UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

STRUCTURE AND STRATIGRAPHY OF THE PYBUS-GAMBIER AREA, ALASKA

by

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This report is preliminary
and has not been edited for
conformity with Geological
Survey format and nomenclature.

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ABSTRACT

The Pybus-Gambier area comprises about 215 square miles of uninhabited land on the southeastern coast of Admiralty Island, southeastern Alaska. The section consists of more than 20,000 feet of intensely folded sedimentary, volcanic, and metamorphic rocks, all probably of marine origin, ranging in age from Silurian(?) to Early Cretaceous, unconformably overlain by more than 10,000 feet of gently dipping nonmarine, coarse-grained sedimentary rocks, and basalt and andesite flows of Eocene age. Diorite plutons and associated contact metamorphic rocks occur in the little-known northwestern part of the area.

The section is here subdivided into nine formations, eight of which are named for the first time, as follows: Gambier Bay formation of Middle(?) Devonian age, composed of greenschist, phyllite, marble, and metachert; Hood Bay formation of Silurian and Devonian age, composed of dark, carbonaceous, thin-bedded chert, argillite, limestone, and graywacke; Cannery formation of Permian age, composed of thin-bedded chert, argillite, and graywacke; Pybus dolomite of Permian age, composed of fossiliferous, cherty dolomite; Hyd formation of Late Triassic age, composed of a basal chert breccia, a limestone member, a thin-bedded argillite member, and a spilitic volcanic member; Seymour Canal formation of Late Cretaceous and Early Cretaceous age, composed of argillite, graywacke, and conglomerate; Brothers volcanics of Early Cretaceous age, composed of andesitic flows and breccia; unnamed conglomerate and sandstone of Eocene age, and Admiralty Island volcanics of Eocene age, composed of basaltic and andesitic flows.

A marked angular unconformity occurs at the base of the Tertiary section, and unconformities of less angularity occur as follows: at the

base of the Cannery formation; at the base of the Hyd formation, and at the base of the Seymour Canal formation. In general pre-Seymour Canal deformation seems to have been mild, but the intensity of the post-Gambier Bay - pre-Cannery deformation is uncertain. The complex structure of the pre-Tertiary rocks seems to be the product chiefly of the post-Seymour Canal - pre-Eocene deformation.

The structure of the pre-Tertiary rocks is studied by graphical statistical analysis of the preferred orientation of the planar and linear structural elements. This analysis indicates that the post-Seymour Canal - pre-Eocene deformation consisted chiefly of three episodes of folding, all of which appear to have resulted from subhorizontal, northeast-southwest compression. The first episode produced isoclinal folds in bedding, and in places associated axial plane foliation, that had north-northwesterly striking axial planes in eastern Pybus-Gambier area, but generally northeasterly striking axial planes west of False Point Pybus. Compression during the second episode deformed the first folds in the west where their axial planes were oriented about parallel to the compression into complex second folds in both bedding and axial plane foliation, having northwesterly striking axial planes. The second folds are absent in the east where the axial planes and limbs of the first folds were oriented about normal to the second compression. The divergence of the axial planes of the first folds in the west from those in the east may have been caused by the crowding of the first folds in the west against the irregular western margin of the geosyncline during the first compression. Northwest-striking thrust and reverse faults occur between domains in which the axial planes of the first folds are strongly divergent. The third episode produced kink folds, having axial planes with subvertical dips but widely varying strikes, that are confined to the thinly fissile schists and

phyllites of the Gambier Bay formation.

The episodes of folding in the Gambier Bay formation are accompanied by metamorphic recrystallization not found in either younger or possibly coeval (Hood Bay formation) pre-Tertiary rocks. If these episodes are contemporaneous with those in nonmetamorphic pre-Tertiary rocks, then the metamorphism dies out both vertically and laterally, and may be part of the regional decrease in metamorphism westward away from the Coast Range batholith, located about 25 miles to the east.

The gently dipping Tertiary strata have been broken into fault blocks by subvertical, north- and northeast-striking, normal and reverse faults.

INTRODUCTION

Location and physical geography

The Pybus-Gambier area is located on the southeast coast of Admiralty Island about 60 airline miles south-southeast of Juneau in southeastern Alaska (fig. 1). Admiralty Island, which is about 100 miles in length, is the northeasternmost large island of the Alexander Archipelago.

The area comprises the Sitka B-1 and the Sumdum B-6, 15-minute quadrangles of which about 215 square miles are land. The highest and most rugged part of the Pybus-Gambier area occurs southwest of Pybus Bay where one peak rises to 3,853 feet above sea level. Elsewhere, except for a few peaks in the northwest, the topography is subdued and seldom rises above the timberline (between 1,500 to 2,000 feet). Below the timberline the country is covered by a dense forest of spruce and hemlock containing scattered muskeg bogs.

