds of petrified logs now lie along the beach and in the surf zone along the northwest shore of Unga Island, between Unga Spit and Bay Point (which lies about 13 km southwest of Unga Spit). Stumps larger than 2 m in diameter and still in their growth positions occur in the cliff face of the debris flow. The trees apparently are all *Metasequoia* (Eakins, 1970). The Unga Island locality contains the largest concentration of petrified wood, but logs and stumps occur in other outcrops of the formation as well; the wood was petrified either in a widespread event or in several related events. The presence of *Metasequoia* does not help in determining the age of the rocks, as the tree lived in southern Alaska from the Late Cretaceous through most of the Tertiary. However, a sample obtained for pollen analysis from the petrified forest horizon on the northwest side of Unga Island contained a pollen flora of about 30 taxa. This rich pollen assemblage was described as middle Miocene in age by T.A. Ager (written commun., 1986). Thus, the horizons containing abundant petrified wood in the Unga Formation probably can all be considered middle Miocene in age. This is approximately the same age as indicated by the gastropod *Turritella sagai* (Marincovich and Kase, 1986) from Ukolnoi Island. Petrified logs and stumps are common in the formation on Ukolnoi Island, as well as on nearby Wosnesenski Island.

The age of the lowermost part of the Unga Formation is not well constrained. The *Crepidula* sp. bed reported by early workers (Dall, 1896; Dall and Harris, 1892; and Atwood, 1911) as being near the base of the formation has not been located by recent workers (Burk, 1965; and this report). *Crepidula* sp. is present in nearby beds of the Stepovak Formation but not in the Unga Formation. A sparse pollen flora from the lower part of the type section (see Atwood, 1911, p. 66) indicates a late Oligocene age for that part of the formation (Virgil Wiggins, written commun., 1986). Thus, the overall age of the Unga is here considered late Oligocene to earliest middle Miocene, on the basis of megafauna and pollen. This age range is supported by K-Ar data obtained from associated volcanic rocks. One sample (83AWs 125) from an intrusive plug on Ukolnoi Island, which is believed to be the source of the tuffaceous sediments containing the molluscan fauna described by Marincovich (1988a) and Marincovich and Kase (1986), was dated by the K-Ar method at 15.69±1.6 Ma (DuBois and others, 1987); this information directly confirms the upper age limit for the Unga Formation. The lower age limit for the unit (late Oligocene) is less precisely substantiated. Several K-Ar ages (DuBois and others, 1987) from the postulated source beds on Unga Island range in age from 31.78±0.61 to 37.13±1.16 Ma. Thus, the lower part of the Unga can be no older than early Oligocene. The late Oligocene pollen obtained from near the base of the type section along the west side of Zachary Bay is considered indicative of a more definitive age assignment.

The contact relations of the Unga with underlying and overlying rock units are poorly defined. The lower contact is considered an unconformity. A seacliff exposure 11 km east of Cape Aliaksin contains a mixed molluscan fauna characteristic of both the Unga and Stepovak Formations. This mixed fauna indicates that Stepovak materials were eroded and reworked into the Unga sediments (Marincovich, 1988a). Also, a reef exposed at low tide offshore from White Bluff (fig. 15*B*) consists of sandstone that is highly discordant to the strike and dip of beds in White Bluff. The age of the reef beds is unknown, but they are lithologically similar to the Stepovak

Formation, which is exposed on the east side of Zachary Bay. The Unga is nearly everywhere overlain by volcanic rocks that range in age from 10.4±0.49 Ma at Cape Aliaksin to 8.43±0.45 Ma on Wosnesenski Island (DuBois and others, 1987).

Bear Lake Formation

Burk (1965, p. 89) gave the name "Bear Lake Formation" to a thick sequence of sandstone and conglomerate exposed along the east shore of Port Moller and in the mountains around Bear Lake (fig. 15*B*). He designated the unit's type locality as the mountains above and eastward from Bear Lake. Detterman and others (1981a) designated the type locality more specifically as the southeast slope of the mountains in secs. 27, 28, and 33, T. 48 S., R. 69 W., Chignik A-7 and Port Moller D-1 1:63,360 quadrangles. Two recently measured partial sections of the Bear Lake are herein included (sections 25, 26; fig. 15) to aid in the description of the formation. Additional measured sections are shown in a report by Lyle and others (1979). Section 25 was measured on the south flank of Mount Veniaminof in sec. 19, T. 48 S., R. 65 W., Chignik A-5 1:63,360 quadrangle; it is about 315 m thick (fig. 15). Section 26 is about 240 m thick and was measured on a south-facing slope of Sandy Ridge in sec. 32, T. 47 S., R. 68 W., and sec. 5, T. 48 S., R. 68 W., Chignik A-6 1:63,360 quadrangle. The thickness of the Bear Lake at both sections is much less than the thicknesses estimated by previous investigators. Burk (1965, p. 89) estimated the thickness of the Bear Lake as 5,000 ft (1,525 m), and Brockway and others (1975) identified 2,360 m of rock in the Gulf Oil Corporation Sandy River #1 borehole as the Bear Lake Formation. The present investigators consider the thickness of the Bear Lake Formation to be no more than about 1,000 m. The section may be repeated by faulting in the Sandy River borehole, as a major thrust fault has been identified a few miles to the east (Wilson and others, 1995).

Section 25. Partial section of the Bear Lake Formation (fig. 15)

Volcanic rocks
Unconformable contact

Bear Lake Formation:	*Thickness (meters)*
17. Sandstone, thin-bedded to massive, medium-grained, olive-gray; slightly tuffaceous; abundant molluscan fossils, including *Acila empirensis*, *Clinocardium*, *Cyclocardia*, *Mizuhopecten mollerensis*, *Glycymeris*, *Mya* cf. *M. cuneiformis*, *Mya truncata*, *Spisula*, *Natica*, and *Neptunea* (M7181 and M7371)	16.7
16. Siltstone, thin-bedded, moderate-yellowish-brown	9.1
15. Conglomerate, thick-bedded, pebble; coarse-sand matrix; fossiliferous (M7372)	3.0
14. Sandstone, thick-bedded, coarse-grained, olive-gray	3.0
13. Sandstone, massive, fine-grained, pale-yellowish-brown; silty	10.7
12. Sandy siltstone, thin-bedded, grayish-green	15.2

Section 25. Partial section of the Bear Lake Formation (fig. 15)—Continued

11. Conglomeratic sandstone, massive, dark-yellowish-brown; abundant fossils, including *Chione*, *Clinocardium*, *Mizuhopecten mollerensis*, *Mya elegans*, *Mytilus*, and *Remondella waldroni* (M7182 and M7373)	18.3
10. Siltstone, thin-bedded, olive-gray	10.7
9. Conglomeratic sandstone, massive, medium-grained, light-olive-gray; poorly sorted	3.6
8. Siltstone, thin-bedded, pale-yellowish-brown	9.7
7. Sandstone, thin-bedded, medium-grained, light-olive-gray	10.7
6. Conglomeratic sandstone and siltstone, thin- to thick-bedded; grayish-olive-green; megafauna in upper part, ?*Neptunea* (M7374)	19.8
5. Siltstone, thin-bedded, greenish-gray; few shale chips	18.3
4. Sandstone, thin-bedded, medium-grained, light-brownish-gray; crossbedded; channels containing lag gravel	42.6
3. Siltstone and shale, thin-bedded, olive-gray	35.9
2. Conglomeratic sandstone, medium- to thick-bedded, medium-grained, olive-gray; crossbedded and channeled; some siltstone interbeds	39.6
1. Siltstone, thin-bedded, olive-gray; crossbedded; plant fragments; few pebbles	47.2
Total exposed section	314.1

Base of exposed section

The Bear Lake Formation is exposed mainly along the northwest side of the Alaska Peninsula from Port Moller northeastward to the Upper and Lower Ugashik Lakes area, and it continues in the subsurface at least as far as Becharof Lake (Brockway and others, 1975). Rocks that are partly age-equivalent to the Bear Lake are mapped as the Tachilni Formation southwest of Port Moller.

The Bear Lake Formation differs from most of the other Tertiary sedimentary units exposed on the peninsula, with the exception of the Tolstoi Formation, in its greater abundance of nonvolcanic detritus. Chert and quartz form a considerable part of the clastic detritus in its sandstones, which exhibit better sorting than is common in the other Tertiary units. These rocks evidently had a source area in the older Mesozoic sedimentary strata and, possibly, in the Alaska-Aleutian Range batholith. Apparently, the Bear Lake depositional basin was isolated from the volcanic-rich sequence of rocks on the southeast side of the Alaska Peninsula. Conglomerate clast composition varies somewhat between conglomerate beds, but an average composition is about 30–40 percent chert, 20–30 percent volcanic rocks, 10–15 percent quartz, and 10–15 percent granitic rocks. All clasts are well rounded and range in size from pebbles to small cobbles.

The Bear Lake Formation was deposited mainly in an inner neritic to tidal flat environment; tidal and fluvial channels commonly cut into its deposits (Nilsen, 1984; Wisehart, 1971). Strong tidal currents were apparently the cause of the better sorting of the clastic sediments. The bulk of the marine invertebrate fauna whose fossils are preserved in the formation lived in shallow, near-shore environments in water depths of less than 100 m (Louie Marincovich, Jr., 1983, and written commun., 1978 and 1985).

