DEPARTMENT OF THE INTERIOR
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TO ACCOMPANY MAP I-1150

GEOLOGIC MAP OF THE SEWARD AND BLYING SOUND QUADRANGLES, ALASKA

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Beach deposits. Beach deposits sufficiently extensive to show on the map are present on Montague Island and in the Blying Sound area. Most of the deposits lie within the area uplifted during the 1964 earthquake and correspond broadly to areas of net Holocene emergence (Plafker, 1969). Montague Island was uplifted as much as 11.6 m during the 1964 earthquake (Plafker, 1967), and deposits mapped in this area include present beach sediments, as well as pre-1964 elevated strandline deposits. The seaward limits of the shoreline (and bedrock) deposits of the island were mapped from post-earthquake aerial photographs. The deposits in the coastal reaches of the Harding Icefield lie in the area that was submerged during the 1964 earthquake and represent new strandline deposits formed near the ends of receding glaciers. These beach deposits were mapped during the present field studies.

Unconsolidated surficial deposits. Unconsolidated sedimentary deposits (other than the beach deposits) are chiefly of glaciofluvial origin. The most extensive descriptions of these deposits are those of Moffit (1906), Martin, Johnson, and Grant (1915), and Karlstrom (1964). Rocks exposed in the eastern two-thirds of the map area have only recently been exhumed from beneath glacial ice. Two large areas of ice remain, and unconsolidated deposits have had little time to form. The western third of the map area has a different late Quaternary glacial history. The Resurrection and Kenai River drainage systems north of the Harding Icefield were last covered by ice during the Naptowne Glaciation (about 10,000 to 14,000 years ago; Hopkins, 1974, table 1), the last major glaciation of southern Alaska. During that time the Harding Icefield expanded northward, and ice filled the river valleys, left only scattered nunataks exposed in the mountains, and flowed west of the map area into the Kenai Lowland to feed a large piedmont ice lobe along the western front of the Kenai Mountains (Karlstrom, 1964, p. 56). The deposits of these glaciers are chiefly glaciofluvial deposits formed during recession of the Naptowne ice.

Much of the Turnagain Arm drainage system (Resurrection, Sixmile, Glacier, and Bird Creeks) was not extensively covered by ice during either of the last two major glaciations (Knik and Naptowne) (Karlstrom, 1964, pl. 1). The unconsolidated sediments are chiefly outwash deposits that must have been reworked over an extended period but also include significant slope wash, talus, and colluvium. Minor glacial deposits of the Alaska Glaciation (post-Naptowne) are widespread in the Turnagain Arm drainage system.

GRANITIC ROCKS

Granitic rocks crop out in the southwestern part of the map area, in the region of the Harding Icefield, and in the north-central and northeastern part of the map area. Granitic rocks of the Harding Icefield region are Eocene in age, foliated, and form a batholith. The Cedar Bay Granite, in the northeast part of the Seward quadrangle, also is probably of Eocene age, but it is not foliated and is less than batholithic size. Granitic rocks in the north-central part of the Seward quadrangle are Oligocene in age, nonfoliate, and less than batholithic size. Small gabbro plutons are closely associated with three of the north-central group of granitic plutons.

Granodiorite and granite. The plutons in the central part of the Seward quadrangle were described in some detail by Grant and Higgins (1910), and Lanphere (1966) obtained potassium-argon ages of 34.4 to 36.6 m.y. from four of them (sample locations are plotted on map; sample data presented in table 1). Other similar plutons in the general area of those dated by Lanphere are considered to be of the same age.

The plutons are small, roughly circular bodies that intrude slate and sandstone of the Cretaceous Valdez Group; slate, sandstone, and mafic igneous rocks of the early Tertiary Orca Group; and gabbro (near Esther Passage) that is of post-Orca age. The contacts are sharp and distinctly crosscut bedding of the country rock. Most of the contacts dip steeply, but those along parts of the Eshamy Granite and the small intrusive body immediately adjacent to the west side of Port Wells dip shallowly. The marginal zones of the plutons contain abundant inclusions of country rock, some as large as 15 m across, and are foliated, in contrast to the more massive interiors of the plutons. Marginal zones in some places are more mafic than the pluton interiors, particularly along the east side of the Eshamy Granite where it intruded pillow basalt and diabase of the Orca Group. Dikes are abundant in country rock adjacent to the plutons.

Thermal aureoles surround all the plutons and range in width from a kilometer to several kilometers. Sillimanite and biotite, with some muscovite, are present in pelitic schist on the north side of the Esther Granite (Grant and Higgins, 1910); sillimanite and biotite occur in pelitic schist on the south side of the granite of Culross Island (near Applegate Island), and on the Lighthouse Reserve south of Port Nellie Juan. These schists probably are representative of the upper part of the hornblende-hornfels facies of metamorphism. Contact metamorphism has affected the sedimentary rocks between the Nellie Juan Granite, Eshamy Granite, and the granite of Culross Island, suggesting that all of these intrusive bodies may be connected at depth. The assemblages are typified by reddish-brown biotite quartz-feldspar assemblages of the hornblende-hornfels facies. The sedimentary rocks adjacent to the granite on Perry Island are typically yellowish-green chlorite- and epidote-bearing strata of the albite-epidote-hornfels facies.

Modal data (fig. 1) indicate a broad compositional range. The points in the tonalite range represent samples from the marginal area

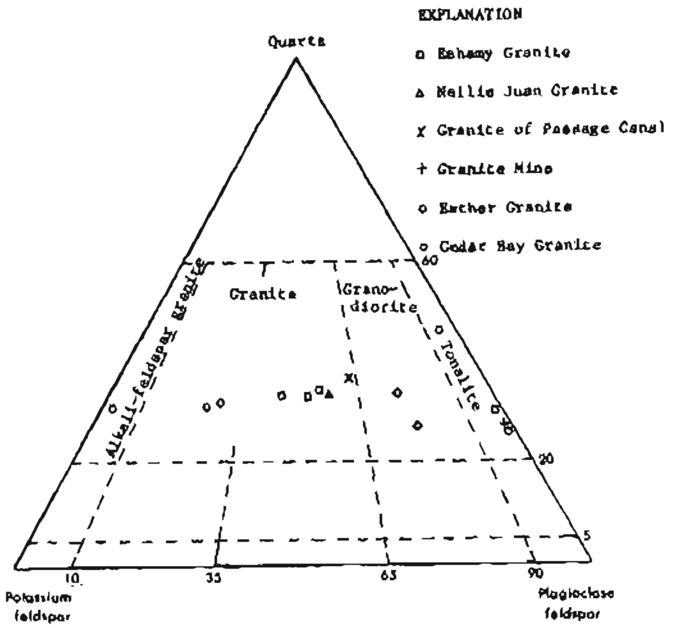

Figure 1.--Modal quartz-feldspar ratios of plutonic rocks from central part of Prince William Sound area. Classification from Geotimes (1973).

of the Eshamy Granite and from the tiny pluton immediately adjacent to the west side of Port Wells. The more mafic nature of the granodiorite samples from the Esther Granite compared to those from the other plutons may reflect incorporation of mafic rocks of the adjacent gabbro, which it intruded. A small range in the quartz content of the granitic rocks but a wide range in the potassium feldspar to plagioclase ratio is shown in figure 1.