The coastline of the area is deeply indented in the south by the northwest-trending Pybus Bay, and in the north by the more westerly trending Gambier Bay. Numerous small islands dot the two bays, and a few occur offshore in Stephens Passage. In a general way the elongations of the bays and the alignment of islands within them reflect the structural grain of the underlying rocks.

The area is drained by numerous small, short rivers many of which occupy in their lower reaches broad U-shaped valleys characteristic of glacial channels. The floors of the valleys contain scattered deposits of glacial clay and gravel together with recent alluvial deposits. The

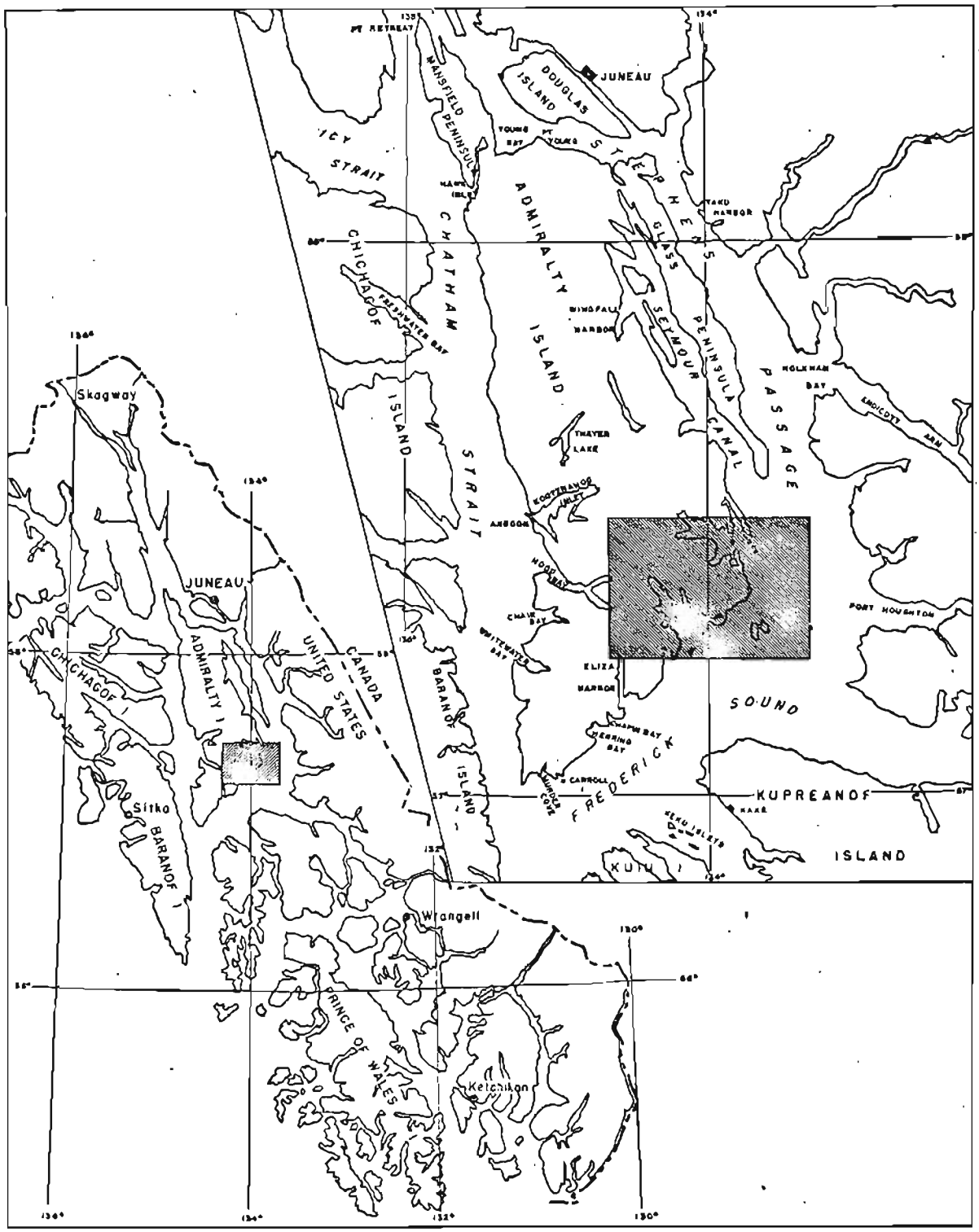


Figure 1.--Index map of southeastern Alaska showing location of the Pybus-Gambier area.

only glacial ice remaining in the area is a small patch glacier west of Little Pybus Bay near the south border of the map.