The two sections of the Bear Lake Formation illustrated in figure 15 are incomplete, and their exact positions within the total formation are questionable. However, section 25 from the south flank of Mount Veniaminof contains a high percentage of siltstone that may be correlative with the lower part of the section encountered in the Sandy River #1 borehole (Brockway and others, 1975). The Sandy Ridge section (section 26), in contrast, contains more sandstone and conglomerate and has a fairly high content of tuffaceous material; this composition is more characteristic of the upper part of the borehole section.

The Sandy Ridge section (fig. 15, section 26) was measured in part by John Bolm (U.S. Minerals Management Service) in 1982 and in part by the present authors in 1982.

Section 26. Partial section of the Bear Lake Formation (fig. 15)

	Thickness (meters)
Top of exposed section	
Bear Lake Formation:	
26. Sandstone, thick-bedded, fine- to coarse-grained, olive-gray; tuffaceous; scattered pebbles; abundant megafossils including *Clinocardium* and *Mya truncata*	4.3
25. Siltstone, thin-bedded, medium-brown; poorly exposed	4.8
24. Sandstone, medium-bedded, fine- to medium-grained, medium-olive-gray; abundant disarticulated bivalves	5.5
23. Sandstone, thick-bedded, medium-grained, light-gray; scattered pebbles and small cobbles; crossbedded; tuffaceous; scattered bivalves	10.0
22. Conglomerate, massive; well-rounded clasts to 30 cm, consist mainly of volcanic fragments	2.1
21. Sandstone, thick-bedded, fine- to medium-grained, medium-olive-gray; scattered pebbles to 10 cm; trough crossbeds; contains few fossils, including *Mya truncata*, *Chlamys*, *Clinocardium*, and ?*Neptunea* (M8511)	12.8
20. Sandstone, thin-bedded to massive, medium- to coarse-grained, light-olive-gray; few pebbles to 4 cm; trough crossbeds; bioturbated	7.9
19. Sandstone, massive, fine-grained, light-olive-brown; pebble-to-cobble layer near top; few *Clinocardium* and *Pecten*	3.6
18. Sandstone, thin- to medium-bedded, fine-grained, light-olive-gray; tuffaceous; 60-cm-thick pebble-conglomerate channel at base	5.5
17. Sandstone, medium-bedded to massive, fine-grained, olive-gray to moderate-yellow-brown; tabular crossbeds; *Clinocardium* fragments	6.0

Section 26. Partial section of the Bear Lake Formation (fig. 15)—Continued

16. Conglomerate, massive, well-rounded pebbles; sandy tuffaceous layer in middle part	1.5
15. Sandstone, massive, medium- to coarse-grained, light-olive-gray; slightly tuffaceous; few pebbles	9.1
14. Conglomeratic sandstone, thick-bedded to massive, fine- to medium-grained, light-olive-brown; volcanic rock clasts to 45 cm; trough crossbeds	6.1
13. Sandstone, thin-bedded to massive, fine- to medium-grained, light-olive-gray; few pebbles to 10 cm; bivalves in upper part; bioturbated in lower part	10.6
12. Sandstone, massive, medium- to coarse-grained, medium-gray; conglomerate bed in middle part; trough crossbeds; bioturbated	9.1
11. Sandstone; rubble	7.6
10. Sandstone, thick-bedded, medium- to coarse-grained, gray; bioturbated; crossbedded	13.7
9. Conglomeratic sandstone, thick-bedded, medium-dark-gray; trough crossbeds; bivalves	10.0
8. Sandstone, medium-bedded, fine- to coarse-grained, medium-gray; conglomerate layer in middle part; bivalves *Cardium* and *Acila*	7.3
7. Sandstone, massive, very fine to fine-grained, light- to medium-gray; pebbles and cobbles at base	18.3
6. Sandstone, thin- to thick-bedded, fine- to medium-grained, medium-gray to brown	18.5
5. Sandstone, massive, fine- to coarse-grained, grayish-brown; scattered pebbles and bivalves	17.9
4. Sandstone, thick-bedded, fine-grained, dusky-yellow to medium-gray; few pebbles; trough crossbeds; few bivalves	22.5
3. Sandstone, medium-bedded, fine- to medium-grained, medium- to dark-gray; scattered pebbles	18.6
2. Sandstone, thin-bedded, fine-grained, olive-gray to dusky-yellow; laminated and crossbedded	7.9
1. Conglomerate, massive; well-rounded clasts to 4 cm	2.4
Total exposed section	243.7
Fault or unconformable(?) contact	

All exposures of the Bear Lake Formation are abundantly fossiliferous, containing mainly bivalves and gastropods. These fossils have been studied in considerable detail by Louie Marincovich, Jr. (1988a, and written commun., 1978, 1980, 1984, 1985) and Allison (1978). They have been correlated with the Newportian to Graysian Stages of middle and late Miocene age; this age assignment is based on about 30 genera of mollusks, two-thirds of which are bivalves. On the basis of its contained megafauna, the Bear Lake Formation is here considered to be middle and late Miocene in age. Some of the genera also are present in the Tachilni Formation, exposed at the southwest tip of the Alaska Peninsula, and the two formations are partly correlative according to Marincovich (1983). The two formations have about 20 genera in common (Marincovich, 1983).

The Bear Lake Formation overlies the Meshik Volcanics, Stepovak Formation, and Tolstoi Formation at various localities. Most of the contacts are disconformities; a few are angular unconformities. The Bear Lake Formation is not in contact with the Unga Formation, which has heretofore been considered to be the basal member of the Bear Lake Formation by numerous authors, including Burk (1965), Allison and Addicott (1973), and Marincovich (1988a). The Bear Lake Formation is overlain at some localities by volcaniclastic and volcanic rocks of the Milky River Formation—most of the contacts are disconformities and a few are angular unconformities—but more commonly the Bear Lake is the uppermost sedimentary rock unit exposed.

Tachilni Formation

The Tachilni Formation was named by Waldron (1961, p. 686–687) for several hundred feet of marine sedimentary rocks exposed along Morzhovoi Bay at the tip of the Alaska Peninsula. The formation is present only near the southwest end of the Alaska Peninsula. We studied the Tachilni Formation only briefly during the present investigation. However, other U.S. Geological Survey workers have studied the formation in considerable detail (see McLean, 1979a, 1979b; McLean and others, 1978; and Marincovich, 1983). We show herein (fig. 15) a reference section (section 27) located on South Walrus Peak near Cape Tachilni that was measured during a U.S. Geological Survey project in the area (see McLean, 1979b; Marincovich, 1983). The section is located in the SE1/4 NE1/4 sec. 19, T. 60 S., R. 89 W., Seward Meridian, False Pass D-3 1:63,360 quadrangle.

Section 27. Reference section of the Tachilni Formation (fig. 15)

Volcanic rocks
Unconformable contact
Tachilni Formation:

	Thickness (meters)
7. Conglomerate, thick-bedded to massive, pebble-size clasts; coarse sandstone matrix; contains fossils *Bulbus fragilis, Neptunea lyrata altispira, Polinices pallidus, Mya truncata* (M7143)	8
6. Sandstone, thin-bedded, fine-grained, silty, gray; grades downward to interbedded dark mudstone; laminated; festoon crossbeds	30
5. Sandstone; contains mollusks, including *Clinocardium* and *Mizuhopecten mollerensis* (M7144)	4
4. Sandstone, medium-bedded, dark-gray; laminated and crossbedded; few pebble layers	11
3. Conglomerate, pebble	1
2. Sandstone, dark-gray; bimodal crossbeds	17
1. Sandstone, medium-bedded, fine- to medium-grained, gray with black laminae; bimodal trough crossbedding; pebble layers with fossils, including 11 genera of bivalves and 6 of gastropods (M7145 and M7146)	61
Total measured section	132

Section continues, not measured

The 132 m of the Tachilni Formation exposed at the reference section is not a complete section; the basal part was not investigated. Stratigraphic and structural data suggest that the Tachilni may be as much as 200 m in total thickness, which is considerably more than the 60 to 65 m exposed at the formation's type locality at Cape Tachilni.

The Tachilni Formation is composed mainly of poorly consolidated subgraywacke sandstone containing 30–35 percent angular quartz, 10–15 percent feldspar, 5 percent pyroxene and amphibole, 30 percent volcanic rock fragments, and 20 percent clay matrix. The gray to brown sandstone is commonly crossbedded and interbedded with volcanic-pebble conglomerate and siltstone. The Tachilni (upper Miocene) and Bear Lake (middle and upper Miocene) Formations are, in part, age equivalents (Allison, 1978; Marincovich, 1983), and they have molluscan fossils in common; but they are distinctly different lithologically even though their exposure areas are separated by only about 125 km. This lithologic difference reflects different source areas for the two formations. The Tachilni Formation is geographically restricted to the southeast side of the Alaska Peninsula, and its source terrane is the abundant volcanic rocks along the Pacific Ocean side of the Alaska Peninsula. In contrast, the Bear Lake Formation was deposited on the Bristol Bay side of the peninsula and was derived from the erosion of the older Mesozoic sedimentary rocks and the Alaska-Aleutian Range batholith. The two formations have about 20 molluscan genera in common, so there apparently was an open seaway between the two depositional areas. The faunal differences between the two formations may reflect the organisms' preference for a particular type of substratum, a difference in preservation of the fossils, or merely poor collecting techniques. Horizons containing abundant bivalve and gastropod fossils are common throughout both units. The fossils indicate shallow-water deposition, generally in less than 100-m water depths (Marincovich, 1983).

