Prepared in cooperation with the National Park Service

Geochronology of Plutonic Rocks and their Tectonic Terranes in Glacier Bay National Park and Preserve, Southeast Alaska

Professional Paper 1776-E

U.S. Department of the Interior
U.S. Geological Survey

COVER

Mount Fairweather (15,300 ft or 4,663 m) in the far distance beyond the peaks and glaciers that surround (and conceal) John Hopkins Inlet. The photo was taken from the complex metamorphosed Paleozoic rocks and Cretaceous plutons east of Reid Inlet looking across the Tarr Inlet suture zone and over the dominant metamorphosed Mesozoic rocks of the Fairweather Range. Mount Fairweather is underlain by layered gabbroic rocks of Tertiary age.

Geochronology of Plutonic Rocks and their Tectonic Terranes in Glacier Bay National Park and Preserve, Southeast Alaska

By David A. Brew, Kathleen E. Tellier, Marvin A. Lanphere, Diane C. Nielsen, James G. Smith, and Ronald A. Sonnevil

Prepared in cooperation with the National Park Service

Professional Paper 1776–E

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

For product and ordering information: World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Brew, D.A., Tellier, K., Lanphere, M.A., Nielsen, D.C., Smith, J.G., and Sonnevil, R.A., 2014, Geochronology of plutonic rocks and their tectonic terranes in Glacier Bay National Park and Preserve, southeast Alaska *in* Dumoulin, J.A., and Galloway, J.P., eds., Studies by the U.S. Geological Survey in Alaska, 2008–2009: U.S. Geological Survey Professional Paper 1776–E, 18 p., http://dx.doi.org/10.3133/pp1776E.

ISSN 2330-7102 (online)

Contents

Figures

Tables

Geochronology of Plutonic Belts and their Tectonic Terranes in Glacier Bay National Park and Preserve, Southeast Alaska

By David A. Brew, Kathleen E. Tellier, Marvin A. Lanphere, Diane C. Nielsen, James G. Smith, and Ronald A. Sonnevil

Abstract

We have identified six major belts and two nonbelt occurrences of plutonic rocks in Glacier Bay National Park and Preserve and characterized them on the basis of geologic mapping, igneous petrology, geochemistry, and isotopic dating. The six plutonic belts and two other occurrences are, from oldest to youngest: (1) Jurassic (201.6–145.5 Ma) diorite and gabbro of the Lituya belt; (2) Late Jurassic (161.0–145.5 Ma) leucotonalite in Johns Hopkins Inlet; (3) Early Cretaceous (145.5–99.6 Ma) granodiorite and tonalite of the Muir-Chichagof belt; (4) Paleocene tonalite in Johns Hopkins Inlet (65.5–55.8 Ma); (5) Eocene granodiorite of the Sanak-Baranof belt; (6) Eocene and Oligocene (55.8–23.0 Ma) granodiorite, quartz diorite, and granite of the Muir-Fairweather felsic-intermediate belt; (7) Eocene and Oligocene (55.8–23.0 Ma) layered gabbros of the Crillon-La Perouse mafic belt; and (8) Oligocene (33.9–23.0 Ma) quartz monzonite and quartz syenite of the Tkope belt. The rocks are further classified into 17 different combination age-compositional units; some younger belts are superimposed on older ones. Almost all these plutonic rocks are related to Cretaceous and Tertiary subduction events.

The six major plutonic belts intrude the three southeast Alaska geographic subregions in Glacier Bay National Park and Preserve, from west to east: (1) the Coastal Islands, (2) the Tarr Inlet Suture Zone (which contains the Border Ranges Fault Zone), and (3) the Central Alexander Archipelago. Each subregion includes rocks assigned to one or more tectonic terranes.

The various plutonic belts intrude different terranes in different subregions. In general, the Early Cretaceous plutons intrude rocks of the Alexander and Wrangellia terranes in the Central Alexander Archipelago subregion, and the Paleogene plutons intrude rocks of the Chugach, Alexander, and Wrangellia terranes in the Coastal Islands, Tarr Inlet Suture Zone, and Central Alexander Archipelago subregions.

Acknowledgments

B.E. John (University of Wyoming), H.C. Berg (USGS, retired), P.J. Haeussler (USGS), and L.J. Patrick Muffler (USGS, emeritus) contributed extremely constructive technical reviews. J.G. Weathers and S. Mayfield provided graphics support. J. Dumoulin was a welcome and effective editor. We are most indebted to our 1966 and 1975–1977 field-mapping colleagues, as well as to the field geologists who preceded and followed them in the study of the park and preserve.

Introduction

This report documents the ages and compositions of the plutonic rocks in Glacier Bay National Park and Preserve (fig. 1) and notes the subregions and tectonic terranes in which they occur. The same rocks and tectonic terranes are present in the adjacent areas, but Glacier Bay contains some of the best-studied examples. The detailed studies reported here were confined to all but the northwesternmost part of the park and preserve; additional information provided by G. Plafker and D.A. Brew was used to delineate and define the plutons in that part. (Only one pluton occurs in the area of expansion that belongs to a belt not observed elsewhere in the park and preserve.) We note that Glacier Bay Preserve is a small area in the northwest. First, we describe the geographic subregions and tectonic terranes because they are the hosts for the plutonic rocks, followed by the plutonic belts, and, briefly, discuss the relations between the two types of features. The significant nonplutonic rocks in the park were briefly described by Brew (1997).

This report contains the first description of the age and compositional characteristics of the plutonic rocks in Glacier Bay National Park and Preserve, including the data on petrography, geochronology, and chemical compositions, as well as an assignment of the rocks to the various subregions and tectonic terranes. Earlier studies used preliminary versions of some of this information (MacKevett and others, 1971; Brew and others, 1978; Brew and Morrell, 1983; Brew, 1994, 1997). This report is intended primarily to provide new compositional and age information to geologists concerned with tectonics and magmatism along the northeastern Pacific Rim, to informed laypersons visiting the park, and to the Glacier Bay National Park and Preserve scientific and interpretative staffs.

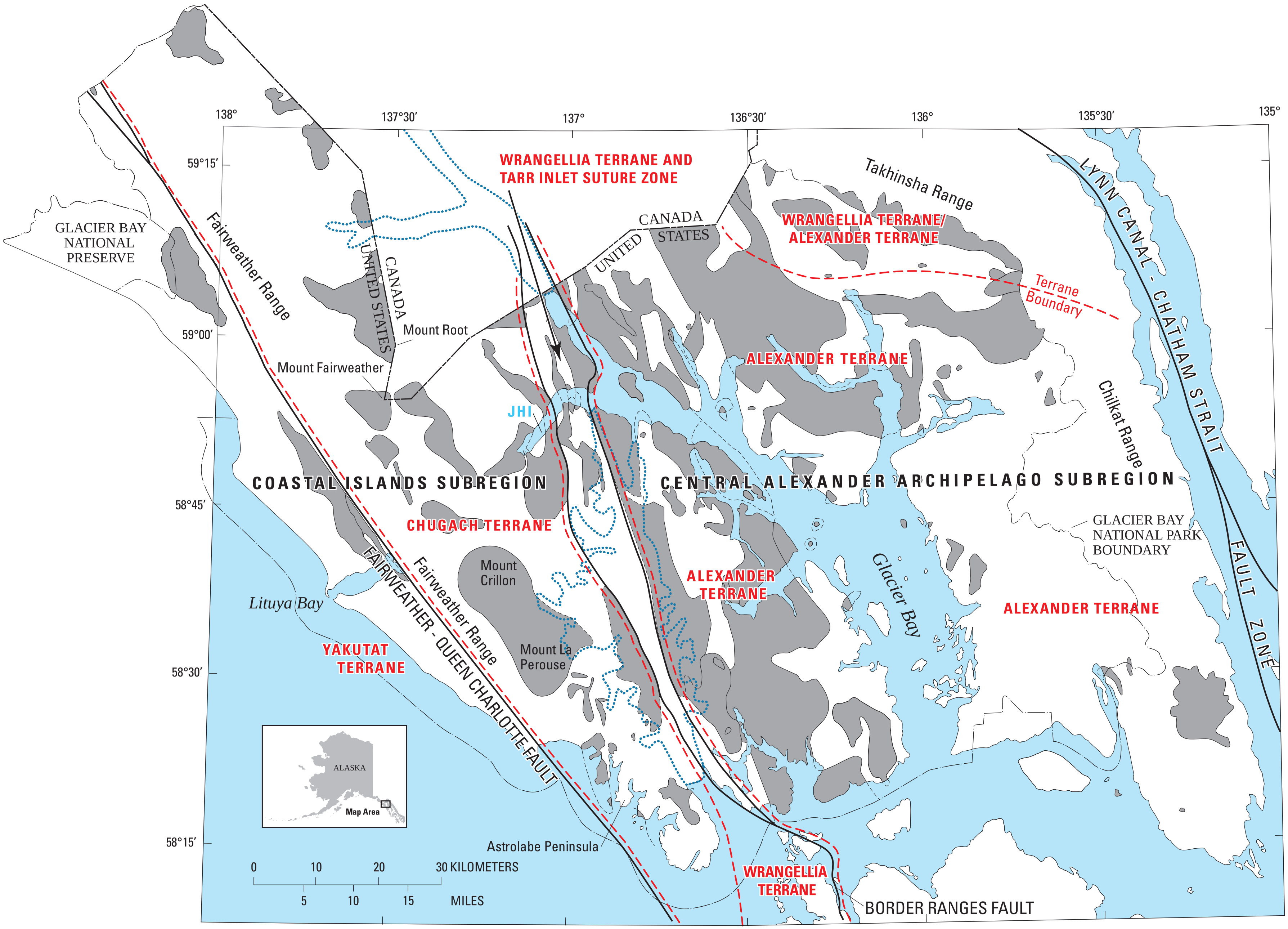


Figure 1. Map showing locations of tectonic terranes and major faults in and near Glacier Bay National Park and Preserve. Dark gray areas indicate plutons that are labeled individually in figure 3. Blue dotted lines show the locations of the Grand Pacific Glacier (north) and the Brady Glacier (south) systems. Thin black dot-dashed line denotes the boundary of Glacier Bay National Park and Preserve. Terranes are outlined with a red dashed line and labeled in red. Contacts are dashed where inferred (underwater). JHI, Johns Hopkins Inlet.