In longitudinal profile the larger streams commonly have a steep-gradient channel in their upper courses where they are cutting a narrow V-shaped valley in bedrock. In their middle courses the streams flow with a low gradient over largely glacial and alluvial deposits, but in a few places they cut narrow gorges in bedrock. Before entering their lower courses, the streams commonly cut steep-gradient gorges with falls and rapids in bedrock. In their lower reaches the stream again assume a low gradient and flow over alluvial deposits and in places bedrock before reaching salt water.

The Pybus-Gambier area has the moist, moderate climate characteristic of southeastern Alaska in general. The nearest weather stations are located at Five Fingers Light just beyond the southeastern corner of the area, and at Angoon on the west coast of Admiralty Island about 10 miles west of the northwestern corner of the area.

The following data from these two stations illustrates the local climate (U. S. Weather Bureau, 1959):

Five Fingers Light	Mean annual temperature (10 year record)	43.3°F.
	Mean annual precipitation (9 year record)	68.8 inches
Angoon	Mean annual temperature (35 year record)	42.2°F.
	Mean annual precipitation (27 year record)	41.34 inches

The heaviest precipitation occurs at these stations during the late summer, fall, and winter months.

The area contains no permanent settlements, and the only evidence of human habitation seen are a few partly ruined cabins some of which are

occupied seasonally by fishermen, hunters, and trappers. No roads or trails exist in the area, and all transportation to and from the area is by air or water; no regularly scheduled transportation of any kind is available.

Previous geologic investigations

The first geological map of the Pybus-Gambier area was that produced by C. W. Wright (1906, p. 138-154) as a result of his reconnaissance of Admiralty Island. His map in a general way delineated the outcrop belts of Paleozoic, and Mesozoic, and Tertiary rocks in the area, but erroneously showed the conglomerate and sandstone unit of Eocene age at Little Pybus Bay as Mesozoic. Wright also mapped the volcanic rocks of the Brothers Islands as correlative with the Tertiary volcanic flows of southern Admiralty Island. In the present paper the volcanic rocks of the Brothers are called the Brothers volcanics, and are considered to be Upper Jurassic and Lower Cretaceous.

Kindle (1907, p. 332) visited Pybus Bay, and gave a brief description of the "Lower Cretaceous beds" (Seymour Canal formation of this report) and the underlying "Upper Carboniferous limestone" (Pybus dolomite of Permian age). He also made fossil collections.

Edwin Kirk (1918, p. 514-515; unpublished notes) studied the stratigraphy of the area around Pybus Bay and collected fossils. He thought that the "conglomerate" overlying "high Carboniferous beds" and underlying "Upper Triassic beds" was probably a tillite, and an indication of Permian glaciation. In the present work this "conglomerate" is considered to be the basal breccia of the Eyd formation of late Triassic age, and to be derived directly from the underlying Pybus dolomite of Permian age. No indication of glacial origin could be found.

Burchard (1920, p. 55), in connection with his study of the marble resources of southeastern Alaska, examined and made fossil collections from the "cherty magnesian limestone" at several localities at Pybus Bay. His fossil collections were determined by G. H. Girty to be of Artinskian age (Permian). This formation is herein called the Pybus dolomite; the Permian age has been substantiated by recent collections.

Martin (1926, p. 376-379) visited Pybus Bay, and studied the stratigraphy of the Mesozoic rocks as part of his work on the Mesozoic stratigraphy of Alaska.

Present investigation and acknowledgements

The geological mapping was undertaken as part of the regional geologic mapping program of the U. S. Geological Survey in southeastern Alaska. The Pybus-Gambier area was selected for detailed study because it appeared to contain one of the most complete and best exposed stratigraphic sections on Admiralty Island. Knowledge of this section is a desirable and effective preliminary to the reconnaissance mapping of Admiralty Island as a whole.

The Pybus-Gambier area contains excellent and extensive shoreline exposures. A large proportion of these are tidal outcrops exposed only at lower tide level, hence the geologic map (pl. 1) includes these low tide exposures. Stream channels afford another important source of geologic data, but as a rule exposures in these are much inferior in quality to those along the shores. Except for the rugged mountains in the southwestern part of the area, ridge crests and other interstream areas are largely covered by heavy forest, and contribute only scattered and commonly poor information.