The reference section of the Tachilni Formation is only part of the total Tachilni sequence exposed in the Cape Tachilni area. McLean (1979b) reported the formation to be about 460 m thick in this area, but structural complications and poor exposures preclude measuring a complete section. Marincovich (1983, p. 66) stated that the fauna from the strata at South Walrus Peak is significantly younger than the fauna obtained from the beds at Cape Tachilni, suggesting that the formation is thicker than shown here.

The Tachilni Formation is richly fossiliferous, containing 36 genera of bivalves and 11 genera of gastropods. The Tachilni fossils show a close correlation with the Wishkahan Stage of the late Miocene; it is on this basis that the age of the unit is regarded as late Miocene in this report. This age assignment is based on such forms as *Acila empirensis, Clinocardium hannibali, Felaniella parilis, Glycymeris grewingki, Macoma astori, Protothaca staleyi, Buccinum* sp., *Natica janthostoma*, and *Neptunea* sp. The complete list of Tachilni fossils is contained in a report by Marincovich (1983).

The Tachilni Formation contains both marine and nonmarine strata that consist mainly of sandstone, mudstone, and conglomerate. The sandstone and conglomerate are composed chiefly of volcanic rock fragments; this composition contrasts sharply with that of the partly coeval Bear Lake Formation, which is mainly nonvolcanic. Lateral and vertical facies changes are common in the Tachilni, and many of its beds are channeled. Bimodal crossbedding in the unit suggests strong tidal influences. The provenance for its sediments is the older Tertiary volcanic rocks located along the southeast side of the peninsula, whereas the provenance for the Bear Lake Formation is the Mesozoic deposits located on the northwest side of the peninsula.

The Tachilni Formation is unconformably overlain by volcanic rocks, presumably part of the Milky River Formation. The lower contact of the formation is unknown, but the Tachilni may overlie the Belkofski Formation (McLean, 1979b).

Milky River Formation

The name "Milky River Formation" was used by Galloway (1974) for volcanic and sedimentary rocks overlying the Bear Lake Formation along the Milky River. Prior to 1974, these rocks were informally referred to as Pliocene volcanic and sedimentary rocks (see Waldron, 1961; Burk, 1965). The formation was formally defined and a type locality designated by Detterman and others (1981a). The type locality is located on the northeast spur of a mountain in sec. 14, 15, and 22, T. 48 S., R. 69 W., Seward Meridian, Chignik A-7 1:63,360 quadrangle. The Milky River in its type locality is about 465 m thick. A considerably thicker section was identified in the Gulf Oil Corporation Sandy River #1 borehole by Brockway and others (1975), approximately 25 km northwest of the type locality (fig. 16). The section from the borehole is in sec. 10, T. 46 S., R. 70 W. Chignik A-7 1:63,360 quadrangle. The section identified as the Milky River Formation, from a depth of −160 ft (−48 m) to −3,480 ft (−1,060 m) is here designated as a reference section of the unit (section 28). Details from the borehole logged by Baroid Well Logging and from ditch samples are shown in section 28.

The Milky River Formation in the Sandy River #1 borehole reference section is more than twice as thick as the section at the type locality. This is probably due to the strata in the type locality being subjected to greater postdepositional erosion than the strata in the area of the borehole. The strata in the type locality are also much more conglomeratic than those at the reference section, indicating their relative proximity to the source area. The formation is entirely nonmarine both at the type locality and in the reference section; however, northeast along the Alaska Peninsula, near Becharof Lake, General Petroleum Corporation's Great Basin #1 borehole encountered bivalves at −1,185 m depth in rocks correlative with the Milky River Formation (Brockway and others, 1975). No data are available on the kind(s) of fossils or their age(s). The fossils may actually be from beds of the Bear Lake Formation, rather than beds correlative with the Milky River Formation. The fossils cannot be recovered, so additional information about them cannot be obtained. A K-Ar age of 3.53±0.27 Ma (Wilson and others, 1981) obtained from a lava flow just below the top of the section at the type locality, as well as another age of 3.87±0.06 Ma (F.H. Wilson, unpub. data, 1991) from near the base of the formation near Port Moller, indicates that the Milky River Formation is of Pliocene age.

Section 28. Reference section of the Milky River Formation (fig. 16)

Quaternary glacial deposits
Unconformable contact

Milky River Formation:	*Thickness (meters)*
18. Basalt flow, fine-grained, porphyritic, black	41.1
17. Sandstone, coarse-grained, brown to orange; conglomeratic; all volcanic rock clasts; tuffaceous	57.9
16. Siltstone, yellow; tuffaceous	16.7
15. Andesite flow; porphyritic	9.1
14. Tuff, olive-brown to yellow	18.3
13. Sandstone and conglomerate, brown, basaltic; minor tuffaceous siltstone	51.8
12. Tuff, lapilli, pale-yellowish-orange	19.8
11. Tuff and scoria	54.8
10. Sandstone and conglomerate, coarse-grained, light-grayish-yellow; tuffaceous; all volcanic debris	10.6
9. Sandstone, tuffaceous, fine- to coarse-grained, light- to dark-gray; some scoria; few pebbles; all volcanic debris	27.4
8. Siltstone, dark, carbonaceous; pumice fragments	18.2
7. Sandstone, tuffaceous, fine- to coarse-grained, light- to dark-gray; some scoria; few pebbles; all volcanic debris	61.6
6. Basalt flow, black to reddish-brown	30.5
5. Siltstone, tuffaceous, black; thin lignite beds	54.8
4. Sandstone, coarse-grained, basaltic; interbedded white tuff	64.0
3. Sandstone, coarse-grained, tuffaceous; interbeds of tuff and scoria	198.0
2. Siltstone, light-gray, tuffaceous	54.8
1. Sandstone and sandy siltstone, tuffaceous, light-gray	156.7
Total section	1,011.7

Unconformable contact
Bear Lake Formation

Late Tertiary Igneous Rocks

Igneous activity on the Alaska Peninsula during Tertiary time can be separated into two main episodes. The first episode, which formed the Meshik arc (Wilson, 1985), ceased in earliest Miocene time. During late Miocene time, after a 10- to 12-m.y. hiatus recognized over much of the Alaska Peninsula, igneous activity resumed with the formation of the

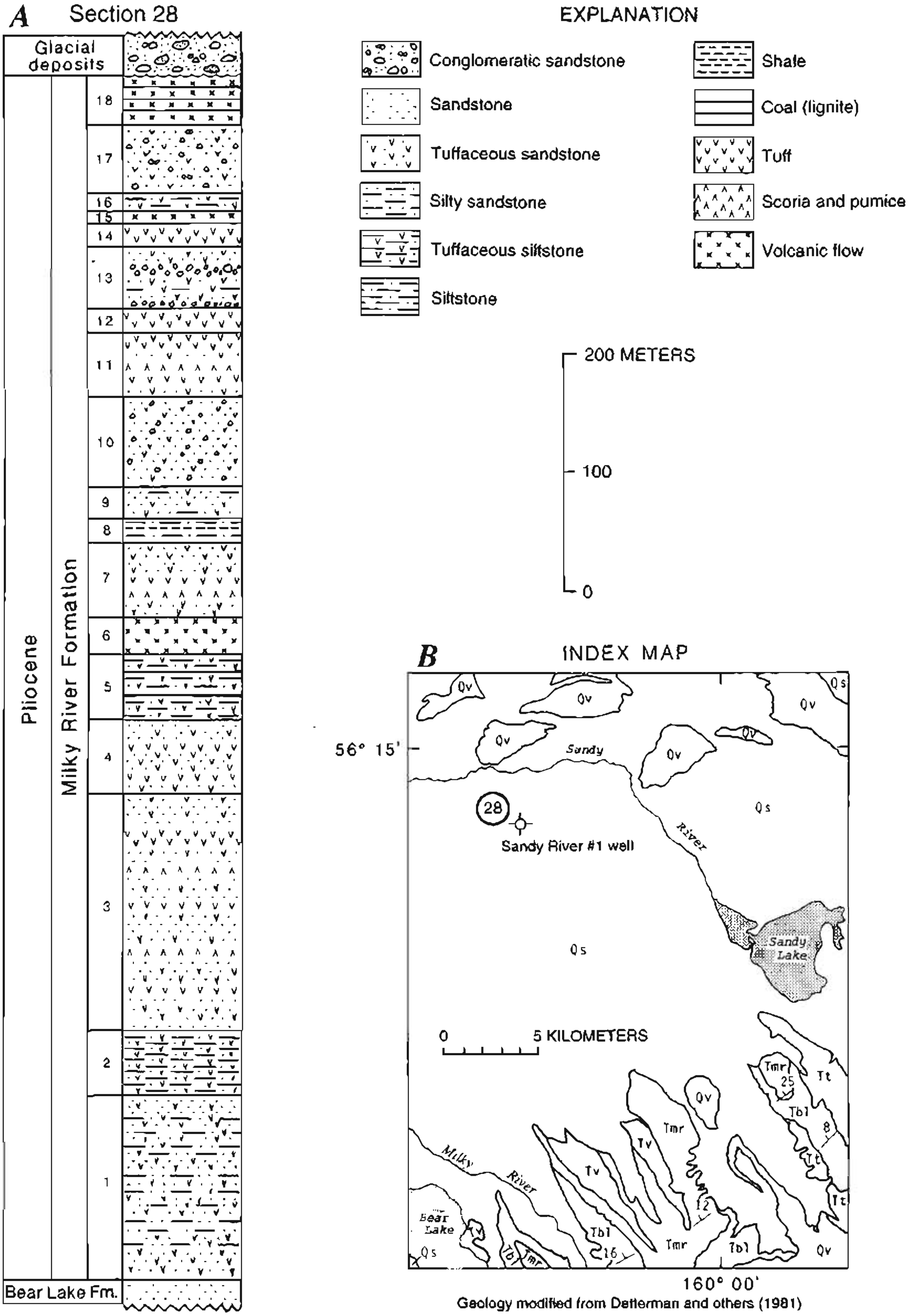


Figure 16. Pliocene Milky River Formation, Alaska Peninsula. *A*, Reference section from Sandy River #1 borehole. Age, formation name, and lithic units (numbered to correspond to text) are shown for section. *B*, Index map. Circled number labels location of section on index map and figure 5. See figure 6 for explanation of other symbols.