Glacier Bay National Monument was established in 1925 and elevated to Glacier Bay National Park and Preserve in 1980 as part of the Alaska National Interest Lands Act. The studies described here began in 1966 in anticipation that the monument might later be designated in part as wilderness area; the studies in 1975 to 1977 were done as the monument was being further evaluated for wilderness status. All studies were in full cooperation with the National Park Service.

Specifically, the studies that are the basis for these descriptions were conducted primarily during the complete field seasons of 1966, 1975, 1976, and 1977 and secondarily during subsequent, topically oriented investigations. Samples and measurements were collected at several thousand localities in the park, using utility runabouts for shoreline traverses and contract helicopters for higher-elevation spot landings and traverses. Rocks, stream sediment, and mineralized material were analyzed for trace-, minor-, major-element contents, and (in some samples) isotopic constituents. Several short drill-core samples were collected for paleomagnetic studies, with indeterminate results (Grommé, 1998). The regional geologic and mineral-resource information acquired was used in an earlier evaluation of undiscovered mineral resources in the monument (MacKevett and others, 1971; Brew and others, 1978, 1991). Marvin A. Lanphere of the U.S. Geological Survey (USGS) provided all of the previously unpublished K-Ar-isotopic ages.

Subregions and Tectonic Terranes

The nonplutonic rocks in Glacier Bay National Park and Preserve (fig. 1) have been classified into both formally named and unnamed formations and groups, as well as into tectonic terranes (Brew, 1997, 2001) and into geographic subregions, most of which extend the length of southeast Alaska and include one or more terranes. The formations and groups in the Coastal Islands subregion (CIS) west of the Fairweather-Queen Charlotte Fault Zone (F-QCFZ) are assigned to the Yakutat terrane, those in the same subregion between the F-QCFZ and the Tarr Inlet Suture Zone (TISZ) to the Chugach terrane, those in the TISZ mostly to the Wrangellia terrane, and those eastward from the TISZ to the Lynn Canal-Chatham Strait Fault Zone (LC-CSFZ) to the Alexander terrane as part of the Central Alexander Archipelago subregion (CAAS). Rocks of the Wrangellia terrane also occur on older rocks of the Alexander terrane in the northeastern part of the park (fig. 1). All of these terranes and subregions belong to the Insular Superterrane of Monger and others (1982) that adjoins the Intermontane Superterrane along the crustal-scale Insular-Intermontane Suture Zone (IISZ), which lies well east of the park against the base of the Coast Mountains (outside area of fig. 1). The above terrane assignments are those of Brew (2001).

Almost all the plate-tectonic movements that juxtaposed both the terranes and superterranes occurred in Mesozoic time, from 200 to 70 Ma. These movements predated some, but not all, of the magmatic/plutonic events that resulted in the granitic and gabbroic intrusions that are now exposed at the surface in Glacier Bay National Park and Preserve. Current tectonic and seismic activity in Glacier Bay National Park and Preserve has no associated magmatism, but consists of right-lateral movements in the F-QCFZ, northward-convergent movements in the offshore Transition Fault (Plafker, 1987), and northeastward-convergent movements at depth (without surface expression) in an east-northeast-trending zone across the northern part of the park and preserve (Brew and others, 1995). The well-known rapid postglacial uplift of Glacier Bay (Barnes, 1984; Brew and others, 1995; Larsen and others, 2004, 2005; Motyka and others, 2007; Elliott and others, 2010) may be partly related to these cryptic movements, as well as to isostatic rebound.

The sequence of assembly of the tectonic terranes into their present configuration is generally interpreted to have been as follows, from west to east:

1. The Yakutat terrane was emplaced by right-lateral strike-slip movement on a precursor of the F-QCFZ. This terrane must have been at its present position before late Tertiary time because its younger formations contain Tertiary mafic-plutonic detritus eroded from the Chugach terrane adjoining it immediately to the east. The northward movement occurred after mid-Cretaceous time, as indicated by the presence in older parts of the Yakutat terrane of detritus that is derived from coeval granitic bodies that occur east of the F- QCFZ and to the south in British Columbia (Plafker, 1987).
2. The Chugach terrane was accreted to the Alexander terrane by subduction the mid- Cretaceous time. The subduction zone is preserved in the TISZ, which contains both deformed and undeformed Early Cretaceous plutons. Brew and Morrell (1978) interpreted juxtaposition of these two terranes to have occurred in two stages, with the leading edge of the first advancing terrane to now be missing.
3. The rocks of the Wrangellia and Chugach terranes that occur in the TISZ as fault- bounded slivers were emplaced by strike-slip movements whose sense is uncertain. A Jurassic pluton in the TISZ could be related to a coeval body in the St. Elias Mountains to the north on the west side of the TISZ (Hudson, 1979), suggesting that the movement was right-lateral. The rocks in the TISZ were also deformed later by apparent right-lateral movements on the Border Ranges Fault, which forms the east boundary of the TISZ (Smart and others, 1996).
4. The Border Ranges Fault forms the boundary between deformed rocks of the TISZ and the generally less deformed rocks of the Alexander and Wrangellia terranes to the east. The Ordovician and Silurian rocks in the lower part of the Alexander terrane are regionally deformed, but the Devonian and younger rocks are interpreted to be part of a coherent, less deformed, but vertical-fault-disrupted, stratigraphic succession with unconformities.

Table 1. Compositions and ages of rocks in the major plutonic belts in Glacier Bay National Park and Preserve.

[CIS, Coastal Islands subregion; TISZ, Tarr Inlet Suture Zone; CAAS, Central Alexander Archipelago subregion; B, biotite; H, hornblende; M, muscovite. Age ranges are from the Geological Society of America (2009)]

Major composition of rocks in belt	Map label on figure 3	Other compositional types	Basis of age assignment	Body numbers on figure 3	Subregion and terrane locations
ROCKS OF OLIGOCENE AGE (33.9 to 23.0 Ma) Quartz monzonites and quartz syenites of the Tkope belt					
Andesite stocks	Tsan	None	Geologic inference	37, 59	CAAS, Alexander
Hornblende quartz monzonite	Tgqm	None	Geologic inference	56	CAAS, Alexander
Porphyritic quartz syenite	Tgqp	Pyroxene-quartz syenite, alkali granite	Geologic inference and cuts the Tggd unit	44, 50	CAAS, Alexander
ROCKS OF EOCENE AND OLIGOCENE AGE (55.8 to 23.0 Ma) Layered gabbros of the Crillon-La Perouse mafic belt					
Pyroxene gabbro	Tgbp	Olivine gabbro, norite, gabbronorite, troctolite, anorthosite	$^{40}Ar/^{39}Ar$ age: 28.0±8.0 Ma (Loney and Himmelberg, 1983)	3, 11	CIS, Chugach
Magnetite-bearing pyroxene gabbro	Tgbm	Gabbronorite, norite, anorthosite, pyroxenite, dunite		14, 17, 18	CIS, Chugach
Hornblende and pyroxene gabbro	Tgbh	None		6	CIS, Chugach
Pyroxene-hornblende gabbro	Tgbg	Diabase		35, 46, 57, 61	CAAS, Alexander
ROCKS OF EOCENE AND OLIGOCENE AGE (55.8 to 23.0 Ma)—Continued Granodiorite, quartz diorite, and granite of the Fairweather-Muir felsic-intermediate belt					
Biotite granodiorite	Tggd	Hornblende-biotite granodiorite	44.4±1.3 Ma (B) 40.8±1.2 Ma (H) 40.2±1.2 Ma (B) 37.5±1.1 Ma (H) 37.3±1.1 Ma (B) 30.7±0.9 Ma (B)	2, 8, 10, 43, 45, 52	CIS, Yakutat, Chugach, CAAS, Alexander
Garnet-biotite granodiorite	Tggg	None		12, 13, 15, 19, 20, 21	CIS, Chugach
Biotite-hornblende quartz diorite	Tggg	Biotite-hornblende diorite Biotite-hornblende tonalite	K-Ar age:. 1±0.8 Ma (B) (Table 2)	4, 5, 7, 16	CIS, Chugach
Hornblende-biotite granite	Tggr	Hornblende-biotite, granodiorite, tonalite	K-Ar ages: 34.3±1.0 Ma (B) 32.4±1.0 Ma (B) 27.6±0.8 Ma (B) (Table 2) $^{40}Ar/^{39}Ar$ age: 33.1±0.3 Ma (B) (Smart and others, 1996)	9, 22, 26, 27, 30, 33, 34, 42	CIS, Chugach, CAAS, Alexander, TISZ, Wrangellia
ROCKS OF EOCENE AGE (55.8 to 33.9 Ma) Granite and granodiorite of the Sanak-Baranof belt					
Muscovite-biotite granite	Tegr	Muscovite-biotite granodiorite	K-Ar age in mid-50s (G. Plafker, unpub. data)	None	CIS

Table 1. Compositions and ages of rocks in the major plutonic belts in Glacier Bay National Park and Preserve.—Continued

Major composition of rocks in belt	Map label on figure 3	Other compositional types	Basis of age assignment	Body numbers on figure 3	Subregion and terrane locations
ROCKS OF PALEOCENE AGE (65.5 to 55.8 Ma) Tonalite stock at Johns Hopkins Inlet					
Hornblende-bearing biotite zone tonalite	Tgto	Quartz diorite	K-Ar age: 58.6±5.2 Ma (H) (Decker and Plafker, 1982)	64	Tarr Inlet Suture
ROCKS OF EARLY CRETACEOUS AGE (145.5 to 99.6 Ma) Granodiorite and tonalite of the Muir-Chichagof belt					
Biotite-hornblende grandiorite	Kggd	Biotite-hornblende quartz, diorite, quartz mono-diorite, tonalite, granite, diorite	115±3.4 Ma (B) 111±3.0 Ma (B) 107±3.2 Ma (H) (Table 2)	28, 36, 38, 39, 40, 41, 47, 48, 49, 54, 58, 60, 62	CAAS, Alexander
Biotite-hornblende zone tonalite	Kgto	Biotite-hornblende grandiorite	K-Ar ages: 119±8 Ma (H) 116±3.5 Ma (H) 110±3.3 Ma (H) 96.7±5.5 Ma (H) (Table 2) $^{40}Ar/^{39}Ar$ ages: 123.3±0.4 Ma (H) (Smart and others, 1996) 120.8±0.6 Ma (H) (Roeske and n others, 1992)	3, 24, 25, 29, 31,3 2, 51, 5	Tarr Inset Suture Zone, CAAS, Alexander
ROCKS OF LATE JURASSIC AGE (161.0 to 145.5 Ma) Leucotonalite in Johns Hopkins Inlet					
Muscovite-bearing zone leucotonalite	Jgto	Muscovite-bearing trondjhemite	$^{40}Ar/^{39}Ar$ ages: Zone 162±0.4 Ma (M) (Roeske and others, 1992) 152.7±0.4 Ma (M) (Smart and others, 1996)	63	Tarr Inlet Suture
ROCKS OFJURASSIC OR LATE JURASSIC (?) AGE (201.6 to 145.5 Ma) Sheared diorite and gabbro of the Lituya belt					
Hornblende diorite	Jgdi	Hornblende quartz diorite, hornblende quartz monzo-diorite, hornblende tonalite hornblende gabbro	Geologic inference; similarity to dated units to south near Sitka, Alaska	1	CIS, Yakutat