The mapping was done on 1:15,840-scale, U. S. Geological Survey multiplex compilation sheets of the Sitka (B-1) and the Sumdum (B-6) topographic

quadrangle maps supplemented by 1:40,000-scale vertical aerial photographs. A few days of preliminary reconnaissance was done in the area during the summer of 1957, but the bulk of the field work was done in the summer of 1958, and part of the summer of 1959. During the summer of 1958, I was assisted by Arthur L. Kimball who, by his knowledge of woodsmanship and boatsmanship, contributed greatly to the summer's work. This summer's field work was accomplished by small boat and foot traverses from base camps. In the summer of 1959 I was assisted by Douglas Barnes, and also had supporting assistance from a helicopter based on the U. S. Geological Survey motor vessel Stephen R. Capps, Robert D. Stacey, master. Henry C. Berg, John S. Pomeroy, and D.W. Winkley of the U. S. Geological Survey assisted me during the summer of 1959 in the reconnaissance mapping of the northwestern part of the Pybus-Gambier area.

I wish to acknowledge the stimulating discussions with Dr. Lionel Weiss of the University of California at Berkeley who also constructively criticized the structural part of the manuscript while it progressed. Dr. Weiss visited the area during the summer of 1959. I also wish to thank Professor Charles M. Gilbert, also of the University of California, who reviewed the manuscript and offered many suggestions for its improvement. Thanks are due my colleagues of the Alaskan Geology Branch, U. S. Geological Survey, for their voluble discussions and assistance. I wish to acknowledge my wife, Sabra O. Loney, for her skillful assistance in the preparation of the illustrations.

Geologic setting

The pre-Tertiary rocks of southeastern Alaska include abundant volcanic rocks associated with marine argillites and volcanic graywackes (Buddington and Chapin, 1929; Lathram and others, 1959; Lathram and others,

1960; Loney and others, in preparation) and comprise part of the eugeosynclinal Fraser Belt of May (1951, p. 35). This belt has been subdivided by Payne (1955; see also Miller and others, 1959, pl. 2) into tectonic elements called geosynclines and geanticlines. As seen today, the geosynclines are belts of Mesozoic rocks, and the geanticlines are belts of Paleozoic rocks. The Pybus-Gambier area lies astride the boundary between two of the most important tectonic elements: the Seymour geosyncline on the east and the Prince of Wales geanticline on the west.

Recent reconnaissance mapping on Admiralty Island north of Gambier Bay has shown that the boundary between Mesozoic and Paleozoic rocks, that is, between the Seymour geosyncline and the Prince of Wales geanticline, is not a straight, north-northwest-trending line as shown by Payne (in Miller and others, 1959, pl. 2), but is instead irregular in detail (Lathram and others, 1960). On the other hand, in the same region the contact between the Triassic rocks and the Jurassic and Cretaceous rocks within the Seymour geosyncline trend much more uniformly north-northwest for more than 50 miles. Farther south in the vicinity of False Point Pybus, the contact between Triassic and Jurassic-Cretaceous rocks bends sharply westward and thence follows a sinuous southwesterly course through Pybus Bay, becoming lost to the south beneath Tertiary rocks. One of the goals of the present work was to investigate this abrupt change in trend.

The northeastern extremity of the Admiralty trough of early Tertiary age (Payne, 1955; in Miller and others, 1959, p. 22, pl. 2) occupies the southwestern part of the area and overlaps both the Prince of Wales geanticline and the Seymour geosyncline. This trough contains nonmarine volcanic and sedimentary deposits of early Tertiary age, which cover the southern part of Admiralty Island and extend south onto parts of Kupreanof and Kuiu Islands. Miller and others (1959, p. 22, 25-26) suggest that the Mesozoic