Aleutian magmatic arc. (Note: In common usage, the term "Aleutian arc" is used for rocks that are herein called the "Meshik arc" and the "Aleutian arc." Here, we restrict usage of the term "Aleutian arc" to the late Tertiary to present magmatic arc in southern Alaska.) Igneous activity along a convergent plate margin is generally believed to be associated with subduction of one plate beneath another, and cessation of activity indicates that little or no subduction is taking place. On the Alaska Peninsula, magmatism has been produced by subduction of the Kula and Pacific plates beneath the North American plate along the ancient and modern Aleutian trenches. DeLong and others (1978, 1980) and Farrar and Dixon (1980) suggested that subduction of the Kula-Pacific ridge occurred during the early Oligocene, about 35 Ma, and that subduction of the ridge resulted in a hiatus in subduction-related igneous activity. Wilson (1985) suggested that the waning of igneous activity on the Alaska Peninsula between the end of the Meshik arc at about 25 Ma and the beginning of the Aleutian arc at about 10 to 15 Ma may reflect the hiatus predicted by DeLong and others (1978, 1980). However, more recent analysis of the history of the Kula plate based on new data (Lonsdale, 1988) changes our understanding of the timing of events affecting the Kula-Pacific ridge; Lonsdale presents evidence suggesting that the Kula-Pacific spreading center ceased activity at 43 Ma. Plate reconstructions by Engebretson and others (1985) suggest that this old spreading center would have been subducted in latest Miocene or early Pliocene time, and Lonsdale (1988, p. 753) doubted "...that the presence of this old plate boundary had any major influence on arc volcanism...." Lonsdale's conclusions are specific to the Aleutian Islands segment of the magmatic arc; however, the timing of ridge subduction in the Alaska Peninsula segment was not greatly different (Engebretson and others, 1985, p. 19–22), and therefore Lonsdale's conclusions should also apply to the Alaska Peninsula. The Miocene hiatus in magmatism may reflect cessation of subduction while the Alaska Peninsula was coupled with the Pacific plate; however, limited paleomagnetic data (Thrupp and Coe, 1987) do not suggest any post-Eocene latitudinal displacement of the Alaska Peninsula and therefore do not support coupling of the Alaska Peninsula to the Pacific plate. The resumed magmatic activity appears to have started near Chignik, in the middle of the peninsula, about 10–15 Ma and then spread northward and southward during the course of a few million years. Quaternary volcanoes along the Alaska Peninsula indicate continued activity along the Aleutian arc.

Intrusive Rocks

Moderate-sized batholiths of late Tertiary age were emplaced along the present Pacific coast of the Alaska Peninsula at fairly regular spacing. These plutons start at King Cove (Cold Bay 1:250,000 quadrangle) and continue northeastward to Moss Cape, Pyramid Mountain, and American Bay (Port Moller 1:250,000 quadrangle), Mitrofania Island (Stepovak Bay 1:250,000 quadrangle), Devils Bay (Chignik 1:250,000 quadrangle), Agripina Bay and Cape Igvak (Ugashik and Karluk 1:250,000 quadrangles), and finally to Kukak Bay and Cape Douglas (Mount Katmai and Afognak 1:250,000 quadrangles) at the northeast end of the peninsula. Smaller stocks and hypabyssal plugs and domes are interspersed between the larger batholithic bodies, generally somewhat farther inland than the batholiths. Some of these smaller intrusions are hypabyssal bodies directly associated with extinct volcanic centers.

The plutonic rocks range in composition from diorite and quartz diorite to granodiorite and also include minor quartz monzonite and monzodiorite. They range from fine to coarse grained, though most are medium grained; they are equigranular and contain pyroxene, hornblende, and (or) biotite in varying amounts. Well-developed hornfels zones surround the batholiths, and many of the batholiths have areas of hydrothermal alteration and mineralization (see, for example, Wilson and others, 1988). Many of the plutonic bodies have been radiometrically dated; ages range from 10.08±0.14 Ma for the Devils batholith (Wilson and others, 1981) to 2.10±0.28 Ma for the Agripina Bay batholith (Wilson and Shew, 1992).

The hypabyssal rocks are mainly andesitic to dacitic, fine to medium grained, and hornblende-bearing. A few small plugs and sills are as silicic as rhyolite or as basic as olivine basalt. Alteration and low-grade mineralization of the rocks are fairly common. Many dikes and sills intrude the sedimentary rocks of the Alaska Peninsula. It is difficult to distinguish hypabyssal rocks of late Tertiary age from similar rocks of Eocene and Oligocene age unless there is good stratigraphic control or else radiometric age determinations are available. The radiometric age determinations available for the late Tertiary hypabyssal rocks have a range similar to that for the plutonic rocks discussed above. Though many of the measured sections of sedimentary rocks in this report show dikes and sills, few of these dikes are radiometrically dated. Although some of these dikes and sills resulted from Aleutian arc magmatism, some undoubtedly were emplaced during Meshik arc magmatism.

Volcanic Rocks

Large volcanic fields associated with hypabyssal intrusive centers are not common on the Alaska Peninsula. Several are present, however, and the largest covers approximately 850 km^2 between the Katmai River and Kukak Bay, near the northeast end of the Alaska Peninsula. Several other moderate-sized areas (less than 300 km^2) of late Tertiary volcanic rocks are near Chiginagak Bay and Cape Douglas, between Cape Aliaksin and Dorenoi Bay, between Morzhovoi Bay and False Pass, and between King Cove and Cold Bay. Small areas are also present on the southwestern part of the peninsula where flow remnants cap ridges. Perhaps the major reason for the relatively small areal extent of Tertiary extrusive rocks is erosion, particularly glacial erosion during the Pleistocene.

Also, structural data indicate that the late Miocene and Pliocene was a time of intense structural deformation and uplift, which would accentuate erosion.

The late Tertiary volcanic rocks are mainly basaltic to andesitic in composition and dark greenish gray to black in color. The rocks commonly are porphyritic and contain phenocrysts of plagioclase and of clinopyroxene, orthopyroxene, or hornblende. Flows, locally columnar jointed, are as much as 15 m thick and are commonly interbedded with lithic tuff and volcanic breccia. Hypabyssal plugs of similar composition, probable erosional remnants of volcanic edifices that produced the flows, are present within or around the volcanic fields. Local alteration and silicification of the volcanic rocks is particularly prevalent near the plugs. Some minor mineralization is found in the altered rocks.

Morzhovoi Volcanics

The name "Morzhovoi Volcanics" was introduced by Waldron (1961) for a sequence of interbedded lava flows and pyroclastic rocks, and some associated volcaniclastic rocks, that are exposed east of Morzhovoi Bay and south of Frosty Peak (fig. 15*B*). Reynolds Head, on the east shore of Morzhovoi Bay, in sec. 5, T. 59 S., R. 90 W., Cold Bay A-3 1:63,360 quadrangle, was designated as the type locality by Waldron (1961, p. 688), who suggested that North and South Walrus Peaks, as well as other high peaks in the area, were remnants of an ancient volcano. The arrangement of the peaks suggest a caldera rim, but we cannot prove or disprove a caldera at this location.

Lava flows of the Morzhovoi Volcanics are light- to pinkish-gray porphyritic basalt composed mainly of plagioclase and augite. The flows contain minor amounts of either hypersthene or olivine, but not both in the same flow. Volcanic breccia and agglomerate enclosed in a tuffaceous matrix are interbedded with the lava flows. These rocks are locally hydrothermally altered and mineralized in the Walrus Peaks area, particularly around South Walrus Peak.

The age of the Morzhovoi Volcanics is not known precisely, but it can be determined fairly accurately by indirect methods. The Morzhovoi overlies the Tachilni Formation, whose age has been established as late Miocene according to Marincovich (1983) and the present authors. The upper part of the Tachilni Formation contains several ash beds that were possibly derived from the Morzhovoi volcano. The Morzhovoi volcanic flows commonly contain olivine, which is rare in Quaternary volcanic rocks on the Alaska Peninsula. Additionally, glaciers have eroded deep, broad, U-shaped valleys that are separated by knife-like ridges in Morzhovoi strata, indicating that the Morzhovoi is in part older than the Pleistocene glacial interval. The best estimate at present for the age of the Morzhovoi Volcanics is late Miocene(?), Pliocene, and early Quaternary(?).