Nonplutonic Rocks of the Subregions

Brew (1997) and D.A. Brew and G. Plafker (unpublished data, 2002) described the nonplutonic rocks of the various subregions and tectonic terranes in greater detail than is appropriate here. Briefly, in the Coastal Islands subregion, the Yakutat terrane consists mostly of Jurassic through Tertiary metasedimentary and metavolcanic rocks, and the Chugach terrane of Jurassic and Cretaceous metasedimentary rocks. The TISZ consists of Triassic metasedimentary and metavolcanic rocks, and the Alexander terrane in the Central Alexander Archipelago subregion of Ordovician through Triassic low- to high-grade metasedimentary and metavolcanic rocks. Fossils are generally rare except in parts of the Tertiary section in the Yakutat terrane and in Permian and some Devonian rocks of the Alexander terrane.

Plutonic Rocks

The granitic and gabbroic rocks of Glacier Bay National Park are classified into six plutonic belts, from west to east: the Sanak-Baranof, Lituya, Crillon-La Perouse, Muir- Fairweather, Muir-Chichagof, and Tkope belts; other areas of rocks are assigned to those belts, but are geographically distant from them (fig. 2), and two areas of nonbelt rocks (both in the Johns Hopkins Inlet area) are known. The three main plutonic belts, the Crillon-La Perouse, Muir-Fairweather, and Muir-Chichagof, trend generally north to south; all of these belts are interpreted to be related to Cretaceous and Tertiary subduction events. The plutonic rocks are classified into 17 different age-compositional units (fig. 3) ranging in age from Jurassic (201.6 Ma), through Cretaceous (ca.145.5–65.5 Ma), to Tertiary (65.5–23.0 Ma; Geological Society of America, 2009) and in composition from syenite to gabbro (table 1) on the basis of modal analyses of specimens, some of which are shown in figures 4 and 5.

In general, the Early Cretaceous plutons intrude rocks of the Alexander and Wrangellia terranes, and the Paleogene plutons intrude rocks of the Yakutat, Chugach, Alexander, and Wrangellia terranes. The plutonic age-compositional distribution patterns are approximately beltlike, and some belts of different age overlap. Also, in general, the compositions of Early Cretaceous plutons are dominantly foliated tonalite, quartz diorite, diorite, and granodiorite; those of Paleogene plutons vary, including gabbro, granodiorite, and minor granite; and those of Oligocene plutons are dominantly quartz syenite and quartz monzonite.

Composition and Geochronology of Rocks in the Plutonic Belts

The outlines of the intrusive bodies in Glacier Bay National Park and Preserve are shown on figure 3, together with the numbers used to identify them in the tables and text. Almost all of these outlines represent intrusive contacts; however, some of the westernmost bodies on the map (Nos. 1 and 2, fig.3) and those in the TISZ (Nos. 30, 31, 63, 64, and part of No. 23) are bounded by faults that are too small to show on in figure 3. The country rocks include a variety of sedimentary, volcanic, and metamorphic rocks ranging in original age from Ordovician through Tertiary. Most of the extensive metamorphism is related to the Cretaceous intrusive rocks, and broad outcrop areas of hornfels are present, especially in the Alexander terrane (Seitz, 1959; Brew and others, 1992; Dusel-Bacon and others, 1996).

As noted above, the plutonic rocks are classified into 17 different age- compositional units, using the geological time scale of Walker and Geissman (2009) and the modal classification scheme of Streckeisen (2002). As summarized in table 1, the rocks range in age from Jurassic through Oligocene and in composition from gabbro to granite and syenite. We discuss eight different age groups below, from youngest to oldest. The new age data presented in this report, together with the supporting data, are listed in table 2. The available major-chemical data are summarized in table 3, and modal-compositional data for some of the major plutonic suites are plotted in figure 4 and 5. With the exception of the Eocene and Oligocene gabbros of the Crillon-La Perouse belt, the younger rocks are generally more silicic than the older ones.

Descriptions of the Plutonic Rocks

The descriptions given below summarize the main characteristics of the rocks in the various plutonic belts.

Rocks of Oligocene Age (33.9 to 23.0 Ma)

Quartz Monzonite and Quartz Syenite of the Tkope Belt

The Oligocene age assignment of the quartz monzonite and quartz syenite of the Tkope belt (figs. 2 and 3) is based on the lithologic similarity of these rocks to those dated at 33–23 Ma to the north across the United States-Canada border (MacKevett and others, 1974; Dodds and Campbell, 1988).

The hornblende-quartz monzonite (unit Tgqm, fig. 3) occurs in one small stock of faintly magmatically foliated, slightly porphyritic fine- to medium-grained hornblende-quartz monzonite that has associated gold and copper mineralization.

Neither age nor chemical data are available for this assignment or for that of the following unit (tables 1, 3). A single stained-slab mode shows the sample to be quartz monzonite.

The porphyritic quartz syenite (unit Tgqp, figs. 3, 4A) includes two slightly different groups of plutons: one

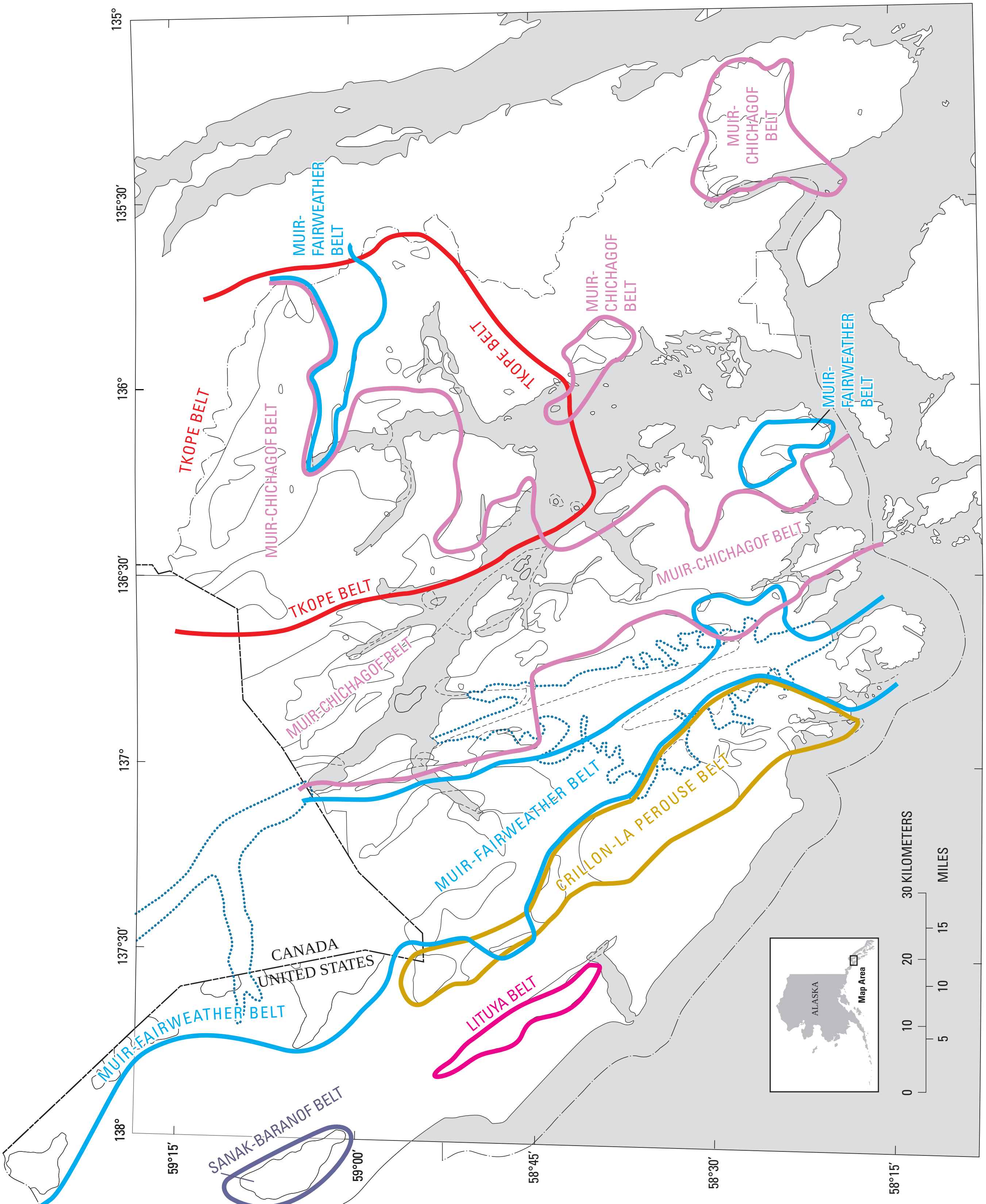


Figure 2. Map showing locations of plutonic belts in Glacier Bay National Park and Preserve. The blue doted lines show the locations of the Grand Pacific (north) and the Brady Glaciers (south) systems. The thin black dot-dashed line denotes the boundary of Glacier Bay National Park and Preserve.

