Digital data for Geology of the Prince William Sound and Kenai Peninsula region, Alaska

Including the Kenai, Seldovia, Seward, Blying Sound, Cordova, and Middleton Island 1:250,000-scale quadrangles

Compiled by Frederic H. Wilson, Chad P. Hults, Nora Shew, and Keith A. Labay

U.S. Geological Survey Open-File Report 2008-1002

Table of contents

Abstract

The Prince William Sound and Kenai Peninsula region includes a significant part of one of the world's largest accretionary complexes and a small part of the classic magmatic arc geology of the Alaska Peninsula. Physiographically, the map area ranges from the high glaciated mountains of the Alaska-Aleutian Range and the Chugach Mountains to the coastal lowlands of Cook Inlet and the Copper River delta. Structurally, the map area is cut by a number of major faults and postulated faults. Most important of these are the Border Ranges, Contact, and Bruin Bay fault systems.

The rocks of this map area belong to the Southern Margin composite terrane, a Tertiary and Cretaceous or older subduction-related accretionary complex and the Alaska Peninsula (or Peninsular) terrane. Between these two terranes are rocks that have been variously assigned to the Peninsular or Hidden terranes. The oldest rocks of the map area are blocks of Paleozoic age within the mélange of the McHugh Complex; however, the protolith age of the greenschist and blueschist within the Border Ranges Fault zone is not known. Extensive glacial deposits mantle the Kenai Peninsula and the lowlands on the west side of Cook Inlet and are locally found elsewhere in the map area.

This map has been compiled from existing mapping, without generalization, and new or revised data has been added where available.

Introduction

The Prince William Sound and Kenai Peninsula region displays a major portion of one of the world's largest accretionary complexes (Plafker and others, 1994) and a small part of the Alaska Peninsula magmatic arc. The accretionary complex, of early Tertiary and Late Cretaceous age is represented by rocks of the Orca Group, Valdez Group, and McHugh Complex. The entire complex has been known under a variety of names as our understanding of the geology of southern Alaska has evolved: the Chugach terrane (Berg and others, 1972; Nielsen and Zuffa, 1982); Chugach and Prince William terranes (Plafker and others, 1977; Jones and others, 1981); and Southern Margin Composite terrane (Plafker, 1990; Plafker and others, 1994). In addition to the rocks of the Southern Margin Composite terrane, older sedimentary and igneous rocks of the Alaska Peninsula and Hidden terranes (Wilson and others, 1985; Wilson and others, 1999) occur on both sides of Cook Inlet. The Alaska Peninsula terrane is roughly equivalent to the Peninsular terrane of Jones and others (1981). Cook Inlet itself is a Tertiary forearc basin lying between the modern Aleutian magmatic arc and the outboard accretionary complex.

Many sources have been used to produce this geologic map. In most cases, data from available maps has been combined, without generalization, and new data added where available. Bedrock geology of the Seward and Blying Sound quadrangles is largely derived from Nelson and others (1985) within the Chugach National Forest and from Tysdal and Case (1979) elsewhere. The northeastern area of the Seward quadrangle includes revised geology by Nelson and others (1999). Surficial geology for Seward and Blying Sound quadrangles is derived from Tysdal and Case (1979). The Cordova and Middleton Island quadrangles were compiled and edited by Richter and others (2005) and were primarily derived from Winkler and Plafker (1993) with minor additions from T.L. Pavlis and V.B. Sisson (written commun., 2002 to D.H. Richter). Seldovia quadrangle geology largely derived from Bradley and others (1999) with addition of surficial geology from Karlstrom (1964). Kenai quadrangle geology is derived from Karlstrom (1964), Magoon and others (1976), Bradley and Wilson (2000), and Wilson and others (2006).

Geographic, Physiographic, and Geologic Framework

The map area borders and includes the northern part of the Gulf of Alaska, a formerly heavily glaciated region. From west to east, it extends from the high glaciated mountains of the Aleutian Range to the coastal lowlands of the Cook Inlet basin to the glaciated coastal mountains surrounding Prince William Sound. Relief is generally high except for the lowlands of the western Kenai Peninsula and the alluvial flats of the Copper River on the eastern margin of the map. The area is best known for the fjords and ice fields surrounding Prince William Sound, particularly in Kenai Fjords National Park. Redoubt Volcano, on the west side of Cook Inlet, is a prominent physiographic feature and the highest point in the map area at 3,108 m.

Extensive glacial deposits on the Kenai Lowlands (Karlstrom, 1964) record Late Wisconsin and earlier advances; whereas glacial and volcanic deposits on the west side of Cook Inlet reflect only Late Wisconsin glaciation, Holocene readvances, and Holocene volcanism. More recently, glaciers covered much of the Prince William Sound region as a result of Little Ice Age cooling, reaching a modern maximum extent about 1900 (Grant and Higgins, 1910). Since that time, glaciers have rapidly receded; in some areas, such as in Northwest Arm as much as 15 km, or as much as 20 km in McCarty Fjord just since 1950. Detailed mapping of the limited surficial deposits of Prince William Sound has largely not been undertaken; however, extensive studies of recent history have been undertaken as a result of the 1964 Great Alaska Earthquake (see for example, Plafker, 1969; Plafker and Page, 1994) and the 1989 Exxon Valdez oil spill.

The 1964 Great Alaska Earthquake had intense local impact and generated far-ranging tsunamis in the Pacific Basin. A brief summary of the effects of the earthquake in Alaska by Stover and Coffman (1993) described "*** vertical displacement over an area of about 520,000 square kilometers. The major area of uplift trended northeast from southern Kodiak Island to Prince William Sound and trended east-west to the east of the sound. Vertical displacements ranged from about 11.5 meters of uplift to 2.3 meters of subsidence relative to sea level. Off the southwest end of Montague Island, there was absolute vertical displacement of about 13 - 15 meters. *** The zone of subsidence covered about 285,000 square kilometers, including the north and west parts of Prince William Sound, the west part of the Chugach Mountains, most of Kenai Peninsula, and almost all the Kodiak Island group." Much more extensive reports on the effects of the earthquake can be found in Wood (1967), Leopold (1969), and Committee on the Alaska Earthquake of the Division of Earth Sciences National Research Council (1971) and related volumes. Studies on Middleton Island and in Kenai Fjords National Park (Plafker and Rubin, 1978, Crowell and Mann, 1998) have suggested a recurrence interval of 900 to 1,000 years for similar great earthquakes in this region.

The dominant geologic feature of the map area is the accretionary flysch and associated mélange of the Southern Margin Composite (SMC) terrane. These deep marine rocks record intermittent subduction-related offscraping and underplating that probably has occurred since Late Triassic time (Plafker and others, 1994). Defined as a composite terrane, the SMC includes the earlier defined Chugach and Prince William terranes as well as the Ghost Rocks Formation of the Kodiak Island region which lies between these two terranes. According to Plafker and others (1994), the Chugach terrane portion of the SMC terrane is composed of three assemblages: 1) Late Triassic to Early Jurassic greenschist and blueschist, represented for example by the Seldovia metamorphic complex; 2) late Mesozoic and older? mélange of the McHugh Complex; and 3) Late Cretaceous flysch of the Valdez Group. The Prince William terrane portion of the SMC terrane is equivalent to the Orca Group. Plafker and others (1994) assigned the Ghost Rocks Formation of the Kodiak Island area to an intervening assemblage of the SMC terrane not represented in the map area.

Two terrane names have been assigned to the rocks west of the SMC in the map area, the Peninsular terrane of Jones and Silberling (1979) and Jones and others (1981) or the Alaska Peninsula terrane of Wilson and others (1985; 1999). Over time, the usage of the term Peninsular terrane has morphed, such that it incorporates some aspects of the definition of the Alaska Peninsula terrane (Nokleberg and others, 1994) although significant differences remain in the definitions. For example the incorporation of the plutonic rocks of the Alaska-Aleutian Range batholith of Reed and Lanphere (1972) as a core part of the Alaska Peninsula terrane and the subdivision of the terrane in to two related sub-terranes, named the Chignik and Iliamna sub-terranes is not reflected in the definition of the Peninsular terrane. Within the map area, both of the sub-terranes defined for the Alaska Peninsula terrane are present on the west side of Cook Inlet, separated by the Bruin Bay Fault system. The essentially batholithic Iliamna sub-terrane is faulted against the Chignik sub-terrane. Clasts in the sedimentary rocks of the Chignik sub-terrane become finer grained as distance from the fault increases, suggesting the fault was active during deposition (R.L. Detterman, oral commun., 1980).

The older rocks on the east side of Cook Inlet at the extreme southwestern end of the Kenai Peninsula have traditionally been assigned to the Peninsular terrane. Aspects of these early Mesozoic rocks are similar to the oldest rocks of the Chignik sub-terrane of the Alaska Peninsula terrane; however, Wilson and others (1999) suggested that they may actually represent remnants of another, mostly lost, terrane which they called the Hidden terrane. The informally named Port Graham and Pogibshi formations of Kelley (1980) have some similarities to rocks of the Alaska Peninsula terrane; however, the Port Graham formation is lithologically distinct from the equivalent age Kamishak Formation and the Pogibshi formation is older than the lithologically equivalent Talkeetna Formation. Rock units assigned by Wilson and others (1999) to this Hidden terrane, such as the Seldovia metamorphic complex of Bradley and others (1999) and similar metamorphic complexes (Raspberry Schist of Roeske and others (1989) and Schist of Iceberg Lake and Schist of Liberty Creek of Winkler and others, 1981) in south central Alaska, and the Triassic Afognak pluton of Roeske and others (1989) have a different history than rocks more typical of the Alaska Peninsula terrane and were interpreted by Roeske and others (1989) to be part of a Late Triassic to Early Jurassic primitive island arc. Each of the metamorphic complexes, all of which are associated with the Border Ranges fault system, show evidence of blueschist facies metamorphism, whereas rocks typical of the Alaska Peninsula terrane are rarely metamorphosed at all. No other plutons of Triassic age are known for the Alaska Peninsula terrane, another reason to separate these rocks from the Alaska Peninsula terrane. A recent U-Pb zircon age of 204.8±2.8 Ma by D.C. Bradley (written commun., June 7, 2007) on the diorite of Point Bede in the Seldovia quadrangle yielded a Triassic age very similar to the Afognak pluton. Kelley (1980) describes this pluton as intruding the Pogibshi formation; as such a conflict exists between the age assigned to the Pogibshi on the basis of fossils versus the radiometrically determined age of the pluton.

In the western part of the map area the Alaska-Aleutian Range batholith of Reed and Lanphere (1973) forms the backbone of the Alaska-Aleutian Range. The volcanoes of the Aleutian magmatic arc, such as Redoubt and Iliamna Volcanoes (most of Iliamna Volcano is just off the western edge of the map) are emplaced on top of this backbone and young volcanic rocks represent only a small fraction of the bedrock even in the immediate vicinity of these volcanoes. Bedrock east of the batholith along the Cook Inlet coast consists of the Talkeetna Formation and overlying Jurassic sedimentary rocks of the Tuxedni Group and other sedimentary rock units as young as Tertiary (Detterman and Hartsock, 1966; Detterman and Reed, 1980; Nelson and others, 1983).

On the west side of Cook Inlet, rocks of Late Cretaceous through Triassic age are products of the development and erosion of a magmatic arc. Triassic siliceous carbonates of the Kamishak Formation represent part of the basement of this magmatic arc, rocks of the Talkeetna Formation the volcanic portion of the arc, the Alaska-Aleutian Range batholith its plutonic core and the sedimentary rocks of Tuxedni Group, Chinitna, and Naknek Formations the products of the erosion of the arc. It is unclear whether these sedimentary rocks represent the forearc or backarc basin of the Jurassic arc; Reed and others (1983) interpretation of the polarity of the arc would make these rocks part of the backarc.

Structurally, the map area is cut by a number of major faults and postulated faults, in addition to many less significant faults mapped only locally. The Border Ranges Fault system is probably the most important of the major faults in the map area, separating the SMC terrane from older rocks. Plafker and others (1994) considered it the suture along which the Chugach terrane was juxtaposed against and beneath older rocks to the north; the fault system has subsequently been modified by strike-slip displacements. The Contact Fault is generally accepted as the boundary between the Chugach and Prince William terranes. Lithologically, the metasedimentary flysch units that are the Valdez and Orca Groups are very similar and the Contact Fault is a point on a continuum of decreasing metamorphic grade and deformation seaward in Prince William Sound. Another major fault system, the Bruin Bay Fault, is sub-parallel to the Cook Inlet coast east of the Alaska-Aleutian Range batholith. It separates the batholith from sedimentary rocks derived from erosion of the batholith and what were overlying volcanic rocks of the Talkeetna magmatic arc. The Bruin Bay Fault is a high-angle reverse fault and may also have left-lateral offset (Detterman and Hartsock, 1966). It was a growth fault during deposition of the Jurassic sedimentary sequence and has approximately 3 km of stratigraphic throw (Detterman and Hartsock, 1966). Finally, cutting through the northwest corner of the map area the Lake Clark Fault has demonstrated high-angle reverse motion (Detterman and others, 1976) and postulated right-lateral strike-slip motion of ranging from 5±1 km (Plafker and others, 1975a) to 26 km of motion in the past 34 to 39 m.y. (Haeussler and Saltus, 2005). Neither Detterman and others (1976) nor Plafker and others (1975a) saw evidence of Holocene movement.

Radiometric dating in the map area has been extensive and is still ongoing; however, the long history of geochronologic studies has resulted in some confusion. In particular, sample locations have not always been correctly reported and, with respect to K-Ar age determinations, a number of reports do not reflect the change in accepted decay constants for potassium reported in Steiger and Jager (1977). As a result, we have assembled a table (Table 1) of all available radiometric dates, using modern decay constants. We have also corrected sample locations, based on original data where available, and also ensured that the sample location falls within the map unit the sample is purported to date. In the table, the map unit is listed, as are source reports.

Description of map units

Unconsolidated deposits

Modern tidal flat and estuarine deposits (Quaternary, Holocene)—Well-sorted, sub-tidal, stratified silt and some sand and local gravel deposited in shallow embayments

Unconsolidated surficial deposits, undivided (Quaternary)—Mainly unsorted boulders, cobbles, gravel, sand, and silt produced, deposited, and reworked by action of wind, water, glaciers, and frost, including solifluction. Includes deposits of present streams, colluvial and alluvial fans; glaciofluvial, glaciolacustrine, and deltaic deposits; unsorted material of morainal deposits; glacial-lake silt, clay, and muskeg deposits; and locally interstratified beach gravel, sand, and clay (Tysdal and Case, 1979; Nelson and others, 1985; Winkler and Plafker, 1993). In the vicinity of the Drift River delta, this unit contains a significant proportion of volcanic debris derived from air fall, mudflows, and lahars from Mt. Redoubt and Iliamna Volcano (Till and others, 1993; Waythomas and Miller, 1999; F.H. Wilson, unpub. data). Includes artificial fill at the Drift River and West Foreland oil production facilities on the west side of Cook Inlet (Riehle and Emmel, 1980; Till and others, 1993). Locally subdivided into:

Alluvial and terrace deposits—Flood-plain alluvium and stream terrace deposits. Consists of poorly- to well-sorted silt, sand, pebbles, cobbles, and boulders. Also includes abandoned channel deposits in outwash above modern floodplains or underfit stream channels, inferred to be relict glacial melt water channels; may include some glacial deposits (Detterman and Hartsock, 1966; Riehle and Emmel, 1980; Till and others, 1993; Richter and others, 2005; F.H. Wilson, unpub. data). Rare natural levee deposits on deltaic or fan delta deposits occur on the west side of Cook Inlet (F.H. Wilson, unpub. data)

Landslide and colluvial deposits—Unsorted, angular rock debris and mud in slumps, earth-debris flows, block glides, and debris avalanches, and poorly- to well-sorted silt to boulders in alluvial fans and cones, and unsorted rock talus (Riehle and Emmel, 1980; Waythomas and Miller, 1999; Richter and others, 2005; F.H. Wilson, unpub. data); in the vicinity of Mount Redoubt and Iliamna Volcano, may include some volcanic mudflow (lahar) deposits (Riehle and Emmel, 1980); in the Cordova quadrangle includes large (more than 10 km^2) and small landslide deposits caused by the 1964 Alaska earthquake (Winkler and Plafker, 1981; Post, 1967). On the west side of Cook Inlet solifluction deposits thought to be poorly sorted sand, silt, and clay derived from local upslope bedrock sources are found associated with plutonic rocks of the Alaska-Aleutian Range batholith (F.H. Wilson, unpub. data)

Lacustrine, swamp, and fine silt deposits—Chiefly silt, clay, fine sand, peat, and other organic material generally of lacustrine origin (Riehle and Emmel, 1980; Richter and others, 2005; F.H. Wilson, unpub. data)

Beach deposits—Sand, gravel, and cobbles of present and former beaches, beach ridges, spits, and tidal flats (Tysdal and Case, 1979; Winkler and Plafker, 1993; Detterman and Hartsock, 1966; Riehle and Emmel, 1980; F.H. Wilson, unpub. data). Wave-deposited, coarse-grained material and driftwood along seacoast; includes fine-grained sediment in mud flats of Copper River Delta; and uplifted marine terraces. Successive spit-building episodes of progressive gradation are preserved in beach sequences along coastal lowland between Cape Yakataga and Bering Glacier (Richter and others, 2005). Includes beaches uplifted by the 1964 Alaska Earthquake; most notably stranded beaches on southeastern side of Montague Island (Tysdal and Case, 1979)

Estuarine deposits—Fine-grained silt rich in organic material, mud, and peat (Winkler and Plafker, 1993). Includes salt-marsh deposits of Detterman and Hartsock (1966) and grades into tidal flat deposits (Riehle and Emmel, 1980; F.H. Wilson, unpub. data). Also includes marine terrace deposits on the west side of Cook Inlet (F.H. Wilson, unpub. data)

Eolian deposits—Dunes consisting of well sorted, fine-grained sand and silt aligned in longitudinal ridges on the Cooper River delta (Winkler and Plafker, 1993). Also includes dunes on top of river bluffs, windblown flats, and river bars (Richter and others, 2005). Includes informally named Bremner sand dunes, a large barchan field, located at confluence of Bremner and Copper Rivers (Richter and others, 2005). Includes cliff-head dunes in the northern Kenai quadrangle on Turnagain Arm (Karlstrom, 1964)

Deltaic deposits—Deltaic deposits, including outwash and alluvial deposits (F.H. Wilson, unpub. data)

Glaciolacustrine deposits—Largely ephemeral glacial lake and lake-related deposits. Well-sorted, well-stratified clay, silt, and fine sand deposited in ephemeral glacial and postglacial lakes. Thought to be typically covered by several feet of muck and peat (F.H. Wilson, unpub. data). Includes stratified and locally foreset-bedded sand and gravel that occur below 125 m elevation on West Foreland and from Katchin Creek to Redoubt Point; these deposits are probable emerged delta and glaciolacustrine deposits (Riehle and Emmel, 1980). Also includes active outwash fans (Riehle and Emmel, 1980). On the Kenai Peninsula, includes hanging delta deposits in former proglacial lakes associated with the last glacial maximum (Karlstrom, 1964)