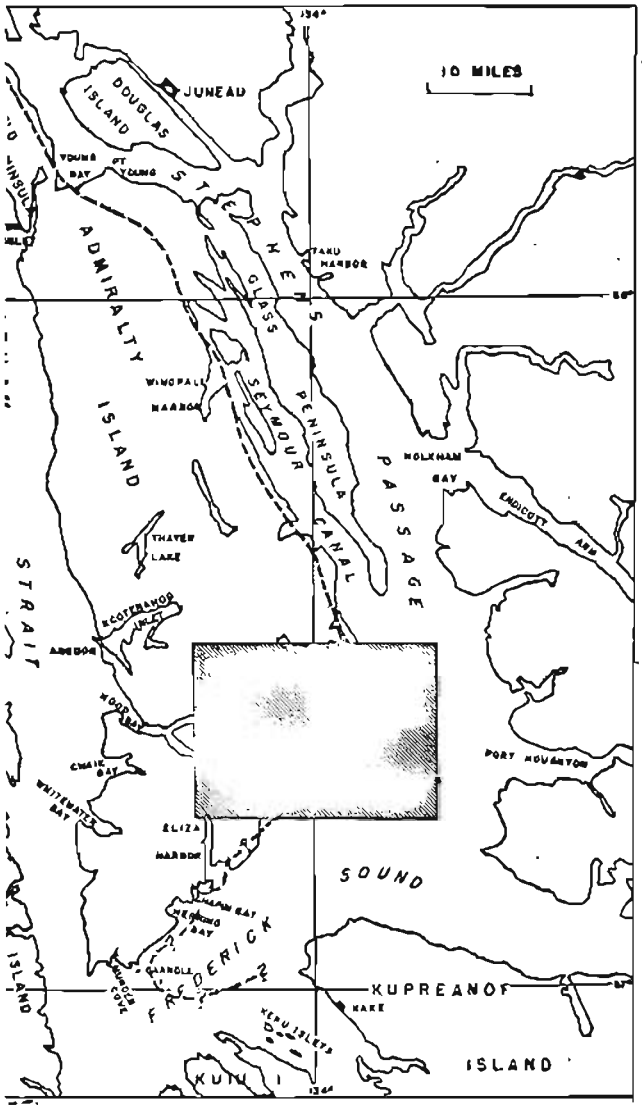


Figure 2.--Sketch map showing contact (dashed line) between Triassic rocks (west), and Jurassic and Cretaceous rocks (east).

and Paleozoic rocks underlying this trough may be favorable for petroleum.

Most of the Seymour geosyncline was involved in the regional metamorphism associated with the Coast Range batholith (Miller and others, 1959, p. 16-19). This metamorphism dies out to the west away from the batholith. The Pybus-Gambier area, situated at the western margin of the geosyncline, lies near the western limit of this metamorphism. In addition, numerous granitic plutons, considered by some to be satellitic or belonging to the same episode of plutonism as the Coast Range batholith (Buddington and Chapin, 1929, p. 173; Dutro and Payne, 1957), intrude both the Seymour geosyncline and the Prince of Wales geanticline. Such plutons on Admiralty Island are commonly surrounded by contact metamorphic aureoles. The area of plutonism and contact metamorphism in the northwestern part of the Pybus-Gambier area represents a southern extension of an important region of plutonism centered around Thayer Lake (Lathram and others, 1960).

STRATIGRAPHY

General features

The pre-Tertiary section of the Pybus-Gambier area consists of formations ranging in age from Silurian(?) to Cretaceous (fig. 3). Sedimentation was not continuous during that interval, however, for hiatuses have been recognized between most of the formations. In large part the section consists of fine-grained sedimentary rocks of marine origin that seem to have been derived mostly from volcanic sources, but it also contains marine limestone, dolomite, and basic volcanic rock. The most abundant rock type is dark-colored argillite interbedded with thin beds of chert or fine-grained graywacke. The latter are graded and crossbedded on a small scale, and resemble closely the turbidites of Kuenen (1953, 1957).

Figure 3.--Composite stratigraphic section of the Pybus-Gambier area, Admiralty Island, Alaska.

System or series	Formation	Description	Thickness (feet)
Quaternary	Unconsolidated deposits	glacial clay and gravel, and alluvial gravel	0-50
	Unconformity		
Tertiary	Admiralty Island volcanics	andesite and basalt flows	9500+
	Unnamed	conglomerate and sandstone	0-2000
	Ang. unconformity		
Lower Cretaceous and Upper Jurassic	Brothers volcanics	andesitic flows and breccias, and minor graywacke	2000+
	Seymour Canal formation	argillite, dark gray, and graywacke and conglomerate	est. 8000+
	Disconformity		
Upper Triassic	Hyd formation	Spilitic lavas, pillow types common.....0-500+; thin-bedded, grayish black chert, argillite, and limestone.....0-280+; limestone, dark brown, medium-bedded.....0-500+; breccia, white chert .....0-30+; breccia, red and green chert..0-350	est. 1300+ incl. volcanic rocks
	Disconformity		
Permian	Pybus dolomite	dolomite, yellowish gray and bluish white chert nodules and beds	0-1000
	Cannery formation	thin-bedded, dark gray and green argillite, chert, and minor graywacke and pillow lava	a few 1000's
	Ang.? unconformity		
Devonian and Silurian?	Gambier Bay formation	greenschist, phyllite, marble, metachert (may be in part coeval with Hood Bay formation)	?
	Hood Bay formation	thin-bedded, grayish black chert, siliceous argillite, and minor marble and graywacke	a few 1000's

With the single exception of the cherty Pybus dolomite of Permian age, the pre-Tertiary strata represent a long, discontinuous episode of flysch sedimentation (Tercier, 1947, p. 163-198); (Pettijohn, 1957, p. 615-618) that was terminated in the Cretaceous by strong deformation and uplift. Nonmarine, coarse-grained sedimentary rocks of Eocene age were deposited after the deformation and are typical post-orogenic, molasse-type deposits (Pettijohn, 1957, p. 618-622). These rest with marked angular unconformity on the older rocks, and are overlain by nonmarine volcanic flows of the Admiralty Island volcanics.