Gabbro. Three gabbro plutons are closely associated with the granitic plutons in the central part of the Seward quadrangle. Grant and Higgins (1910) described two phases of a gabbro pluton that intrudes sandstone of the Valdez Group on Esther Island. One phase consists of poikilitic crystals of clinopyroxene enclosing labradorite; the other consists of clinopyroxene, labradorite, and olivine. At the southwesternmost corner of the body, fine-grained gabbro is cut by a porphyritic phase that contains plagioclase phenocrysts in a medium-grained groundmass. The gabbro is intruded by the Esther Granite.

Another gabbro body, intruded by the Eshamy Granite, crops out in a small area north of Paddy Bay. It is medium grained and composed of subequal amounts of labradorite and clinopyroxene; the clinopyroxene is largely altered to hornblende. We interpret this pluton to be of the same suite as the gabbro of Esther Island.

On Culross Island, where a granite pluton meets Culross Passage, Grant and Higgins (1910) observed an altered gabbro (not shown on map) that displays a partial ophitic texture and contains abundant labradorite. Although they noted the possibility that the gabbro might be a mafic phase of the granite, they believed this body to be a separate intrusion. This intrusion was not examined in the course of our study. It may represent the third occurrence of gabbro in this suite.

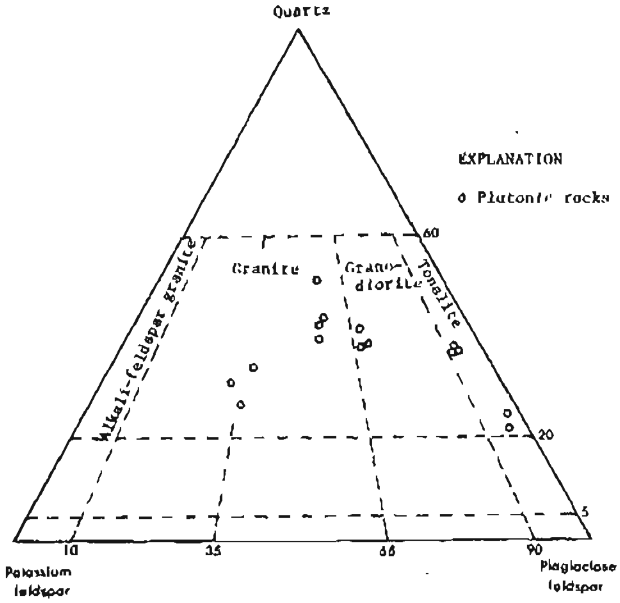

Figure 2.--Modal quartz-feldspar ratios of plutonic rocks of the Harding Icefield region. Classification from Geotimes (1973).

Because two of the three intrusive bodies of the suite intrude the Paleocene and early Eocene(?) Orca Group, the suite can be no older than Paleocene. If the bodies are in some way genetically related to the granodiorite and granite as their spatial distribution suggests, then the gabbros could be as young as Oligocene. Because of these uncertainties, this unit is assigned a Paleocene, Eocene, or Oligocene age.

Cedar Bay Granite. The Cedar Bay Granite, described originally by Grant and Higgins (1910), intrudes slate and sandstone of the Orca Group. The contacts are sharp, steep, and discordant to bedding of the country rock. The country rock adjacent to the granite is thermally metamorphosed near the granite. Samples of the Cedar Bay Granite plot in the potassium-rich part of the granite field, in the alkali-feldspar granite field, and in the tonalite field (fig. 1). The tonalite samples are from the marginal parts of the pluton. Table 2 lists chemical analyses of samples from the Cedar Bay, Esther, Nellie Juan, and Sheep Bay plutons. The Sheep Bay body, located about 60 km east of the boundary of the Seward quadrangle, is very similar chemically to the Cedar Bay Granite and has yielded an Eocene potassium-argon radiometric age of 41.3 m.y. on hornblende and 51.9 m.y. on coexisting biotite (Plafker, oral commun., 1977). Thus, on a chemical basis, the Cedar Bay Granite is considered to be of probable Eocene age.

Table 1. Potassium-argon ages and analytical data for Tertiary plutons of the Seward and Blying Sound quadrangles, Alaska

Locality No.	Name	Mineral	K_2O analyses (percent)	Average K_2O (percent)	^{40}Ar rad (10^{-10} moles/g)	^{40}Ar rad / ^{40}Ar total	Age (millions of years)	Location	Reference
1	Granite of Passage Canal	Biotite	8.00,8.05	8.02	4.388	0.61	36.6±1.0	North shore of Passage Canal; lat 60°50'N., long 148°29'W.	Lanphere (1966)
2	Esther Granite	Biotite	8.18,8.20	8.19	4.332	.59	35.5±0.9	East shore of Esther Lake; lat 60°50'N., long 148°03'W.	Lanphere (1966)
3	Nellie Juan Granite	Biotite	8.02,8.03	8.02	4.325	.85	36.1±0.9	South shore of Deep Water Bay; lat 60°29'30"N., long 148°23'W.	Lanphere (1966)
4	Eshamy Granite	Biotite	8.22,8.31	8.26	4.457	.81	36.2±1.0	East shore of Eshamy Lake; lat 60°27'N., long 148°06'30"W.	Lanphere (1966)
		Hornblende	.619, .626	.622	.3194	.48	34.4±1.2		
5	Granite of Harding Icefield Region	Biotite	9.260,9.250	9.255	8.266	.406	59.2±1.8	South tip of Aialik Peninsula; lat 59°42'25"N., long 149°31'23"W.	M.W. Silberman, written commun. (1977)
		Muscovite	9.130,9.090	9.110	7.464	.802	54.6±1.6		