Glacial deposits—Glacial drift consisting of sand, gravel, and boulders. Includes ground, recessional, end, medial, and lateral moraine deposits; as well as colluvium, talus, landslide debris, alluvium, and silt, locally (Riehle and Emmel, 1980; F.H. Wilson, unpub. data). As shown also includes active and recently active rock glaciers consisting chiefly rubble and coarse rock debris (F.H. Wilson, unpub. data) as well as fresh, poorly sorted, debris on surfaces of glaciers (Detterman and Hartsock, 1966; Winkler and Plafker, 1993). In the vicinity of Mount Redoubt and Mount Iliamna, may include a significant component of ash and other air-fall debris from eruptions (F.H. Wilson, unpub. data) Locally subdivided into:

Drift of Neoglacial age (Holocene)—Neoglacial terminal, recessional, lateral, and ground moraine consisting of unsorted boulders, cobbles, gravel and sand deposited during retreat of glaciers. Includes deposits of the Tunnel and Tustumena Stade (Detterman and Hartsock, 1966); Tunnel Stade moraines are barren deposits as much as 1.6 km in front of present glaciers. Tustumena Stade deposits consist of partially dissected spruce and brush covered moraine 1.6 to 10 km in front of present glaciers (Detterman and Hartsock, 1966). Includes on the Kenai Peninsula unmodified moraine deposits which may be mantled by loess, generally 2 to 6 feet thick (Karlstrom, 1964). Locally includes kames and outwash proximal to present glaciers (Richter and others, 2005)

H■ **Outwash of the Neoglacial age** (Holocene)—Outwash deposits associated with modern and Holocene glaciers (Karlstrom, 1964; F.H. Wilson, unpub. data). Consist of poorly- to well-sorted silt, sand, and gravel in terraces and outwash fan plains (Detterman and Hartsock, 1966; Riehle and Emmel, 1980)

HI **Glacial deposits of the Naptowne and Brooks Lake Glaciations** (Pleistocene)—Terminal, recessional, lateral, medial, and ground moraine and other deposits. Moderately weathered moraine along Cook Inlet shoreline; heavily spruce and brush covered (Detterman and Hartsock, 1966; F.H. Wilson, unpub. data). Internal contacts on west side of Cook Inlet reflect subdivisions of the Brooks Lake Glaciation; the Iliuk, Newhalen, and Iliamna advances. On the east side of Cook Inlet, includes prominent and little modified morainal deposits, mantled by 2 to 6 feet of loess (Karlstrom, 1964)

HII **Outwash and valley train deposits** (Pleistocene)—Silt, sand, and gravel graded to moraines of Naptowne age (map unit HI) on the Kenai Peninsula (Karlstrom, 1964) and to Brooks Lake age moraines on the west side of Cook Inlet (F.H. Wilson, unpub. data)

H. **Older glacial deposits** (Pleistocene)—Included here are the prominent, but modified morainal deposits of the Knik and Eklutna Glaciations. These deposits are widely exposed north of Homer on the Kenai Peninsula (Karlstrom, 1964). On the Kenai Peninsula, moraines of Knik and Eklutna age are terraced below approximately 228 m (750 ft), reflecting deposition in proglacial lakes. Also includes pebble- and boulder-bearing diamicton observed at one upland location at West Foreland and in sea cliffs along West Foreland and from Katchin Creek south to near Redoubt Point (Riehle and Emmel, 1980)

H.I **Outwash associated with older glacial deposits** (Pleistocene)—Silt, sand, and gravel graded to moraines of Knik and Eklutna age on the Kenai Peninsula (Karlstrom, 1964)

H⊞ **Moraine of the Caribou Hills Glaciation** (Pleistocene)—Highly modified morainal deposits in the Caribou Hills and exposed as remnant deposits elsewhere on the Kenai Peninsula (Karlstrom, 1964). These deposits are terraced below elevations of about 305 m (1,000 ft) and discontinuously mantled by proglacial lake sediment deposits (Karlstrom, 1964)

Rock units west of the Border Ranges Fault System

Bedded rocks

•Ⲁ **Kenai Group** (Tertiary, Pliocene to Oligocene)—Coal-bearing clastic unit consisting of, in descending order, the Sterling, Beluga, and Tyonek Formations and Hemlock Conglomerate in the vicinity of Cook Inlet. According to Calderwood and Fackler (1972) unit is at least 8,000-m-thick in the subsurface of Cook Inlet. Calderwood and Fackler (1972) included, the West Foreland Formation within the Kenai Group; however, it was separated as a distinct unit by Magoon and others (1976). Subdivided into:

- **Sterling Formation** (Pliocene and Miocene)—Weakly lithified massive sandstone, conglomeratic sandstone and interbedded claystone; includes interbedded lignitic coals typically less than 1-m-thick in the upper part of the unit, but may be as much as 3-m-thick in the lower part of the unit (Calderwood and Fackler, 1972). According to Flores and others (1997, cited in Bradley and others, 1999), sandstone grades upward from coarse- to very fine-grained in trough crossbedded sequences; siltstone is typically ripple-laminated and contains roots or burrows. Bradley and others (1999) indicated that only the lowest 700 m of the more than 3,000-m-thick Sterling Formation is exposed at the surface, consisting of siltstone, mudstone, carbonaceous shale, lignite coal, and minor volcanic ash. Triplehorn and others (1977) and Turner and others (1980) reported a number of K-Ar and fission-track age determinations from ash partings within coal beds within this unit (Table 1). These dates range from 4.2±1.4 to 8.9±1.0 Ma; some older reported ages were interpreted to be contaminated by detrital material (Turner and others, 1980)

- **Beluga Formation** (Miocene)—Nonmarine, interbedded, weakly lithified sandstone, siltstone, mudstone, carbonaceous shale, coal, and minor volcanic ash (Bradley and others, 1999). Calderwood and Fackler (1972) reported a distinctive feature of the Beluga Formation is its lack of massive sandstone beds and massive coal seams that characterize the underlying Tyonek Formation; however, lignitic to subbituminous coal seams can be as much as 4-m-thick in the upper part of the Beluga Formation. The contact between the Beluga and overlying Sterling Formation may be an unconformity (Calderwood and Fackler, 1972), but in any case can be difficult to pinpoint (Calderwood and Fackler, 1972; Turner and others, 1980). Triplehorn and others (1977) and Turner and others (1980) reported a number of K-Ar and fission-track age determinations from ash partings within coal beds in this unit ranging from 7.2±1.3 to 12.9±5.1 Ma (Table 1)

- **Tyonek Formation** (Miocene and Oligocene)—Nonmarine conglomerate and subordinate sandstone, siltstone, and coal within the map area as described by Bradley and others (1999). However, in general, the Tyonek Formation is identified by the presence of massive sandstone beds and lignitic to subbituminous coal beds as much as 9-m-thick (Calderwood and Fackler, 1972). Its contact with the overlying Beluga Formation is believed to be a disconformity where sandstone beds and coal beds become markedly thinner (Calderwood and Fackler, 1972). Plant fossils comprising the Seldovian Stage of early and late Miocene age as well as plants representing the Angoonian Stage of Oligocene age provide age control for the unit (Wolfe and Tanai, 1980)

- **Hemlock Conglomerate, undivided** (Oligocene)—Sandstone, conglomerate, and siltstone assigned to this unit, as defined by Calderwood and Fackler (1972) occur only in the vicinity of Harriet Point in the Kenai quadrangle on the west side of Cook Inlet. On the basis of the description in Detterman and others (1976) these rocks are inferred to consist of fluvial conglomeratic sandstone and conglomerate containing minor interbeds of siltstone, shale, and coal. Magoon and others (1976) mapped these rocks in a unit consisting of the combined Tyonek Formation and Hemlock Conglomerate whereas Detterman and others (1976) assigned these rocks to the Hemlock Conglomerate. The

Hemlock Conglomerate is lithologically transitional with the Tyonek Formation, leading to some confusion; the Hemlock Conglomerate is best known from the subsurface. Plant fossils suggest an Oligocene age; Wolfe and Tanai (1980) suggested early Oligocene and Wolfe (cited in Detterman and others, 1996) suggested late Oligocene for rocks assigned to this unit south of the map area. Wolfe and Tanai (1980) suggested the rocks at Harriett Point may be isochronous with beds considered typical of the Tyonek Formation

••• **West Foreland Formation** (Tertiary, Eocene and Paleocene)—Exposed only on the west side of Cook Inlet, thin unit consists of tan to light-yellow-brown cobble conglomerate interbedded with lesser sandstone, laminated siltstone, and silty shale (Detterman and Hartsock, 1966). Thin coal beds are interbedded with the siltstone and shale. Detterman and Hartsock (1966) also describe a lenticular bed of "carbonaceous ashstone breccia" that may have been referred to as obsidian by Martin and Katz (1912). However, Detterman and Hartsock (1966) indicate that along with quartz and feldspar grains and probably glass shards, the bed also contains plant fragments and is clearly of sedimentary origin. Clasts in conglomerate are mainly rounded to sub-rounded quartz diorite, volcanic rock, argillite, sandstone, siltstone, quartzite, tuff, and coal fragments. Intrusive and volcanic rock fragments each make up about 35 percent of the clasts in conglomerate. Medium- to coarse-grained arkosic sandstone forms the matrix of the conglomerate as well as distinct lenticular beds. The siltstone and shale interbedded with conglomerate is a very fine-grained sub-arkosic equivalent of the sandstone. Originally mapped as the Kenai Formation by Detterman and Hartsock (1966); Calderwood and Fackler (1972) raised this unit to group status and subdivided it into a number of formations. The rocks here were assigned to the West Foreland Formation. The West Foreland was assigned an Oligocene age by Kirschner and Lyon (1973) and later reassigned an early Eocene and late Paleocene age by Magoon and others (1976). Recent dating of zircon from an interbedded tuff about 1-m-thick from north of the map area yielded a 43-Ma-age (middle Eocene) (P.J. Haeussler and D.W. Bradley, USGS, oral commun., 2005). The West Foreland Formation was removed from the Kenai Group because it was separated by a major unconformity from the overlying Hemlock Conglomerate (Magoon and Egbert, 1986). Lower contact of these rocks was described by Detterman and Hartsock (1966) as an angular unconformity with the Upper Jurassic Naknek Formation; subsequent work by Magoon and others (1980) showed there to be a nonmarine Upper Cretaceous sedimentary unit between the rocks of the West Foreland and Naknek Formations. Those Cretaceous rocks are shown here as map unit ▬

▬ **Saddle Mountain section of Magoon and others (1980)** (Upper Cretaceous, Maastrichtian)—Nonmarine sandstone, conglomerate, and minor siltstone and coal found northeast of Chinitna Bay in a section 83-m-thick (Magoon and others, 1980). Consists dominantly of fine- to medium-grained sandstone that becomes finer grained upward. Unit is generally massive though some crossbedded sections are present. It is soft and friable except where calcite cemented. Conglomerate contains volcanic and plutonic rock boulders as much as 30 cm in diameter in a sandy matrix. Coal beds, which tend to occur in the upper part of the section are as much as 2.7-m-thick and locally has underclay ("undersoils", Magoon and others, 1980). Siltstone is most abundant in the middle part of the section. Sporomorphs *Cranwellia striata* (Couper) Srivastava, *Balmeisporites* spp., *Wodehouseia spinata* Stanley, *Proteacidites* spp., *Aquilapollenites bertillonites* Funkhouser, *A. reticulatus* Mtchedlishvili, *A delicatus* Stanley (Magoon and others, 1980) were recovered from the unit, indicating a

Maastrichtian age. This unit was assigned in the Kaguyak Formation by Bradley and others (1999), but is separated here because its lithology and depositional environment are distinctly different from the Kaguyak Formation. This map unit overlies the Jurassic Naknek Formation with angular unconformity and is in turn overlain by rocks of the West Foreland Formation with angular unconformity

Naknek Formation (Upper Jurassic; Tithonian to Oxfordian)—Originally named Naknek Series by Spurr (1900, p. 169-171, 179, 181) for exposures at Naknek Lake on the Alaska Peninsula. Largely consists of sandstone, conglomerate, and siltstone having a primarily plutonic provenance. This rock unit is widespread in southern Alaska, exposed in a long belt running from south-central Alaska (Wilson and others, 1998) to the southwest end of the Alaska Peninsula (Wilson and others, 1999), a distance of about 1,150 km (Detterman and others, 1996). The aggregate thickness of the individual members exceeds 3,000 m, though the average thickness of the formation is more typically 1,700 to 2,000 m (Detterman and others, 1996). Megafossils, particularly the pelecypod *Buchia* (Detterman and Reed, 1980, p. B38; J.W. Miller, written commun., 1982 to 1988), are common, and the fauna, which also includes ammonites, indicate an age range of Oxfordian to late Tithonian (Late Jurassic). Detterman and others (1996; see also, Detterman and Hartsock, 1966; Martin and Katz, 1912) have subdivided unit into members of which the following appear in the map area:

Pomeroy Arkose Member (Kimmeridgian and Oxfordian?)—Massive light-gray, medium- to coarse-grained arkose containing many interbedded thin beds of dark-gray to brownish siltstone and pebble conglomerate (Detterman and Hartsock, 1966). The sandstone is rich in quartz (40-45 percent) and sodic feldspar (30-35 percent) and also contains 15-20 percent hornblende and tourmaline. Volcanic lithic fragments make up 2-3 percent of the rock. Grains are sub-angular to sub-rounded. The matrix is generally clay, but locally, is tuffaceous. The siltstone is mineralogically distinctive from the arkose and resembles the graywacke of older units according to Detterman and Hartsock (1966); we interpret this to indicate it contains a higher proportion of volcanic- and sedimentary-sourced components. Detterman and Hartsock (1966) indicated that most sections of the Pomeroy Arkose Member have a 70- to 350-foot-thick (21 to 113 m) gray, medium-bedded to massive, arenaceous siltstone horizon, usually in the lower part of the member. The Pomeroy Arkose is sparsely fossiliferous, containing *Lytoceras*, *Phylloceras*, and *Buchia concentrica*, suggesting an age no younger than early Kimmeridgian. Detterman and Hartsock (1966) suggested that the nearby Jurassic part of the Alaska-Aleutian Range batholith was the source for this unit and the subangular character of the easy-to-destroy grains (hornblende, tourmaline, and feldspar) indicate short transport and rapid burial

Snug Harbor Siltstone Member (Kimmeridgian and Oxfordian)—Dominantly massive to thin-bedded, dark-gray to black siltstone; calcareous gray sandstone beds are minor part of the unit (Detterman and Hartsock, 1966). Hard gray limestone concretions and lenses are locally abundant; rare thin layers of volcanic ash and tuff are found locally (Detterman and Hartsock, 1966). Deposited in moderately deep water, well below wave base and above carbonate compensation depth, in a basin having restricted circulation (Detterman and others, 1996). It is the lowest abundantly fossiliferous member of the

Naknek; main fossils present are *Buchia*, including *Buchia concentrica* as well as the ammonites *Amoeboceras*, *Phylloceras*, and *Perisphinctes*

Northeast Creek Sandstone Member (Oxfordian)—Light-gray, thin-bedded to massive arkosic sandstone, graywacke, and siltstone. Originally called the "lower sandstone member" by Detterman and Hartsock (1966) who considered this unit to have only local significance. Later work on the Alaska Peninsula (Detterman and others, 1996) showed that the lateral equivalent of this unit, which they named the Northeast Creek Sandstone Member, is present along the entire length of the Alaska Peninsula. According to Detterman and Hartsock (1966), some beds have a tuffaceous matrix, zones of small pebbles, as well as thin beds of arenaceous siltstone. Fossils are most common in the lower part of this unit and include ammonites, particularly *Cardioceras*, but also include *Phylloceras* and *Lytoceras*. Detterman and Hartsock (1966) assigned a latest Callovian and early Oxfordian age to this unit based on the presence of *Cardioceras martini* in the lower part of the member and its association with *Cardioceras distans*, which then without *Cardioceras martini* continues to the top of the member. Detterman and others (1996) assigned only an Oxfordian age to the unit based on reinterpretation of the available information. Pelecypods including *Pleuromya*, *Quenstedtia*, *Oxytoma*, *Thracia*, and *Astarte* are present but not common as are gastropods, echinoids, and belemnites (Detterman and Hartsock, 1966). Lower contact of member intertongues with the Chisik Conglomerate Member. Upper contact is gradational with the overlying Snug Harbor Siltstone Member

Chisik Conglomerate Member—Consists of massive to thick-bedded conglomerate and interbedded, crossbedded, quartzose sandstone. Clasts, as large as 2 m, are mainly granitic rocks, but up to 20 percent metamorphic and volcanic rocks are present (Detterman and others, 1996). The unit in the map area is mainly restricted to the area adjacent to Iniskin and Tuxedni Bays. A K-Ar age determination (Table 1, sample 62Ale 6e) on a quartz diorite cobble yielded a protolith age of 156.6 Ma on biotite and 159.7 on hornblende (Detterman and others, 1965)

Chinitna Formation (Middle Jurassic, Callovian)—Massive gray arenaceous siltstone. Unit is best exposed along the west coast of Cook Inlet where it is subdivided into two members, the upper Paveloff Siltstone Member and the lower Tonnie Siltstone Member (Detterman and Hartsock, 1966). This unit is a partial age equivalent of the Shelikof Formation of the Alaska Peninsula (Detterman and others, 1996). Subdivided into:

Paveloff Siltstone Member—Consists of massive dark-gray arenaceous siltstone in the upper part and a thick sandstone unit at its base (Detterman and Hartsock, 1966). Large ellipsoidal concretions and lenticular beds of limestone occur throughout the unit and thin interbeds of sandstone occur in the siltstone. A few siltstone beds contain abundant finely disseminated pyrite, causing the beds to weather rusty brown. The siltstone is well-indurated and the uppermost part is thin-bedded and fractures into angular fragments. The graywacke sandstone of the lower unit is "…thin bedded to massive, locally lenticularly bedded, fine to coarse grained, gray to greenish gray" (Detterman and Hartsock, 1966, p. 43). Limestone concretions and interbeds are common and on fresh surfaces are very dark-gray, but weather buff to cream colored. Locally the limestone is bioclastic (Detterman and Hartsock, 1966). Many non-diagnostic pelecypods and gastropods have been collected from the lower sandstone (Detterman and Hartsock, 1966), whereas a wide variety of ammonites have been collected from the siltstone and limestone concretions higher in the section. Many genera of ammonites, including *Cadoceras*, *Stenocadoceras*, P*seudocadoceras*, *Kepplerites*, *Kheraiceras*, and *Lilloettia,* have been collected from the unit (Detterman and Hartsock, 1966), indicating a Callovian age, although the uppermost zone of the Callovian has not been identified. The Paveloff Siltstone Member is the age equivalent of the Shelikof Formation of the Alaska Peninsula; the Shelikof contains a higher proportion of coarse volcanic debris (Detterman and others, 1996)