The contact between the Morzhovoi Volcanics and the underlying Tachilni Formation is generally conformable, but it is locally unconformable where volcanic flows have filled former stream valleys cut into the Tachilni Formation.

Quaternary System

Deposits of Quaternary age cover about 75 percent of the land area of the Alaska Peninsula. Two processes, volcanism and glaciation, are responsible for the formation of most of these deposits. Subsequent minor modification of these deposits has occurred through the action of water, wind, and gravity; however, only the major deposits attributable to volcanism and glaciation will be described here.

Volcanic rocks

An increase in magmatic activity that began in the late Miocene continues to form the present Aleutian arc. Thirty-seven Quaternary volcanic centers have been identified along the Alaska Peninsula, 30 of which have erupted in Holocene time (fig. 17; Miller and Richter, 1994). Eight caldera-forming eruptions have occurred along the Alaska Peninsula during the Holocene (Miller and Smith, 1987), one of which, the Novarupta eruption of 1912, is the largest volcanic eruption of this century. Two eruptive centers have formed since 1900. Some of the highest peaks along the peninsula are formed by its stratovolcanoes, the highest of which is Pavlof Volcano at just over 2,500 m.

The Quaternary volcanic centers define a narrow belt of volcanic activity that trends northeast-southwest along the axis of the peninsula about 15 to 30 km from the Pacific coast. The most marked offset of this volcanic line is in the central peninsula where Mount Kialagvik, Mount Chiginagak, and Yantarni Volcano (Riehle and others, 1987c) are approximately 32 km closer to the trench than their neighbors on either side. This offset may be due to structural control exerted by faults in the upper crust, or it may be related to deep transcurrent fractures, perhaps in the Pacific plate being subducted beneath the peninsula. Nakamura and others (1980) used a 60-km-long belt of cinder cones transcurrent to the arc across Mount Veniaminof as an indicator of crustal stress patterns.

The spacing of Quaternary volcanic centers along the volcanic front is variable, normally ranging from 20 to 54 km between the major centers. Volcanic vents are more closely spaced in the Mount Katmai area, in the Pavlof Volcano area, and southwest of Mount Kupreanof. Mount Katmai, Trident Volcano, Novarupta, Mount Griggs, Falling Mountain, Mount Cerberus, Mount Mageik, and Mount Martin are no more than 10 km apart. In the vicinity of Pavlof Volcano, the most active volcano in the Aleutian arc, several late Pleistocene to Holocene stratovolcanoes trend northeastward from Mount Emmons to Pavlof Sister at intervals of 5 to 8 km. About 15 km southwest of Mount Kupreanof is a series of at least three Holocene volcanic vents 3.6 to 6 km apart (Yount and others, 1985; Wilson, 1989).

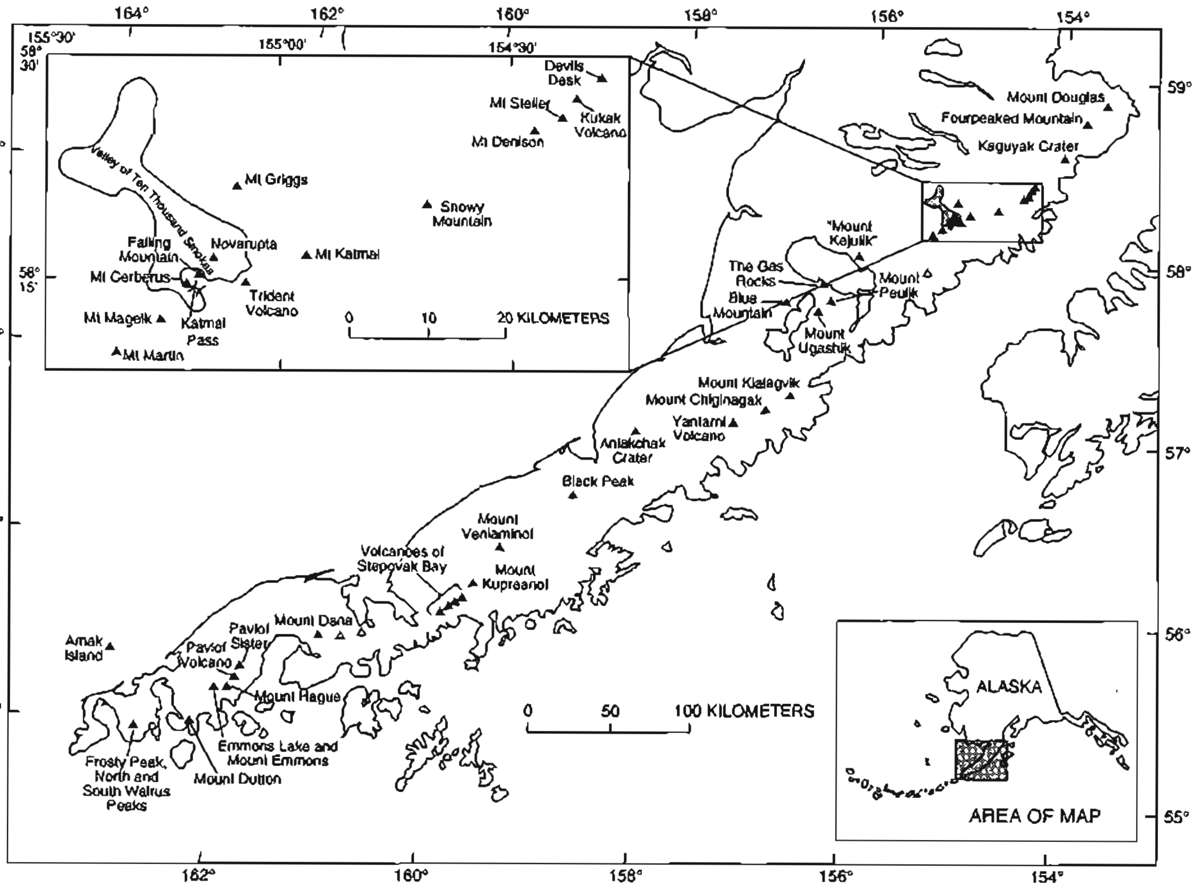


Figure 17. Selected Quaternary volcanic centers and associated features on the Alaska Peninsula. Solid triangles, named volcanic centers; open triangles, unnamed volcanic centers. "Mount Kejulik" is an informal name.

Eight calderas of varying sizes and ages occur along the Alaska Peninsula. Emmons Lake caldera, which has a diameter of 19 km and a total postulated eruptive volume of more than 50 km^3, is one of largest and oldest (Miller and Smith, 1987). Its caldera-forming eruption is pre-Holocene in age but probably no older than early Wisconsin according to Miller and Smith (1987). Veniaminof, Black Peak, and Aniakchak calderas in the central peninsula formed 3,700 yr B.P., between 3,660 and 4,170–4,700 yr B.P., and 3,430 yr B.P., respectively, according to Miller and Smith (1987). Ash deposits on the Seward Peninsula approximately 970 km northwest of Aniakchak caldera (= Aniakchak Crater) have been identified as originating from Aniakchak's caldera-forming eruption (Riehle and others, 1987b). A spectacular 60-hr eruption in 1912 formed Novarupta and Katmai calderas and filled the Valley of Ten Thousand Smokes with more than 11 km^3 of ash-flow tuff (Fenner, 1920, 1926; Griggs, 1922; Curtis, 1968; Hildreth, 1983, 1987; Fierstein and Hildreth, 1986).

Clusters of dacitic domes at The Gas Rocks and Blue Mountain (on the west shore of Upper Ugashik Lake) give K-Ar ages ranging from 0.134±0.058 Ma to 1.66±0.072 Ma (Wilson and Shew, 1992). The domes may have been associated with early Quaternary calderas; if so, subsequent glacial erosion has removed associated cone-building lava flows and ash-flow tuff sheets. Other Quaternary dome clusters occur at Kaguyak caldera (= Kaguyak Crater), in Ugashik and Black Peak calderas, and in the vicinity of Katmai Pass.

Several of the Quaternary volcanic sequences near the southwest end of the Alaska Peninsula were formally named as the result of investigations initiated in 1945 by the War Department (now the Department of Defense) and the U.S. Geological Survey. The volcanic sequences so named consist of the Frosty Peak Volcanics (Waldron, 1961) and the Arch Point Basalt, Black Point Basalt, and Dushkin Basalt (Kennedy and Waldron, 1955). The last three units are part of the Pavlof Volcano sequence. These named volcanic rock sequences are mainly basalt; they will not be discussed individually in this report.

Glacial deposits

The Alaska Peninsula contains abundant evidence that it was extensively glaciated during the Pleistocene. The low, nearly flat land along the northwest side of the peninsula is constructed mainly of glacial drift, and the surface is covered by arcuate morainal hills and dotted by numerous kettle lakes. The mountainous southeastern side of the peninsula contains many U-shaped valleys with hanging tributary valleys. Numerous small valley glaciers are present on the peninsula. Most originate on the higher stratovolcanoes.

Evidence obtained as the result of recent studies on the Alaska Peninsula indicates that glaciers crossed the peninsula at least four times (Detterman, 1986). The data further indicate that significant intervals of time elapsed between these major glacial advances. During these intervals the climate ameliorated, the glacial deposits were reworked, soil was formed, and vegetation was reestablished. The record for the last two major glaciations is well preserved and indicates that each was made up of two or more minor advances.