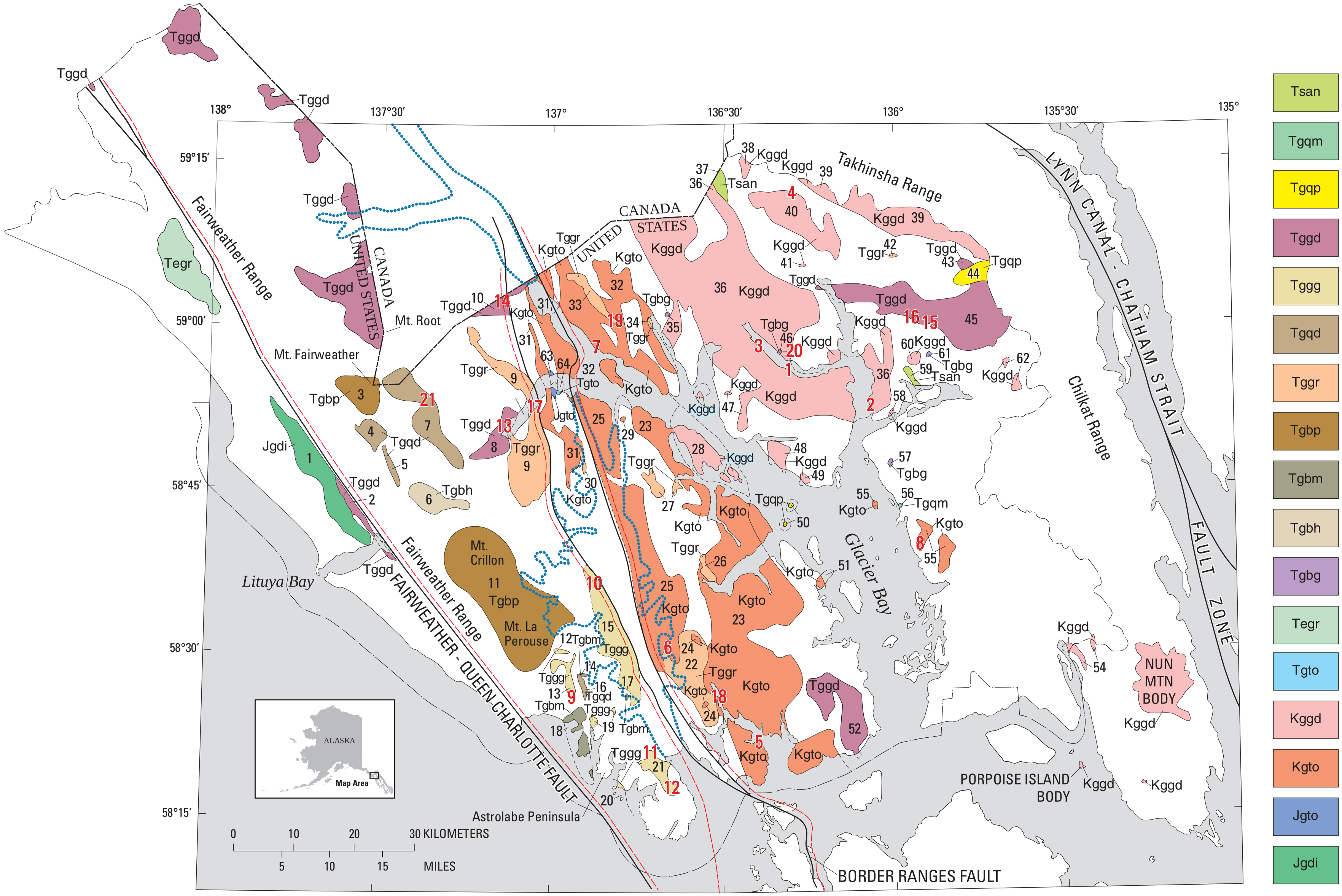


Figure 3. Map showing individual plutonic bodies in Glacier Bay National Park and Preserve. Black numbers correspond to individual plutons identified in the text; numbers in red show locations of the U.S. Geological Survey K-Ar ages listed in table 2. Labeled, but unnumbered, plutons in northwestern part of map area are those for which we lack detailed information. Blue dotted lines show the locations of the Grand Pacific (north) and the Brady Glaciers (south) systems. Thin black dot-dashed line is the boundary of Glacier Bay National Park and Preserve.

Table 2. Potassium-argon ages of plutonic rocks from Glacier Bay National Park and Preserve. See figure 3 for locations and table 1 for summary.
[Ages calculated with constants in use at the time of analysis (1967-1978). All analyses by M.A. Lanphere, U.S. Geological Survey]

Map no.	Body no.	Map unit	Sample no.	Latitude	Longitude	Mineral, %K_2O Rock type	Average %K_2O	$^{40}Ar_{rad}$ (moles/gm)	$^{40}Ar_{rad}$/$^{40}Ar_{tot}$	Age (Ma)
1	36	Kggd	66ABd272A	58°56'54"	136°22'54"	Hornblende, 0.623, 0.626 Sphene-biotite-hornblende grandiorite	0.6245	1.035×10^{-10}	0.72	112±3.4
2	36	Kggd	66ABd147	58°52'18"	136°03'48"	Hornblende, 0.635, 0.636 Sphene-biotite-hornblende grandiorite	0.6355	5.752×10^{-10} ? [1]	0.73?[1]	109±3.3
3	36	Kggd	75KB025A	58°59'15"	135°24'42"	Hornblende, 0.654, 0.651 Sphene-biotite-hornblende grandiorite	0.6525	1.041×10^{-10}	0.35	107±3.2
4	40	Kggd	66ABd297B	59°11'15"	136°20'06"	Biotite, 7.14, 7.24 Hornblende, 0.739, 0.741 Biotite-hornblende grandiorite	7.19 0.740	1.224×10^{-9} 1.237×10^{-10}	0.71 0.23	115±3.4 113±3.4
5	23	Kgto	66ABd632B	58°21'51"	136°22'45"	Hornblende, 1.00, 1.01 Biotite-hornblende tonalite	1.005	1.649×10^{-10}	0.83	110±3.3
6	25	Kgto	75CN121A	58°30'22"	136°39'39"	Hornblende, 0.196, 0.198 Biotite-hornblende tonalite	0.197	1.545×10^{-11}	0.39	53.7±1.6
7	32	Kgto	75BJ121A	58°58'03"	136°52'34"	Hornblende, 0.786, 0.790 Pyroxene-biotite-hornblende quartz diorite	0.788	1.279×10^{-10}	0.81	109±3.3
8	55	Kgto	66ABd359B	58°40'18"	135°54'00"	Hornblende, 0.500, 0.505 Biotite-hornblende quartz diorite	0.5025	8.703×10^{-11}	0.79	116±3.5
9	13	Tggg	76DB147A	58°26'09"	136°56'57"	Biotite, 8.24, 8.29 Muscovite, 8.33, 8.47 Garnet-muscovite-biotite grandiorite	8.26 8.40	8.485×10^{-11} 2.022×10^{-10}	0.23 0.66	7.12±0.2 16.6±0.5
10	15	Tggg	66AFd458	58°37'33"	136°53'27"	Biotite, 7.63, 7.78 Muscovite, 9.96, 9.98 Muscovite-biotite granite	7.705 9.97	3.618×10^{-10} 5.719×10^{-10}	0.55 0.69	32.3±1.0 39.4±1.2
11	21	Tggg	76DB123A	58°20'15"	136°40'18"	Biotite, 8.06, 7.97 Muscovite-garnet-biotite tonalite	8.015	4.456×10^{-10}	0.38	38.2±1.1
12	21	Tggg	76CN034A	58°17'56"	136°39'48"	Biotite, 8.99, 9.12 Garnet-biotite grandiorite	9.055	4.007×10^{10}	0.60	30.5±0.9
13	8	Tggd	66ABd699	58°50'10"	137°08'00"	Biotite, 1 analysis Hornblende, 0.615, 0.625 Magnetite-biotite-hornblende monzonite	9.00 0.620	4.008×10^{-10} 3.684×10^{-11}	0.70 0.52	30.7±0.9 40.8±1.2
14	10	Tggd	77BJ038A	59°02'25"	137°07'22"	Biotite, 6.60, 6.63 Magnetite-biotite-hornblende tonalite	5.97	3.865×10^{-10} 2.649×10^{-11}	0.43 0.34	44.4±1.3 37.5±1.1
15	45	Tggd	75BJ105A	58°59'38"	135°55'37"	Biotite, 6.86, 6.90 Chlorite-biotite-hornblende grandiorite	6.615	3.592×10^{-10}	0.61	37.3±1.1
16	45	Tggd	66ABd353	59°01'57"	135°57'21"	Biotite 6.86, 6.90 Chlorite-biotite-hornblende grandiorite	6.88	4.022×10^{-10}	0.55	40.2±1.2
17	9	Tggr	66AFd404	58°52'21"	137°02'54"	Biotite 8.52, 8.62 Hornblende-biotite granite	8.57	4.031×10^{-10}	0.84	32.4±1.0
18	22	Tggr	66ABd564B	58°26'54"	136°31'21"	Biotite 6.75, 6.77 Hornblende-biotite granite	6.76	3.369×10^{-10}	0.80	34.3±1.0
19	33	Tggd	66AOv1442	59°01'52"	136°51'24"	Biotite 7.28, 7.34 Hornblende-biotite granite	7.31	2.923×10^{-10}	0.80	27.6±0.8
20	46	Tbgb	76DB330G	58°59'37"	136°24'34"	Hornblende 0.172, 0.173 Hornblende gabbro	0.1725	9.449×10^{-12}	0.33	37.6±1.1
21	7	Tggd	77BJ029A	58°53'27"	137°21'58"	Biotite, 9.22, 9.23 Horn-blende-biotite grandiorite	9.225	3.768×10^{-10}	0.60	28.1±0.8

[1]The age of sample represented by map number 2 is considered to be correct, but the data given are incorrect; the original data have been lost, so the correction cannot be made. The constants used for all of these determinations have been retrospectively calculated by F.H. Wilson (U.S. Geological Survey) and found to be those of Steiger and Jäger (1977).

Table 3. Summary of major chemical compositional information for intrusive rock suites in Glacier Bay National Park and Preserve, southeast Alaska.