Tonnie Siltstone Member—Massive dark-gray to brownish-gray arenaceous siltstone, which weathers brownish-gray to red-brown (Detterman and Hartsock, 1966). Numerous small yellowish-brown weathering limestone concretions occur in parallel bands and randomly throughout the section. The limestone concretions are generally ovoid and as much as 12-13 cm in diameter. They are extremely hard and commonly fossiliferous (Detterman and Hartsock, 1966). Thin fine-grained, greenish-gray sandstone interbeds occur in the siltstone and a more massive sandstone unit is found at the base of the section. The sandstone interbeds are compositionally similar, but coarser grained than the siltstone. The thick (6-30 m) sandstone bed present at the base of the unit is medium-bedded to massive, fine- to medium-grained and grayish-brown. On Chisik Island, a thick (65 m) channel conglomerate, consisting mainly of volcanic rock cobbles and boulders, is present at the base of the section. "The Chisik Island section also contains numerous thin beds of volcanic ash (Detterman and Hartsock, 1966, p. 41)." The Tonnie Siltstone is abundantly fossiliferous, yielding many mollusks, particularly ammonites. *Paracadocreas*, *Pseudocadoceras*, *Phylloceras*, *Lilloettia*, *Kheraiceras*, *Kepplerites*, and *Xenocephilites* are among the collections as are numerous pelecypods and rare belemnites, gastropods and brachiopods allowing an age assignment of early Callovian (Detterman and Hartsock, 1966)

Tuxedni Group (Middle Jurassic, Callovian to Bajocian)—Light- to dark-gray and green marine graywacke, conglomerate, siltstone, and shale (Detterman and Hartsock, 1966). Graywacke ranges from feldspathic to lithic to laumontitic, conglomerate composed mainly of volcanic clasts in a graywacke matrix. Unit is locally subdivided into the Red Glacier Formation, Gaikema Sandstone, Fitz Creek Siltstone, Cynthia Falls Sandstone, Twist Creek Siltstone, and Bowser Formation, descriptions of which shown below are derived from Detterman and Hartsock (1966):

Bowser Formation (Callovian and Bathonian)—Heterogeneous assemblage of sandstone, conglomerate, shale and siltstone characterized by rapid facies changes (Detterman and Hartsock, 1966). Massive light- to dark-gray sandstone and conglomerate are the dominant lithologic types on the Iniskin Peninsula. The sandstone and the conglomerate matrix are coarse-grained and composed of angular fragments of feldspar and quartz, having biotite, augite, and magnetite as common accessory minerals. Light-gray sandstone is commonly calcareous and contains numerous coquina beds composed almost entirely of the pelecypods *Retroceramus* (formerly most Middle Jurassic Alaska inoceramids were referred to the genus *Inoceramus*) and *Trigonia* and is also interbedded with dark-gray sandstone. Clasts in the conglomerate are dominantly felsic volcanic rocks and basalt, but include about 10 percent granitic rocks. Siltstone beds are massive to thin-bedded, medium- to coarse-grained, dark-brownish gray, weathering to light-brown. Siltstone beds as much as 100-m-thick are interbedded with the conglomerate and sandstone and north of Chinitna Bay occurs in units as much as 250-m-thick, where the siltstone forms the dominant lithology of the Bowser Formation. Lenticular limestone concretions containing ammonites are common north of Chinitna Bay. The formation ranges in overall thickness from 380 to 560 m. Abundantly fossiliferous, containing ammonites and pelecypods, this formation can be divided into two faunal zones that occur on either side of the break between Callovian and Bathonian. The lower faunal zone immediately overlies the unconformity with the Twist Creek Siltstone and contains the ammonites *Cranocephalites*, *Arctocephalites*, *Siemiradzkia*, *Cobbanites*, and *Parareineckia* and is middle Bathonian in age. The upper faunal zone contains the ammonites *Xenocephalites*, *Kheraiceras*, and *Kepplerites* of Callovian age

Twist Creek Siltstone (Bajocian)—Soft, poorly consolidated, thin-bedded to massive siltstone and silty shale as much 125-m-thick (Detterman and Hartsock, 1966). The siltstone is dark-gray, weathers to dark-rusty brown, and contains many thin beds of volcanic ash that weather a bright-orange color. Small, commonly fossiliferous, limestone concretions are common throughout the unit. The Twist Creek Siltstone has an abundant ammonite fauna which includes *Oppelia* (*Liroxyites*), *Megasphaerceras*, *Leptosphinctes*, *Lissoceras*, and *Normannites* (*Dettermanites*), but which is restricted to the contained limestone concretions

Cynthia Falls Sandstone (Bajocian?)—Massive to thick-bedded graywacke sandstone and pebble conglomerate about 200-m-thick (Detterman and Hartsock, 1966). The sandstone is medium- to coarse-grained, greenish-gray to dark-green, has graded bedding and weathers mottled light-gray due to the presence of zeolites. The sandstone consists mainly of angular fragments of feldspar and volcanic rocks in a compositionally similar silt-size matrix. The pebble conglomerate occurs in thin lenticular beds within the sandstone and is well sorted within individual beds. Clasts consist of "red and green felsitic volcanic rocks, aphanitic igneous rocks, and a few metasedimentary rocks that are primarily dark-gray quartzite" (Detterman and Hartsock, 1966, p. 32). Coarse-siltstone is interbedded with the sandstone and may contain a few limestone concretions. Siltstone makes up 10 to 20 percent of the formation. Like the underlying Fitz Creek Siltstone and Gaikema Sandstone, the Cynthia Falls Sandstone is coarsest grained in the vicinity of Gaikema Creek and finer grained away from this area. Fossils are relatively uncommon in this unit, thought in part due to rapid deposition in a nearshore environment. The sparse fauna includes the ammonites *Chondroceras* and *Stephanoceras*, as well as the pelecypods *Retroceramus* (formerly *Inoceramus*) sp. and *Mytilus* sp.

Fitz Creek Siltstone (middle Bajocian)—Thick sequence (up to 400-m-thick) of massive, bluish dark-gray, arenaceous, coarse- to fine-grained siltstone that commonly weathers rusty orange and contains many small limestone concretions (Detterman and Hartsock, 1966). Fine-grained sandstone and, locally, conglomerate is interbedded. In the upper part of the unit the siltstone could possibly be called silty shale. The unit is coarsest in the vicinity of Gaikema Creek and rapidly becomes finer-grained in all directions away from the Gaikema Creek section. This unit is abundantly fossiliferous and is the lowest unit of the Tuxedni Group where ammonites are more numerous than pelecypods. A few non-diagnostic brachiopods are also present. The ammonites include *Normannites*, *Teloceras*, and *Chondroceras* and many other genera; pelecypods include *Retroceramus* (formerly *Inoceramus*) and *Pleuromya*, both in forms distinctly different than those found in the lower parts of the Tuxedni Group

Gaikema Sandstone (lower middle Bajocian)—Resistant, cliff-forming, massive to thin-bedded graywacke sandstone and cobble conglomerate 150- to 260-m-thick (Detterman and Hartsock, 1966). Sandstone commonly occurs in graded beds up to 3-m-thick, whereas conglomerate is well-sorted within individual beds and rarely shows grading (Detterman and Hartsock, 1966). Conglomerate is confined to the Iniskin Peninsula; clasts in it consist of "red and green felsitic volcanic rocks, aphanitic igneous rocks, and minor metasedimentary rocks" (Detterman and Hartsock, 1966, p. 26), all thought to be derived from the Talkeetna Formation. Rare granitic clasts in the Gaikema Sandstone are the first appearance of rocks presumably derived from the Alaska-Aleutian Range batholith. Siltstone, occurring mainly as thin interbeds in sandstone, is thin-bedded to massive, generally coarse-silt to sandy, gray to olive-gray, and brownish to rusty brown weathering. In general, siltstone constitutes less than 10 percent of the unit, though, locally it can constitute as much as 40 percent. Siltstone apparently does not occur in close proximity to the conglomeratic parts of the formation (Detterman and Hartsock, 1966). Unit is fossiliferous throughout, containing pelecypods *Meleagrinella*, *Trigonia*, and *Retroceramus* (formerly *Inoceramus*) and ammonites *Witchellia(?)*, *Stephanceras* and locally, *Sonninia (Papilliceras)*, *Lissoceras*, and *Emileia*

Red Glacier Formation (lower Bajocian to lower middle Bajocian)—Thin-bedded to massive, red-brown weathering, dark-gray to moderate olive-gray, highly arenaceous siltstone, locally containing lenticular interbeds and concretions of reddish-gray, dense limestone and very minor coal seams (Detterman and Hartsock, 1966). Underlying this is light-tan to buff arkosic sandstone and a thick black, silty to arenaceous, very fissile, shale. Siltstone constitutes about 40 percent of the unit, concentrated in the upper part, sandstone about 25 percent, and shale the remainder. Overall thickness ranges from 600 to as much as 2,000 m. Fossils are most abundant fossiliferous in the upper part of the Red Glacier Formation; no fossils are known from the lowermost part (as much as 600 m) of the unit. Pelecypods include *Meleagrinella*, *Trigonia*, *Retroceramus* (formerly *Inoceramus*), *Camptonectes*, and *Pleuromya*. Ammonites occur in two distinct faunal assemblages; the lower assemblage includes *Erycites*, *Tmetoceras*, and *Pseudolioceras* and this faunal zone ranges from 450 to 1,400 m below the top of the formation. The upper assemblage in the upper 400 m of the formation includes *Soninia*, *Emileia*, *Parabigottes* and in the uppermost 150 meters, *Papilliceras*, *Strigoceras*, *Lissoceras*, *Stephanoceras*, *Stemmatoceras*, and *Skirroceras*

Talkeetna Formation, undivided (Lower Jurassic)—Bedded volcanic rocks widely distributed in the Seldovia and Kenai quadrangles west of Cook Inlet. Where undivided, unit consists of flows, breccia, tuff, and agglomerate and locally interbedded minor sandstone and shale, all typically somewhat altered or metamorphosed (Detterman and Hartsock, 1966; Detterman and Reed, 1980). Detterman and Hartsock (1966) formally divided unit into three members. Within the map area, the Talkeetna Formation is locally subdivided, from top to bottom, into:

Horn Mountain Tuff Member—Bedded tuff and tuffaceous feldspathic sandstone, locally containing porphyritic andesite flows. Bedded tuff is tan, red, green, purple, or mottled-color, thin-bedded to massive and fine- to coarse-grained (Detterman and Hartsock, 1966). Locally, tree stumps are preserved within the tuff beds, suggesting subaerial deposition. However, thin-bedded laminated units that have graded bedding and contain rare belemnite fragments indicate some parts of the unit are marine. Measured thickness is as much as 870 m (Detterman and Hartsock, 1966). The above mentioned belemnites and plant fragments occur near the top of the unit; the fossils are not age diagnostic. In the Talkeetna Mountains north of the map area, fossils in the upper part of the Talkeetna Formation, which is considered correlative to the rocks of the Horn Mountain Tuff Member, indicate a late Pliensbachian and Toarcian (Early Jurassic) age (Arthur Grantz, oral commun., 1963, cited in Detterman and Hartsock, 1966)

Portage Creek Agglomerate Member—Reddish fragmental volcanic debris, primarily rounded volcanic bomb-like fragments and lapilli tuff grading to fine-grained tuff, clastic sedimentary rocks and flows northward in the map area (Detterman and Hartsock, 1966). Interbedded flows, tuff, and sedimentary rocks are thicker than in the underlying Marsh Creek Breccia Member, suggesting to Detterman and Hartsock (1966) a decrease in violent volcanism in the source area. These rocks are generally more felsic, although commonly described as andesitic (Detterman and Hartsock, 1966), than those of the Marsh Creek Breccia Member and their distribution suggests a separate source (Detterman and Hartsock, 1966). The estimated thickness of this unit is between 685 and 870 m. No fossil control is known for this map unit

Marsh Creek Breccia Member—Massive dark-green to green volcanic breccia having a tuff matrix (Detterman and Hartsock, 1966). Consists of angular fragments of aphanitic pink and green volcanic rocks ranging in size from 1 cm to nearly 1 m and in general, fine upward. Interbedded flows of andesite and basalt, thought to be partly submarine, are common, and increase in abundance and thickness southward (Detterman and Hartsock, 1966; Detterman and Reed, 1980). Bedded tuff is locally important, thickest in the southern exposures of the unit, and coarser in the more northern exposures. This member has an estimated minimum overall thickness of 1,000 m although no complete section has been measured and the sections that have been measured are cut by extensive faulting. Locally this member has obscure contact relationships with plutons of the Alaska-Aleutian Range batholith or has been assimilated into the Holocene magma chamber under Iliamna Volcano (Detterman and Hartsock, 1966). No fossils are known from this unit in the map area and its age is only inferred based on correlations with rocks in the Talkeetna Mountains type area

Pogibshi formation of Kelley (1980), undivided (Lower Jurassic, Sinemurian to Hettangian and older?)—Informally named Pogibshi formation of Kelley (1980) is exposed on east side of Cook Inlet and consists of volcaniclastic rocks interbedded with small amounts of limestone, coal, and tuffaceous argillite. Kelley (1980) divided the unit into three members on the basis of rock type, modal composition, and depositional texture. His stratigraphically lowest member, the Dangerous member, consists of volcaniclastic breccia, conglomerate, and sandstone and is in depositional contact with his informal Port Graham formation (. herein). Locally tuffaceous dark-gray sedimentary rocks in the Dangerous member make it hard to distinguish from the Port Graham formation. The July member consists of dacitic pyroclastic rocks, tuffaceous sandstone, granule conglomerate, and mudstone. Kelley (1980) indicated that the high quartz content and abundance of glassy debris help to distinguish this unit from other parts of his Pogibshi formation. The uppermost member, the Naskowhak, consists of greenish-gray tuffaceous mudstone and siltstone, and tuff. Locally, the basal part of the Naskowhak member includes laterally extensive coal-bearing units. The presence of these coal-bearing units helps to distinguish the Pogibshi formation of Kelley (1980) from the otherwise lithologically similar Talkeetna Formation on the west side of Cook Inlet. The Pogibshi formation of Kelley (1980) is reportedly intruded by the tonalite of Dogfish Bay (.–•) and possibly by the diorite of Point Bede (.–•); if so the recently determined Triassic age on the diorite (D.C. Bradley, oral commun., 2007) may indicate that the Pogibshi is, in part, significantly older than the Talkeetna Formation. Martin (1915) and Martin (1926) reported a diverse Lower Jurassic fauna along the coast southwest of Seldovia. Bradley and others (1999) erroneously attributed these Jurassic collections by Martin (1915) to the Port Graham formation of Kelley (1980); however, those collections were from localities within the outcrop area Bradley and others (1999) assigned to the Talkeetna Formation, which we reassign back to the Pogibshi formation of Kelley (1980). Fossils noted in the two Martin reports (1915; 1926) included several species of scleractinian corals, numerous bivalves (mostly pectinaceans), gastropods, and ammonites. A brief visit by R.B. Blodgett (written commun., 2007) to a section of early Sinemurian age exposed about 3 km west of Seldovia showed it to contain numerous pectinacean bivalves, gastropods, and several species of scleractinian corals. The bivalves were found both as articulated and disarticulated specimens, and most appear to belong to the genus Weyla, an Early Jurassic index fossil found primarily along the western coast of North and South America. Lower Jurassic ammonites from these same rocks were discussed and, in part, illustrated in Imlay (1981), who recognized both Sinemurian and Hettangian fossil assemblages. A fossil determination by A.K. Armstrong of a collection made by J.S. Kelley yielded poorly preserved Permian corals (sample 75JK-151B, www.alaskafossil.org). Due to the poor state of preservation of the coral material, we tentatively discount this collection until further material can be collected and identified from this locality. Connelly (1978) and Connelly and Moore (1979) suggested correlation of these rocks with the Upper Triassic Shuyak Formation of the Afognak Island which is intruded by the Afognak pluton of Triassic age (see also Wilson and others, 2005)

Port Graham formation of Kelley (1980) (Upper Triassic; Norian)—Dominantly dark-gray, carbonaceous limestone and silty limestone containing varying amounts of silica cement (Kelley, 1980). Fine-grained, dark-gray siliceous to limy mudstone, silty sandstone, and dark-gray to dark-olive-gray, thin- to medium-bedded chert having mudstone partings are also common lithologies according to Kelley (1980). Limy beds tend to be most common in the lower (middle Norian) part of the unit (R.B. Blodgett, written commun., 2007 and unpublished data of Humble Oil Company [now Exxon-Mobil] reported by R.B. Blodgett); whereas the upper part (of late Norian age) is composed of considerably more volcaniclastic fragment-rich and shaly beds. The volcaniclastic fragment-rich beds contain a diverse, but uncommon molluscan fauna consisting of both bivalves and gastropods, while the shaly beds tend to have a monotaxic fauna of monotid bivalves. Fossils are locally abundant, as reported by Kelley (1980) these are mostly thin-shelled mollusks, but also include corals, echinoids, ammonites, and trace fossils. Martin and others (1915) and Martin (1926) reported the bivalves *Halobia* cf. *H. superba* Mojsisovics, *Pseudomonotis subcircularis*

Gabb (this species is now referred in the genus *Monotis*), *Nucula*?, as well as the coral *Astrocoenia*? sp. The *Halobia* cf. *H. superba* was suggested by Martin to possibly indicate a Carnian age (this species was later re-identified as belonging to middle Norian age species of Halobia by Silberling and others, 1997), while the *Monotis subcircularis* was noted to indicate a late Norian age. Silberling and others (1997) provided a detailed analysis of the known Late Triassic bivalve fauna known from the Port Graham area and reported that the middle Norian age *Halobia lineata* and *H. dilitata* were found in collections reported by Martin (1915; USGS Mesozoic localities 6380 and 6382, respectively). Two different species of Late Triassic *Monotis* were reported from these rocks by Silberling and others (1997): *Monotis* (*Pacimonotis*) *subcircularis* and *Monotis* (*Monotis*) *alaskana*, as well as the late middle Norian ammonite *Steinmannites*. Kelley (1984) and Bradley and others (1999) assigned an upper age limit of Early Jurassic to this unit, although no fossils of this age are found in this unit. Fossils of this age do occur in the upper part of the overlying Pogibshi formation of Kelley (1980)

Metamorphic rocks

Kakhonak Complex (Jurassic, Triassic, and Permian(?) or older(?))—The Kakhonak Complex, defined by Detterman and Reed (1980) is a lithologically diverse and complex assemblages of metamorphosed mafic plutonic, volcanic, and sedimentary rocks found on the west side of Cook Inlet. Detterman and Hartsock (1966) mapped "metalimestone", argillite, quartzite, metatuff, greenstone, and phyllite from this unit. Detterman and Reed (1980) described the unit as largely consisting of roof pendants within the Alaska-Aleutian Range batholith and believed that the Kakhonak Complex represents, in part, the metamorphic equivalent of Upper Triassic and Lower Jurassic rocks, the Kamishak and Talkeetna Formations, of the vicinity. However, quartzite and quartz-mica schist occurring within the Kakhonak Complex have no direct equivalent within the sedimentary rocks of the vicinity, indicating other protoliths may have contributed to the complex. As Permian rocks were known from Puale Bay, south of the map area, a possible Paleozoic age was not excluded by Detterman and Reed (1980). Internal contacts are typically faults, resulting in a tectonic mix of lithologies. Although most of the rocks of this complex are at greenschist facies, the rocks range from nonmetamorphosed to granulite facies. No age control is known from the Kakhonak Complex

Igneous rocks

Quaternary

Volcanic rocks, undivided (Quaternary)—Andesite, dacite, and basalt lava flows, volcanic breccia, lahar deposits, and debris-flow deposits. Includes air-fall tuff, volcanic dome deposits, block-and-ash-flow deposits, ash-flow tuffs, volcanic-rubble flows, debris flows, and hot-blast avalanche deposits. Also includes tephra-rich colluvium in the vicinity of and west of Redoubt Volcano where these deposits both mantle and are incorporated into deposits of Holocene glaciation (Till and others, 1993; F.H. Wilson, unpub. data). Lava flows and clasts are porphyritic, typically glassy, gray to black, and commonly vesicular. Andesite is dominant composition and probably constitutes 60 percent or more of rocks. Unit typically forms volcanic edifices. Rocks of this unit mapped at Redoubt and Iliamna