The first detailed investigations of the glacial record on the Alaska Peninsula were by Muller (1952a, 1952b, 1953) in the Naknek Lake area. This was followed by a study by Funk (1973) at Cold Bay. More recently the glacial deposits in the central part of the peninsula were mapped (Detterman and others, 1981b, 1987b).

The glacial chronology for the Alaska Peninsula is still poorly understood, owing in part to a scarcity of radiocarbon ages. In the absence of radiocarbon ages, and because the older deposits are beyond the range of present dating methods, other criteria have been developed to identify the different deposits. These criteria are based on morphology, extent of weathering, and position of the various deposits. To facilitate mapping and discussion, the drift sheets were named, except for the poorly defined oldest deposit. In ascending order the drift sheets are (1) oldest drift, (2) drift of Johnston Hill glaciation (Abrahamson, 1949; Muller, 1953), (3) drift of Mak Hill glaciation (Abrahamson, 1949; Muller, 1953), and (4) drift of Brooks Lake glaciation (Muller, 1953). Well-defined morainal deposits of the Brooks Lake drift sheet can be further subdivided into deposits of informally named advances, namely the Kvichak, Iliamna, Newhalen, and Iliuk stades (Detterman and Reed, 1973). In addition, several minor glacial advances have left deposits on the Alaska Peninsula during the Holocene. These deposits are unnamed and are referred to as deposits of the Neoglaciation of Porter and Denton (1967). Modern glaciers are remnants of the last pulse of the Neoglaciation, which probably had its maximum extent about 200 years ago.

The oldest drift sheet is exposed only in coastal bluffs along Bristol Bay near Naknek, where it unconformably underlies drift of Johnston Hill age. The deposit consists of a deeply weathered, compact boulder clay containing clasts of granitic, metavolcanic, and sedimentary rocks. All of the clasts have a thick weathering rind, which, along with the deeply weathered character of the boulder clay, suggests great age.

Johnston Hill drift also is found only along the Bristol Bay coastline, where morainal ridges of this drift sheet are preserved. Mass wasting has greatly altered the moraines and filled in swales and kettle lakes. We do not have any age data for this drift, but it is undoubtedly pre-Wisconsin.

Drift of the next youngest glaciation, the Mak Hill drift sheet, retains a well-defined arcuate morainal character although the sharp crests of the moraine are considerably subdued by mass wasting. Outwash plains are still present but somewhat modified. Radiocarbon samples obtained from this drift all indicate an age greater than 40,000 yr B.P.

Drift of the Brooks Lake glaciation covers most of the lowland northwest of the Alaska-Aleutian Range. Its individual advances are well defined, and little modification of arcuate morainal ridges and kettle lakes has occurred. The modern topography is largely the result of this glaciation. The positions of the moraines indicate that the glaciers moved northwestward across the peninsula, probably from an ice-cap located on the continental shelf.

Deposits of the Neoglaciation are generally restricted to valleys that still contain glaciers. These deposits are little altered and lie no more than 1 to 2 km in front of the present-day glaciers.

The large lakes on the Alaska Peninsula are all remnants of formerly much larger lakes that were dammed by moraines of the glacial advance that took place during the Kvichak stade of the Brooks Lake glaciation. These lakes are now dammed by moraines of the advance that took place during the later, Iliamna stade.

A general warming trend began on the Alaska Peninsula about 10,000 yr B.P., with maximum deglaciation occurring before 8,000–8,500 yr B.P. High lake levels resulting from this deglaciation formed terraces still present around the large lakes. Radiocarbon ages from these terraces range from 8,000–8,500 yr B.P. (Detterman, 1986). Minor glacial advances during the Neoglaciation have taken place since then, but their deposits are undated on the peninsula.

SUMMARY

The Alaska Peninsula contains a well-exposed and extremely thick sequence of Mesozoic and Cenozoic rocks, as well as a very thin Paleozoic section at Puale Bay. The cumulative thickness is about 14,000 m, but the average thickness at most localities probably does not exceed 7,000–8,000 m; this is due mainly to lateral depositional thinning of strata and postdepositional erosion. Volcanic rocks are included in the overall thickness where they are interbedded with the sedimentary sequence.

Paleozoic rocks are known from only one locality, a small islet at the mouth of Puale Bay, where about 40 m of mid-Permian limestone is exposed (Hansen, 1957; Detterman and others, 1985, 1987a). Metamorphic rocks exposed in the Mount Katmai area (Riehle and others, 1987a) may include some strata with Paleozoic protoliths.

The Mesozoic section on the Alaska Peninsula is about 8,500 m thick and is divided into 12 formations (fig. 4). In ascending stratigraphic order, these are the Kamishak Formation (Upper Triassic); Talkeetna Formation (Lower Jurassic); Kialagvik Formation (Lower and Middle Jurassic); Shelikof

Formation (Middle Jurassic); Naknek Formation (Upper Jurassic); Staniukovich Formation, Herendeen Formation, and Pedmar Formation (Lower Cretaceous); and Chignik Formation, Hoodoo Formation, Shumagin Formation, and Kaguyak Formation (Upper Cretaceous). In addition, the Naknek Formation is subdivided into five members; in ascending order, these are the Chisik Conglomerate, Northeast Creek Sandstone, Snug Harbor Siltstone, Indecision Creek Sandstone, and Katolinat Conglomerate Members.

The Mesozoic strata are predominantly marine in origin, but they include a significant thickness of continental beds in the upper part of the section, particularly in the Upper Jurassic and Upper Cretaceous. The provenance for these sediments was initially a volcanic arc that was subsequently sutured to southern Alaska in Middle Jurassic time. During the late Mesozoic, the provenance shifted to the Alaska-Aleutian Range batholith and associated metamorphic rocks. The reworking of previously deposited sediments is increasingly common upward in the Mesozoic section.

Marine Mesozoic strata contain the fossils of an abundance of life forms that are very valuable in assigning ages to the enclosing beds. Nearly 1,000 collections of megafossils were obtained during recent field work on the Alaska Peninsula; this large quantity of samples greatly reduces possible errors in age assignments that can result from inadequate sampling. Megafaunal data for the central part of the Alaska Peninsula were reported by Detterman and others (1981c, 1985). In addition to age data, the marine megafauna may provide a key to the latitudinal position of the depositional area at the time of its formation (Taylor and others, 1984).

Tertiary strata are nearly as thick as the Mesozoic sequence but are mostly restricted to the southwestern part of the Alaska Peninsula. Tertiary rocks, in contrast to the Mesozoic ones, are mainly of continental origin. Marine beds locally intertongue with the continental deposits, and in nearly all cases they are nearshore to tidal-flat facies. Volcanic detritus composes the main part of the sedimentary constituents. Their provenance was the volcanic terrane of the Alaska Peninsula. The older Mesozoic strata and the Alaska-Aleutian Range batholith provided some detrital input to the sedimentary regime, but only locally were they major contributors, as for example, in the Bear Lake and Tolstoi Formations.

The Cenozoic section is divided into 11 formations (fig. 12). In ascending stratigraphic order, these are the Tolstoi (upper Paleocene to middle Eocene) and Copper Lake Formations (Paleocene? and lower Eocene), Stepovak Formation and Meshik Volcanics (upper Eocene and lower Oligocene), Hemlock Conglomerate (upper Oligocene), Belkofski Formation (upper Oligocene? and lower and middle Miocene?), Unga Formation (upper Oligocene to lowermost middle Miocene), Tachilni Formation (upper Miocene), Bear Lake Formation (middle and upper Miocene), Milky River Formation (Pliocene), and Morzhovoi Volcanics (upper Miocene? to lower Quaternary?). The Stepovak Formation is further subdivided into informal (lower) siltstone and (upper) sandstone members.

Several of the formations that are mainly volcanic units, namely the Meshik Volcanics and the Belkofski, Unga, and Milky River Formations, are interbedded with the sedimentary sequence and are included and described with the sedimentary rocks.

Marine megafauna are greatly restricted in the Tertiary sedimentary rocks on the Alaska Peninsula because most of these rocks are composed of continental debris. Well-preserved megafloral specimens are abundant and diversified and have been used in conjunction with available megafauna to determine the ages of the various stratigraphic units. K-Ar age determinations from interlayered volcanic rocks in the sedimentary sections have helped to further refine the ages of these units. The age of the Belkofski Formation is poorly constrained and may be subject to change with additional work.

Volcanic and intrusive rocks constitute a large part of the exposed stratigraphic sequence on the Alaska Peninsula. Most of these rocks were formed during three well-defined time intervals—Early to Middle Jurassic (Talkeetna Formation and Alaska-Aleutian Range batholith), late Eocene to early Miocene (Meshik arc = Meshik Volcanics, Popof volcanic rocks, and associated hypabyssal, intrusive, and volcaniclastic rocks), and late Miocene(?) to Holocene (Milky River Formation; Morzhovoi Volcanics; Pleistocene to Holocene volcanoes; and Devils, Agripina Bay, and similar-age batholiths). One group of intrusive rocks does not fit any of these igneous episodes. This group consists of the batholiths on the outer Shumagin Islands, Sanak Island, and the Semidi Islands. These intrusive rocks probably belong to a different province that was juxtaposed against the Alaska Peninsula after their formation.