Deformation and the lack of marker beds has prevented the accurate determination of stratigraphic thicknesses in all but the thinnest pre-Tertiary formations. In many thick units, vertical lithologic change cannot be distinguished from lateral change. The following stratigraphic descriptions therefore, are lacking in accurately measured sections, but the total thickness must be at least a few tens of thousands of feet. A more precise estimate than this would be without adequate basis.

Definitions

The rock classification used in this report is that of Williams, Turner, and Gilbert (1954) unless otherwise stated. The grade scale used is the Wentworth scale as modified by Dunbar and Rogers (1957). The color terminology of this paper follows that of the Rock-Color Chart (Goddard and others, 1951).

All gradations between chert and nonsiliceous argillite occur among the rocks of the Pybus-Gambier area. The term chert is applied to those extremely fine-grained rocks that fracture with a glossy conchoidal or smooth, angular surface, and which cannot be scratched by a knife blade. The term siliceous argillite is applied to fine-grained rocks that cannot be scratched, or can be scratched only slightly with a knife blade, but which fracture with a dull, rough surface.

The rocks of the area have been studied by optical petrographic methods only, and very fine grained minerals have not been identified with certainty. Argillites and graywackes are especially rich in such minerals, and it has been necessary to use certain mineral names arbitrarily. Thus, fine-grained, colorless, micaceous minerals having a strong birefringence are called sericite. The name chlorite is applied to pale green, commonly pleochroic, micaceous minerals having a low birefringence. It is well understood that these two terms probably include other micaceous minerals.

The feldspar determinations are based largely upon the four-axis universal stage method of Turner (1947). The actual determinations were based upon curves newly derived by Slemmons and as yet unpublished.

Silurian(?) and Devonian systems

Gambier Bay formation

The name Gambier Bay formation is here proposed for low-grade metamorphic rocks exposed along the shores of western Gambier Bay and in the area immediately to the south and west. Typical sections of the formation are exposed along the shore of western Gambier Bay from Snug Cove on the south to the vicinity of the triangulation station "Butt" on the north. The formation underlies the area west of Gambier Bay and north of the eastern part of the Gambier fault. The northwestern portion of the map area has been examined only by reconnaissance, but the phyllites, greenschists, and marbles of this region are tentatively correlated with the metamorphic rocks bordering Gambier Bay.

The Gambier Bay formation is identified among the formations mapped by the metamorphic foliation of its rocks. These are fine-grained greenschists and phyllite in which individual minerals are too small to be identified in hand specimen, the chief types being: chlorite-epidote-calcite phyllite or schist, quartz-albite, marble, and phyllitic slates (see

Appendix for petrographic details). All of the rocks have been intensely deformed, and some are phyllonitic, The latter contain abundant relict mineral grains considerably larger than the metamorphic mineral grains present; metamorphic crystallization has not eliminated all of the mylonitic layers associated with the larger relict grains.

The pervasive foliation that penetrates these rocks on an intergranular scale, and along which they invariably break, is chiefly defined by the preferred orientation of platy minerals and by mylonitic layers. Lenticular masses of marble and basic volcanic fragments are aligned with their longest dimensions about parallel to the foliation (fig. 23a). Field evidence indicates that this foliation is parallel to the axial planes of folds in the bedding (see p, 75, fig. 23b). The foliation surfaces contain abundant small folds and crenulations.

Primary bedding is inconspicuous. Partly this is because of original thick-bedded character of the rocks; partly it is the consequence of intense folding that was accompanied by slip along the foliation surfaces and resulted in the disruption and transposition of the bedding (see p. 75). Original bedding is usually seen as discontinuous streaks of contrasting composition crossing the foliation surfaces (see p. 77; also fig. 24a), and only rarely, chiefly in thin-bedded phyllitic slates, can continuous beds be traced around fold hinges (see p. 75; also fig. 23b). In such rocks precise measurement of stratigraphic thickness is meaningless.

Fossils indicative of Devonian age (probably middle Devonian) are poorly preserved in the prominent marble mapped west and south of Gambier Bay. This unit is probably stratigraphically high in the Gambier Bay formation, but the possibility of rocks in the formation both older and younger than Devonian is not precluded.