Volcanoes include Holocene rocks which cap ridges and include massive lava flows, agglomerate, and lahar deposits. May include Tertiary volcanic rocks as mapped by Magoon and others (1976). Locally subdivided into:

Debris-flow deposits (Holocene)—Volcanic debris-flow and mudflow deposits from Redoubt Volcano in the Crescent River valley. Includes several small (older?) deposits in the upper valley and a 3,500-year-old debris flow in the lower valley (F.H. Wilson, unpub. data). The older deposits are from multiple debris flows off the west and southwest flanks Redoubt Volcano. Oldest(?) deposit is derived from west flank of Redoubt. Next oldest deposit appears to be derived from presently glaciated valley draining to the southwest off Redoubt. These older deposits are of relatively limited extent. They may have dammed the North Fork of the Crescent River, creating a temporary lake in the valley. Deposits of the youngest, most extensive, and probably most fluid debris flow derived from southwest flank of Redoubt Volcano. Flow was apparently derived from the only presently glacier-free valley draining south from Redoubt. This debris flow has been dated at 3,500 yrs. BP (Riehle and others, 1981), young enough to possibly explain the lack of glaciers in the source valley, as all surrounding valleys have extensive glaciers and glacial deposits. This debris flow extends to the coast of Cook Inlet and back flowed up the main fork of the Crescent River, creating Crescent Lake. Also includes mudflow deposits in the Drift River valley draining north and east from Redoubt Volcano (Till and others, 1993) of Holocene age; many of which are historic including 1966 and later flows

Andesite and dacite domes (Pleistocene)—Composite dome complex of Double Glacier Volcano consisting of medium- to coarsely porphyritic hornblende andesite and dacite. Three K-Ar andesite whole-rock ages were determined on these domes, two are considered minimum ages at 627±24 and 763±17 ka on sample 78AR 290 and one, on sample 90AR 99, yielded 887±15 ka (Reed and others, 1992, Table 1 herein)

Tertiary

Lava flows (middle? to late? Tertiary)—A small exposure of dark-blue-gray to black, cryptocrystalline to vesicular basalt and andesite occurs on the mainland northwest of Chisik Island (Detterman and Hartsock, 1966) and is one of a number of scattered exposures in their map area. As described, the flows are slightly altered and locally contain irregular veins of hematite and malachite in altered zones along shear planes. The flows unconformably overlie an exposure of the Talkeetna Formation. Detterman and Hartsock (1966) inferred the flows were of middle(?) or late(?) Tertiary age on the basis of their degree of dissection and correlation with flows in the Lake Iliamna region where they overlie sedimentary rocks of known Tertiary age

Tertiary and (or) Cretaceous

Granodiorite (Tertiary and [or] Cretaceous)—Medium-grained, hypidiomorphic granular, seriate granodiorite. Biotite tends to more abundant than hornblende. Occurs in the northwest corner of the Kenai quadrangle west of the Lake Clark fault and also in the adjacent Lake Clark quadrangle (Reed and Lanphere, 1972, 1973; Magoon and others, 1976; Detterman and others, 1976). K-Ar ages on biotite and hornblende range between

65.1±1.9 and 70.5±2.0 Ma (Reed and Lanphere, 1972; 1973; Magoon and others, 1976; Detterman and others, 1976)

Cretaceous

Quartz diorite (Cretaceous)—Locally foliated, largely medium-grained hornblende-biotite quartz diorite, but includes hornblende-pyroxene gabbro and diorite, quartz diorite, tonalite, and minor granodiorite (Magoon and others, 1976; Nelson and others, 1983; Reed and others, 1992). Located in the northwest part of the map area, east of the Lake Clark fault, these rocks were mapped as Tertiary or Cretaceous by Magoon and others (1976). Biotite-hornblende ratio is quite variable although color index remains constant. Deuteric epidote is common. On the basis of K-Ar dates on biotite and hornblende between 67.2±1.9 and 74.4±2.2 Ma (Reed and Lanphere, 1972), they are shown as Cretaceous here (Age recalculated using constants of Steiger and Jager, 1977)

Cretaceous and (or) Jurassic

Quartz monzodiorite (Cretaceous and (or) Jurassic)—Medium-gray, medium-grained, hypidiomorphic granular hornblende-biotite quartz monzodiorite containing variable amounts of clinopyroxene located in the extreme northwest part of the Kenai quadrangle. Flow structures locally present and hornblende and plagioclase are aligned in a north-northeast direction. Two samples from outside the map area yielded strongly discordant K-Ar biotite and hornblende ages between 58.8 and 97.5 Ma (Nelson and others, 1983). Part of the Alaska-Aleutian Range batholith of Reed and Lanphere (1969, 1972)

Jurassic

Alaska-Aleutian Range batholith (Jurassic phase)—Subdivided into:

Trondhjemite (Late Jurassic)—Medium- to coarse-grained, seriate, leucocratic trondhjemite containing 10 percent muscovite and about 5 percent interstitial, perthitic potassium feldspar. Occurs in two bodies in the Kenai quadrangle immediately west of Redoubt Volcano and in the headwaters of Big River north of Double Glacier (Reed and others, 1983). It also comprises a large body in the central part of the batholith in the Iliamna quadrangle west of Chinitna Bay. A single K-Ar age on muscovite from the Iliamna quadrangle was 148 Ma (Reed and Lanphere, 1972, analytical error not reported)

Quartz diorite, tonalite, and diorite (Jurassic)—Locally foliated medium-grained quartz diorite and tonalite; this is by far the dominant map unit of the Alaska-Aleutian Range batholith in this area. Hornblende is the primary mafic mineral, biotite increases in proportion to the presence of quartz and potassium feldspar. Detterman and Reed (1980) reported that the rocks of this unit grade to diorite but they did not observe it grading into quartz monzonite or granodiorite of their unit Jqm. As mapped here, this unit includes that quartz monzonite unit which consists of medium-grained, pinkish light-gray quartz monzonite and whitish-gray, medium-grained, biotite granodiorite containing minor hornblende and accessory primary muscovite. The quartz monzonite and granodiorite unit is exposed only on the eastern margin of the batholith within the map area. Potassium-argon ages generally range from 146±4.3 to 183 Ma for the batholith; a number of samples yielded younger ages which were considered suspect or reset by younger plutonism. Within the map area the maximum reported age is 174 Ma (Table 1). Two small exposures of gabbro and diorite are included in unit

Triassic

Quartz diorite and tonalite (Late Triassic)—In the Seldovia quadrangle, this unit includes the diorite of Point Bede and the tonalite of Dogfish Bay of Bradley and others (1999), both on the east side of Cook Inlet. The diorite of Point Bede of Bradley and others (1999) is fine- to medium-grained nonfoliated quartz diorite that Bradley and others (1999) assumed to be of Jurassic age based on correlation with a quartz diorite pluton in the Barren Islands, just south of the Seldovia quadrangle that yielded a K-Ar hornblende age of 191±1.3 Ma (Cowan and Boss, 1978, age recalculated using constants of Steiger and Jager, 1977). However, a Triassic age was recently determined on zircon from the diorite (D.C. Bradley, oral commun., 2007). The tonalite of Dogfish Bay of Bradley and others (1999) is medium-grained nonfoliated tonalite which shows chloritic alteration similar to that found in the diorite of Point Bede and hence was assigned a Jurassic age by Bradley and others (1999); we have shown the diorite and tonalite as a single map unit to which we have assigned a Triassic age. Bradley and others (1999) also mapped a light-gray, fine-grained to aphanitic felsite body south of the tonalite of Dogfish Bay. This felsite is undated and is tentatively assigned a Triassic age due to its proximity and similar setting to the tonalite and diorite of this map unit. Bradley and others (1999) suggested the felsite could be early Tertiary in age; however, no other rocks of Tertiary age are reported in this vicinity. Kelley (1980, 1984) mapped an intrusive contact between the diorite and his informal Pogibshi formation (Jp); however, the newly determined Triassic zircon date from the diorite and the Jurassic fossils from the Pogibshi indicate that there is some error in interpretation of the available data. Possible scenarios include an incorrectly mapped contact, a wider range of age for the Pogibshi formation of Kelley (1980), or inheritance in the zircon

Rock units within the Border Ranges Fault System

Metamorphic rocks

Seldovia metamorphic complex (Early Jurassic)—Marble, quartzite, garnet-mica schist, and glaucophane-bearing amphibolite whose protoliths were interpreted to consist of limestone, chert, argillite, and greenstone by Bradley and others, (1999). This unit occurs as narrow fault slices within the Border Ranges fault zone south of Seldovia and has been correlated with the Raspberry Schist of Roeske and others (1989) to the southwest and the Schist of Liberty Creek and Schist of Iceberg Lake of Winkler and others (1981) to the northeast. All these units preserve mineral assemblages representing blueschist facies metamorphism. Carden and others (1977) reported a series of 10 K-Ar ages on micas (including chlorite) and amphiboles from this unit ranging from 158.3±8.3 to 197.1±11.0 Ma and Bradley and Karl (2000) reported ^{40}Ar-^{39}Ar plateau ages on mica of 191.1±0.3 and 191.7±0.3 Ma and on hornblende of 191.9±0.6 Ma. Dating of the blueschist facies metamorphism of this metamorphic complex appears to support a pattern of decreasing age from west to east as originally suggested by Sisson and Onstott (1986)

Rock units east or south of the Border Ranges fault system

Bedded rocks

Yakataga Formation (Quaternary, Pleistocene to Tertiary, Miocene)—"Consists of diverse marine and glaciomarine clastic rocks more than 1,670-m-thick on Kayak and Wingham Island and at least an additional 1,200-m-thick on Middleton Island (Plafker and Addicott, 1976). Much of the continental shelf between Middleton Island and Kayak Island also is underlain by the Yakataga [Formation] (Plafker and others, 1975b). Interbedded gray to dark-gray and greenish-gray siltstone, mudstone, and sandstone predominate in lower third of formation. Till-like diamictite is interbedded with siltstone and sandstone in all but the lowest part of the formation and is the dominant rock type in the upper part of the formation, particularly on Middleton Island. Conglomerate is a minor lithology throughout the formation and scattered clasts—presumably dropstones—are present in all lithologies. Sandstone and conglomerate combined constitute about 10 percent of the section on Kayak Island and about 12 percent on Middleton Island" (Winkler and Plafker, 1993). In most exposures the Yakataga Formation is conformable and gradational to the underlying Poul Creek Formation but in some areas there is an angular unconformity of up to 15 degrees (Plafker and Addicott, 1976). Age control derived from abundant mollusks and foraminifers, although most are identical to living species (Winkler and Plafker, 1981; Plafker and Addicott, 1976). Foraminifera are typical of the lower or middle Miocene Saucesian or Relizian Stages of Washington (Rau and others, 1977). Paleomagnetic and biostratigraphic dating indicate the upper part of the formation on Middleton Island was deposited during the Matuyama reversed polarity epoch (Plafker and Addicott, 1976)

Redwood Formation (Tertiary, Pliocene to Oligocene?)—Marine mudstone, siltstone, sandstone, and conglomerate (Winkler and Plafker, 1981). "Lower unnamed sandstone member consists of about two-thirds thick-bedded sandstone and one-third silty sandstone and siltstone. Upper Puffy Member is more diverse and consists of about 50 percent siltstone, mudstone, and claystone, 30 percent conglomeratic mudstone and conglomerate, and 20 percent sandstone. Characteristic conglomeratic beds show complete gradation from coarse-grained, clast-supported conglomerate to matrix-supported conglomeratic mudstone and sandstone where coarse-grained clasts are suspended in the matrix. Siltstone, mudstone, and claystone are similar in appearance to parts of the underlying Poul Creek Formation but contain few or no concretions, no glauconitic or volcanic beds, and are sandier and more resistant to erosion" (Winkler and Plafker, 1993). "The fauna and lithology of the Redwood Formation indicate deposition below wave base in cold water at depth from neritic to probably bathyal. The well rounded character of clasts in the conglomerate indicates that the coarser clastic material was thoroughly abraded before being resedimented in the marine environment. The sparse and poorly preserved molluscan fauna from the formation suggests a correlation with the upper Galavinian ("Lincoln") and Matlockian ("Blakeley") Stages of the Pacific Northwest, or a range in age from late Eocene through Oligocene (Addicott and others, 1978). Foraminiferal control is extremely sparse, but suggests that the upper part of the formation may be as young as late Miocene (Rau and others, 1977); however, the USGS has accepted an age of late Oligocene(?) through early Pliocene for the unit Plafker (1987). Thus, the Redwood Formation in the Don Miller Hills apparently correlates with the upper part of the Poul Creek Formation and the lower part of the Yakataga Formation exposed on Kayak and Wingham Islands" (Winkler and Plafker, 1981)

Poul Creek Formation (Tertiary, early Miocene to late Eocene)—Originally named the Katalla Formation (Martin, 1905) whose definition was revised by Miller (1975); however, unit name was abandoned and Poul Creek Formation name was extended into the map area from the east by Nelson and others (1985). Unit consists of "Shale, and minor sandstone that is, in part, glauconitic, rich in organic material, and intercalated with intrabasinal, water-laid alkalic basaltic tuff, breccia, and pillow lava. Unit exposed intermittently along coastal belt in Gulf of Alaska region from Kayak Island through Ragged Mountain eastward to Icy Bay in the adjoining Bering Glacier quadrangle. Unit also penetrated in wells drilled along the coast and offshore in adjacent outer continental shelf. In Chugach National Forest area of Nelson and others (1985), unit conformably overlies the Tokun Formation; in Don Miller Hills, unit conformably underlies the Redwood Formation, but on Kayak Island unit is separated from the overlying Yakataga Formation by an apparent disconformity" (Winkler and Plafker, 1993). Although reported to conformably underlie the Redwood Formation and overlie the Tokun Formation, defined ages for the three units suggest the contacts may be locally time-transgressive. Subdivided into:

Sedimentary rocks—"Concretionary, pyritic, glauconitic, reddish-weathering, dark-gray to greenish-gray siltstone, claystone, and sandstone; subordinate dark-brown, laminated shale that is rich in organic material, silty shale, and gray calcareous sandstone; locally includes thin interbeds of basaltic tuff" (Winkler and Plafker, 1993). Thickness is approximately 1,600 m (Miller, 1975). "Deposited in cool neritic to bathyal marine environment, mostly below wave base. Occurrence of shales as much as 244-m-thick with high organic carbon contents (to 7.57 percent), extractable petroleum (0.8 gallons per ton), abundant glauconite, and common pyrite are suggestive of deposition in part under conditions of restricted bottom circulation. Intercalated basaltic fragmental rocks and less common pillow basalt (map unit Tpv) indicate episodic submarine mafic volcanism in the basin (Plafker, 1974). Mollusks indicate a range in age from late Eocene (Galvinan or "Keasey") through much of the Oligocene (Matlockian or "Blakeley") (Addicott and others, 1978). In general, foraminifera from the same localities indicate slightly younger ages, ranging from late Eocene through early Miocene (Refugian, Zemorrian, and Saucesian Stages) (Rau and others, 1977)" (Winkler and Plafker, 1981)

Volcanic rocks—"Basaltic pyroclastic and flow rocks, including minor pillowed lava flows; locally interbedded with marine sedimentary rocks, including tuffaceous or glauconitic strata, probably related genetically to mafic dikes, sills, and plugs unit ( )" (Winkler and Plafker, 1993). Winkler and Plafker (1981) reported a K-Ar whole rock date of 31.2±1.3 Ma on a sample from the mafic dike unit ( ) intruding unit on the southeast side of Kayak Island, providing a minimum age for the unit

Tokun Formation (Tertiary, Eocene)—"Consists predominantly of concretionary siltstone and lesser, variable amount of interbedded sandstone, chiefly in lower part of formation. Thick sandstone beds exposed near Point Hey and on Kayak and Wingham Islands presumably correlate with lower part of formation to the north but were closer to the sediment source. Siltstone generally is medium to dark gray and nearly massive; locally, thin beds and lenses of lighter gray, brown-weathering calcareous siltstone and silty limestone are found within darker siltstone. Spheroidal calcareous concretions as much as 1 m in maximum dimension are distributed randomly or along bedding surfaces in siltstone. Near Bering Lake, thin beds of glauconitic sandstone are found near top of formation. Interbedded sandstone in Tokun, which generally is lighter gray than the siltstone, is micaceous, feldspathic, and brown weathering. Isolated, intertidal outcrops of coarse- to fine-grained, brown-weathering feldspathic sandstone on Wessels Reef, which are exposed only at low tide, may correlate with the Tokun Formation" (Winkler and Plafker, 1993). "Lithology and megafauna indicate general deposition under quiet bottom conditions seaward of the surf zone in tropical to warm temperature water (Miller, 1975)" (Winkler and Plafker, 1981). Gradational with the underlying mostly non-marine Kulthieth Formation and has gradational to abrupt contact with the overlying Poul Creek Formation (Winkler and Plafker, 1981). Represents a transgressive marine sequence approximately 1,070-m-thick (Winkler and Plafker, 1981). Fossil crabs are abundant, especially in the upper part of the formation and occur intact in concretions (Winkler and Plafker, 1981). Sparse mollusks indicate middle and upper Eocene "Tejon" and "Keasey" Stages of the Pacific Coast standard section (Addicott and others, 1978)

Kulthieth Formation (Tertiary, Eocene)—"Includes at least 1,500 m of interbedded, massive to thin-bedded, coal bearing arkosic sandstone, dark-gray to black carbonaceous siltstone and shale, and minor coal. Sandstone to shale ratios in measured sections of the Kulthieth Formation (Martin, 1908) average about 1:1. Sandstone varies from massive intervals as much as 150-m-thick to thin-bedded and shaly intervals. Bituminous to semi-anthracite coal in beds as much as 3-m-thick is conspicuous, but minor part of sequence. Commonly intensely deformed into imbricated stacks of fault-bounded chevron folds displaying shearing and structural thinning and thickening of coal beds" (Winkler and Plafker, 1993). "Mostly nonmarine, with minor tongues of transitional marine strata lithologically similar to the underlying Stillwater Formation (Tsu [in their report, •.. herein]) and overlying Tokun Formation (Tt). Represents major progradational cycle into an otherwise marine lower Tertiary sequence" (Winkler and Plafker, 1981). Age control derived from widespread fossil plant collections and single mollusk collection near the top of the section (Winkler and Plafker, 1981). Mollusk collection indicates a late Eocene (Tejon) age, whereas fossil plant collections indicate wider range from lower Ravenian (late middle Eocene) to lower Kummerian (early Oligocene) (Winkler and Plafker, 1981; Wolfe, 1977); however, the accepted age for the unit is Eocene