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APPENDIX—LIST OF FOSSIL MEGAFAUNA AND MEGAFLORA COLLECTIONS

Megafauna and megaflora are abundantly preserved in the Mesozoic and Tertiary rocks of the Alaska Peninsula. The nearly 1,000 collections obtained during the present investigation have aided greatly in assigning ages to the rock sequences. The following list includes only those collections obtained from sections shown in figures 6 through 16. The complete list of fossils obtained from the central part of the Alaska Peninsula is included in reports by Detterman and others (1981b, 1985). Data on fossil collections from the Port Moller and Mount Katmai areas are being prepared for publication.

Megafauna from the Kamishak Formation, reference section, Puale Bay (section 1; fig. 6). Fossils identified by N.J. Silberling, U.S. Geological Survey. Numbers are field locality numbers.

Locality D11288
  Bivalve
    Monotis subcircularis (Gabb) (early late Norian)

Locality 79AEg5-4G
  Ammonite
    Holoritinid (Indeterminate)

Locality 79AEg5-4D
  Bivalve
    Monotis subcircularis (Gabb) (early late Norian)
  Hydrozoan
    Heterastridium sp.

Locality 79AEg5-3
  Bivalve
    Plicatula sp.
  Coral
    Colonial scleractinian (Indeterminate)

Locality 79AEg5-2A
  Ammonite
    Alloclionites sp. (late middle Norian)
  Gastropod
    (Indeterminate)

Locality 79AEg5-1
  Coral
    Colonial scleractinian (Indeterminate)

Megafauna from the Talkeetna Formation, Puale Bay (section 2; fig. 6). Fossils identified by R.W. Imlay, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Washington, D.C.

Locality 32302
  Bivalve
    ?*Corbicellopsis* sp.
  Gastropod
    (Indeterminate)

Locality 32303
  Ammonite
    Arnioceras cf. *A. densicostata* (Queenstedt) (late early Sinemurian)
  Bivalve
    Oxytoma sp.

Locality 31822 (middle Hetangian)
  Ammonites
    Discamphiceras cf. *D. toxophorum* (Gumbel)
    Psiloceras sp.
    Waehneroceras cf. *W. portlocki* (Wright)

Locality 31823 (middle Hettangian)
  Ammonites
    ?*Discamphiceras* sp.
    Waehneroceras cf. *W. portlocki* (Wright)

Early Bajocian (Middle Jurassic) megafauna from the Kialagvik Formation, principal reference section, Wide Bay (section 3; fig. 7). Fossils identified by R.W. Imlay, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Washington, D.C.

Locality 31974
  Bivalve
    Inoceramus lucifer (Echwald)

Locality 31975
  Ammonite
    Holcophylloceras sp.
  Bivalves
    Inoceramus lucifer (Echwald)
    Grammatodon sp.

Locality 31976
  Ammonite
    Parabigotites crassicostatus Imlay
  Bivalves
    Inoceramus lucifer (Echwald)
    Camptonectes sp.

Locality 21256
  Ammonites
    Parabigotites cf. *P. crassicostatus* Imlay
    Bradfordia cf. *B. costidensa* Imlay
  Bivalve
    Inoceramus lucifer (Echwald)

Locality 21255
  Ammonites
    Arkelloceras sp.
    Pelekodites? sp.
    Lytoceras sp.
    Macrophylloceras sp.

Locality 21254 and 31978
  Ammonites
    Pseudolioceras whiteavesi (White)
    Tmetoceras kirki Westermann
    T. kirki flexicostatum Westermann
    T. scissum (Benecke)
    Erycitoides howelli (White)
    E. spinatus Westermann

Locality 19748 and 21245
  Ammonites
    Erycitoides howelli (White)
    E. (*Kialagvikes*) *kialagvikensis* (White)
    E. (*K.*) *spinatus* Westermann
    E. (*K.*) *levis* Westermann
    Pseudolioceras whiteavesi (White)

Locality 21248
  Ammonites
    Pseudolioceras sp.

Tmetoceras scissum (Benecke)

Locality 21247
Ammonites
Tmetoceras scissum (Benecke)

Megafauna from the Kialagvik Formation, reference section, Puale Bay (section 4; fig. 8). Fossils identified by R.W. Imlay, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Washington, D.C.

Locality 31818 (late early Callovian)
Ammonite
Cadoceras tenuicostatum (Imlay)

Locality 32301 (early Bajocian)
Ammonites
Eudmetoceras cf. *E. amplectens* (Buckman)
Pseudolioceras maclintocki Westermann
Tmetoceras scissum (Benecke)
Bivalves
Oxytoma sp.
Pleuromya sp.

Locality 31819 (early Bajocian)
Bivalves
Inoceramus lucifer (Echwald)
Inoceramus cf. *I. lucifer* (Echwald)
Pleuromya dalli (White)
Trigonia sp.

Locality 19804 (late Toarcian)
Ammonite
Haugia sp.

Late early Callovian to early late Callovian (Middle Jurassic) megafauna from the Shelikof Formation, type section, Puale Bay (section 5; fig. 8). Fossils identified by R.W. Imlay and J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Washington, D.C.

Locality 32024
Bivalve
Meleagrinella sp.

Locality 32032
Ammonite
Cadoceras (*Stenocadoceras*) cf. *C.* (*S.*) *striatum* Imlay

Locality 32026
Ammonite
Cadoceras (*Stenocadoceras*) cf. *C.* (*S.*) *striatum* Imlay

Locality 32023
Ammonite
Cadoceras (*Stenocadoceras*) sp.

Locality 32022
Ammonite
Cadoceras (*Stenocadoceras*) cf. *C.* (*S.*) *stenoloboide* Pompeckj

Megafauna from the Snug Harbor Siltstone Member of the Naknek Formation, reference section, Northeast Creek (section 8; fig. 9). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M7822 (late Kimmeridgian)
Bivalves
Buchia mosquensis (von Buch)
Buchia rugosa (Fischer)

Locality M7823 (late Kimmeridgian)
Bivalves
Buchia mosquensis (von Buch)
Buchia rugosa (Fischer)
Ammonite
Lytoceras sp.

Locality M7824 (late Kimmeridgian)
Bivalves
Buchia mosquensis (von Buch)
Buchia rugosa (Fischer)

Locality M7825 (Kimmeridgian)
Bivalve
Buchia rugosa (Fischer)
Gastropod
Trochus sp.

Locality M7826 (early Kimmeridgian)
Bivalves
Buchia concentrica (Sowerby)
Buchia rugosa (Fischer)
Pleuromya sp.

Locality M7827 (early Kimmeridgian)
Bivalves
Buchia concentrica (Sowerby)
Buchia rugosa (Fischer)
Entolium sp.

Locality M7828
Bivalves
Nuculana sp.
Pleuromya sp.
Pseudolimnea sp.
Gastropod
Trochus sp.
Scaphopod
Dentalium sp.

Locality M7829
Bivalves
Corbicula sp.
Oxytoma sp.

Locality M7830 (late Oxfordian)
Bivalve
Buchia concentrica (Sowerby)

Locality M7831 (late Oxfordian)
Bivalves
Buchia concentrica (Sowerby)
Oxytoma sp.

Locality M7832 (late Oxfordian)
Bivalves
Buchia concentrica (Sowerby)
Oxytoma sp.
Placunopsis sp.
Gastropod
Trochus sp.

Megafauna from the Indecision Creek Sandstone Member of the Naknek Formation, type section, Indecision Creek (section 9; fig. 9). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M7696 (middle Tithonian)
  Bivalve
    Buchia blanfordiana (Stoliczka)

Locality M7697 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Entolium sp.
    Nuculana sp.

Locality M7698 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Camptonectes sp.

Locality M7699 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Pholadomya sp.

Locality M7700 (middle Tithonian)
  Bivalve
    Buchia blanfordiana (Stoliczka)

Locality M7701 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Pleuromya sp.
  Ammonite
    Phylloceras sp.

Locality M7702 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Entolium sp.

Locality M7703 (middle Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Entolium sp.

Locality M7704 (early Tithonian)
  Bivalves
    Buchia blanfordiana (Stoliczka)
    Buchia mosquensis (von Buch)
    Pholadomya sp.
    Pinna sp.
    Pleuromya sp.

Locality M7705 (early Tithonian)
  Bivalves
    Buchia mosquensis (von Buch)
    Pholadomya sp.
    Pleuromya sp.

Locality M7706 (early Tithonian)
  Bivalves
    Buchia mosquensis (von Buch)
    Pleuromya sp.

Locality M7707 (early Tithonian)
  Bivalve
    Buchia mosquensis (von Buch)

Locality M7708 (early Tithonian)
  Bivalve
    Buchia mosquensis (von Buch)

Late Jurassic megafauna from the Katolinat Conglomerate Member of the Naknek Formation, type section, east of Lake Grosvenor (section 10; fig. 9). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M8350
  Bivalve
    Buchia mosquensis (von Buch)

Locality M8351
  Bivalve
    Buchia mosquensis (von Buch)

Early Cretaceous megafauna from the Staniukovich Formation, reference section, Staniukovich Mountain (section 11; fig. 10). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M8214
  Bivalves
    Inoceramus sp. (fragments)
    Pleuromya sp.
  Belemnite
    Cylindroteuthis sp. (reworked)

Locality M8213 (Valanginian)
  Bivalve
    Buchia crassicollis solida (Lahusen)

Locality M8212 (Berriasian)
  Bivalve
    Buchia uncitoides (Pavlow)

Locality M8211 (Berriasian)
  Bivalve
    Buchia uncitoides (Pavlow)

Early Cretaceous (late Albian) megafauna from the Pedmar Formation, type section, Mount Pedmar (section 13; fig. 10). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M7373
  Ammonites
    Calliphylloceras cf. *C. aldersoni* (Anderson)
    Marshallites cumshewaensis (Whiteaves)

Locality M7374
  Ammonites
    Desmoceras (*Pseudoughligella*) *dawsoni* (Whiteaves)
    Turrilites(?) sp.