[Data is from Plafker and MacKevett (1970), Himmelberg and Loney, (1981), and D.A. Brew (unpub. data)]

Unit name	Map symbol(s)	# of samples	Chemical classification	SiO_2 range or value, in percent	SiO_2 gap(s), in percent
Intrusive rocks of Oligocene age					
Rocks of the Tkope plutonic belt	Tgqp	1	Alkalic, 70.1 peraluminous	NA	NA
Intrusive rocks of Oligocene age					
Rocks of the Fairweather-felsic-intermediate plutonic belt	Tggd, Tggg, Tggr, Tgqd	13	Calc-alkalic, subaluminous	57.5–75.3	60.2–65.2
Rocks of Eocene age					
Rocks of the Crillon-La Perouse mafic plutonic belt	Tgbp, Tgbg	30	Calc-alkalic, subaluminous	38.8–51.2	None
Intrusive rocks of Paleocene age					
Tonalite stock on south side of Johns Hopkins Inlet	Tgto	0	No data	No data	No data
Intrusive rocks of Early Cretaceous age					
Intrusive rocks of the Muir-Chichagof belt	Kggd, Kgto	9	Calc-alkalic, metaluminous	43.8–66.8	43.8–50.3
Intrusive rocks of Late Jurassic age					
Leucotonalite stock	Jgto	0	No data	No data	No data
Intrusive rocks of Early Jurassic age					
Sheared intrusive rocks west of Fairweather Fault	Jgdi	0	No data	No data	No data

subunit that contains no pyroxene and has potassium feldspar phenocrysts that are perthitic, and another that contains pyroxene and plagioclase-feldspar phenocrysts that are extensively replaced and rimmed by potassium feldspar. Otherwise, the two subunits are similar. The pyroxene-free subunit consists of porphyritic, alkali feldspar-quartz syenite to quartz syenite, is greenish-gray to pink, and has a color index (mafic-mineral content) of 1 to 3. Two modes plot as alkali feldspar granite and as quartz syenite. One chemical analysis is available for this unit (table 3), but no isotopic-age data are available from within the Glacier Bay region.

A third unit included here of hornblende andesite (Tsan, fig. 3) that occurs as intrusive stocks and dikes consists of gray or greenish-gray porphyritic andesite.

Rocks of Eocene and Oligocene Age (55.8 to 23.0 Ma)

Gabbros of the Crillon-La Perouse Mafic Belt

All of the gabbros of the Crillon-La Perouse mafic belt (figs. 2, 3) are conspicuously layered at a scale of one to tens of centimeters, and several gabbros include cumulate phases. The pyroxene gabbro (unit Tgbp, fig. 3) comprises two bodies in the Fairweather Range: one at Mount Fairweather (body 3, fig. 3) and another at Mounts La Perouse and Crillon (body 11), the first of which was studied by Plafker and MacKevett (1970) and E. Redman (written commun., 1985) and the second by Himmelberg and Loney (1981) and Loney and Himmelberg (1983). The most common rock types in these two bodies are olivine gabbro, norite, gabbronorite, troctolite, and anorthosite. Ultramafic rocks are rare except in the basal part of the La Perouse body, where peridotite, feldspathic peridotite, olivine gabbro, harzburgite, feldspathic harzburgite, gabbro, troctolite, and anorthosite occur as cumulates. Chemically, the rocks are subaluminous and calc-alkalic. Sulfides and ilmenite are locally concentrated at the contact of the La Perouse-Crillon body with hornfelsed Cretaceous graywacke country rock; one such concentration, the Brady Glacier nickel-copper deposit, is a world-class nickel resource (Brew and others, 1978; Himmelberg and Loney, 1981). The age data (table 1) are from the report by Loney and Himmelberg (1983), who evaluated all the earlier dating efforts, including those of Hudson and Plafker (1980); the chemical analyses (table 3) are from the reports by Plafker and MacKevett (1970) and Himmelberg and Loney (1981). No detailed modal information is available.

Magnetite-bearing pyroxene gabbro (unit Tgbm, fig. 3) occurs in three bodies south of the La Perouse-Mt. Crillon body. The most detailed study was by Rossman (1963). The bodies consist of light-gray to very dark gray, fine- to coarse-grained, magnetite-bearing two-pyroxene gabbro interlayered with gabbronorite, norite, anorthosite, pyroxenite, and dunite. The body on the Astrolabe Peninsula (body 18, fig. 3) is well exposed and readily accessible; the others (bodies 14, 17) are small and poorly exposed. The chemical analyses (table 3) are from Rossman (1963). No detailed modal information in available.

The hornblende gabbro and pyroxene gabbro (unit Tgbh, fig. 3) consists of two poorly known bodies of medium- to very coarse-grained hornblende gabbro and pyroxene gabbro. Both bodies are in the Fairweather Range: one at high elevation at Mount Orville that is almost inaccessible (body 6, fig. 3) and the other at low elevation but small and poorly exposed (body 17, fig 3). The rocks are brownish-gray to green and have a color index of 20 to 80.

The pyroxene-hornblende gabbro (unit Tgbg, fig. 3) comprises dikes and small stocks in the vicinity of Muir Inlet and in the Chilkat Range that consist of fine-grained pyroxene-hornblende gabbro and diabase. The rocks are generally medium gray to dark brown and have a color index of 40 to 90. Chemically, a sample (table 3) is similar to samples of the two-pyroxene gabbro (unit Tgbp). Although these rocks are distant from the main part of the Crillon-La Perouse mafic belt, they are similar in general composition and structure to the magnetite- bearing pyroxene gabbro (unit Tgbm, fig. 3) described above and probably do not represent a separate belt of gabbroic rocks.

The rocks in the Crillon-La Perouse mafic belt are reported to have an $^{40}Ar/^{39}Ar$ age of 28.0±8.0 Ma (tables 1, 2).

Granodiorite, Quartz Diorite, and Granite of the Muir-Fairweather Felsic-Intermediate Belt

The granodiorite, quartz diorite, and granite of the Muir-Fairweather felsic-intermediate belt comprises three subunits: (1) the biotite granodiorite (unit Tggd) consists of six bodies (table 1) spread across the map area, composed of nonfoliated light- to medium-gray, hornblende-biotite granodiorite, tonalite, and quartz monzodiorite with color a index of 6 to 24 (bodies 43, 45, 52); (2) slightly foliated very light red (pink) to gray biotite-hornblende granodiorite quartz diorite, tonalite, and monzodiorite form a second subunit (bodies 8, 10); and (3) locally foliated, medium- to coarse-grained, very light gray to light-gray hornblende-biotite granodiorite having a color index of 10 to 18 and containing inclusions of diorite, amphibolite, granodiorite, and tonalite (body 2). All of the foliations present are interpreted here to be subsolidus features. All modal analyses plot in or close to the granodiorite field (fig. 4*B*).

The garnet-biotite granodiorite (unit Tggg, fig. 3) consists of six plutons clustered in the southern part of the Fairweather Range (table 1, fig. 5*A*). The plutons intrude rocks of the Chugach terrane, and all locally have weak subsolidus foliation. The rocks are generally medium- to coarse-grained and contain biotite and garnet; muscovite and hornblende are locally present. Modal compositions of the various bodies plot in the granodiorite and quartz diorite fields (fig. 4*C*).

Three plutonic bodies in the northern part of the Fairweather Range (figs. 1, 3) and one plutonic body (No. 16, fig. 3) in the southern part are assigned to the biotite-hornblende-quartz diorite (unit Tgqd; table 1). Hornblende and biotite generally occur in approximately equal proportions, and the rocks have a color index averaging 30. Stained-slab-counted samples range from tonalite to diorite (fig. 4*D*).

The hornblende-biotite granite (unit Tggr, fig. 3) comprises six bodies (table 1, fig 6) in the Alexander terrane, one in the Chugach terrane just west of the Tarr Inlet Suture Zone (body 9, fig. 3), and one in that zone (body 30, fig. 3). The rocks are medium- to coarse-grained grained, very light-gray to light-gray, hornblende-biotite granite and granodiorite, together with smaller amounts of tonalite and quartz monzonite (fig. 6). Color indices range from 1 to 20, and most of the bodies have weak subsolidus foliations, particularly near their margins. Stained-slab-counted samples range from granite to tonalite. All of these units have isotopic ages that range from 44.4±1.3 Ma to 27.6±08 Ma (K-Ar on biotite; tables 1, 2).

Rocks of Eocene Age (55.8 to 33.9 Ma)

Granite and Granodiorite of the Sanak-Baranof Belt

The Sanak-Baranof belt (figs. 2, 3) comprises a single large pluton (unit Tegr) of Eocene age that occurs west of the Fairweather Fault in the Yakutat terrane. According to the description by D.A. Brew and G. Plafker (unpublished data, 2002), the pluton is composed of fine- to coarse-grained, equigranular to seriate, hypidiomorphic, massive to foliated, locally potassium-feldspar poikilitic muscovite-biotite granite and granodiorite, with common myrmekite. No modal or chemical data are available. The pluton occurs in country rocks of the Yakutat group. G. Plafker (unpublished data, 2002) established that K-Ar ages on this family of plutons farther north are closely concordant and range from 46.8 to 51.1 Ma. This pluton is considered part of the Sanak-Baranof plutonic belt (Hudson, 1983), which has no other representatives in Glacier Bay National Park and Preserve.

Rocks of Paleocene Age (65.5 to 55.8 Ma)

Tonalite Stock in Johns Hopkins Inlet

A small stock (body 64, fig. 3) of hornblende-bearing biotite tonalite (unit Tgto, fig. 3) occurs in the TISZ on the