Table 3.--Description of fossil localities shown on the map

Map Locality No.	USGS fossil location No.	Field Station No.	Collector and year of collection	Fossil (identifier)	Age	Location	Reference
A	M 5846	71ACs328	S.H.B. Clark and G.R. Winkler (1971)	Mollusc. Inoceramus kusiroensis (D.L. Jones)	Maestrichtian (Late Cretaceous)	North shore of Turnagain Arm; lat 60°57'23"N., long 149°25'09"W.	Jones and Clark (1973); Clark (1972)
B	M 5369	69ACs68 69ACs388	S.H.B. Clark (1969)	Mollusc. Inoceramus kusiroensis (D.L. Jones)	Maestrichtian (Late Cretaceous)	North shore of Turnagain Arm; lat 60°57'06"N., long 149°24'12"W.	Jones and Clark (1973); Clark (1972)
C	M 5848	71ACs2033	S.H.B. Clark, M.S. Yount, and P.S. Morse (1971)	Mollusc. Inoceramus kusiroensis (D.L. Jones)	Maestrichtian (Late Cretaceous)	South shore of Turnagain Arm; lat 60°54'40"N., long 149°27'35"W.	Jones and Clark (1973); Clark (1972)
D	M 6009		R.D. Budnik (1972)	Mollusc. Inoceramus kusiroensis (D.L. Jones)	Maestrichtian (Late Cretaceous)	Near Cooper Landing, Kenai Lake; lat 60°28'30"N. long 149°52'30"W.	Budnik (1974)
E	8603 (float)	13AJ218	B.L. Johnson (1913)	Mollusc. Inoceramya concentrica (T.W. Stanton)	Maestrichtian (Late Cretaceous)	Point Cochrane; about lat 60°46'N., long 148°22'W.	Johnson (1914)
F	Mf 3802	76ATz547A	R.G. Tysdal (1976)	Foraminifera. probably Globigerina or Subbotina (R.Z. Poore)	Probably Tertiary (specimens poorly preserved)	Northernmost tip of Evans Island; lat 60°09'35"N., long 147°58'15"W.	This report

Table 2.--Average chemical compositions (in percent) of two to four samples from each of Nellie Juan, Esther, Cedar Bay, and Sheep Bay Granites (from Grant and Higgins, 1910).

	Nellie Juan Granite	Esther Granite	Cedar Bay Granite	Sheep Bay Granite
SiO_2	72.7	66.7	77.6	79.4
Al_2O_3	13.8	15.6	11.7	10.1
Fe_2O_3	0.57	1.4	0.2	0.45
FeO	1.43	3.0	0.3	1.07
MgO	0.9	2.9	0.3	0.8
CaO	1.6	3.6	1.5	1.6
Na_2O	1.3	1.6	0.8	0.7
K_2O	7.4	4.9	7.3	5.4
H_2O	0.2	0.8	---	0.1
MnO	0.1	0.1	---	---
Total	100.0	98.6	99.7	99.62

Granite of Harding Icefield region. Granitic rocks of the Harding Icefield region form a batholith that crops out on many islands and two peninsulas in the southwest corner of the map area, westward from Rugged Island to Harris Bay. A sample of the batholith from the south tip of the Aialik Peninsula yielded an age of 59.2 m.y. from biotite and 54.6 m.y. from muscovite (table 1) (M. W. Silberman, written commun., 1977). This intrusion was first mapped in the coastal areas by Martin, Johnson, and Grant (1915). Our work shows that it continues a few kilometers west from Harris Bay, into the Seldovia quadrangle, then trends north for about 50 km, cropping out on several ridges and forming many nunataks in the Harding Icefield. The east boundary of the batholith lies 1 to 4 km west of the west boundary of the Seward and Blying Sound quadrangles, where the intrusion ranges in width from about 6 to 10 km along most of its length. The small intrusion in T. 1 N., R. 4 W. is interpreted as a cupola of the batholith. The batholith intrudes slate and sandstone of the Cretaceous Valdez Group and, near the Resurrection Peninsula, probably intrudes mafic igneous rocks of the Valdez Group as well. It cuts across the strike of bedding in many areas but, on the whole, is elongate parallel to regional structural trends. The contacts are sharp and steeply dipping and are bordered by a well-developed thermal aureole. In the inner part of the Northwestern Lagoon of Harris Bay, in the Seldovia quadrangle, the thermally altered rock weathers reddish brown. Samples from the main body of the batholith plot in the granite to granodiorite field of the modal diagram of figure 2, but samples from marginal parts commonly plot in the tonalite field. Inclusions of country rock several meters across are common near the margin of the intrusion, and pegmatite of quartz-feldspar-muscovite was observed near the margin in some places. Hornblende is best developed in a granite pegmatite a few kilometers west of the cupola of T. 1 N., R. 4 W. Black tourmaline crystals associated with muscovite and biotite occur in a pegmatitic phase of the tonalite on Hive Island in Resurrection Bay.

Felsic dikes are abundant locally in the Harding Icefield region and are most pronounced near the cupola of T. 1 N., R. 4 W. where they cut the tonalite. The dikes are composed almost wholly of plagioclase, with minor muscovite, quartz, and potassium feldspar. Some contain biotite and hornblende. Just north of the cupola, as many as 50 felsic dikes, about 1 m wide, intrude dark-colored rocks of the Valdez Group and form a pattern of black and white stripes on a glacially carved wall of bedrock. The dikes decrease in abundance farther to the north but are traceable intermittently for at least 20 km.

ORCA GROUP

The Orca Group is a thick sequence of isoclinally folded sedimentary rocks and basaltic igneous rocks that crop out in the eastern part of the map area. The sedimentary rocks mainly are rhythmically interbedded flysch of sandstone, siltstone, and, less commonly, mudstone. These strata were mapped as an undivided unit, except south of Knight Island where siltstone and mudstone were mapped separately. Pillow basalts, sheeted basalt dikes, and gabbro constitute mappable units of the Orca Group in some areas and were mapped with sedimentary rocks to form composite map units in a few other areas. Most of the Orca is metamorphosed to the chlorite zone of the greenschist facies, but rocks east of the Montague Strait fault are metamorphosed to zeolite or prehnite facies. A summary of the different rock units historically assigned to the Orca Group was presented by Moffit (1954); an interpretation of the depositional environment of the Orca Group was given by Winkler (1976); emplacement schemes for the igneous rocks of the group were presented by Tysdal, Case, Winkler, and Clark (1977).