Stillwater Formation (Tertiary, Eocene)—"Primarily consists of dense hard dark-gray siltstone. Where siltstone is carbonaceous, it has a coal-like appearance; where it is calcareous, it may be variegated from reddish brown to pale green and usually contains foraminifers" (Winkler and Plafker, 1993). Lithology and microfauna of lower section indicate marine deposition in neritic to upper bathyal depths (Tysdal and others, 1976; Winkler and Plafker, 1981); in "*** exposures north of the Bering River, which may constitute a higher part of the formation, ***" lithology and megafauna indicate regressive shallow marine deposition (Winkler and Plafker, 1981). Grades upward into the non-marine rocks of the overlying Kulthieth Formation (Miller, 1951; MacNeil and others, 1961). "Dominantly marine strata of the Stillwater Formation in the map area may be coeval with the nonmarine lower part of the Kulthieth Formation 65 km to the east in the Bering Glacier quadrangle (Miller, 1961; MacNeil and others, 1961)" (Winkler and Plafker, 1981). "The Stillwater Formation is complexly deformed and is characterized by tight folds and shearing in incompetent strata; hence its thickness can be estimated only crudely to be at least 1,500 m (Plafker, 1971)" as reported in Winkler and Plafker (1981). Age control derived from poorly constrained ages of forams and mollusks. "According to W.W. Rau, the foraminifera indicate a range from possibly the Paleocene and early Eocene Bulitian Stage to the middle Eocene Ulatisian Stage. The mollusks indicate a younger age, late middle or early late Eocene (F. S. MacNeil *in* Wolfe, 1977)" (Winkler and Plafker, 1981)

Orca Group (Tertiary, early middle Eocene to late Paleocene)—Originally named by Schrader (1900), this unit consists of widespread complexly deformed flyschoid sedimentary and intercalated mafic volcanic and intrusive rocks (Winkler, 1976; Tysdal and Case, 1979; Nelson and others, 1985). Thick monotonous sequence of turbiditic sedimentary rocks including thin- to thick-bedded sandstone, siltstone, mudstone, and local conglomerate which represent middle (and possibly inner) submarine fan deposits (Winkler and Tysdal, 1977; Dumoulin, 1987). Mafic rocks include ultramafic intrusive rocks, gabbro, sheeted basalt dikes, and pillow basalt (Winkler, 1976; Winkler and Tysdal, 1977; Nelson and others, 1985). The igneous rocks, while remaining part of the defined Orca Group, are described here under the heading of "Ophiolitic rocks of Prince William Sound" in the igneous rocks section of these unit descriptions. The Orca Group as a whole is variably metamorphosed from laumontite (prehnite-pumpellyite) to lower-greenschist facies; hornfels is developed near plutons (Nelson and others, 1985). "The lowest grade rocks form a northeast-southwest-trending belt that includes Montague and Hinchinbrook Islands; metamorphic grade increases to the north and the northwest" (Dumoulin, 1987). The northeastern contact between the Orca and Valdez Groups is generally accepted to lie along the Jack Bay, Gravina, and Bagley Faults in the Cordova quadrangle (Bol and Roeske, 1993; Winkler and Plafker, 1993; Dumoulin, 1987). The western contact with the Valdez Group is less well established due to poor age control and similarities between the two units (Dumoulin, 1987; Bol and Gibbons, 1992). The western contact is shown here to lie along the Contact Fault, but alternatively the contact may instead lie along the Johnstone Bay or Bainbridge Bay Fault of Helwig and Emmet (1981) as suggested by Dumoulin (1987), or elsewhere. Dumoulin (1987), on the basis of sandstone petrography, suggested "*** that the Valdez and Orca Groups form a single flysch sequence derived from one progressively unroofing source ***." The Orca Group is bounded on southeast along the Wingham, Ragged Mountain, and Chugach Faults in the Cordova quadrangle by rocks of the Stillwater (•..) and Tokun (••) Formations (Winkler and Plafker, 1981, 1993). Unit subdivided into:

•ı. **Sedimentary rocks, undivided**—Thin- to thick-bedded graywacke sandstone, siltstone, mudstone, slate, and locally, minor conglomerate, which display abundant sedimentary structures, such as graded bedding, crossbedding, and ripple marks, along with flute, groove, and load casts, indicating deposition from turbidity currents (Tysdal and Case, 1979; Nelson and others, 1985). Graywacke sandstone is more abundant than finer-grained rocks (Tysdal and Case, 1979). Bioturbated limestone lenses and concretions are found locally, and along with conglomerate, are characteristic of sedimentary rocks belonging to the Orca Group (Moffat, 1954; Tysdal and Case, 1979; Nelson and others, 1985). Lenticular matrix-supported conglomerate and pebbly mudstone and sandstone lenses are widespread, and contain clasts of intrabasinal and extrabasinal sedimentary rocks, felsic igneous rocks, and quartz (Winkler and Plafker, 1993). Thin-section petrography indicates that most of the sandstone is feldspathic to feldspatholithic (Nelson and others, 1985) and contains abundant monocrystalline quartz, indicating a plutonic provenance (Dumoulin, 1987, 1988). Winkler and Plafker (1993) reported unit is metamorphosed to zeolite or prehnite-pumpellyite facies in the Cordova and Middleton Island quadrangles; Nelson and others (1985) reported alteration ranges from diagenetic recrystallization of the matrix to low greenschist facies metamorphism. In the Seward and Blying Sound quadrangles, this unit also includes rocks mapped as siltstone by Tysdal and Case (1979). Their siltstone unit is locally tightly folded and metamorphosed to slate; medium-gray and green lenses of micritic limestone as much as 2-m-thick are present locally. At several places in the islands south of Knight Island Passage Tysdal and Case (1979) describe locally folded and contorted sequences of siltstone and isolated greenstone blocks mixed in with sandstone and siltstone within otherwise uniformly layered sections. Tysdal and Case (1979) thought these sequences were olistostromes. Tysdal and Case (1979) reported the same sedimentary rock types are included in their sedimentary rock-greenstone map units containing basalt sills (Togs) and pillow basalt (Tops) which are herein assigned to units •ı .✶and •ı ✶, respectively. Fossils reported by Nelson and others (1985) include: *Alnus* (Alder) pollen; foraminifers: *Globogerina* sp., *G. senni*, *Globogerina* sp. (hispid), and *Globorotalia* sp.; and echinoids: *Holaster* sp., *?Hypsopygaster* sp., and *Nucleopygus*

•ı . **Conglomerate**—"Ranges from matrix-supported pebbly mudstone and sandstone to massive clast-supported pebble, cobble, and boulder conglomerate" (Nelson and others, 1985). Generally well-rounded clasts consist primarily of extrabasinal felsic volcanic and igneous rocks (felsic porphyry and tuff, granitic rocks, and white quartz); and intrabasinal sedimentary and mafic rocks (greenstone, sandstone, siltstone argillite, and limestone (Nelson and others, 1985; Winkler and Plafker, 1993; Winkler and Tysdal, 1977; Moffit, 1954). Usually occurs as lenses 90- to 210-m-thick within flyschoid rocks; though the thickest lens, located in Miners Bay, measured 900-m-thick (Nelson and others, 1985). Matrix-supported conglomerate and pebbly mudstone may have been formed by sub-marine landslides on unstable slopes, whereas inversely and normally graded clast-supported conglomerate beds are channel fill deposits in feeder and distributary channels (Winkler and Tysdal, 1977). Fossils reported by Addicott and Plafker (1971, cited in Nelson and others, 1985) include a crab, *Branchioplax washingtoniana*, and a pelecypod, *Acila decisa* which suggest an age assignment of Paleocene(?) to late Eocene

Valdez Group (Upper Cretaceous)—A widespread unit of the coastal region of south central Alaska, the Valdez Group consists primarily of complexly deformed metasedimentary graywacke, siltstone, and shale generally considered to be the deposits of turbidity currents in an oceanic trench (Tysdal and Case, 1979; Nelson and others, 1985; Winkler and Plafker, 1981; 1993). It also includes a variety of interbedded, tholeiitic meta-volcanic and meta-intrusive rocks and locally a mélange facies. The Valdez Group ranges in metamorphic grade from laumontite- to mid-greenschist-facies and locally reaches amphibolite facies east of the Copper River (Nelson and others, 1985; Winkler and Plafker, 1981). The Valdez Group is correlative with the Kodiak Formation (Capps, 1937; Wilson and others, 2005), the Shumagin Formation (Wilson and others, 1999), and partially with the Sitka Graywacke (Gehrels and Berg, 1992), which together make up the Chugach terrane that extends for more than 1,700 km along the southern coast of Alaska. The Valdez Group is subdivided here into:

Metasedimentary rocks, undivided—Dark-gray thin- to thick-bedded, laumontite to mid-greenschist facies metamorphosed, moderately to poorly sorted sandstone, siltstone, and mudstone flysch; sandstone is fine- to coarse-grained and mainly composed of plagioclase, quartz, and igneous rock fragments (Tysdal and Case, 1979; Dumoulin, 1987). Unit is a thick sequence of rhythmically alternating, multiply-deformed, metamorphosed sandstone-siltstone turbidites having beds generally ranging from a few centimeters to a few meters thick and locally, massive beds as much as tens of meters thick (Winkler and Plafker, 1981; Nelson and others, 1985; Winkler and Plafker, 1993; Bradley and others, 1999). Point count analysis by Dumoulin (1987) showed Valdez Group sandstone contains between 6 to 30 percent quartz, 23 to 45 percent feldspar, and 28 to 68 percent lithic fragments; lithic fragments are dominantly volcanic rocks. Proportion of lithic fragments decreases from west to east, as feldspar and quartz increases (Nelson and others, 1985). Conglomeratic sandstone containing clasts of quartzite, intermediate and felsic volcanic rocks, and rare sandstone, limestone, and granitic rocks is uncommon but widely distributed, occurring at base of some sandstone beds (Bradley and others, 1999; Bradley and Miller, 2006). In some places, primary sedimentary structures such as graded bedding, current-ripple cross-lamination, convolute bedding, and sole markings are preserved (Nelson and others, 1985; Winkler and Plafker, 1993). *Inoceramus kusiroensis*, *Inoceramus ulrichi*, and *Inoceramus concentrica* of Maastrichtian or Late Cretaceous age have been reported (Tysdal and Plafker, 1978; Tysdal and Case, 1979; Nelson and others, 1985; Bradley and others, 1999). A K-Ar date on biotite semischist of 51.5±1.5 Ma was reported by Nelson and others (1985). D.C. Bradley (USGS, oral commun., 2007) reported 70 Ma detrital zircons from unit near Anchorage

Interbedded metavolcanic and metasedimentary rocks—Approximately equal portions of interbedded metavolcanic and metasedimentary rocks (Winkler and Plafker, 1981; Nelson and others, 1985; Winkler and Plafker, 1993). Metavolcanic rocks include semischistose volcanic breccia, tuff, tuffaceous sediment, and minor pillow basalt; metasedimentary rocks include slate and phyllite, although metamorphosed sandstone, siltstone, and chert are interbedded in many places (Winkler and Plafker, 1981; Nelson and others, 1985; Winkler and Plafker, 1993). Unit crops out in two locations; in the north central Cordova quadrangle, and on the east side of the Resurrection Peninsula in the Seward quadrangle. Winkler and Plafker (1993) report unit tends to be "variably metamorphosed regionally from zeolite to lower greenschist facies, although near Cordova, Woodworth, and Schwan Glaciers rocks are transitional to amphibolite facies"

Metavolcanic rocks, undivided—Tholeiitic metabasalt, massive greenstone, and basaltic metatuff, including local pillow lava, pillow breccia, and gabbroic dikes and sills (Winkler and Plafker, 1993) in the Cordova quadrangle. Metabasalt forms rugged, nearly massive outcrops, whereas semischistose metatuff forms more subdued outcrops (Winkler and Plafker, 1993)

Aquagene tuff—Metamorphosed aquagene tuff is green to dark-gray, fine-grained, and finely laminated containing plagioclase phenocrysts; metamorphosed to chlorite and biotite zones of greenschist facies; chlorite, epidote, and locally, actinolite are abundant; remnants of glossy shards are present (Tysdal and others, 1977; Tysdal and Case, 1979). Whole rock age for metatuff on Fox Island of 54.4 ±2.7 Ma was interpreted by Miller

(1984) as possibly reset during a thermal event; alternatively, the metatuff on Fox Island (formerly Renard) is closely associated with the ophiolitic rocks of the Resurrection Peninsula, now considered to be of Eocene age. In any case, a whole-rock age determination on a metamorphosed rock must be considered suspect

📺. **Schist**—In the Valdez Group, schistose metamorphic rocks are found in two general modes of occurrence. In the Cordova quadrangle, Winkler and Plafker (1993) describe a "chiefly homogenous pelitic schist and minor amphibolite; [unit which] also includes spotted biotite-plagioclase-quartz (±muscovite) schist containing porphyroblasts of cordierite, andalusite, garnet, and staurolite in several places. Common banding probably represents original layering inherited from protoliths; transitional into gneissose rocks to the east and into greenschist-facies rocks of the metasedimentary rocks unit (📺) to the west." In contrast with these rocks, in the Seward and Blying Sound quadrangles, Tysdal and Case (1979) describe a schist unit as consisting "interbedded siltstone, graywacke, and less abundant tuff, tuffaceous sandstone, and basalt (pillow basalt?) ***." These rocks are primarily localized on the west side of the Placer River fault and "*** metamorphosed chiefly to biotite zone of greenschist facies, but locally to chlorite zone; typical metamorphic-mineral assemblages of biotite zone are biotite-muscovite-chlorite-quartz-epidote-calcite-albite ***" (Tysdal and Case, 1979). Nelson and others (1985) chose to not distinguish the schistose rocks mapped by Tysdal and Case (1979) as a distinct map unit because they reported them to be only semi-schistose and interlayered with rocks that have no penetrative deformation; Nelson and others (1985) reported that rocks such as these were common throughout the Valdez Group, especially near faults and in areas of finer-grained sedimentary protolith. However, we have retained the belt of schistose rocks along the Placer River fault by Tysdal and Case (1979), which they reported as being conspicuously schistose and the only extensive area of schistose rocks in their map area. Nelson and others (1985) reported other areas of schistose rocks are common in the Valdez Group, yet none been distinguished on maps to date except for areas on Fox [Renard] Island and the Resurrection Peninsula by Tysdal and Case (1979); the Resurrection Peninsula occurrence is included in map unit 📺 here, following the mapping of Bradley and Miller (2006)

📺. **Gneiss**—"Muscovite-biotite-quartz-plagioclase (± sillimanite and garnet) schist, banded gneiss, and migmatitic gneiss; potassium-feldspar-bearing segregations in migmatite; many local intrusive stringers, dikes, and sills of granodiorite and granite; transitional into schistose rocks to the north, south, and west" (Winkler and Plafker, 1993). Nelson and others (1985) describe the unit as a paragneiss of "predominantly metasedimentary rocks with well-developed gneissic foliation consisting of alternating quartz and feldspar-rich layers with biotite-rich layers. *** Locally some layers in the paragneiss contain 1-in.-long [2.5 cm] porphyroblasts of andalusite." Unit contains as much as 10 percent cream colored or light-gray, coarse-grained orthogneiss that locally grades into normal textured granitic rocks containing abundant inclusions of country rock (Nelson and others, 1985). Metamorphic grade ranges from middle to upper amphibolite facies (T.L. Pavlis and V.B. Sisson, written commun., 2002). Hornblende and biotite ages of 51.5±2 and 46.7± respectively were reported by Hudson and others (1979). Unit is a gneissic equivalent of the Valdez Group found along the Wernicke Glacier

Mélange of Iceworm Peak of Kusky and others (1997)—Tectonic mélange consisting of blocks of graywacke in a phacoidally cleaved matrix of slate having a Valdez Group protolith for both matrix and blocks (Bradley and others, 1999; Bradley and Wilson, 2000). Mapped only in the Seldovia and Kenai quadrangles but may be more extensive along the McHugh Complex and Valdez Group contact (Kusky and others, 1997). Intruded by Paleocene dikes (Kusky and others, 1997) not shown here

McHugh Complex (Cretaceous to Mississippian)—"Mélange of siltstone, sandstone, mud-chip sandstone, conglomeratic sandstone, tuff, and less abundant gabbro, serpentinite, bedded chert, and pillow basalt; fine-grained sedimentary strata commonly streaked out; sedimentary and igneous rocks are broken and discontinuous; metamorphic minerals include muscovite, epidote, calcite, chlorite, albite, and veinlets of prehnite" (Tysdal and Case, 1979). Paraphrasing Clark (1981), the McHugh Complex is a heterogeneous, chaotic assemblage that includes metamorphosed clastic and volcanic rocks of diverse ages. Clastic rocks, which are the most abundant, comprise thick, fault-bounded sequences of weakly metamorphosed graywacke, arkose, siltstone, and conglomeratic sandstone. Bedding is rarely seen and commonly discontinuous. Volcanic rocks in the McHugh Complex, also in fault-bounded sequences, are greenstone, mostly of basaltic composition, and are associated with radiolarian metachert, metasiltstone, and argillite. Clark (1981) thought the volcanic rocks represent oceanic crust and that the clastic sedimentary rocks were deposited in an oceanic trench. Sedimentary rocks of the matrix of the mélange have yielded Early Cretaceous (Valanginian) fossils, whereas protolith ages on blocks in the mélange have yielded radiolarians of Cretaceous (Albian-Aptian), Jurassic, and Triassic age (Bradley and others, 1999; Winkler and others, 1981), Permian conodonts and fusilinids (Bradley and others, 1999), and Mississippian to Pennsylvanian conodonts (Nelson and others, 1986). D.C. Bradley (USGS, oral commun., 2007) reported 70 Ma detrital zircons from metasandstone within the McHugh Complex collected along Turnagain Arm in the Anchorage quadrangle to the north of the map area. Bradley and others (1999) locally subdivided the McHugh Complex into distinct lithologic packages:

McHugh Complex, graywacke and conglomerate (Early Cretaceous to Early Jurassic, Pliensbachian)—Consists of fault-bounded blocks of massive conglomerate and graywacke that range up to several kilometers in structural thickness (Bradley and others, 1999). Bradley and others (1999) reported that deformation has generally obliterated primary sedimentary features; they interpreted the conglomerate and massive graywacke to be of turbiditic origin and locally noted the presence of thin- and medium-bedded turbiditic graywacke. Graywacke is matrix-supported, poorly sorted, and has clasts consisting primarily of chert and volcanic rock fragments (Bradley and others, 1999). Bradley and others (1999) reported Pliensbachian radiolaria in conformably underlying ribbon chert at one locality and considered this McHugh Complex unit to range in age regionally from Early Jurassic, Pliensbachian to as young as Early Cretaceous

McHugh Complex, basalt and chert (Early Cretaceous, Albian to Middle Triassic, Ladinian)—"Pillow and massive basalt, depositionally overlain by complexly folded and faulted radiolarian chert" (Bradley and others, 1999). Bradley and others (1999, citing a C.D. Blome, USGS written commun. of 1994) reported radiolaria in bedded chert ranging in age from Middle Triassic, Ladinian to Early Cretaceous, Albian

Gabbro (Mesozoic)—Dark-green, medium- to coarse-grained gabbro and minor leucogabbro and plagiogranite (Bradley and others, 1999). Occurs as fault-bounded bodies in the McHugh Complex; following Bradley and others (1999), only the larger bodies are shown here; others are too small to map. Associated with McHugh Complex basalt and chert unit ( ), which Bradley and others (1999) suggested may indicate a genetic relationship and therefore they thought may indicate a Triassic to mid-Cretaceous age. However, they assigned an undifferentiated Mesozoic age to the unit. Bradley and Karl (2000) reported a concordant U-Pb zircon age of 227.7±0.6 Ma from this unit