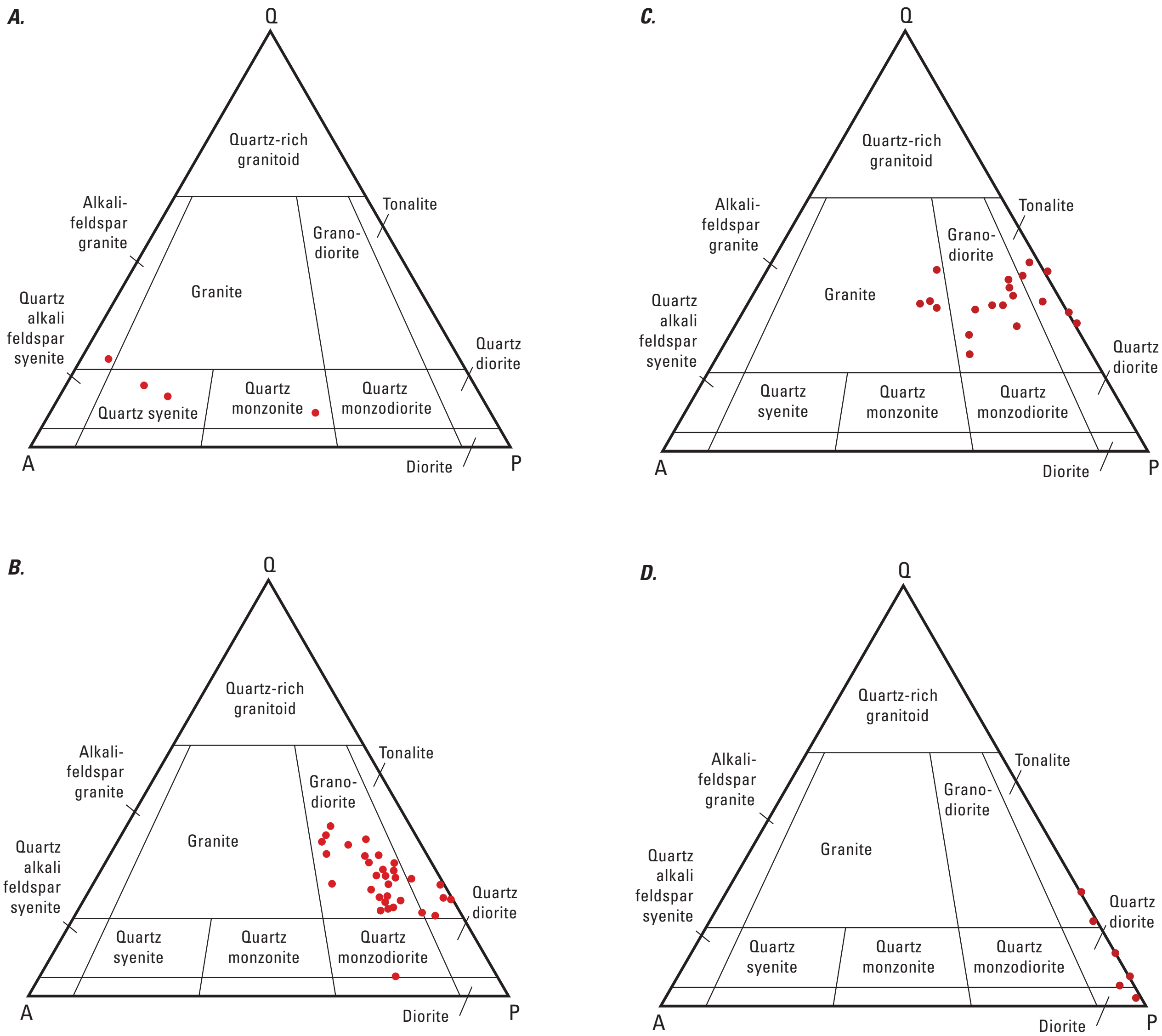
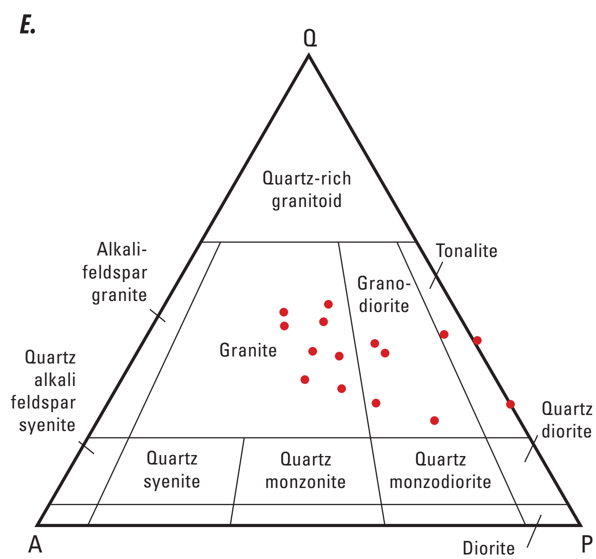


Figure 4. QAP diagrams (after Streckeisen, 2002) showing modal compositions of Tertiary plutonic rocks in Glacier Bay National Park and Preserve, southeast Alaska. *A,* Units Tgqm and Tgqp of the Tkope belt (4 modes); *B,* unit Tggd of the Fairweather-Muir belt (32 modes); *C*, unit Tggg of the Fairweather- Muir belt (21 modes); *D*, unit Tgqd of the Fairweather-Muir belt (6 modes); *E*, unit Tggr of the Fairweather-Muir belt (15 modes).



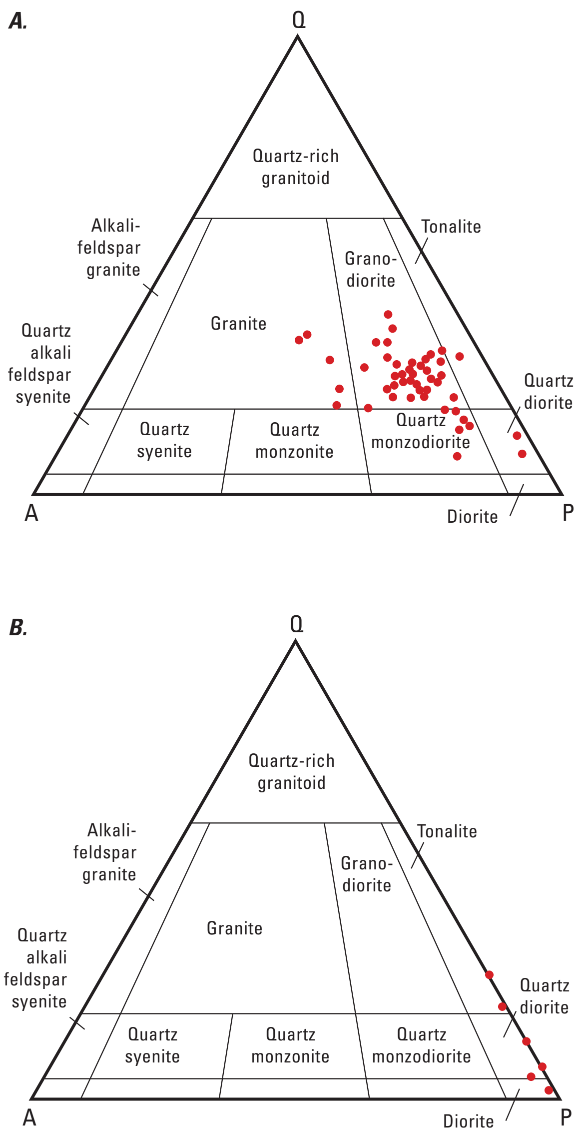


Figure 5. QAP diagrams (after Streckeisen, 2002) showing modal compositions of Cretaceous plutonic rocks in Glacier Bay National Park and Preserve, southeast Alaska. *A*, Unit Kggd of the Muir-Chichagof belt (49 modes); *B,* unit Kgto of the Muir-Chichagof belt (6 modes).

south side of Johns Hopkins Inlet. No modal or chemical analyses are available. A Paleocene K-Ar age of 58.6±5.2 Ma was reported for the unit (table 1; Decker and Plafker, 1982).

Rocks of Early Cretaceous Age (145.5 to 99.6 Ma)

Granodiorite and Tonalite of the Muir-Chichagof Belt

The Muir-Chichagof belt (figs. 2, 3; table 1) is one of several plutonic belts in southeast Alaska described by Brew and Morrell (1983); its rocks are the most extensive of any belt in the Glacier Bay region (fig. 2).

The biotite-hornblende granodiorite (unit Kggd) consists of 13 plutonic bodies whose postemplacement foliations consistently parallel those of the host rocks except for local divergences near contacts. Migmatites are locally present, and border zones consist of mafic rocks that are diked and brecciated by leucocratic granodiorite. The plutons are generally medium-grained, very light gray to gray; and have a color index of 4 to 30, mostly 15 and 25. Modal analyses are plotted in figure 5*A*. Isotopic ages of these rocks range from 115±3.4 Ma (K-Ar on biotite) to 107±3.2 Ma (K-Ar on hornblende; tables 1, 2).

The biotite-hornblende tonalite (unit Kgto, fig. 3) includes two slightly different groups of plutons that have been combined because their differences appear to be insignificant. The unit was labeled "tonalite" in the field, on the basis of its color index and apparent quartz content; modal analyses, however, suggest that quartz diorite may actually be the most common rock type (fig. 5*B*).

One subgroup in the biotite-hornblende tonalite consists of four bodies in the Alexander terrane that range in composition from granite through diorite; they are medium- to coarse-grained, very light to medium gray, and have color indices from 6 to 40, but most commonly 20–30 (bodies 23, 24, 25, 29, fig. 3). Another subgroup consists of four bodies, also in the Alexander terrane (bodies 31, 32, 51, 55, fig. 3), in which the most common rock types are foliated white to dark-gray-green biotite-hornblende-quartz diorite and tonalite, but ranging in composition from granodiorite to diorite (fig. 5B.) and in texture from fine- to coarse-grained, averaging medium grained. Color indices range from 3 to 68 and average 25.

Inclusions are common near body margins and consist of hornblende diorite and amphibolite that parallel postemplacement foliations. K-Ar and $^{40}Ar/^{39}Ar$ ages for this unit range from 123.3±0.4 Ma to 96.7±5.5 (tables 1, 2).

Rocks of Late Jurassic Age (161.0 to 145.5 Ma)

Leucotonalite in Johns Hopkins Inlet

A small stock (body 63, fig. 3) of muscovite-bearing leucotonalite (unit Jgto, fig. 3) occurs in the TISZ. No modal or chemical analyses are available. Jurassic $^{40}Ar/^{39}Ar$ ages of 162±0.4 Ma and 152.7±0.4 have been reported for this unit (table 1).

Rocks of Jurassic Age (201.6 to 145.5 Ma)

Sheared Diorite and Gabbro of the Lituya Belt

The sheared diorite and gabbro of the Lityua belt consists of one elongate northwest- trending body of hornblende diorite (unit Jgdi, fig. 3) north of Lituya Bay (body 1, fig. 3). Most of the east edge of the body is the Fairweather Fault. Younger biotite granodiorite (unit Tggd, fig. 3) intrudes part of this body. The pluton is foliated owing to hypersolvus deformation and is highly sheared and altered; the only available modal analysis indicates that the sample is quartz monzodiorite, but field and thin-section examinations indicate that most samples are composed of diorite, quartz diorite, or tonalite and have a color index from 15 to 70, mostly 20 to 30. Hornblende-augite gabbro or diorite is common as a border phase along the western margin. No isotopic age or chemical analyses are available for the body. A Jurassic age is inferred from the pluton's pervasive foliation and alteration which are like those in lithologically and structurally similar bodies near Sitka on Baranof Island to the south that are dated at about 190 Ma (S.M. Karl, written commun., 2005).

Discussion

The plutonic belts in Glacier Bay National Park and Preserve are parts of regional magmatic belts of varying extents in southeast Alaska that reflect different episodes of tectonic activity. Various names have been applied to these belts by different authors; the following paragraphs trace the evolution of these names for the benefit of the interested reader.