Fossil identifications and age correlation were made by W. A. Oliver,

J. Berdan, and Helen Duncan of the U. S. Geological Survey (written communication, 1959, 1960) on the basis of the following fossil collections (numbers in parentheses refer to locations shown in fig. 56):

(1) 58ALy448; dark-gray marble on point of land 0.9 mile south-southwest of Gem Point on south shore of Snug Cove, Gambier Bay.

digonophylinid coral
Thamnopora? sp.
[illegible]? sp.

(2) 58ALy448a; same lithology as 448 on northwest side of same point of land.

unidentifiable colonial coral, hydrozoan, or bryozoan

(3) 58ALy456; dark-gray marble on south point of Muse Island, Gambier Bay.

Thamnopora? sp.
[illegible]? sp.

(4) 59ALy54: dark-gray marble in creek bed 1.7 miles south-southwest of Gem Point, Snug Cove, Gambier Bay.

poorly preserved dendroid tabulates and other corals

Reconnaissance mapping (Lathram and others, 1960) indicates that the exposures of the Gambier Bay formation at Gambier Bay are the southeastern end of a discontinuous belt of metamorphic rocks extending from Gambier Bay northwestward along the west side of Admiralty Island to Point Retreat at the northernmost tip of the island. Barker (1957) named the metamorphic rocks in the latter area the Retreat group which he considered to be possibly Triassic to Cretaceous in age. He, however, had no fossils either from the metamorphic rocks or from the overlying rocks upon which to base his age correlation. Probably the Retreat group is correlative with

the Gambier Bay formation, but certain correlation is impossible, because the two units crop out in localities separated by a broad area of plutonism and contact metamorphism centered around Thayer Lake (Lathram and others, 1960). Known fossil control is confined to the southern area of outcrop.

The Gambier formation also resembles in a general way the Wales group of southern southeastern Alaska, a name applied by Brooks (1902, p. 40-52) to "crystalline white limestones and argillites or phyllites, with closely associated greenstones" cropping out on Prince of Wales, Long, and Dall Islands. Buddington and Chapin (1929, p. 45-49) considered this group to be "probably of pre- Ordovician to Devonian" in age.

The Cannery formation, which overlies the Gambier Bay formation near Gambier Bay, is Permian. Therefore, the two formations are separated by a hiatus equivalent at least to the Mississippian and Pennsylvanian systems, and an unconformity between them is inferred. The character of this unconformity cannot be directly observed, but angular discordance is suggested by the more intense deformation in the rocks of the Gambier Bay formation. However, because the Gambier Bay formation is mapped on the basis of metamorphic features that may have been acquired after the deposition of the Cannery formation (p. 12), the contact shown on plate 1 represents the limit of visible metamorphism and may not coincide with the unconformity originally separating the two formations. The metamorphic contact may cross bedding surfaces, and rocks coeval with the Cannery formation may be included in the Gambier Bay formation.

Hood Bay formation

Fossils of Devonian or Silurian age have been collected from calcareous strata in a sequence of dark-hued, carbonaceous cherts, siliceous argillites, graywacke, and limestones that crop out along streams flowing into the head

of the North Arm of Hood Bay. Similar rocks are also exposed along the southwest shore of Pybus Bay northward from Donkey Bay. The name Hood Bay formation is here proposed for these rocks. The lower contact is not exposed and older formations are unknown in the Pybus-Gambier area. Like the Gambier Bay formation, they are unconformably overlain by the Cannery formation of Permian age, but this contact is largely covered.

Rocks of the Hood Bay formation crop out in a roughly triangular area west of Pybus Bay and south of the Gambier Fault. To the southwest, the Hood Bay formation is buried unconformably by the Admiralty Island volcanics of Tertiary age. To the northeast, rocks of the Hood Bay formation are in fault contact with the Cannery and younger formations in a complex manner along the Pybus fault zone, which follows the main arm of Pybus Bay. In general, the topography of the country underlain by the Hood Bay formation consists of rounded mountains and hills without prominent features.

The Hood Bay formation lacks distinctive members and has been isoclinally folded, so that the measurement of accurate stratigraphic thickness is impossible. Although the formation crops out over a relatively large area, its total stratigraphic thickness may be only a few thousands of feet, and the lithology must be described in general terms without implying stratigraphic sequence.

The predominant rocks of the formation are thinly bedded, grayish black radiolarian chert and siliceous argillite. Dark gray limestone, calcareous argillite, and fine-grained graywacke are locally interbedded with the argillite (see Appendix). The general dark color of all therocks is the result of disseminated fine carbonaceous material and fine pyrite crystals (see Appendix for petrographic details). The lithologic aspects of the formation as a whole suggest a black shale or euxinic facies, as described by Pettijohn (1957, p. 622-626).