Ultramafic plutonic rocks (Mesozoic)—Predominantly layered, variably serpentinized dunite containing rare to locally abundant layers of chromite and pyroxenite and fault slices of garnet pyroxenite and serpentinite (Bradley and others, 1999). Bradley and others (1999) reported at least 7 fault-bounded bodies, all associated with the McHugh Complex. Most bodies are bounded by low angle thrust faults. This was originally suggested for the Red Mountain body, but as discussed in Bradley and others (1999), it is not a klippe as interpreted by Magoon and others (1976), but rather is bounded by late stage, sub-vertical faults. However, Bradley and others (1999) did suggest a thrust may bound the Red Mountain body at depth. They also inferred that the gabbro ( ) and ultramafic rocks, while not spatially associated are comagmatic and therefore by extension may be of Triassic to mid-Cretaceous age; nonetheless, they assigned a Mesozoic to these rocks

Igneous rocks

Tertiary

Dacite of Cape Saint Elias (Tertiary, Pliocene or Miocene)—Described by Winkler and Plafker (1993) as follows: "Prominent very pale gray dacite plug complex that forms Cape Saint Elias and Pinnacle Rock at the southwestern end of Kayak Island (Plafker, 1974). Dacite is very dense and hard and is conspicuously jointed. Unit has a microgranitic and porphyritic texture and consists of about 35 percent plagioclase, 35 percent quartz, 25 percent orthoclase, and 5 percent relict brown hornblende and biotite. Unit has sharp, nearly vertical contacts with adjacent dark-gray argillaceous rocks of the Yakataga and Poul Creek Formations, which are metamorphosed to dark hornfels for at least 100 m around the intrusion. Intrudes lower part of Yakataga Formation (unit) and, therefore, must be at least as young as late Miocene and more likely Pliocene because unit was emplaced after enclosing strata were deformed." A whole-rock K-Ar age of 6.2±0.3 Ma (Table 1, herein) was reported by Nelson and others (1985)

Mafic plugs (Tertiary, Oligocene?)—Strongly altered dikes, sills, and plugs of diabase, alkalic basalt, olivine basalt, and lamprophyre, mostly on or near Kayak Island. Winkler and Plafker (1993) suggested these hypabyssal rocks were probably genetically related to extrusive volcanic rocks in the Poul Creek Formation ( ). Winkler and Plafker (1981) described these rocks as coarse-grained and diabasic in the plugs west of the Nichawak Hills and fine-grained and glassy elsewhere. The two plugs immediately west of the Nichawak Hills are diabasic, containing 45 percent euhedral plagioclase intergrown with 30 percent anhedral augite and enstatite, 5 percent opaque minerals and 20 percent secondary chlorite. An isolated plug east of Ragged Mountain is nepheline syenite. Lithologic associations and cross-cutting relationships suggest an Oligocene age; nowhere do they intrude rocks younger than the upper part of the Poul Creek Formation (Winkler and Plafker, 1981). K-Ar whole rock date of a mafic dike on Kayak Island was 31.2±1.3 Ma (Winkler and Plafker, 1981)

• **Granitic rocks** (Tertiary, Oligocene? and latest Eocene)—Plutons in the Seward quadrangle are dominantly light-gray, medium- to coarse-grained biotite ±hornblende granodiorite and granite stocks; larger stocks commonly grade inward from marginal zones containing more biotite (and locally hornblende) to more leucocratic zones; large areas of intrusions are porphyritic and contain orthoclase phenocrysts in a medium-grained groundmass; plagioclase ranges from oligoclase to andesine in composition, and biotite constitutes between 5 and 15 percent (Tysdal and Case, 1979). Also includes the Cedar Bay granite of Tysdal and Case (1979), a light-gray and pink medium- and coarse-grained muscovite (±biotite) granite; plagioclase ranges from oligoclase to andesine in composition, and biotite is commonly less than 1 percent. Hypidiomorphic-granular texture is most common, but equigranular as well as porphyritic varieties also exist. Primary biotite is the most abundant mafic mineral and is sometimes accompanied by hornblende. Towards the pluton margins, however, hornblende commonly dominates over biotite (Nelson and others, 1985). K-Ar dates on biotite and hornblende range from 34.2±1.7 to 37.1±1 Ma (Tysdal and Case, 1979; Nelson and others, 1985; ages recalculated using constants of Steiger and Jager, 1977). ^{40}Ar/^{39}Ar ages were 29.2±0.1 and 31.7±0.1 on potassium feldspar; however these dates are inherently suspect as potassium feldspar is not generally considered suitable for dating emplacement of plutonic rocks

• **Gabbro and diorite** (Tertiary, Oligocene and older)—Dominantly, dark-gray medium- to coarse-grained gabbro and subordinate diorite, both having finer grained borders of quartz gabbro and quartz diorite (Tysdal and Case, 1979; Nelson and others, 1985). Gabbro generally composed of subequal amounts of labradorite and clinopyroxene; locally contains olivine on Esther Island; pyroxene largely altered to hornblende north of Paddy Bay (Tysdal and Case, 1979). Texturally, the rocks are mostly subophitic; however, some are hypidiomorphic- to allotriomorphic-granular and a few are porphyritic (Nelson and others, 1985). Rocks of this unit are considered to be an early mafic phase associated with granitic plutons of the granitic rocks unit (•). A K-Ar date on biotite of 37.6±1.0 Ma (age recalculated using constants of Steiger and Jager, 1977), was originally assigned to the Granite of Passage Canal by Tysdal and Case (1979); Nelson and others (1985) assigned the sample locality to this map unit although the reported rock type for the date was granodiorite. Grant and Higgins (1910) and Tysdal and Case (1979) suggested, and Nelson and others (1985) supported, a genetic and chronological relation of these mafic rocks to the granitic rocks unit (•)

• **Granite and granodiorite** (Tertiary, Eocene)—Generally medium- and medium- to coarse-grained hypidiomorphic-granular biotite granite having border phases of biotite-hornblende granite, granodiorite, and tonalite (Nelson and others, 1985) located in the Cordova quadrangle. Also includes uncommon dacite (George Plafker, written commun., 1985) Mafic mineral content varies with composition, as a result the color index of the granite ranges from 5 to 10, the granodiorite color index ranges from 10 to 20, and the tonalite color index ranges from 15 to 35. In the Cordova quadrangle, plutons also include biotite-muscovite ±garnet tonalite and trondhjemite (T.L. Pavlis and V.B. Sisson, written commun., 2002). These Cordova area plutons include strongly foliated and lineated plutons, weakly foliated, syn-deformation plutons, and nonfoliated, post-deformation plutons (T.L. Pavlis and V.B. Sisson, 2002, written commun.). K-Ar and $^{40}Ar/^{39}Ar$ ages range from 47.23 Ma on dacite to 53.5±1.6 Ma on hornblende from a sample reported only as granitic rock; a U-Pb monazite age on a sill located near Van Cleve glacier was about 54 Ma (Poole, 1996). U-Pb analyses of zircon from this sill were unsuccessful due to inheritance and lead loss (J.N. Aleinikoff, USGS, written commun., 2007). Also included in this unit is a small pluton in the northern part of the Seward quadrangle on the west side of Port Wells. Surrounded by plutons assigned to unit •.., this small pluton is most appropriately assigned to this map unit (•..) on the basis of reported age (56±1 Ma, listed in Table 1 for the Granite Mine in the section on hydrothermal alteration dates). Other small plutons having similar, but slightly younger ages, occur to the north in the adjacent Anchorage quadrangle

•. ⊞ **Granitic rocks of Harding Icefield region** (Tertiary, Eocene and Paleocene)—Primarily "medium- to dark-gray foliated medium- to coarse-grained biotite-muscovite-(hornblende) granite and granodiorite; marginal phases are locally biotite-muscovite-(hornblende) tonalite" (Tysdal and Case, 1979). Consists of a large batholith extending from Nuka and Aialik Bays and offshore islands northward more than 60 km into the Harding Icefield where it is exposed in many nunataks and westward into the Seldovia quadrangle around Harris Bay; "*** mafic minerals, almost wholly biotite, constitute 20 to 30 percent of minerals in tonalitic rocks, 15 to 20 percent of granodiorite, and 5 to 10 percent of granite; muscovite, a late but primary mineral, commonly makes up less than 2 percent" (Tysdal and Case, 1979). Unit includes the Nuka, Aialik, and Tustumena plutons, as well as the Chernof stock of Bradley and others (1999). A K-Ar date from a sample collected at Aialik Cape yielded 61.0±1.8 Ma on biotite and 56.0±1.6 Ma on muscovite (Tysdal and Case, 1979, ages recalculated using constants of Steiger and Jager, 1977), whereas a sample of the Aialik pluton from Harris Bay yielded a weighted mean $^{40}Ar/^{39}Ar$ age of 52.2±0.9 Ma (Bradley and others, 2000) and the Paguna stock of Bradley and others (1999) yielded a $^{40}Ar/^{39}Ar$ plateau age of 53.4±1.5 Ma. The apparent large size of the pluton and wide ranging age determinations, from 52.2 to 61.0 Ma, which overlap that of unit •.., suggest these rocks are part of a multiphase batholith rather than a single pluton. Lytwyn and others (2000) described a suite of dikes (part of map unit TKd, herein) that they associated with the same ridge subduction related system thought responsible for these plutons

Ophiolitic rocks of Prince William Sound

The ophiolitic rocks of Prince William Sound are composed of ultramafic rocks, gabbro, plagiogranite, sheeted basalt dikes, and pillow basalts that represent mid-oceanic ridge rocks (Crowe and others, 1992; Tysdal and others, 1977) and are generally considered part of the Orca Group. These rocks crop out in a fault(?) bounded window in the Valdez Group along the Resurrection Peninsula and interbedded and intruded within the Orca Group sedimentary rocks on Knight and Glacier Islands and to the northwest to Valdez Arm. The chemistry of the mafic rocks indicates a mid-ocean ridge origin (Crowe and others, 1992; Tysdal and others, 1977; Lytwyn and others, 1997). An aeromagnetic high associated with the ophiolitic rocks of Knight Island extends to similar rocks on Glacier Island, suggesting the ophiolite is a continuous belt through the Prince William Sound (Case and others, 1979; Barnes, 1991).

Historically, the Resurrection Peninsula rocks had been included within the Upper Cretaceous Valdez Group, although age control was lacking. With the report of a 57 Ma age on a zircon from a plagiogranite (Nelson and others, 1989), it was recognized that the Resurrection Peninsula rocks are similar in age to the Knight Island ophiolite, which is assigned to the Orca Group. Workers have consistently commented on the similarities between the two ophiolitic complexes (Tysdal and others, 1977; Tysdal and Case, 1979; Miller, 1984; Nelson and others, 1985; Lytwyn and others, 1997). Grant and Higgins (1910) originally showed these complexes as part of the same unit. Because the units are the same age and are similar in character, herein we include the Resurrection Peninsula ophiolitic rocks, along with the Knight Island ophiolitic rocks, as part of the Orca Group. The Resurrection Peninsula ophiolitic rocks represent a single-sided west-dipping sequence (Tysdal and others, 1977). The Knight Island ophiolitic rocks represent a mirrored or antiformal sequence having a core of gabbro cut by sheeted dikes with pillow basalt on the west having tops facing west and pillow basalt on the east having tops facing east (Tysdal and others, 1977). Although these ophiolitic rocks might be mapped as a separate unit from the Orca Group trench fill sedimentary rocks, the interfingering nature of the contact makes assigning a definitive demarcation difficult. Following Lytwyn and others (1997), we also include the metavolcanic rocks described by Winkler and Plafker (1981; 1993, unit •ı ⩛) included in the Orca Group in the Cordova quadrangle in the ophiolitic rocks of Prince William Sound, On the Resurrection Peninsula, the contact between the Valdez Group and the ophiolitic rocks is in dispute (Bradley and Miller, 2006; Kusky and Young, 1999). Bradley and Miller (2006) interpreted the contact between the Valdez Group and the ophiolitic rocks as faulted on all sides. Kusky and Young (1999) interpreted the contact as stratigraphic on the west side of the peninsula near Humpy and Thumb Coves. Complicating matters is the recognition of tuffaceous rocks cropping out on Fox Island. These rocks are petrographically, and metamorphically different from typical rocks of the Valdez Group (Bradley and Miller, 2006; Kusky and Young, 1999; Tysdal and Case, 1979) and have been mapped as a distinct unit of the Valdez Group by all workers. Further complicating matters is the observation by Tysdal and Case (1979) of an intrusive contact between the gabbroic rocks and sedimentary rocks of the Valdez Group. Tysdal and Case (1979) mentioned a chilled margin and a 200m wide thermal aureole along the contact on the east side of the peninsula, but this was not observed by Nelson and others (1985). Tysdal and Case (1979) also mention an intrusive contact near the pass at the head of Likes Creek. Future study of the tuffaceous rocks and the nature of contact between the ophiolitic rocks and the surrounding sedimentary rocks are necessary to resolve this controversy.

•ı ⩛ **Volcanic rocks, undivided** (Tertiary, Eocene)—"Thick and thin tabular bodies of altered tholeiitic basalt consist of pillowed, massive, or crudely columnar flows, but also include pillow breccia, aquagene tuff, and diabase or gabbro sills; pillows have chilled margins that are palagonitic and amygdaloidal. Minor mudstone and siltstone that have interbedded basalt are included locally. Commonly contains green, gray, or red chert in interstices between pillows, rarely includes interpillow clots of pink limestone or black mudstone. *** Metamorphosed to zeolite or prehnite-pumpellyite facies" (Winkler and Plafker, 1993). Also includes areas mapped as greenstone that were probably pillow basalt, basaltic tuff, and sills (Tysdal and Case, 1979, unit Tog; Nelson and others, 1985, unit Tov). May be equivalent in part to units •ı ⊛, •ı ⩛, and •ı →. Locally subdivided into:

•ı ⊛ **Pillow basalt**—"Pale- to dark-green aphyric to porphyritic, frequently amygdaloidal, pillow basalt composed of plagioclase and clinopyroxene; plagioclase commonly replaced by albite and epidote, and clinopyroxene by hornblende, actinolite, and(or) chlorite; vesicles mostly filled with chlorite; pillow basalt in some areas is interlayered with subordinate pillow breccia and tuff' (Tysdal and Case, 1979). Discrete pillows average 2 ft [50 cm] in diameter on the Resurrection Peninsula and average about 1 m where they were mapped in the Orca Group by Nelson and others (1985) and are metamorphosed to as high as low greenschist facies (Nelson and others, 1985). The pillows have fractured surfaces, chilled margins, palagonitic coatings, and cracks that radiate outward from pillow centers, indicating rapid cooling (Tysdal and others, 1977; Tysdal and Case, 1979). Altered brown-colored volcanic glass makes up much of the matrix, especially in the outer parts of pillows (Nelson and others, 1985). Inter-pillow material consists of extrusive breccia, agglomerate, and hyaloclastite; and locally, thin sequences of siliceous mudstone and argillite, sandstone, and carbonate rocks, and minor red, green, and gray chert (Capps, 1915; Tysdal and others, 1977; Tysdal and Case, 1979; Miller, 1984; Nelson and others, 1985). Interbedded sedimentary layers locally display crossbedding and graded beds (Tysdal and others, 1977; Tysdal and Case, 1979). "Pillow basalt and lesser massive basalt and broken pillow breccia make up most of the western flank of the mafic complex on the Resurrection Peninsula" (Nelson and others, 1985; Tysdal and Case, 1979) where flows dip westward roughly 30˚ and are as much as 1000-m-thick (Tysdal and others, 1977). Flows dip west on the west side of Knight Island and eastward on the east side of the island and are more than 5000-m-thick (Tysdal and others, 1977). This unit is gradational into and cut by sheeted dikes of unit •ı _ over a wide zone on Glacier and Knight Islands and interbedded with volcanic and sedimentary rocks of unit •ı ✖ in eastern Prince William Sound (Nelson and others, 1985; Tysdal and Case, 1979)

•ı ✖ **Volcanic and sedimentary rocks**—Consists of locally variable amounts of tholeiitic basalt, and tuffaceous and generally minor turbiditic sedimentary rocks (Winkler and Plafker, 1993; Nelson and others, 1985; Tysdal and others, 1976). The lithology is quite variable throughout the study area. "Basalt consists of pillowed and massive flows, pillow breccia, and tuff. Turbidites, in most places, are mudstone, siltstone, and fossiliferous volcanogenic sandstone; in a few places nonvolcanogenic sandstone is interbedded" (Winkler and Plafker, 1993). "In the Ragged Mountains of the Cordova quadrangle, volcaniclastic and tuffaceous sedimentary rocks are abundant, and pillow basalt is rare" (Nelson and others, 1985, Tysdal and others, 1976). In this area the lower part of unit is interlayered with abundant aquagene tuff, tuff breccia, and calcareous sandstone containing shells (Tysdal and others, 1976). Another variation of the unit is found north of the Martin River where Nelson and others (1985) mapped a unit, Tots, consisting of tuffaceous sedimentary rocks, volcaniclastic sandstone, and minor chert. The majority of the Tots unit is found south of the Martin fault where minor pillow basalt and abundant volcanic breccia is included with the sedimentary rocks of the unit and the "rocks are altered to a bright orange-weathering gossan *** intruded by numerous porphyritic dikes for a distance of 10 mi along the south side of the Martin fault" (Nelson and others, 1985). As shown here, in the vicinity of Knight Island, this map unit is composed as much as 92 percent volcanic rocks; in this area these were mapped by Tysdal and Case (1979) as a pillow basalt and sedimentary rocks unit (Tops) and a greenstone and sedimentary rocks unit (Togs) and by Nelson and others (1985) as a pillow basalt and sedimentary rocks unit (Tops). Nelson and others (1985) distinguished this pillow basalt and sedimentary rocks unit from a separately mapped interbedded sedimentary and mafic volcanic rocks unit (Tosv) on the basis of the predominance of pillow basalt in the section; however we have combined the units herein. Locally, this combined unit is marginal to and probably gradational to thicker sequences composed of pillowed and massive basalt flows (•ı ☼). Nelson and others (1985) reported a number of varieties of foraminifers of Paleocene to late middle Eocene age from this unit in the Seward and Cordova quadrangles and north of the Martin River the tuffaceous sedimentary rocks of this unit contain locally abundant radiolarians and diatoms of late Paleocene to Eocene age (Tysdal and others, 1976; Nelson and others, 1985). A 47.6±1.4 Ma K-Ar hornblende age from a greenschist sample (Table 1, sample number 71Apr 23A, Winkler and Plafker, 1981; George Plafker field notebook, 1971; Nelson and others, 1985) collected from the head of Port Fidalgo in the Cordova quadrangle was originally assigned to the Valdez Group by Winkler and Plafker (1981) and Nelson and others (1985); however, Winkler and Plafker (1993) reassigned rocks in the vicinity of this sample to the Orca Group, which at face value would constrain the age of this unit to no younger than early Eocene

•ı _ **Sheeted basalt dikes** (Tertiary, Eocene)—Mafic sheeted-dike complexes consisting of dark-green, gray, and brown, aphanitic to porphyritic; chiefly basaltic, but locally gabbroic to dioritic, dikes (Tysdal and others, 1977; Tysdal and Case, 1979). In the Knight Island area, felsic plagioclase-quartz dikes occur locally and plagioclase-clinopyroxene-olivine dikes are present but not common (Tysdal and Case, 1979). On the Resurrection Peninsula, olivine is present in a few dikes (Tysdal and Case, 1979). The dikes are commonly 1- to 2-m-thick, vertical or nearly so, and generally strike north (Tysdal and others, 1977; Tysdal and Case, 1979). The dikes contain greenschist facies mineral assemblages ascribed to ocean-floor metamorphism by Bradley and Miller (2006); according to Tysdal and Case (1979), plagioclase replaced by albite, clinopyroxene by hornblende and actinolite, and olivine partly altered to serpentine. The dikes crosscut one another, intrude the adjacent pillow basalt (map unit •ı ☼), and on Knight Island, locally intrude sedimentary rocks of the Orca Group (Tysdal and others, 1977). Double- and single-sided chilled margins were observed on the dikes, indicating a spreading center setting (Bradley and Miller, 2006; Tysdal and Case, 1979). Pillow basalt screens are common in the up to 2000 m wide transition zone between the pillow basalt and sheeted dike units (•ı ☼ and •ı _) (Tysdal and others, 1977; Tysdal and Case, 1979; Miller, 1984; and Bradley and Miller, 2006). Xenoliths of gabbro and peridotite are present locally on Knight Island (Richter, 1965; Nelson and others, 1985). Small irregular pods, veins, and dikes of plagiogranite are also present in the dike complex north of Bay of Isles on Knight Island (Nelson and others, 1985). The dikes are intruded by and also intrude the gabbro in the transition zone between the gabbro and sheeted dike units (•ı . • and •ı _) (Tysdal and Case, 1979; Tysdal and others, 1977). The dikes make up the topographically high and rugged cores of the Resurrection Peninsula, Knight Island, and Glacier Island (Tysdal and others, 1977). Whole rock K-Ar ages on greenstone reported by Miller (1984) are 35.0±1.3 Ma and 38.8±1.9 Ma on Knight Island; and 49.6±2.5 Ma, 45.7±2.3 Ma, and 47.3±2.4 Ma on the Resurrection Peninsula.