Regional Magmatic Belts

Stocks and small plutons of the Oligocene age quartz monzonite and quartz syenite of the Tkope belt of this report compose part of the Tkope-Portland Peninsula regional belt of Brew (1994). The origin of this magmatism is discussed below. Most of the bodies in that belt are in the Skagway quadrangle north of the Glacier Bay region (Wilson and others, 1994) and farther north in British Columbia (Dodds and Campbell, 1988).

The Eocene and Oligocene gabbros of the Crillon-La Perouse mafic belt of this report were included in the Fairweather-Baranof belt by Brew and Morrell (1983). This plutonic belt is confined to the Glacier Bay region except for its extension on Yakobi Island and vicinity to the south (Himmelberg and others, 1987).

The Eocene and Oligocene granodiorite, quartz diorite, and granite units of the Muir-Fairweather felsic-intermediate belt of this report correspond to part of the Fairweather-Baranof belt of Brew and Morrell (1983) and Brew (1994) and to the Glacier Bay regional belt of Brew (1994). The felsic-intermediate belt has analogs to the north in the Yakutat and Skagway quadrangles (Wilson and others, 1994). Brew and Morrell (1983) considered the rocks of the felsic-intermediate belt to be part of the Sanak-Baranof belt of Hudson (1983); however, newer (and better) age controls and other data suggest that the bodies in that belt may be slightly older and are all oceanward of those of the Muir-Fairweather felsic-intermediate belt (Bradley and others, 1993).

The late Early Cretaceous granodiorite and tonalite of the Muir-Chichagof belt of this report, which extends southward through southeast Alaska (Brew and Morrell, 1983) and into western British Columbia near Prince Rupert (Hutchison, 1982; Woodsworth and others, 1989), is considered (Monger and others, 1982) to be the roots of a volcanic-plutonic arc associated with the juxtaposition of the Insular and Intermontane Superterranes. The volcanic part of the arc has been eroded from all the area underlain by intrusive rocks, but its distant products are preserved as part of the Gravina overlap-assemblage rocks to the east (Berg and others, 1972; Brew and Ford, 1998). Immediately south of Glacier Bay National Park and Preserve, on the northwestern part of Chichagof Island, a significant number of plutons of Jurassic age occur in the belt. These plutons cannot be distinguished from the bodies of mid-Cretaceous age on the basis of field criteria alone (Loney and others, 1975; Johnson and Karl, 1985; Karl and others, 1988). Similarly, the Muir-Chichagof belt extends northward into British Columbia and Yukon Territory, where the compilation by Dodds and Campbell (1988) indicates that both Cretaceous and Jurassic plutonic bodies are present; there, also, the noncoeval bodies cannot be distinguished on the basis of field criteria (R.B. Campbell, oral comm., 1985). This belt includes some plutons east of Glacier Bay that were assigned to the Chilkat-Prince of Wales province by Sonnevil (1981). All of these late Early Cretaceous rocks were assigned to the Nutzotin-Chichagof belt by Hudson (1979, 1983). We have assigned or reassigned all of the plutons described in this report to the belts that are described here.

As part of how the plutonic belts in Glacier Bay National Park and Preserve fit into previous, but now-discarded, regional-belt nomenclature, we note that Hudson (1979, 1983) and Brew and Morrell (1983) suggested that a distinct belt of Middle Jurassic plutons extended into the Glacier Bay region from the north and continued southward into the northeastern part of Chichagof Island. Hudson assigned the Jurassic rocks to his Tonsina-Chichagof belt and Brew and Morrell (1983) termed it the Muir-Chichagof Belt II. All of these plutons are now included in the late Early Cretaceous Muir-Chichagof belt, even though some may be Jurassic. No Jurassic plutons have been recognized in this belt south of Baranof Island (south of Glacier Bay) in southeast Alaska.

Distribution and Origin of the Major Plutonic Belts in Glacier Bay National Park

The distribution of the plutonic belts in Glacier Bay National Park and Preserve is mapped in figure 2. The granitic rocks of the late Early Cretaceous Muir-Chichagof belt are dominant in the central and eastern part of the park and preserve, in the Alexander and Wrangellia terranes. These rocks are clearly related to the major accretionary events that joined the Chugach terrane to the Alexander terrane to form the Insular Superterrane, which was subsequently joined to the Intermontane Superterrane to the east.

Granitic rocks of the Eocene and Oligocene Muir-Fairweather felsic-intermediate belt are dominant to the west in the Chugach terrane in the Fairweather Range; they also occur as scattered outliers in the eastern part of the park and preserve, in the Alexander terrane. They distinctly postdate (44±1.3 Ma to 27.6±0.8 Ma) the Eocene plutons that make up the Sanak-Baranof belt of Hudson (1983), which are all dated to about 50 Ma. The rocks are probably not the simple expression of the ridge-subduction-related slab-window magmatism that formed the Sanak-Baranof belt (Bradley and others, 1993; 2003). The gap of about 20 m.y. between the ages of these two belts is difficult to explain, except to interpret the younger rocks as related either to a cryptic tectonic event or to a delayed expression of some earlier subduction event, which would likely be the later stages of the subduction of the recently recognized Resurrection tectonic plate in the northeastern Pacific (Haeussler and others, 2001, 2003; Madsen and others, 2003). This subduction event may be the slightly later, obscure event that was vaguely hypothesized by Brew (1994). The presence of layered gabbroic rocks of the Crillon-La Perouse belt that slightly postdate the felsic rocks in essentially the same location suggests that both the felsic and mafic magmas were a late-generated product of the same event. The gabbroic and felsic rocks may even be a deeper and northwesternmost expression of the Kuiu-Etolin volcanic-plutonic belt of central southeast Alaska (Brew and others, 1979).

Rocks from almost all of the plutonic belts occur in or near the TISZ (fig. 1), as do the small and uncommon Paleocene and Late Jurassic bodies. As first recognized by Plafker and Campbell (1979), the TISZ contains the Border Ranges Fault. Almost all the intrusive rocks in the TISZ are strongly sheared, and some are altered much more than is common in other localities. We interpret the small bodies in the TISZ to be slices that have been transported there from unknown areas.

Conclusions

The Ordovician through Tertiary country rocks of Glacier Bay National Park and Preserve are laced with belts of plutonic rocks. The resulting complexities, together with the presence of two major fault zones and one crustal-scale tectonic boundary, present an intricate web of diverse geologic features. The plutonic belts profoundly influence our understanding the park and preserve. The oldest belt, consisting of Jurassic plutons, is poorly preserved and may have been generated during tectonic subduction events whose record has otherwise been lost. We (and other workers) interpret the extensive belt of northwest-trending Early Cretaceous plutons to have resulted from eastward and northeastward Late Jurassic and Cretaceous subduction of now-vanished parts of the Chugach terrane beneath the Alexander terrane long before the initiation of the major Fairweather-Queen Charlotte Fault in the western part of the park. The Tarr Inlet Suture Zone is a remnant of the original subduction zone that evolved into the Border Ranges Fault system. Only one pluton in Glacier Bay National Park and Preserve belongs to the regionally important Eocene Sanak-Baranof belt that represents ridge-subduction-related slab-window magmatism along the northeastern Pacific Rim. The later Tertiary plutons of the Fairweather-Muir belt contrast with the earlier Tertiary ones because the later plutons are slightly more felsic and alkalic and because their distribution crosses the tectonic grain of the region. These younger plutons may be related to subduction of the Resurrection Plate, but alternatively they may be the deeper and northwesternmost expression of the Kuiu-Etolin volcanic-plutonic belt of central southeast Alaska (Brew and others, 1979).

References Cited

Barnes, D.F., 1984, No measurable gravity change at Glacier Bay uplift area, *in* Reed, K.M., and Bartsch-Winkler, S., eds. The United States Geological Survey—accomplishments during 1982: U.S. Geological Survey Circular 939, p. 88–90.

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: U.S. Geological Survey Professional Paper 800-D, p. D1–D24.

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

Bradley, D.C., Kusky, T., Haeussler, P., Goldfarb, R., Miller, M., Dumoulin, J., Nelson, S.W., and Karl, S., 2003, Geologic signature of early Tertiary ridge subduction in Alaska, in Sisson, V.B., Roeske, S.M., and Pavlis, T.L., eds., Geology of a transpressional orogen developed during ridge-trench interaction along the North Pacific margin: Geological Society of America Special Paper 371, p. 19–49.

Brew, D.A., 1994, Latest Mesozoic and Cenozoic magmatism in southeastern Alaska, chap. 19 *of* Plafker, G., and Berg, H.C., eds., The Geology of North America, v. G-1: Boulder, Colo., Geological Society of America, p. 621–656.

Brew, D.A., 1997, Reconnaissance bedrock geologic map of Glacier Bay National Park, Alaska, in Glacier Bay Ecosystem GIS CD-ROM: U.S. Geological Survey, Biological Resources Division, available from J. Geiselman, USDS/BRD, 4210 University Drive, Anchorage, AK 99508.

Brew, D.A., 2001, The Insular-Intermontane Suture Zone (IISZ) of the western Coast Mountains of southeastern Alaska and British Columbia and the Adria-Europe Suture Zone (AESZ) of southern Europe—descriptions and comparison of global-scale tectonic features, *in* Gough, L.P., and Wilson, F.H., eds., The U.S. Geological Survey in Alaska—geologic studies in Alaska by the U.S. Geological Survey in 1999: U.S. Geological Survey Professional Paper 1633, p. 35–50.

Brew, D.A., Berg, H.C., Morrell, R.P., Sonnevil, R.S., and Hunt, S.J., 1979, The mid-Tertiary Kuiu-Etolin volcanic-plutonic belt, southeastern Alaska, in Johnson, K.M., and Williams, J.R., eds., The United States Geological Survey in Alaska—accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B129–B130.

Brew, D.A., Drew, L.J., Schmidt, L.M., Root, D.H., and Huber, D.F, 1991, Undiscovered locatable mineral resources of the Tongass National Forest and adjacent areas, southeastern Alaska: U.S. Geological Survey Open-File Report 91–10, 370 p., 15 pls., scales 1:250,000, 1:500,000.

Brew, D.A., and Ford, A.B., 1998, The Coast Mountains shear zones in southeastern Alaska— descriptions, relations, and lithotectonic terrane significance, *in* Gray, J.E., and Riehle, J.R., eds., The U.S. Geological Survey in Alaska—geologic studies in Alaska by the U.S. Geological Survey in 1996: U.S. Geological Survey Professional Paper 1595, p. 183–192.