Locality M7260
  Ammonites
    Desmoceras (*Pseudoughligella*) *dawsoni* (Whiteaves)
    Lytoceras sp.
  Bivalve
    Mesopuzosia sp.

Late Cretaceous (Campanian) megafauna from the Chignik Formation, reference section, Chignik Lagoon (section 14; fig. 11). Fossils identified by J.W. Miller and D.L. Jones, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M6977
  Ammonite
    Canadoceras sp.
  Bivalve
    Inoceramus sp.

Locality M6976
Ammonite
Canadoceras sp.

Locality M7084
Ammonite
Canadoceras newberryanum (Meek)
Bivalve
Inoceramus schmidti (Michael)

Locality M6975
Bivalves
Inoceramus balticus var. *kunimiensis* (Nagao and Matsumoto)
Inoceramus schmidti (Michael)

Locality M6974
Bivalves
Anomia sp.
Calva sp.

Late Cretaceous (early Maestrichtian) megafauna from the Kaguyak Formation, type section, along the shore between the Swikshak and Big Rivers (section 16; fig. 11). Fossils identified by J.W. Miller, U.S. Geological Survey. Numbers are U.S. Geological Survey Mesozoic locality numbers, Menlo Park, Calif.

Locality M7813
Bivalve
Inoceramus ex. gr. *I. subundatus* (Meek)

Locality M7903
Ammonites
Didymoceras sp.
Diplomoceras notabile (Whiteaves)
Bivalve
Inoceramus balticus var. *kunimiensis* (Nagao and Matsumoto)

Locality M7814
Ammonites
Didymoceras aff. *D. hornbeyense* (Whiteaves)
Diplomoceras notabile (Whiteaves)
Gaudryceras tenuiliratum (Yabe)
Neophylloceras ramosum (Meek)
Pachydiscus (*Pachydiscus*) *hazzardi* Jones
Bivalves
Inoceramus balticus var. *kunimiensis* (Nagao and Matsumoto)
Glycymeris sp.

Late middle Eocene megafauna from the Tolstoi Formation, type section, Pavlof Bay (section 17; fig. 13). Fossils identified by Louie Marincovich, Jr., U.S. Geological Survey. Numbers are U.S. Geological Survey Cenozoic locality numbers, Menlo Park, Calif.

Locality M8906
Bivalves
Microcallista (*Costacallista*) *conradiana* (Gabb) Turner
Corbicula? sp.
Ostrea sp. indet.
Gastropod
Turritella uvasana stewarti Merriam

Locality M8382
Gastropod
Turritella uvasana stewarti Merriam
Plants
(Indeterminate)

Locality M8380 and M8386
Bivalves
Solena cf. *S. clarki* (Weaver and Palmer)
Corbicula sp.

Locality M8379 and M8385
Bivalves
Microcallista (*Costacallista*) *conradiana* (Gabb) Turner
Nuculana sp.
Corbicula? sp.

Late Paleocene megaflora from the Tolstoi Formation, reference section, Ivanof Bay (section 18; fig. 13). Fossils identified by J.A. Wolfe, U.S. Geological Survey. Numbers are U.S. Geological Survey Cenozoic locality numbers, Menlo Park, Calif.

Locality 11416
Acer arcticum Heer
Alnus new species
Cocculus new species
Hamameidacaea new species
Liquidambar new species
Platycarya new species
Protophyllum semotum Hickey
Metasequoia occidentalis (Newberry) Chaney
Thuites interruptus (Newberry) Bell

Locality 11415
Acer arcticum Heer
Alnus new species

Locality 11413
Cocculus flabela (Newberry) Wolfe

Locality 11412
Metasequoia occidentalis (Newberry) Chaney
Thuites interruptus (Newberry) Bell

Locality 11411
Chaetoptelea microphylla (Newberry) Hickey
Dicotylophyllum richardsoni (Heer) Wolfe
Grewiopsis auriculaecordatus (Hollick) Wolfe
(late Paleocene)
Protophyllum semotum Hickey
Metasequoia occidentalis (Newberry) Chaney
Thuites interruptus (Newberry) Bell

Megafauna from the Stepovak Formation, reference section, ridge east of Chichagof Bay (section 20; fig. 14). Fossils identified by Louie Marincovich, Jr., U.S. Geological Survey. Numbers are U.S. Geological Survey Cenozoic locality numbers, Menlo Park, Calif.

Locality M8352
Bivalve
(Indeterminate)

Locality M8351
Bivalves
Spisula callistaeformis Dall
Unio sp.? indet.
Acila sp. indet.

Locality M8353
Bivalve
Spisula sp.

Locality M8349
Bivalves
Acila sp. indet.
?*Ostrea tigiliana* Slodkewitsch

Spisula callistaeformis Dall
?*Yoldia breweri* Dall
?*Yoldia palachei* Dall
Gastropod
Trochidae genus indet.

Locality M8350
Bivalves
Acila sp. indet.
Ostrea tigiliana Slodkewitsch
Spisula callistaeformis Dall
Spicula cf. *S. Callistaeformis* Dall
Gastropods
Naticidae genus indet.
Trochidae genus indet.

Locality M8354
Bivalve
Spisula sp.

Locality M8355
Bivalves
?*Ostrea tigiliana* Slodkewitsch
?*Spisula callistaeformis* Dall
Gastropod
Crepidula sp.

Locality M8356
Bivalve
Spisula sp. indet.

Late Miocene megafauna from the Bear Lake Formation, section 25, Mount Veniaminof (fig. 15). Fossils identified by Louie Marincovich, Jr., U.S. Geological Survey. Numbers are U.S. Geological Survey Cenozoic locality numbers, Menlo Park, Calif.

Locality M7181 and M7371
Bivalves
Acila (Truncacila) empirensis Howe
Acila (Truncacila) sp.
Clinocardium hannibali Keen
Cyclocardia sp.
?*Cyclocardia* sp.
Mizuhopecten mollerensis (MacNeil)
Glycymeris sp.
Macoma sp.
Mya (Mya) cf. *M. (M.) cuneiformis* (Boehm)
Mya (Mya) truncata Linnaeus
Nuculana sp.
?*Pandora* sp.
Spisula sp.
?*Spisula* sp.
?*Thracia*
Gastropods
Natica sp.
Neptunea sp.
Turritella sp.

Locality M7372
Bivalves
Clinocardium sp.
Mizuhopecten mollerensis (MacNeil)
Mya (Mya) cf. *M. (M.) truncata* Linnaeus
Mytilus (Plicatomytilus) gratacapi Allison and Addicott
Gastropod
?*Neptunea* sp.

Locality M7373
Bivalves
Clinocardium sp.
Mizuhopecten mollerensis (MacNeil)
Glycymeris sp.
Mya (?*Arenomya*) aff. *M. (A.) elegans* (Echwald)
?*Mytilus* sp.

Locality M7182
Bivalves
Chione sp.
Clinocardium hannibali Keen
Mya sp.
?*Thracia* sp.
Mytilus sp.
Gastropods
?*Colus* sp.
Neptunea (Neptunea) sp.
Echinoid
Remondella waldroni (Wagner)

Locality M7374
Gastropod
?*Neptunea* sp.

Early late Miocene megafauna from the Tachilni Formation, South Walrus Peak (section 27; fig. 15). Fossils collected and identified by Louie Marincovich, Jr., U.S. Geological Survey. Numbers are U.S. Geological Survey Cenozoic locality numbers, Menlo Park, Calif.

Locality M7143
Bivalves
Mya (Mya) truncata Linnaeus
Panomya izumo Nomura and Hatai
Gastropods
Bulbus fragilis (Leach)
Polinices (Euspira) pallidus (Broderip)
Neptunea (Neptunea) lyrata altispira Gabb
Oenopota cf. *O. candida* Yokoyama

Locality M7144
Bivalves
Clinocardium sp.
Mizuhopecten mollerensis MacNeil

Locality M7145 and M7146
Bivalves
Chlamys (Swiftopecten) cosibensis (Yokoyama)
Clinocardium cf. *C. ciliatum* (Fabricius)
Clinocardium hannibali (Keen)
Clinocardium meekianium (Gabb)
Clinocardium cf. *C. pristinum* Keen
Cyclocardia cf. *C. roundiformis* Ilyina
Glycymeris grewingki Dall
Macoma uncongrua (von Martens)
Musculus (Musculus) niger (Gray)
Mya (Arenomya) elegans (Echwald)
Periploma (Periploma) cf. *P. (P.) aleutica* (Krause)
Peronidia aff. *P. lutea alternidentata* (Broderip and Sowerby)
Siliqua cf. *S. alta* Broderip and Sowerby
Spisula (mactromeris) brevirostrata Packard
Spisula (mactromeris) polynyma Simpson
Gastropods
Beringius herleini MacNeil
Buccinum cf. *B. planeticum* Dall
Fusitriton oregonensis (Redfield) Smith
Margarites (Papillaria) new species
Natica (Cryptonatica) clausa Broderip and Sowerby
Neptunea (Neptunea) aff. *N. (N.) modesta* (Kuroda)

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