Miller (1984) interpreted these ages as representing minimum ages for accretion due to heating during the event that caused argon loss

•ı . ⬢ **Gabbro** (Tertiary, Eocene)—"Medium- and dark-gray to green coarse-grained chiefly clinopyroxene-plagioclase rocks with ophitic to subophitic texture and gabbroic to dioritic composition; locally pegmatitic with clinopyroxene crystals as much as 5 cm long; clinopyroxene commonly is partly replaced by uralitic amphibole and chlorite; plagioclase is partly replaced by albite; epidote and minor opaque minerals are common" (Tysdal and Case, 1979). Several small intrusive bodies of gabbro occur on Knight Island, the largest of which crops out east of Drier Bay, where it intrudes sheeted dikes (Nelson and others, 1985). Other gabbro bodies are too small to show at the scale of this map, but most are elongate parallel to the trend of the sheeted dikes. At the north end of Latouche Island a 30-m-wide exposure of gabbro intrudes slate and sandstone and is itself cut by several small gabbro-pegmatite dikes (Grant and Higgins, 1910, p. 49-50; Tysdal and Case, 1979; Nelson and others, 1985). On the Resurrection Peninsula, Miller (1984) described local occurrences of west dipping magmatic mineral layering and cumulate textures within the gabbro. Dikes and plugs of fine- to medium-grained plagiogranite are also present (Miller, 1984; Bradley and Miller, 2006), the largest of which crop out northwest of the head of Drier Bay on Knight Island and south side of Killer Bay on the Resurrection Peninsula (Tysdal and Case, 1979; Miller, 1984). The gabbro grades into the sheeted dike map unit (•ı →herein) and is generally elongate and parallel to the sheeted dikes, but it also crosscuts the dikes locally (Tysdal and Case, 1979; Miller, 1984). Tysdal and Case (1979) state that on the Resurrection Peninsula, "The gabbro intrudes slate and sandstone of the Valdez Group, crosscuts the bedding, and forms aphanitic sills in other places. A blue-gray and whitish thermal aureole, at least 200 m wide, marks the contact zone with the sedimentary rocks." Nelson and others (1985) and Bradley and Miller (2006) instead interpreted the contacts between the gabbro and Valdez metasedimentary rocks on the Resurrection Peninsula as faults. On Knight Island, the gabbro intrudes rocks of the Orca Group. Nelson and others (1989) reported a 57 Ma U-Pb zircon age on a plagiogranite intruding the gabbro on the Resurrection Peninsula

•ı . **Ultramafic rocks** (Tertiary, Eocene)—"Dunite, locally with layers of chromite, moderately to mostly altered to serpentine, serpentine-talc, and talc schist; lustrous pale- to dark-green and black, locally reddish weathering rock that forms dike-like and irregularly shaped intrusive bodies" (Tysdal and Case, 1979) on the Resurrection Peninsula. "In most places enough relict texture and mineralogy remains to recognize original clinopyroxenite, dunite, and harzburgite" (Miller, 1984). Unit occurs as small pods in gabbro and fault-bounded slices within Valdez Group metasedimentary rocks (Miller, 1984; Nelson and others, 1985). On Knight Island, xenoliths of peridotite in sheeted dikes were observed by Richter (1965) but not by subsequent workers (Tysdal and Case, 1979; Nelson and others (1985). However, Nelson and others (1985) mapped three peridotite bodies, including two that lie within or near a shear zone in the sheeted dikes unit (•ı →) and the other body occurs as a xenolith in sheeted dikes unit. These ultramafic rocks weather orange brown in color and form subdued rubble outcrops

•.. **Mafic and ultramafic plutonic rocks** (Tertiary, Eocene and Paleocene?)—"Compositionally and texturally variable unit consists mainly of clinopyroxene gabbro, two-pyroxene gabbro, and local diabase, hornblende gabbro, peridotite, and orthopyroxenite. Gabbro commonly is medium-grained and equigranular and is slightly to moderately foliated except near contacts with country rocks where it locally is strongly foliated or mylonitic" (Winkler and Plafker, 1993). Also in the Cordova quadrangle, near the head of Port Fidalgo Nelson and others (1985) mapped a small area of both banded and massive dark- to light-green serpentinized dunite and peridotite. There, blocks of serpentinite and serpentinized peridotite crop out within the metasedimentary rocks unit of the Valdez Group ( ). Their strongly shared margins suggest that these rocks have been tectonically emplaced (Nelson and others, 1985). Within country rocks of the Orca Group, these intrusions commonly have well-developed thermal aureoles and where they intrude sedimentary rocks have prominent zones of iron-staining (Winkler and Plafker, 1993). Winkler and Plafker (1993) considered the age of the unit as uncertain; two hornblende K-Ar ages of 64.5±2.1 and 48.5±1.5 Ma were reported on the unit; the older of the two was considered suspect because it is older than the Orca Group, which the mafic rocks intrude

Tertiary and (or) Cretaceous

Dikes (early Tertiary to Early Cretaceous)—Dikes of dacite, rhyolite, andesite, and rare basalt intrude rocks of the Valdez Group ( ) and McHugh Complex ( ) (Bradley and others, 1999). Analyzed samples of dikes yield a wide range of ages, as shown in Table 1. A basaltic-andesite dike intruding McHugh Complex yielded an ^{40}Ar-^{39}Ar hornblende plateau age of 115±2 Ma, whereas an intermediate composition dike yielded an ^{40}Ar-^{39}Ar isochron(?) age of 57.0±0.22 Ma (W. Clendenin, written commun., cited in Bradley and others, 1999) whereas felsic dikes mapped by Nelson and others (1999) yielded a ^{40}Ar-^{39}Ar isochron age as young as 31.1±0.2 Ma on potassium feldspar, as well as a ^{40}Ar-^{39}Ar plateau of 38.6±0.6 Ma on biotite and a ^{40}Ar-^{39}Ar disturbed age of 40±1 Ma, also on biotite. Lytwyn and others (2000) described a suite of dikes ranging in composition from basalt to rhyolite that they associated with the near-trench intrusions commonly related to the subduction of the Kula-Farallon spreading center. A ^{40}Ar-^{39}Ar plateau amphibole age on andesite from this suite of dikes yielded an age of 58.64±0.52 Ma. Lytwyn and others (2000) considered the dikes they studied to represent the same system as the plutons we have included in map unit here. Even discounting the potassium feldspar age as a minimum age, the data indicate that the dikes this map unit include rocks of multiple ages, possibly representing multiple events throughout the region

References cited

Addicott, W.O., and Plafker, George, 1971, Paleocene mollusks from the Gulf of Alaska Tertiary province – A significant new occurrence on the North Pacific Rim, *in* Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750-B, p. B48-B52.

Addicott, W.O., Winkler, G.R., and Plafker, George, 1978, Preliminary megafossil biostratigraphy and correlation of selected stratigraphic sections in the Gulf of Alaska's Tertiary province: U.S. Geological Survey Open-File Report 78-491, 2 sheets.

Barnes, D.F., 1991, Map showing geologic interpretation of aeromagnetic data for the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1645H, 8 p. 1 sheet, scale 1:250,000.

Berg, H.C., Jones, D.L., and Richter, D.H., 1972, Gravina-Nutzotin belt - Tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska, *in* Geological Survey Research 1972: U.S. Geological Survey Professional Paper 800D, p. D1-D24.

Bol, A.J., and Gibbons, Helen, 1992, Tectonic implications of out-of-sequence faults in an accretionary prism, Prince William Sound, Alaska: Tectonics, v. 11, n. 6, p. 1288-1300.

Bol, A.J., and Roeske, S.M., 1993, Strike-slip faulting and block rotation along the Contact fault system, eastern Prince William Sound, Alaska: Tectonics, v. 12, n. 1, p. 49-62.

Bradley, D.C., and Karl, S.M., 2000, Field guide to the Mesozoic accretionary complex in Kachemak Bay and Seldovia, south central Alaska: Anchorage, Alaska Geological Society, 19 p.

Bradley, D.C., and Miller, M.L., 2006, Field guide to south-central Alaska's accretionary complex Anchorage to Seward: Anchorage, Alaska Geological Society, 32 p.

Bradley, D.C., and Wilson, F.H., 2000, Reconnaissance bedrock geology of the southeastern part of the Kenai quadrangle, Alaska, *in* Kelley, K.D., and Gough, L.P., eds., Geologic Studies in Alaska: U.S. Geological Survey Professional Paper 1615, p. 59-64.

Bradley, D.C., Haeussler, P.J., and Kusky, T.M., 1993, Timing of early Tertiary ridge subduction in southern Alaska, *in* Dusel-Bacon, Cynthia, Till, A.B., eds., Geologic Studies by the U.S. Geological Survey, 1992: U.S. Geological Survey Bulletin 2068, p. 163-177.

Bradley, D.C., Kusky, T.M., Haeussler, P.J., Karl, S.M., and Donley, D.T., 1999, Geology of the Seldovia quadrangle: U.S. Geological Survey Open-File Report 99-18, scale 1:250,000.

Bradley, D.C., Parrish, Randall, Clendenen, William, Lux, Daniel, Layer, P.W., Heizler, Matthew, and Donley, D.T., 2000, New geochronological evidence for the timing of early Tertiary ridge subduction in southern Alaska, *in* Kelley, K.D., and Gough, L.P., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1998: U.S. Geological Survey Professional Paper 1615, p. 5-21.

Calderwood, K.W., and Fackler, W.C., 1972, Proposed stratigraphic nomenclature for Kenai Group, Cook Inlet basin, Alaska: American Association of Petroleum Geologists Bulletin, v. 56, n. 4, p. 739-754.

Capps, S.R., 1915, Some ellipsoidal lavas on Prince William Sound, Alaska: Journal of Geology, v. 23, n. 1, p. 45-51.

Capps, S.R., 1937, Kodiak and adjacent islands, Alaska: U.S. Geological Survey Bulletin 880-C, p. 111-184, scale 1:250,000.

Carden, J.R., Connelly, W., Forbes, R.B., and Turner, D.L., 1977, Blueschists of the Kodiak Islands, Alaska — an extension of the Seldovia schist terrane: Geology, v. 5, p. 529-533.

Case, J.E., Tysdal, R.G., Hillhouse, J.W., Grommé, C.S., 1979, Geologic interpretation of aeromagnetic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological survey Miscellaneous Field Studies Map MF-880D, 2 sheets, scale 1:250,000.

Clark, S.H.B., 1981, Guide to the bedrock geology along the Seward highway north of Turnagain Arm: Anchorage, Alaska, Alaska Geological Society Publication no. 1, 36 p.

Committee on the Alaska Earthquake of the Division of Earth Sciences National Research Council, 1971, The Great Alaska Earthquake of 1964 – Geology: Washington, D.C., National Academy of Sciences, 834 p.

Connelly, William, 1978, Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, no. 5, p. 755-769.

Connelly, William, and Moore, J.C., 1979, Geologic map of the northwest side of the Kodiak and adjacent islands, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1057, 2 sheets, scale 1:250,000.

Cowan, D.S., and Boss, R.F., 1978, Tectonic framework of the southwestern Kenai Peninsula, Alaska: Geological Society of America Bulletin, v. 89, p. 155-158.

Crowe, D.E., Nelson, S.W., Brown, P.E., Shanks, W.C., III, and Valley, J.W, 1992, Geology and geochemistry of volcanogenic massive sulfide deposits and related igneous rocks, Prince William Sound, south-central: Economic Geology, v. 87, n. 7, p. 1722-1746.

Crowell, A.L., and Mann, D.H., 1998, Archaeology and coastal dynamics of Kenai Fjords National Park, Alaska: National Park Service, Alaska Region Research/Resources Management Report ARRCR/CRR-98/34, 196 p., appendix 38 p.

Detterman, R.L., and Hartsock, J.K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geological Survey Professional Paper 512, 78 p., 6 plates, scale 1:63,360.

Detterman, R.L., Hudson, Travis, Plafker, George, Tysdal, R.G., and Hoare, J.M., 1976, Reconnaissance geologic map along Bruin Bay and Lake Clark faults in Kenai and Tyonek quadrangles, Alaska: U.S. Geological Survey Open-File Report 76-477, scale 1:250,000.

Detterman, R.L., Miller, J.W., Case, J.E., Wilson, F.H., and Yount, M.E., 1996, Stratigraphic framework of the Alaska Peninsula: U.S. Geological Survey Bulletin 1969-A, 74 p.

Detterman, R.L., and Reed, B.L., 1980, Stratigraphy, structure, and economic geology of the Iliamna quadrangle, Alaska: U.S. Geological Survey Bulletin 1368-B, 86 p., 1 sheet, scale 1:250,000.

Detterman, R.L., Reed, B.L., and Lanphere, M.A., 1965, Jurassic plutonism in the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 525-D, p. D16-D-21.

Dumoulin, J.A., 1987, Sandstone composition of the Valdez and Orca Groups, Prince William Sound, Alaska: U.S. Geological Survey Bulletin 1774, 37 p.

Dumoulin, J.A., 1988, Sandstone petrographic evidence and the Chugach-Prince William terrane boundary in southern Alaska: Geology, v. 16, p. 456-460.

Flores, R.M, and Stricker, G.D., and Bader, L.R., 1997, Stratigraphic architecture of the Tertiary alluvial Beluga and Sterling Formations, Kenai Peninsula, Alaska, *in* Karl, S.M., Vaughan, N.R., and Ryherd, T.J., eds., 1997 Guide to the geology of the Kenai Peninsula, Alaska: Alaska Geological Society, Anchorage, Alaska, p. 36-53.

Forbes, R.B., and Lanphere, M.A., 1973, Tectonic significance of mineral ages of blueschists near Seldovia, Alaska: Journal of Geophysical Research, v. 78, no. 8, p. 1383-1386.

Gehrels, G.E., and Berg, H.C., 1992, Geology of southeastern Alaska: U.S. Geological Survey Miscellaneous Investigation Series Map I-1867, pamphlet, 24 p., 1 plate, scale 1:600,000.

Grant, U.S., and Higgins, D.F., 1910, Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U.S. Geological Survey Bulletin 443, 88 p.

Haeussler, P.J, and Saltus, R.W., 2005, 26 km of offset on the Lake Clark Fault since Late Eocene time, *in* Haeussler, P.J., and Galloway, J.P., eds., Studies by the U.S. Geological Survey in Alaska, 2004: U.S. Geological Survey Professional Paper 1709-A, 4 p. (online only, http://pubs.usgs.gov/pp/pp1709a/)

Haeussler, P.J., Bradley, D.C., Goldfarb, Richard, Snee, L.W., and Taylor, Cliff, 1995, Link between ridge subduction and gold mineralization in southern Alaska: Geology, v. 23, no. 11, p. 995-998.

Helwig, J., and Emmet, P., 1981, Structure of the early Tertiary Orca Group in Prince William Sound and some implications for the plate tectonic history of southern Alaska: Journal of the Alaska Geological Society, v. 1, p. 12-35.

Hudson, Travis, Plafker, George, and Peterman, Z.E., 1979, Paleogene anatexis along the Gulf of Alaska margin: Geology, v. 7, p. 573-577.

Imlay, R.W., 1981, Early Jurassic ammonites from Alaska: U.S. Geological Survey Professional Paper 1148, 49 p., 12 plates.

Jones, D.L., and Silberling, N.J., 1979, Mesozoic stratigraphy--The key to tectonic analysis of southern and central Alaska: U.S. Geological Survey Open-File Report 79-1200, 39 p.

Jones, D.L., Silberling, N.J., Berg, H.C., and Plafker, George, 1981, Map showing tectonostratigraphic terranes of Alaska, columnar sections, and summary description of terranes: U.S. Geological Survey Open-File Report 81-792, 20 p., 2 sheets, scale 1:2,500,000.

Karlstrom, T.N.V., 1964, Quaternary geology of the Kenai Lowland and Glacial history of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 443, 69, p., 7 plates, various scales.

Kelley, J.S., 1980, Environments of deposition and petrography of Lower Jurassic volcaniclastic rocks, southwestern Kenai Peninsula, Alaska: Davis, California, University of California – Davis, Ph.D. dissertation, 304 p.

Kelley, J.S., 1984, Geologic map and sections of the southwestern Kenai Peninsula west of the Port Graham fault, Alaska: U.S. Geological Survey Open-File Report 84-152, 1 sheet, scale 1:63,360.

Kirschner, C.E., and Lyon, C.A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province, *in* Pitcher, M.G., ed., Arctic Geology: American Association of Petroleum Geologists Memoir 19, p. 396-407.

Kusky, T.M., and Young, C.P., 1999, Emplacement of the Resurrection Peninsula ophiolite in the southern Alaska forearc during a ridge-trench encounter: Journal of Geophysical Research, v. 104, n. B12, p. 28,025-29,054.

Kusky, T.M., Bradley, D.C., Haeussler, P.J., and Karl, S.M., 1997, Controls on accretion of flysch and melange belts at convergent margins: Evidence from the Chugach Bay thrust and Iceworm melange, Chugach accretionary wedge, Alaska: Tectonics, v. 16, n. 6, p. 855-878.

Lanphere, M.A., 1966, Potassium-argon ages of Tertiary plutons in the Prince William Sound region, Alaska, *in* Geological Survey Research 1966: U.S. Geological Survey Professional Paper 550-D, p. D195-D198.

Leopold, L.E., editor-in-chief, 1969, The Prince William Sound, Alaska, earthquake of 1964 and aftershocks, Volume II Research Studies: Seismology and Marine Geology, Parts B Seismology and Part C Marine geology: U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, Publication 10-3, v. 2 part B and C, 350 p.