Brew, D.A., Himmelberg, G.R., Loney, R.A., and Ford, A.B., 1992, Distribution and characteristics of metamorphic belts in the southeastern Alaska part of the North American Cordillera: Journal of Metamorphic Geology, v. 10, p. 465–482.

Brew, D.A., Horner, R.B., and Barnes, D.F., 1995, Bedrock-geologic and geophysical research in Glacier Bay National Park and Preserve—Unique opportunities of local to global significance: Proceedings of the Third Glacier Bay Science Symposium, 1993, *in* Engstrom, D.R., ed., National Park Service, Anchorage, Alaska, p. 5–14.

Brew, D.A., Johnson, B.R., Grybeck, D., Griscom, A., Barnes, D.F., Kimball, A.L., Still, J.C., and Rataj, J.L., 1978, Mineral resources of Glacier Bay National Monument Wilderness Study Area, Alaska: U.S. Geological Survey Open-File Report 78–494, 670 p.

Brew, D.A., and Morrell, R.P., 1978, Tarr Inlet suture zone, Glacier Bay National Monument, Alaska, *in* Johnson, K.M., ed., The U.S. Geological Survey in Alaska—sccomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B90–B92.

Brew, D.A., and Morrell, R.P., 1983, Intrusive rocks and plutonic belts in southeastern Alaska *in* Roddick, J.A., ed., Circum-Pacific plutonic terranes: Geological Society of America Memoir 159, p. 171–193.

Decker, J.E., and Plafker, G., 1982, Correlation of rocks in Tarr Inlet suture zone with the Kelp Bay Group, *in* Coonrad, W.L., ed., The United States Geological Survey in Alaska—accomplishments during 1980: U.S. Geological Survey Circular 844, p. 119–123.

Dodds, C.J., and Campbell, R.B., 1988, Potassium-argon ages of mainly intrusive rocks in the Saint Elias Mountains, Yukon and British Columbia: Geological Survey of Canada Paper 87–16, 43 p.

Dusel-Bacon, C., Brew, D. A., and Douglass, S.L., 1996, Metamorphic facies map of southeastern Alaska: U.S. Geological Survey Professional Paper 1497-D, scale 1: 1,000,000, 42 p.

Elliott, J.L., Larsen, C.F., Freymueller, J.T., and Motyka, R.J., 2010, Tectonic block motion and glacial isostatic adjustment in southeast Alaska and adjacent Canada constrained by GPS measurements: Journal of Geophysical Research, v. 115, B09407, doi:10.1029/2009JB007139,.

Grommé, S., 1998, Magnetic properties and paleomagnetism of the La Perouse and Astrolabe intrusions, Fairweather Range, southeastern Alaska, *in* Gray, J.E., and Riehle, J.R., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1996: U.S. Geological Survey Professional Paper 1595, p. 99–115.

Haeussler, P.J., Bradley, D.C., Wells, R., Rowley, D.B., Miller, M., Otteman, A., and Labay, K., 2001, Life and death of the Resurrection Plate—evidence for an additional plate in the NE Pacific in Paleocene-Eocene time [abs.]: Eos (American Geophysical Union Transactions), v. 82, Fall meeting supplement, abs. T12C–0926.

Haeussler, P.J., Bradley, D.C., Wells, R.E, Miller, M.L., 2003, Life and death of the Resurrection Plate—evidence for its existence and subduction in the northeastern in Paleocene-Eocene time: Geological Society of America Bulletin, v. 115, p. 867–880.

Himmelberg, G.R., and Loney, R.A., 1981, Petrology of the ultramafic and gabbroic rocks of the Brady Glacier nickel-copper deposit, Fairweather Range, southeastern Alaska: U.S. Geological Survey Professional Paper 1195, 26 p.

Himmelberg, G.R., Loney, R.A., and Nabelek, P.I., 1987, Petrogenesis of gabbronorite at Yakobi and northwest Chichagof Islands, Alaska: Geological Society of America Bulletin, v. 98, p. 265–279.

Hudson, T., 1979, Mesozoic plutonic belts of southern Alaska: Geology, v. 7, p. 230–234.

Hudson, T., 1983, Calc-alkaline plutonism along the Pacific rim of southern Alaska, in Roddick, J.A., Circum-Pacific Pacific plutonic terranes: Geological Society of America Memoir 159, p. 159–169.

Hudson, T., and Plafker, G., 1980, Emplacement age of the Crillon-La Perouse pluton, Fairweather Range, *in* Albert, N.R.D., and Hudson, T., eds., The U.S. Geological Survey in Alaska—accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. 90–94.

Hutchison, W.W., 1982, Geology of the Prince Rupert-Skeena Map Area, British Columbia: Geological Survey of Canada Memoir 394, 116 p., 1 pl. scale 1:250,000.

Johnson, B.R., and Karl, S.M., 1985, Geologic map of western Chichagof and Yakobi Islands, southeastern Alaska: U.S. Geological Survey Map I-1506, 15 p., 1 pl. scale 1:125,000.

Karl, S.M., Johnson, B.R., and Lanphere, M.A., 1988, New K-Ar ages for plutons on western Chichagof Island and on Yakobi Island, in Galloway, J.P., and Hamilton, T.D., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 164–168.

Larsen, C.F., Motyka, R.J., Freymuller, J.T., Echelmeyer, K.A., and Ivins, E.R., 2004, Rapid uplift of southern Alaska caused by recent ice loss: Geophysical Journal International, v. 158, p. 1118–1133.

Larsen, C.F., Motyka, R.J., Freymuller, J.T., Echelmeyer, K.A., and Ivins, E.R., 2005, Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat: Earth Planetary Scientific Letters v. 237, p. 548–560.

Loney, R.A., Brew, D.A., Muffler, L.J.P., and Pomeroy, J.S., 1975, Reconnaissance geology of Chichagof, Baranof, and Kruzof Islands, Alaska: U.S. Geological Survey Professional Paper 792, 105 p.

Loney, R.A., and Himmelberg, G.R, 1983, Structure and petrology of the La Perouse gabbro intrusion, Fairweather Range, southeastern Alaska: Journal of Petrology, v. 24, no. 4, p. 377–423.

MacKevett, E.M., Jr., Brew, D.A., Hawley, C.C., Huff, L.C., and Smith, J.G., 1971, Mineral resources of Glacier Bay National Monument, Alaska: U.S. Geological Survey Professional Paper 632, 90 p.

MacKevett, E.M., Jr., Robertson, E.C., and Winkler, G.R., 1974, Geology of the Skagway B-3 and B-4 quadrangles, southeastern Alaska: U.S. Geological Survey Professional Paper 832, 33 p.

Madsen, J., Thorkelson, D., Friedman, R., Marshall, D., and Anderson, R.G., 2003, Slab windows drive Eocene forearc magmatism on Vancouver Island [abs]: Geological Society of America Abstracts with Programs, v. 34, no. 7, p. 428.

Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70–75.

Motyka, R.J., Larsen, C.F., Freymuller, J.T., and Echelmeyer, K.A., 2007, Post Little Ice Age glacial rebound in Glacier Bay National Park and surrounding areas: Alaska Park Science Journal, v. 6, no. 1, p. 37–41.

Plafker, G., 1987, Regional geology and petroleum potential of the northern Gulf of Alaska, *in* Scholl, D.W., Grantz, A., and Vedder, J.G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins—Beaufort Seat to Baja California: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 29–268.

Plafker, G., and Campbell, R.B., 1979, The Border Ranges fault in the St. Elias Mountains, *in* Johnson, K.M., and Williams, J.R., eds., The United States Geological Survey in Alaska— accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. 102–104.

Plafker, G., and MacKevett, E.M., Jr., 1970, Mafic and ultramafic rocks from a layered pluton at Mount Fairweather, Alaska, in Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-B, p. B21–B26.

Roeske, S.M., Pavlis, T.L., Snee, L.W., and Sisson, V.B., 1992, $^{40}Ar/^{39}Ar$ isotopic ages from the combined Wrangellia-Alexander terrane along the Border Ranges fault system in the eastern Chugach Mountains and Glacier Bay, Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 180–195.

Rossman, D.L. 1963, Geology and petrology of two stocks of layered gabbro in the Fairweather Range, Alaska: U.S. Geological Survey Bulletin 1121-F, 50 p.

Seitz, J.F., 1959, Geology of the Geikie Inlet area, Glacier Bay, Alaska: U.S. Geological Survey Bulletin 1058-C, p. 61–120.

Smart, K.J., Pavlis, T.L., Sisson, V.B., Roeske, S.M., and Snee, L.W., 1996, The Border Ranges fault system in Glacier Bay National Park, Alaska—evidence for major early Cenozoic dextral strike-slip motion: Canadian Journal of Earth Science, v. 33, p. 1268–1282.

Sonnevil, R.A., 1981, The Chilkat-Prince of Wales plutonic province, southeastern Alaska, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska— accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B112–B115.

Streckeisen, A.I., 2002, Plutonic rocks, in LeMaitre, R.W., ed., Igneous rocks—a classification and glossary of terms—recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks (2d ed.): New York, International Union of Geological Sciences, Cambridge University Press, p. 21–29.

Steiger, R.H., and Jäger, E., 1977, Subcommission on geochronology—Convention on the use of decay constants in geo- and cosmo-chronology: Earth and Planetary Science Letters, v. 36, p.359–363.

Walker, J.D., and Geissman, J.W., 2009, 2009 Geologic time scale: Boulder, Colo., Geological Society of America.

Wilson, F.H., Shew, N., and DuBois, G.D., 1994, Map and table showing isotopic age data, pl. 8 of Plafker, G., and Berg, H.C., eds., The Geology of North America, v. G-1: Boulder, Colo., Geological Society of America, scale 1:2,500,000.

Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L., 1989, Plutonic regimes in the Canadian Cordillera: Geological Survey of Canada Open-Files 1982 and 1983, CD-ROM.

Menlo Park Publishing Service Center, California
Manuscript approved for publication March 20, 2013
Edited by George Havach and Claire M. Landowski
Design and layout by Cory Hurd

Brew and others—**Geochronology of Plutonic Belts and their Tectonic Terranes in Glacier Bay National Park and Preserve**—Professional Paper 1776-E

http://dx.doi.org/10.3133/pp1776E/

ISSN 2330-7102 (online)