Rocks originally assigned to the Orca Group are those on most of the islands in Prince William Sound and, in the Cordova quadrangle, those on the immediately adjacent mainland (Schrader, 1900; Grant and Higgins, 1910). In the Seward and Blying Sound quadrangles, rocks eastward from the trend of Bainbridge and Knight Island Passages to the west and north margins of Glacier Island previously were considered part of the Orca Group; those to the west of the trend were considered part of the Valdez Group (Grant and Higgins, 1910; Moffit, 1954). We were not able to distinguish a stratigraphic break along this trend during the course of our study. The north limit of the Orca Group in the map area, and throughout the regional extent of the unit and correlative rocks, is defined by the Contact fault system, a major structure that juxtaposes a late Mesozoic terrane on the north against the early Tertiary Orca Group on the south (Winkler and Plafker, 1975). The Orca extends eastward from the map area to near the Canadian border (Winkler and Plafker, 1975; George Plafker, Travis Hudson, and G. R. Winkler, unpub. data, 1976) and correlative rocks mapped on Kodiak Island to the south (Moore, 1967; 1969).

No certain age-diagnostic fossils have been obtained from the Orca Group in the map area. From west of the Montague Strait fault, however, on Evans and Bainbridge Islands, poorly preserved planktonic foraminifers that are probably referable to Globigerina or Subbotina suggest a Tertiary age (table 3); no taxa clearly of Cretaceous age were identified (R. Z. Poore, written commun., 1976). In the Cordova quadrangle, about 15 km east of Heather Island of the northeast corner of the Seward quadrangle, strata contiguous with those between the Montague Strait and Contact faults yielded a megafauna of crabs and pelecypods that originally was assigned an Eocene age (Plafker and MacNeil, 1966) but later was assigned a late Paleocene one (Addicott and Plafker, 1971). Microfossils suggestive of middle or late Paleocene age were found on Hinchinbrook Island of the Cordova quadrangle (Winkler, 1976) in strata that are on strike with those east of the Montague Strait fault of the Seward quadrangle. Farther east in the Cordova quadrangle, Orca strata yielded microfossils of late Paleocene or early Eocene(?) age (Tysdal and others, 1976). The paleontological data, combined with the stratigraphic and structural continuity of Orca rocks in the map area and to the east, indicate a Paleocene and early Eocene(?) age for the Orca Group in the map area.

Sedimentary rocks, undivided. Sedimentary rocks of the Orca Group make up a monotonous sequence of thin- to thick-bedded sandstone, siltstone, and mudstone showing abundant sedimentary structures indicative of deposition from turbidity currents. Common structures include graded bedding, crossbedding, ripple marks, and flute, groove, and load clasts. Sandstone is volumetrically more abundant than the finer grained rocks. It forms particularly prominent massive beds in a belt that trends from Johnstone Bay on the south through Nassau Fiord to the Unakwik Inlet area on the north. Pebbly sandstone and conglomeratic sandstone are widespread but volumetrically minor. They commonly occur at the base of sandstone beds and typically contain clasts of extrabasinal sedimentary rocks. Conglomerate is present at several places, as much as 100 m or more thick, and clearly resedimented (Winkler and Tysdal, 1977). It is intercalated with the turbidites, but as much as 50 percent of the clasts consist of well-rounded pebbles, cobbles, and boulders of felsic porphyry and granite that are foreign to the area. The sandstones are composed chiefly of quartz and plagioclase with a small to moderate percentage of volcanic rock fragments and a few percent potassium feldspar grains. Minor detrital grains include biotite, epidote, and metamorphic rock fragments. Limestone locally forms small bioturbated lenses and, on Montague Island, forms abundant concretions in sandstone. Limestone lenses are described more fully in the section on the composite map unit of pillow basalt and sedimentary rocks (Tops).

Siltstone. Siltstone and mudstone are common in the sedimentary rocks of the Orca Group, but they were mapped as a separate unit only in the area of Elrington, Evans, and Bainbridge Islands where an extensive coastline permitted rapid reconnaissance mapping. These fine-grained rocks are distributed more widely than is readily apparent from the map as they also constitute most of the sedimentary rocks that are intruded or interlayered with the basaltic sills, pillow flows, and pillow breccias of the composite greenstone-sedimentary rock map units. The unit is composed of siltstone, mudstone, local thin interbeds of sandstone, and a few lenses of limestone, all of which are tightly folded and have undergone low-grade metamorphism.

On the northwest ends of Evans and Flemming Islands are lenses of limestone as much as 2 m thick and several tens of meters long. One of the limestone lenses on Evans Island is about 2 m thick and grades into calcareous siltstone (slate) that envelops the lens. The lower slate unit overlies pillow basalt and the upper slate unit is overlain by pillow basalt. On Flemming Island a 2-m-thick limestone lens lies directly on pillow breccia and is succeeded by slate that is overlain by pillow basalt. Smaller lenses of limestone occur at other places on these islands and on Bainbridge Island.

At several places within the same group of islands, locally folded and contorted sequences of strata are present within an otherwise uniformly layered section. These sequences are believed to be olistostromes. They involve not only disharmonically folded sedimentary rocks but also patches of isolated greenstone blocks mixed with sandstone and siltstone.

Pillow basalt. Pillow basalts of the Orca Group in Prince William Sound were described by several workers, most extensively by Capps (1915) and Richter (1965). Pillow basalt and associated breccia and tuff of the Orca Group make up large parts of Glacier, Lone, Knight, and Elrington Islands, forming a unit that is more than 5,000 m thick on Knight Island. The pillows are closely packed; individual pillows commonly are as large as 4 m across. Most are elongate, some being about a meter across and as much as 8 m long. Elongation generally is parallel to the dip direction of the pillow sequences. Many of the elongate pillows are multilobed, and pillow bifurcations generally indicate flow crudely parallel to the present dip direction. The pillows have chilled margins, many with palagonitic coatings, and cracks that radiate outward from the pillow centers. Amygdaloids are common, characteristically in the pillow rind, but also extending radially in streamers toward the pillow center. The amygdules are as much as 3 cm in diameter but decrease in size inward through the pillows. Some pillows have hollow cores that were subsequently filled with quartz.

Pillow breccia and tuff are common between pillows but are subordinate in quantity to the pillows. Breccia and tuff make up a greater percentage of the pillow sequence on Glacier Island than on the other islands. Minor red, green, and gray chert is present locally in interpillow areas, and tiny clots of limestone occur in a few places. At the north end of Knight Island, the pillows are larger, more vesicular, and less deformed than farther south, and pillow breccia is less abundant. The transition from pillow basalt to sheeted basalt dikes is not abrupt but occurs over a wide zone, and dikes are abundant within the marginal zone of the pillow basalt. A few dikes are distributed randomly throughout the flow sequences and probably were the feeders for the pillows.