Lytwyn, Jennifer, Casey, John, Gilbert, Susan, and Kusky, Timothy, 1997, Arc-like mid-ocean ridge basalt formed seaward of a trench-forearc system just prior to ridge subduction: An example from subaccreted ophiolites in southern Alaska: Journal of Geophysical Research, v. 102, no. B5, p. 10,225-10,243.

Lytwyn, Jennifer, Lockhart, Susan, Casey, John, and Kusky, Timothy, 2000, Geochemistry of near-trench intrusives associated with ridge subduction, Seldovia quadrangle, southern Alaska: Journal of Geophysical Research, v. 105, no. B12, p. 27,957-27978.

MacNeil, F.J., Wolfe, J.A., Miller, D.J., and Hopkins, D.M., 1961, Correlation of Tertiary formations of Alaska: American Association of Petroleum Geologists Bulletin, v. 45, p. 1801-1809.

Magoon, L.B., and Egbert, R.M., 1986, Framework geology and sandstone composition, *in* Magoon, L.B., ed., Geologic studies of the Lower Cook Inlet COST No. 1 Well, Alaska Outer Continental Shelf: U.S. Geological Survey Bulletin 1596, p. 65-90.

Magoon, L.B., Adkison, W.L., and Egbert, R.M, 1976, Map showing geology, wildcat wells, Tertiary plant localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1019, scale 1:250,000, 3 sheets.

Magoon, L.B., Griesbach, F.B., and Egbert, R.M., 1980, Nonmarine Upper Cretaceous rocks, Cook Inlet, Alaska: American Association of Petroleum Geologists Bulletin, v. 64, no. 8, p. 1259-1266.

Martin, G.C., 1905, Notes on the petroleum fields of Alaska: U.S. Geological Survey Bulletin 259, p. 128-139.

Martin, G.C., 1908, Geology and mineral resources of the Controller Bay region, Alaska: U.S. Geological Survey Bulletin 335, 141 p.

Martin, G.C., 1915, The western part of the Kenai Peninsula, *in* Martin, G.C., Johnson, B.L, and Grant, U.S., Geology and mineral resources of Kenai Peninsula, Alaska: U.S. Geological Survey Bulletin 587, p. 41-111.

Martin, G.C., 1926, The Mesozoic stratigraphy of Alaska: U.S. Geological Survey Bulletin 776, 493 p.

Martin, G.C., and Katz, F.J., 1912, A geologic reconnaissance of the Iliamna region, Alaska: U.S. Geological Survey Bulletin 485, 138 p.

Martin, G.C., Johnson, B.L., and Grant, U.S., 1915, Geology and mineral resources of Kenai Peninsula, Alaska: U.S. Geological Survey Bulletin 587, 243 p.

Miller, D.J., 1951, Preliminary report on the geology and oil possibilities of the Katalla district, Alaska: U.S. Geological Survey Open-File Report 50-20, 66 p., 4 sheets, scale 1:96,000.

Miller, D.J., 1961, Geology of the Katalla district, Gulf of Alaska Tertiary province, Alaska: U.S. Geological Survey Open-File Report 61-99, 2 sheets, scale 1:96,000.

Miller, D.J., 1975, Geologic map and sections of the central part of the Katalla district, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-722, 2 sheets, scale 1:40,000.

Miller, M.L., 1984, Geology of the Resurrection Peninsula, *in* Winkler, G.R., Miller, M.L., Hoekzema, R.B., and Dumoulin, J.A., eds., Guide to the bedrock geology of a traverse of the Chugach Mountains from Anchorage to Cape Resurrection: Anchorage, Alaska, Alaska Geological Society Guidebook, p. 25-34.

Mitchell, P.A., Silberman, M.L., and O'Neil, J.R., 1981, Genesis of gold vein mineralization in an Upper Cretaceous turbidite sequence, Hope-Sunrise district, southern Alaska: U.S. Geological Survey Open-File Report 81-103, 18 p.

Moffat, F.H., 1954, Geology of the Prince William Sound region, Alaska: U.S. Geological Survey Bulletin 989-E, p. 225-310.

Nelson, S.W., Blome, C.D., Harris, A.G., Reed, K.M., and Wilson, F.H., 1986, Later Paleozoic and Early Jurassic fossil ages from the McHugh Complex, *in* Bartsch-Winkler, Susan, and Reed, K.M., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Circular 978, p. 60-64.

Nelson, W.H., Carlson, Christine, and Case, J.E., 1983, Geologic map of the Lake Clark quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1114A, scale 1:250,000.

Nelson, S.W., Dumoulin, J.A., and Miller, M.L., 1985, Geologic map of the Chugach National Forest: U.S. Geological Survey Miscellaneous Field Studies Map MF-1645B, scale 1:250,000.

Nelson, S.W., Miller, M.L., and Dumoulin, J.A., 1989, The Resurrection Peninsula ophiolite, *in* Nelson, S.W. and Hamilton, T.D., eds., Guide to the geology of the Resurrection Bay - eastern Kenai Fjords area: Anchorage, Alaska, Alaska Geological Society, p. 10-18.

Nelson, S.W., Miller, M.L., Haeussler, P.J., Snee, L.W., Phillips, P.J., and Huber, Carol, 1999, Preliminary geologic map of the Chugach National Forest Special Study Area, Alaska: U.S. Geological Survey Open-File Report 99-362, scale 1:63,360.

Nilsen, T.H., and Zuffa, G.G., 1982, The Chugach terrane, a Cretaceous trench-fill deposit, southern Alaska, *in* Leggett, J.K., ed., Trench-forearc geology; sedimentation and tectonics on modern and ancient active plate margins, conference: Geological Society of London Special Publication 10, p. 213-227.

Nokleberg, W.J., Plafker, George, and Wilson, F.H., 1994, Geology of south-central Alaska, *in* Plafker, George, Jones, D.L., and Berg, H.C., eds., Geology of Alaska: Geological Society of America, The Geology of North America, Boulder, Colorado, v. G-1, p. 311-366.

Plafker, George, 1969, Tectonics of the March 27, 1964, Alaska Earthquake: U.S. Geological Survey Professional Paper 543-I, 74 p.

Plafker, George, 1971, Possible future petroleum resources of Pacific-margin Tertiary basin, Alaska, *in* Future petroleum provinces of North America: American Association of Petroleum Geologists Memoir 15, p. 120-135.

Plafker, George, 1974, Preliminary geologic map of Kayak and Wingham Islands, Alaska: U.S. Geological Survey Open-File Report 74-82, scale 1:31,680.

Plafker, George, 1987, Regional geology and petroleum potential of the northern Gulf of Alaska continental margin, *in* Scholl, D.W., Grantz, Arthur, and Vedder, J.A., Geology and Resource potential of the continental margin of western North America and adjacent ocean basins, Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 6, p. 229-267.

Plafker, George, 1990, Regional geology and tectonic evolution of Alaska and adjacent parts of the northeast Pacific Ocean margin: Proceedings of the Pacific Rim Congress 90: Queensland, Australia, Australasian Institute of Mining and Metallurgy, p. 841-853.

Plafker, George, and Addicott, W.O., 1976, Glaciomarine deposits of Miocene through Holocene age along the Gulf of Alaska margin, Alaska: U.S. Geological Survey Open-file Report 76-84, 36 p.

Plafker, George, and Lanphere, M.A., 1974, Radiometrically dated plutons cutting the Orca Group, *in* Carter, Claire, ed., U.S. Geological Survey Alaskan Program, 1974: U.S. Geological Survey Circular 700, p. 53.

Plafker, George, and Page, R.A., 1994, The Great 1964 Alaska earthquake; a 30-year perspective: Seismological Research Letters, v. 65, no. 3-4, 239 p.

Plafker, George, and Rubin, Meyer, 1978, Uplift history and earthquake recurrence as deduced from marine terraces on Middleton Island, Alaska, in Proceedings of Conference VI, Methodology for identifying seismic gaps and soon-to-break gaps, p. 687-721: U.S. Geological Survey Open-File Report 78-943.

Plafker, George, Bruns, T.R., and Page, R.A., 1975b, Interim report on petroleum resource potentia1 and geologic hazards in the outer-continental shelf of the Gulf of Alaska Tertiary province: U.S. Geological Society Open-File Report 75-592, 74 p.

Plafker, George, Detterman, R.L., and Hudson, Travis, 1975a, New data on the displacement history of the Lake Clark Fault, *in* Yount, M.E., ed., United States Geological Survey Alaska Program, 1975: U.S. Geological Survey Circular 722, p. 44-45.

Plafker, George, Jones, D.L., and Pessagno, E.A., Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin, *in* Blean, K.M., ed., the United States Geological Survey in Alaska: Accomplishments during 1976: U.S. Geological Survey Circular 751-B, p. B41-B43.

Plafker, George, Keller, Gerta, Nelson, S.W., Dumoulin, J.A., and Miller, M.L., 1985, Summary of data on the age of the Orca Group, Alaska, *in* Bartsch-Winkler, Susan, ed., The United States Geological Survey in Alaska: Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 74-76.

Plafker, George, Moore, J.C., and Winkler, G.R., 1994, Geology of the southern Alaska margin, in Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, v G-1, p. 389-449.

Poole, A.R., 1996, Age and geochemical constraints on ridge subduction for igneous rocks of the eastern Chugach Mountains, Alaska: Houston, Rice University, unpublished Master's thesis, 83 p.

Post, Austin, 1967, Effects of the March 1964 Alaska earthquake on glaciers: U.S. Geological Survey Professional Paper 544-D, p. D1-D42.

Rau, W.W., Plafker, George, and Winkler, G.R., 1977, Preliminary foraminiferal biostratigraphy and correlation of selected stratigraphic sections and wells in the Gulf of Alaska Tertiary Province: U.S. Geological Survey Open-File Report 77-747, 54 p., 3 sheets.

Reed, B.L., and Lanphere, M.A., 1969, Age and chemistry of Mesozoic and Tertiary plutonic rocks in south-central Alaska: Geological Society of America Bulletin v. 80, p. 23-44.

Reed, B.L., and Lanphere, M.A., 1972, Generalized geologic map of the Alaska-Aleutian Range batholith showing K/Ar ages of the plutonic rocks: U.S. Geological Survey Miscellaneous Field Studies Map MF-372, scale 1:1,000,000.

Reed, B.L., and Lanphere, M.A., 1973, Alaska-Aleutian Range batholith: geochronology, chemistry, and relation to circum-Pacific plutonism: Geological Society of America Bulletin, v. 84, p. 2583-2610.

Reed, B.L., Lanphere, M.A., and Miller, T.P., 1992, Double Glacier volcano, a 'new' Quaternary volcano in the eastern Aleutian volcanic arc: Bulletin of Volcanology, v. 54, p. 631-637.

Reed, B.L., Miesch, A.T., and Lanphere, M.A., 1983, Plutonic rocks of Jurassic age in the Alaska-Aleutian Range batholith: Chemical variations and polarity: Geological Society of America Bulletin, v. 94, p. 1232-1240.

Richter, D.H., 1965, Geology and mineral deposits of central Knight Island, Prince William Sound, Alaska: Alaska Division of Mines and Minerals Geologic Report 16, 37 p., 1 sheet, approximate scale 1:42,240.

Richter, D.H., Preller, C.C., Labay, K.A., and Shew, N.B., 2005, Geology of Wrangell-Saint Elias National Park and Preserve, southcentral Alaska: U.S. Geological Survey Scientific Investigations Series Map SIM-2877, scale 1:350,000.

Riehle, J.R., and Emmel, K.S., 1980, Photointerpretation map of the surficial geology, Polly Creek to MacArthur River, Cook Inlet, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 64, 2 sheets, scale 1:63,360.

Riehle, J.R., Kienle, Juergen, and Emmel, K.S., 1981, Lahars in Crescent River valley, lower Cook Inlet, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 53, 10 p.

Roeske, S.M., Mattinson, J.M.,, and Armstrong, R.L., 1989, Isotopic ages of glaucophane schists on the Kodiak Islands, southern Alaska, and their implications for the Mesozoic tectonic history of the Border Ranges fault system: Geological Society of America Bulletin, v. 101, p. 1021-1037.

Schrader, F.C., 1900, A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska in 1898: U.S. Geological Survey 20th Anniversary Report, pt. 7, p. 341-423.

Silberling, N.A., Grant-Mackie, J.A., and Nichols, K.M., 1997, The Late Triassic bivalve *Monotis* in accreted terranes of Alaska: U.S. Geological Survey Bulletin 2151, 21 p.

Silberman, M.L., Mitchell, P.A., O'Neil, J.R., 1981, Isotopic data bearing on the origin and age of the epithermal lode gold deposits in the Hope-Sunrise mining district, northern Kenai Peninsula, Alaska: U.S. Geological Survey Circular 823-B, p. B81-B84.

Sisson, V.B., and Onstott, T.C., 1986, Dating of blueschist metamorphism: A combined 40Ar/39Ar and electron microprobe approach: Geochimica et Cosmochimica Acta, v. 50, p. 2111-2117.

Spurr, J. E., 1900, A reconnaissance in southwestern Alaska in 1898: U.S. Geological Survey 20th Annual Report, part 7, p. 31-264.

Steiger, R.H., and Jager, E., 1977, Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359-362.

Stover, C.W. and Coffman, J.L., 1993, Seismicity of the United States, 1568-1989 (Revised): U.S. Geological Survey Professional Paper 1527, 418 p.

Till, A.B., Yount, M.E., and Riehle, J.R., 1993, Redoubt Volcano, southern Alaska: A hazard assessment based on eruptive activity through 1968: U.S. Geological Survey Bulletin 1996, 19 p., 1 plate, scale 1:125,000.

Triplehorn, D.M., Turner, D.L., and Naeser, C.W., 1977, K-Ar and fission-track dating of ash partings in coal beds from the Kenai Peninsula, Alaska: A revised age for the Homerian Stage-Clamgulchian Stage boundary: Geological Society of America Bulletin, v. 88, no. 8, p. 1156-1160.

Turner, D.L., Triplehorn, D.M., Naeser, C.W., and Wolfe, J.A., 1980, Radiometric dating of ash partings in Alaska coal bed and upper Tertiary paleobotanical stages: Geology, v. 8, p. 92-96.

Tysdal, R.G., and Case, J.E., 1979, Geologic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1150, scale 1:250,000.

Tysdal, R.G., Case, J.E., Winkler, G.R., and Clark, S.H.B., 1977, Sheeted dikes, gabbro, and pillow basalt in flysch of coastal southern Alaska: Geology, v. 5, p. 377-383.

Tysdal, R.G., Hudson, Travis, and Plafker, George, 1976, Geologic map of the Cordova B-2 quadrangle and northern part of the Cordova A-2 quadrangle, south-central Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-783, scale 1:63,360.

Tysdal, R.G., and Plafker, George, 1978, Age and continuity of the Valdez Group, southern Alaska, *in* Sohl, N.F., and Wright, W.B., Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1977: U.S. Geological Survey Bulletin 1457-A, p. A120-A124.

Waythomas, C.F., and Miller, T.P., 1999, Preliminary volcano-hazard assessment for Iliamna Volcano: U.S. Geological Survey Open-File Report 99-373, 31 p. 1 plate, scale not reported.

Wilson, F.H., and Hults, C.P., 2008, Digital data for the Geology of the Prince William Sound and Kenai Peninsula region, Alaska, including the Kenai, Seldovia, Seward, Blying Sound, Cordova, and Middleton Island 1:250,000-scale quadrangles: U.S. Geological Survey Open-File Report 2008-1001.

Wilson, F.H., Detterman, R.L., and Case, J.E., 1985, The Alaska Peninsula terrane; a definition: U.S. Geological Survey Open-File Report 85-450, 17 p.

Wilson, F.H., Detterman, R.L., and DuBois, Gregory, 1999, Digital data for the geologic framework of the Alaska Peninsula, southwest Alaska, and the Alaska Peninsula terrane: U.S. Geological Survey Open-File Report 99-317, online only: http://wrgis.wr.usgs.gov/open-file/of99-317/

Wilson, F.H., Dover, J.H., Bradley, D.C., Weber, F.R., Bundtzen, T.K., and Haeussler, P.J., 1998, Geologic map of Central (Interior) Alaska: U.S. Geological Survey Open-File Report 98-133, 3 sheets, scale 1:500,000, 63 p. pamphlet, 13 p. appendix.

Wilson, F.H., Labay, K.A., Mohadjer, Solmaz, and Shew, Nora, 2005, Digital datasets for geologic map by Wilson, F.H.: Preliminary Integrated Geologic Map Databases for the United States: Digital Data for the Reconnaissance Geologic Map for the Kodiak Islands, Alaska: U. S. Geological Survey Open-File Report 2005-1340, online only: http://pubs.usgs.gov/of/2005/1340/

Wilson, F.H., Mohadjer, Solmaz, Labay, K.A., and Shew, Nora, 2006, Digital datasets for geologic map by Wilson, F.H., Blodgett, R.B., Blome, C.D., Mohadjer, Solmaz, Preller, C.C., Klimasauskas, E.P., Gamble, B.M., and Coonrad, W.L., Preliminary Integrated Geologic Map Databases for the United States: Digital Data for the Reconnaissance Bedrock Geologic Map for the Northern Alaska Peninsula area, Southwest Alaska; including the Dillingham, Iliamna, Lake Clark, Taylor Mountains, and the western part of the Kenai and Seldovia 1:250,000-scale quadrangles: U.S. Geological Survey Open File Report 2006-1303, online only: http://pubs.usgs.gov/of/2006/1303/

Winkler, G.R., 1976, Deep-sea fan deposition of the Lower Tertiary Orca Group, eastern Prince William Sound, Alaska, *in* Miller, T.P., ed., Recent and ancient sedimentary environments in Alaska: Anchorage, Alaska, Alaska Geological Society Symposium volume, p. R1-R20.

Winkler, G.R., and Plafker, George, 1981, Geologic map and cross sections of the Cordova and Middleton Island quadrangles, southern Alaska: U.S. Geological Survey Open-file Report 81-1164, scale 1:250,000.

Winkler, G.R., and Plafker, George, 1993, Geologic map of the Cordova and Middleton Island quadrangles, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-1984, scale 1:250,000.

Winkler, G.R., and Tysdal, R.G., 1977, Conglomerate in flysch of the Orca Group, Prince William Sound, southern Alaska, *in* Blean, K.M., ed., The United States Geological Survey in Alaska: Accomplishments During 1976: U.S. Geological Survey Circular 751-B, p. 43-44.

Winkler, G.R., Silberman, M.L., Grantz, Arthur, Miller, R.J., and MacKevett, E.M., Jr., 1981, Geologic map and summary geochronology of the Valdez quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 80-892-A, 2 sheets, scale 1:250,000.

Wolfe, J.A., 1977, Paleogene floras from the Gulf of Alaska region: U.S. Geological Survey Professional Paper 997, 108 p.

Wolfe, J.A., and Tanai, T., 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper, 1105, 52 p.

Wood, F.J., editor-in-chief, 1967, The Prince William Sound, Alaska, earthquake of 1964 and aftershocks, Volume II Research Studies: Seismology and Marine Geology, Part A Engineering Seismology: U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey, Publication 10-3, v. 2, part A, 392 p.

Table 1. Radiometric ages from the Prince William Sound region, Alaska

http://pubs.usgs.gov/of/2008/1002/PWSage.pdf