Thin sequences of siltstone and minor sandstone are locally interbedded with the pillow basalt (Capps, 1915; Moffit, 1954; Richter, 1965; Tysdal and others, 1977). The sandstone contains wispy crossbeds and graded beds that indicate top directions in agreement with pillow tops. At the north end of Knight Island, a bioturbated lens of limestone is present in the interbedded sedimentary sequence. At several places it is apparent that pillows were extruded onto mud, which oozed around the pillows and filled cooling cracks in their rinds, a feature also observed by Capps (1915) in eastern Prince William Sound. Baking of the mud in the process is commonly indicated by bleached mudstone immediately adjacent to pillows. The pillows presumably had shallow dips when they were deposited originally. Most of those on Glacier Island have gentle dips. On Storey Island, where only one flow sequence is known, pillows form several layers with interbedded argillite in a section that is chiefly sandstone; the entire section is deformed into a series of anticlines and synclines.

Pillow basalt and sedimentary rocks. Areas that contain about equal amounts of pillow basalt and sedimentary rocks are shown as a separate map unit. These areas are present chiefly on Elrington, Evans, and Bainbridge Islands. Its sedimentary rocks are composed of siltstone and minor sandstone.

Sheeted basalt dikes. Sheeted dikes of the Orca Group crop out on Glacier and Knight Islands, but the dikes of Knight Island are much more extensive. The dikes are aphyric to porphyritic, locally gabbroic, and mainly are mafic rocks of basaltic composition; felsic plagioclase-quartz dikes are present in a few places. Xenoliths of gabbro and peridotite were observed by Richter (1965) in "massive rocks" (sheeted dikes) of the east and southeast shores of Drier Bay. The dikes are commonly 1 to 2 m thick and are vertical or nearly so. Most of them trend a few degrees east of north, forming the topographically rugged central part of Knight Island, but divergent trends were observed in the zone of transition to the pillow basalt sequence in the Drier Bay area. Dikes were intruded between, into, and across preexisting dikes. Isolated patches of slate within the area of sheeted dikes were observed by Richter (1965).

The dikes of both islands are flanked by pillow basalt sequences that are interpreted as the surface expression of the dikes. One of the best exposures of the transition from dikes to pillow basalt occurs adjacent to Chamberlain Bay on Glacier Island, across a zone that is more than 2 km wide. Rocks on the east side of the bay are nearly all dikes, those on the west side are subequal dikes and screens of pillow basalt and breccia, and rocks farther west are nearly all pillow basalt and breccia.

Greenstone and sedimentary rocks. Basalt sills in steeply dipping slate and sandstone form mappable units at the north and south ends of the sheeted dike complex on Knight Island. On Elrington, Evans, and Bainbridge Islands, extensive basalt sills intrude a steeply dipping sedimentary sequence that is chiefly siltstone metamorphosed to slate. Thermal metamorphism of the sedimentary rocks adjacent to these sills is evident for as much as 1 m away from the contact and is characterized by hard, bleached, siliceous siltstone. The sills are commonly 2 to 3 m thick, but some several tens of meters thick were seen on the west side of Evans Island. The composition and texture of the sills are similar to those of the sheeted dikes. In the Bay of Isles area of Knight Island, the sills show evidence that they are transitional into the sheeted dike complex. The sills commonly occur as isolated tabular bodies separated by sedimentary rocks, but in some places they are adjacent and locally are intruded by younger basalt sills.

Gabbro and diorite. Several small intrusive bodies of gabbro and diorite occur on Knight Island. Two small bodies of diorite, mapped by Richter (1965), crop out northwest of the head of Drier Bay and are elongate about parallel to the trend of the sheeted dikes. The other gabbro and diorite bodies, some too small to show on the map, are irregularly shaped and crosscut the sheeted dikes. At the head of Hogan Bay, siltstone and sandstone are thermally altered adjacent to a gabbro intrusive body and form xenoliths within it. A gabbro dike that intrudes slate and sandstone at the north end of Latouche Island was described by Grant and Higgins (1910, p. 49-50). It is at least 30 m wide and is itself cut by several small gabbro-pegmatite dikes.

Greenstone, undivided. A few small areas of mafic igneous rocks were mapped as undivided greenstone because a more definitive classification is uncertain. Several outcrops of greenstone on the north side of Blying Sound are sheared, and the original form of the mafic rocks is unknown; some may have been pillow flows, others tuffs or sills. One greenstone body on the northeast side of Whidbey Bay forms a dike that cuts sedimentary rocks in a small outcrop, but in its overall extent the greenstone may be better classified as a sill. Small outcrops of greenstone on the northwest side of Knight Island Passage and on Outpost Island (west of Glacier Island) were mapped as greenstone by previous workers and were not visited during the course of our study.

VALDEZ GROUP

The Valdez Group constitutes most of the rocks in the west half of the map area and is composed chiefly of rhythmically interbedded sandstone, siltstone, and minor mudstone and pebble conglomerate; these strata are mapped as Valdez Group, undivided. On the Resurrection Peninsula, the Valdez Group contains mappable units of tuff and pillow basalt interbedded with the sedimentary rocks, sheeted basalt dikes, gabbro, and ultramafic rocks. North of Resurrection Peninsula, sedimentary rocks of the Valdez Group and interbedded tuff and (?)pillow basalt that are metamorphosed to a schist were mapped separately, as was a distinct ridge-forming mud-chip sandstone in the northwest corner of the Seward quadrangle. Depositional environments of some of the sedimentary rocks were interpreted by Budnik (1974) and by Clark (1972); description and interpretation of the igneous rocks was presented by Tysdal, Case, Winkler, and Clark (1977).

The areal distribution of the Valdez Group was presented by Tysdal and Plafker (1978) and the distribution of rocks previously assigned to the group was summarized by Moffit (1954). The Valdez Group has been traced east from the northwest corner of the map area across the Valdez, Cordova, and Bering Glacier quadrangles to the Canadian border (George Plafker, Travis Hudson, and G. R. Winkler, unpub. data, 1976) and southwest from the map area across the Kenai, and Seldovia quadrangles (R. G. Tysdal and J. E. Case, unpub. data, 1976; George Plafker, unpub. data, 1975). The south limit of the Valdez Group is defined by the Contact fault system, described previously. The north limit is defined by the Border Ranges fault system, a major system of faults that extends eastward from the Kodiak group of Islands, across part of the Seward quadrangle, into Canada, and probably into southeastern Alaska (MacKevett and Plafker, 1974; Plafker and others, 1977), or by the Eagle River thrust fault and related faults (Clark, 1972; Plafker and others, 1977; Tysdal and Case, 1977a). The entire sequence is intensely folded and regionally metamorphosed to grades ranging from zeolite facies and lowermost greenschist facies, to the upper zones of the amphibolite facies.

The Valdez Group had been considered Jurassic or Cretaceous mostly because the few poorly preserved Inoceramus and Inoceramya specimens from the unit could not be identified at species level and because correlation of the Valdez with other strata was uncertain (Plafker and MacNeil, 1966; Case and others, 1966). However, recent mapping in the Chugach Mountains by Plafker and Hudson (unpub. data, 1976) has demonstrated continuity of the Valdez Group between Port Valdez, its type area, and the Seward quadrangle. With the study of new collections and restudy of previously collected specimens from the Valdez Group, fossils identified to species level are Inoceramus kusiroensis or Inoceramya concentrica, indicative of a Maestrichtian (latest Cretaceous) age (Jones and Clark, 1973) (table 3). Even though the Inoceramya from the type area of the Valdez Group is identifiable only to the genus level, the Valdez rocks of the Chugach terrane form an uninterrupted mappable unit and are considered Cretaceous (Tysdal and Plafker, 1978). No Jurassic fauna is known from the Valdez Group, and no pre-Late Cretaceous intrusive rocks are known to be emplaced within the sequence.

Sedimentary rocks, undivided. The sedimentary rocks of the Valdez Group form a flysch unit that is several thousand meters thick. Sedimentary structures indicative of turbidite deposition, other than graded bedding, were observed only locally in the flysch, probably owing to deformation and metamorphism. The most extensive study of the Valdez Group in the map area is that of Budnik (1974), who described strata between Moose Pass and the west margin of the Seward quadrangle. Although he recognized five mappable rock units, our reconnaissance work requires a more generalized description.

The distribution of rock types in the Valdez Group is broadly parallel to the major faults. Siltstone and mudstone, metamorphosed to slate, are abundant in a belt several kilometers wide that trends northward from the southern part of the map area through Upper Russian Lake, Gilpatrick Mountain, and the Bird Creek area. This belt of fine-grained rocks has yielded the Inoceramus specimens on which the age of the Valdez Group is largely based (localities shown on map). Similar fine-grained rocks are present in a poorly defined belt west of the Contact fault (west of Cochrane Bay) that trends northward along the west side of Port Wells into the Barry Arm area of the Anchorage quadrangle. Inoceramus specimens have been collected from these strata in both quadrangles (Johnson, 1914). The area adjacent to the east side of the Placer River fault is dominated by massive beds of sandstone and less abundant slate. East of the Eagle River fault(?), the amount of sand in these sedimentary rocks decreases eastward into the belt of siltstone and mudstone and then, about the longitude of the highway from Sunrise to Summit Lake, increases eastward. Beds of chert have been found in the siltstone rocks on Marathon Mountain west of Seward.

Tuff. Bedded tuffs crop out on the west side of the Resurrection Peninsula and continue northward as part of a belt of schist (unit Kvs). Most of the tuff beds are too thin and discontinuous to map separately, but on Renard Island, west of Resurrection Peninsula, tuffs form mappable lenticular sequences a few meters thick and several tens to hundreds of meters long (Grant and Higgins, 1910; Martin and others, 1915). The fine layering of the tuffs appears similar to that of compressed welded tuffs, having a wavy foliation. The tuffs interlayer and interfinger with slate and sandstone turbidites of the Valdez Group and are therefore believed to be aquagene tuffs. They probably represent products of submarine explosive volcanism closely related to formation of the mafic and ultramafic rocks of the Resurrection Peninsula (Tysdal and others, 1977). Chemical analyses show that the tuffs are basaltic in composition (G. R. Winkler, oral commun., 1976).

Pillow basalt. Pillow basalt and less abundant pillow breccia and tuff make up most of the western flank of the sequence of mafic and ultramafic rocks of the Resurrection Peninsula. The pillows are right side up, dip 30° to 50° W., with long axes of the pillows and pillow bifurcations plunging westward downdip. Siltstone, metamorphosed to slate, is interbedded locally with the pillows, as first described by Grant and Higgins (1909, p. 99). Some of the siltstone is siliceous and contains interbeds of crossbedded sandstone that indicate the sequence is right side up. Pillow basalt also is present locally at the base of the tuff-turbidite sequence of Renard Island.

Sheeted basalt dikes. Sheeted dikes make up the topographically rugged backbone of the Resurrection Peninsula and occur between the pillow basalt (Kvp) and gabbro (Kvg). The dikes intrude the pillow basalt sequence and are intruded by the gabbro. Basalt dikes were observed to cut the gabbro. Most of the dikes dip steeply and trend about north, parallel to the axis of the peninsula, but a significant number in the southern part of the peninsula trend west to northwest. No evidence of structural reorientation was found for the westerly trending dikes. A traverse across 100 dikes near the south end of the peninsula showed that most dikes have chilled margins on both sides and thus were intruded between existing dikes. A few dikes, however, intruded into previously formed dikes. Dikes in two-dimensional exposures commonly appear to be oriented parallel to one another, like sheeted sills, but crosscutting relations are evident in three-dimensional exposures. The thicknesses of the dikes measured in the 100-dike sequence range from a few centimeters to as much as 5 m, but most dikes are 1 to 2 m thick.

Gabbro. A gabbro pluton, with local dioritic phases, crops out on the east side of the Resurrection Peninsula. It is chiefly medium to coarse grained with widely scattered areas of pegmatite (clinopyroxene crystals as much as 5 cm long), but it is fine grained near its margins. Pyroxene makes up as much as 60 percent of the rock in some areas. 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. The pluton also cuts across the sheeted dikes but, on the whole, is elongate north-south, parallel to (and east of) them. A gabbro pluton too small to show on the map is located on the west side of the Resurrection Peninsula in the pass at the head of Likes Creek. This pluton intrudes phyllitic metasedimentary rocks that are interbedded with pillow basalt nearby.

Ultramafic rocks. Serpentinized dunite forms pods and dikelike intrusions in gabbro and metasedimentary rocks on the east side of the Resurrection Peninsula. All of the dunite bodies are serpentinized to some extent, strongly sheared, and slickensided. From the Placer River fault to about 500 m west, interrupted exposures of altered gabbro and dunite are present. The dunite is broken into irregular slickensided blocks and locally is sheared into a schist (Martin and others, 1915, p. 223-224). The associated gabbro is fractured, and locally sheared and altered, in areas of intrusion of the serpentinized rock. About 1.5 km west of the Placer River fault, serpentinized dunite forms irregularly shaped intrusions in the metasiltstone and metatuff. One dunite intrusive several meters wide is oriented parallel to foliation of metatuff and is traceable a few hundred meters along strike. It also fills small fractures in the metatuff that are oriented perpendicular to foliation. About 1 km farther west, a 20- to 30-m-wide, nearly vertical, dikelike serpentinized dunite intrudes gently dipping metasedimentary and metatuff rock and is traceable along strike for more than 2 km. The most competent parts of this tabular body form reddish-weathering boulders that contain visible layers of chromite. The serpentinized bodies are believed to have been emplaced when relatively cool, as no thermal metamorphism of adjacent country rock is evident. Fractured and sheared country rock marks the locus of some of these intrusions, and all of them probably were intruded along fault zones.

Schist. Schist forms a north-trending belt of rocks about 5 km wide and more than 70 km long in the western part of the map area. The belt is the only extensive area of schistose rocks in the map area and is conspicuous by virtue of its schistosity. The Placer River fault (Tysdal and Case, 1977b) marks the east limit of the schist unit, which grades into phyllite on the west, north, and south sides. Rocks of this belt are metamorphosed sandstone, siltstone, tuff, tuffaceous sandstone, and basalt (pillow basalt?) of the Valdez Group. The igneous rocks clearly are interbedded with the sedimentary rocks but are discontinuous along strike. Most of the rocks in the schist belt have been metamorphosed to the biotite zone of the greenschist facies, and they decrease in grade to the chlorite zone in the flanking phyllitic rocks.

Schist also is present on Renard Island and on the Resurrection Peninsula. Between these isolated areas and the main part of the schist belt farther north, the rocks are phyllitic or massive and are metamorphosed to the chlorite zone, except along the west margin of the pillow basalt unit (Kvp), where phyllite of the biotite zone is present locally. Metatuff units, too thin to map separately, are present in the undivided Valdez Group rocks of the same area.

McHugh Complex. The McHugh Complex was named by Clark (1972, 1973) for an assemblage of rocks that crop out in the Anchorage quadrangle, north of Turnagain Arm. Clark recognized a clastic and a volcanic unit in the McHugh, stating that the two are lithologically distinct but chaotically juxtaposed and that a melange-like structure is characteristic of parts of the complex. In the McHugh Complex of the Seward quadrangle, melange is characteristic of the rocks between the Border Ranges fault and the unnamed fault to the east. The melange is chiefly sheared sandstone and streaked-out, fine-grained rocks that probably were siltstone and mudstone. Also present are blocks of unsheared sandstone like that of the massive sandstone (unit KJm?) (described below) and isolated pods of sheared mafic and ultramafic rocks; the mafic and ultramafic rocks are not nearly so abundant as in the McHugh north of Turnagain Arm. Bedded chert, tuff, pillow basalt, and minor conglomerate occur in some areas.

A massive sandstone unit (KJm?) contains abundant debris of mafic volcanic rocks and chips of mudstone that give the sandstone a distinctive spotted appearance. Thin beds of white chert are present locally, and a few thin sequences of thin-bedded sandstone grading upward to siltstone also occur. The unit contains local beds of conglomeratic sandstone and, in the area north of Little Indian and Cripple Creeks, is a conglomerate. The clasts are pebbles, cobbles, and a few boulders of granite, greenstone, sandstone, siltstone, limestone, and chert.

In a previous publication (Tysdal and Case, 1977a), we interpreted this sandstone immediately west of the Eagle River thrust fault(?) to be a unit transitional with the Valdez Group, but we now suspect that its lithology and topographic expression are more suggestive of clastic rocks of the McHugh Complex as defined by Clark (1973). No compelling evidence was found for a fault at the contact of the massive sandstone with Valdez strata, but we believe this lack of evidence probably reflects tectonic juxtaposition of indurated massive sandstone against only semilithified sediments of the Valdez Group, as discussed later in the section on faults.

No fossils were obtained from the McHugh Complex during the course of our investigation. On the basis of radiometric dates on granitic clasts obtained from conglomerate, and on fossils, Clark (1973) concluded that the McHugh Complex was Late Jurassic and(or) Cretaceous in age. The correlative Uyak Complex of Kodiak Island yielded radiolarians (identified by E. A. Pessagno, Jr.) as young as Valanginian and Aptian (Early Cretaceous) (W. Connelly, personal commun., in Cowan and Boss, 1978, p. 157).

FAULTS

The Orca and Valdez Groups and the McHugh Complex are parts of a highly deformed flysch belt that extends along the north side of the Gulf of Alaska from Kodiak Island to southeastern Alaska. The Valdez Group and the McHugh Complex are believed by Plafker, Jones, and Pessagno (1977) to have been deformed and accreted to the continent by latest Cretaceous time, whereas we believe that these processes probably continued into the early Tertiary. The Orca Group was deformed and accreted to the continent along the south side of the Valdez Group and equivalent rocks during the Paleogene (Winkler and Plafker, 1975; Plafker and others, 1977). Both subduction complexes underwent regional deformation during at least 90° of counterclockwise oroclinal bending that took place in latest Cretaceous and Paleogene time (Plafker and others, 1977). These deformative processes were accompanied by intense folding and faulting which, at least in some areas, combined to shorten the section of rocks by as much as 50 percent or more (Plafker, 1969). The faults in the map area are described below in order from west to east.

The Border Ranges fault is the landward contact of the wedge of rocks composed of the McHugh Complex and the Valdez Group that were accreted to southern Alaska (MacKevett and Plafker, 1974; Plafker and others, 1977). This plate boundary fault juxtaposes upper Paleozoic rocks overlain by Mesozoic shelf deposits on the north against mainly upper Mesozoic deep marine rocks on the south for more than 1,700 km in the northern Kodiak, Kenai, Chugach, and Saint Elias Mountains and the Alexander Archipelago (MacKevett and Plafker, 1974; Plafker and others, 1976, 1977). In the Seward quadrangle, the fault is believed to trend northeastward beneath the Holocene deposits of Chickaloon Bay and the Kenai Lowland, as shown by MacKevett and Plafker (1974) and Tysdal (1976).

The unnamed fault east of the Border Ranges fault trends across the northwest corner of the Seward quadrangle and has apparent dips that range from as low as 30° W. to nearly vertical. This well-defined fault marks the east margin of rocks in the McHugh Complex that were deformed into a melange.

The Eagle River thrust fault was named by Clark (1972) for the structure that marks the east limit of the McHugh Complex in the Anchorage quadrangle. The location of the fault in the Seward quadrangle is probably delimited by the east margin of the ridge forming massive sandstone (KJm?) and is not expressed well, but must be steep along most of its length. This sandstone unit is not severely broken up and apparently behaved as a coherent mass that was thrust over the Valdez Group during accretion of McHugh and Valdez rocks to the continent. Sediments of the Valdez Group most likely were only semilithified during this time, and thrusting of the McHugh Complex over the Valdez probably was accomplished in some places by semiplastic flowage of fine-grained Valdez strata, producing a fault contact that is poorly expressed along some segments.

The Placer River fault (Tysdal and Case, (1977b) extends from Day Harbor at the south to beyond Turnagain Arm at the north, a distance of about 70 km. It constitutes a shear zone that ranges from about 50 to 150 m wide and locally is marked by surface features that include notches, stream valleys, and benches on the downthrown side. The fault dips about 65° W. or more along most of its length, although a dip of 50° W. was measured east of Seward. The fault juxtaposes slate, sandstone, and greenstone of the Valdez Group, metamorphosed to the chlorite and biotite zones of the greenschist facies, over other rocks of the Valdez Group that largely are metamorphosed to the chlorite zone of the greenschist facies. Rocks west of the fault form a prominent metamorphic belt characterized by well-developed schistosity. No trace of the fault was seen in the unconsolidated sediment east of Turnagain Arm, and no evidence of recent movement was found along any part of the fault.

The Port Wells fault is a nearly vertical fracture that is marked by a zone of sheared and broken rock several hundred meters wide. It is believed to have undergone both strike-slip (right lateral?) and dip-slip movement with the west side up. A large part of the movement probably preceded the regionally widespread granitic intrusions.

The Contact fault is a major structure along the south margin of the Valdez Group that extends north from Kodiak Island through the Prince William Sound area and east to near the Canadian border (Winkler and Plafker, 1975). It is the contact along which the Orca Group was accreted to southern Alaska in Paleogene time (Plafker and others, 1977). In the Seward quadrangle, the fault is represented by sheared and fractured rock in a zone that generally ranges from about 2 to 4 km wide, increasing in width in the southern part of the quadrangle. The contrast in metamorphic grade decreases across the fault from north to south. North of Wells Passage, the upper plate contains rocks belonging to the biotite zone of the greenschist facies, whereas the lower plate contains rocks belonging to the chlorite zone. South of Wells Passage, rocks of the chlorite zone occur on both sides of the fault zone, and the exact location of the fault is difficult to define. The intensity of deformation along the fault zone decreases from north to south. North of Wells Passage, both protomylonite and microbreccia are common; between Wells Passage and Kings Bay, microbreccia is more common; south of Kings Bay, protomylonite is uncommon and microbreccia is widespread. North of Wells Passage, where the fault was mapped by George Plafker (unpub. data, 1974), a fairly well defined fault plane is present and dips about 50° W. Between Wells Passage and Kings Bay, the fault is drawn along the locus of the most intensely deformed rocks. Shearing of the strongly deformed rocks along nearly vertical planes suggests that the fault zone is oriented similarly. South of Kings Bay, segments of a well-defined, nearly vertical fault were observed in the area west of Ellsworth Glacier. The dashed extensions from this area southward represent a trace through rock that is the most extensively fractured. Away from the zone of the greatest fracturing, deformation of cataclastic textures in the rocks are most obvious in thin section.

The Johnstone Bay fault is a minor structure that dips steeply to the west and has a zone of breccia a few tens of meters wide. The fault was mapped from aerial photographs by Condon and Cass (1958) whose map shows it to be connected with the small fault north of Icy Bay. We found no evidence of a fracture that would connect the two faults. Packer, Brogan, and Stone (1975) state that along the fault, as mapped by Condon and Cass (1958), tensional forces may be active. We did not observe any evidence of Holocene activity along the Johnstone Bay fault, as mapped by us. Vegetated talus deposits along much of the fault are cut by a linear fissure a few meters deep. Local filling of the fissure with younger talus deposits that are not cut by fissures, however, suggests that no slippage on the fault has taken place since the talus was deposited.

The Beatson fault, recognized in the early part of the century during exploration for copper, is characterized by a zone of gouge, sheared and shattered rock, and cavey ground (Bateman, 1924). Underground studies at the Beatson mine (loc. 256 of Tysdal, 1978) by Bateman showed that the fault dips about 60° W. From there, the fault was mapped a few kilometers to the north and south, and Moffit (in Bateman, 1924, p. 348) believed that it extended nearly the full length of the island. The southern part of the fault (queried on the map) was not observed in the field during the course of this study.

The Montague Strait fault, concealed beneath Prince William Sound for its entire length, is required to explain geologic contrasts between the rocks of Montague Island and those of Knight, Latouche, and the other islands west of Montague Strait. West of the strait, the rocks are indurated sandstone and slate metamorphosed to the chlorite zone of the greenschist facies. East of the strait, the rocks are less indurated sandstone and shale and are metamorphosed to the prehnite facies and(or) zeolite facies. The strike of rocks west of the strait is a few degrees east of north. East of the fault, the rocks strike about N. 45 E. on Seal and Green Islands.

The Hanning Bay fault, mapped and described by Plafker (1967), is a smaller fault about 6.5 km long that dips 50° to 75° W. During the 1964 Alaska earthquake, the fault underwent a dip-slip component of movement of as much as 6 m with the west side upthrown.

The Patten Bay fault as exposed on Montague Island was mapped and described by Plafker (1967). This fault dips about 50° to 75° W. for most of its 35-km length. Active during the 1964 Alaska earthquake, the fault underwent a dip-slip component of movement of as much as 7.9 m, west side upthrown. It is represented by a complex system of right-stepping en echelon reverse faults and associated flexures. The fault system can be traced on the sea floor southwest of the island for about 27 km, as shown by Malloy and Merrill (1969), and may extend southwestward on the sea floor for as much as 500 km (Plafker, 1969).

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