The approximate age of the Hood Bay formation (Devonian or Silurian) has been determined from poorly preserved fossils collected from limestones and calcareous argillites in two localities. The fossils are recrystallized, making precise identification and correlation impossible. Helen Duncan (written communication, 1960) identified the fossils from locality 59ALy240 and J. Thomas Dutro, Jr. (written communication, 1960) identified those from locality 59ALy276. (Numbers in parentheses refer to localities in fig. 56).

(5) 59ALy240; dark-gray clastic limestone 2.5 airline miles upstream from mouth of stream flowing southwest into North Arm of Hood Bay:

branching favositid coral
Stromatoporoids

(6) 59ALy276; dark-gray, calcareous argillite interbedded with grayish-black chert 0.5 mile upstream from mouth of stream flowing northwest into North Arm of Hood Bay:

Atrypa? sp.

Limestone, argillite, and graywacke of Silurian or Devonian age also occur on Carroll Island and vicinity near the southern tip of Admiralty Island (Lathram and others, 1960; fig. 1). These rocks are lighter in color than the Hood Bay formation and contain no interbedded chert. Available information suggests that the beds at Carroll Island are more probably Silurian than Devonian (E. H. Lathram, oral communication, 1960). If these beds are correlative with the Hood Bay formation, then the Hood Bay formation is probably older than the Gambier Bay formation.

Buddington and Chapin (1929, p. 82-91, 97, 103-109) described sedimentary and volcanic rocks of Silurian and Devonian age on Kupreanof,

Kuiu, and Keku Islands about 50 miles to the south of the Pybus-Gambier area (see fig. 1). The lithologic sections described, however, do not correspond closely to the uniformly dark-colored, siliceous, fine-grained rocks of the Hood Bay formation.

Another section of Devonian and possibly Silurian sedimentary rocks occurs near Freshwater Bay on Chichagof Island about 45 miles northwest of the Pybus-Gambier area (Loney and others, in press; fig. 1). Here a thick sequence of interbedded medium-gray graywacke, dark-gray slate, and conglomerate of possible Silurian age underlies a thick sequence of Middle Devonian limestone and minor graywacke (Kennel limestone and Cedar Cove formation) which is in turn overlain by a thick sequence of Upper Devonian volcanic rocks (Freshwater Bay formation). The rocks of this section are, in general aspect, quite unlike those of the Hood Bay formation.

Correlation of the Hood Bay and Gambier Bay formations is suggested by their similar ages, their similar stratigraphic positions, and their separate areas of outcrop. But the metamorphism of the latter as compared to the lack of metamorphism of the former requires explanation. If the metamorphism of the Gambier Bay formation occurred in the Cretaceous period along with the strong folding of the younger pre-Tertiary formations (see p. 119), then the nonmetamorphic character of the Hood Bay formation indicates a decrease in metamorphism in a southwesterly direction from Gambier Bay, regardless of the exact temporal correlation of the two formations. The "contact" of the Gambier Bay formation both upward and laterally would be a zone of transition from metamorphic to nonmetamorphic rocks. (See p. 15 for further discussion.) Unfortunately the area between the principal outcrops of the Hood Bay and Gambier Bay formations in which the transition should occur is poorly exposed and covered by younger rocks.

Alternately, if the metamorphism of the Gambier Bay formation occurred

in Devonian time after deposition of the Gambier Bay rocks, the possibility exists that the Hood Bay may have been deposited in late Devonian time upon the metamorphosed Gambier Bay rocks. Against this possibility is the fact that the two formations appear to be confined to different areas. However, the absence of the Hood Bay rocks in the Gambier Bay area may be due to nondeposition or erosion over a topographic high in the Gambier Bay metamorphic rocks. In this circumstance a thin unit of Hood Bay rocks could be present at Gambier Bay mapped as part of the basal nonmetamorphic Cannery formation.

The boundary between nonmetamorphic and metamorphic rocks follows a sinuous course through the Gambier Bay area, but to the west it coincides with the Gambier fault. Metamorphic rocks north of the fault may include rocks with a variety of origins, as they include both hornfels associated with local plutonism and greenschist possibly correlative with the Gambier Bay formation, but in a general way, metamorphism decreases in a southerly direction. This is also true for Admiralty Island as a whole, since a continuation of the line of the Gambier fault southwestward to Chatham Strait separates nonmetamorphic rocks on the south from metamorphic rocks on the north (Lathram and others, 1960).

Intertonguing of Hood Bay and Gambier Bay lithologies, and hence their contemporaniety, is suggested in the northwestern part of the metamorphic terrane on Admiralty Island. Near Hawk Inlet and to the south, thick layers of dark gray, graphitic, highly quartzose phyllite and schist, which may be equivalent to the chert and argillite of the Hood Bay formation are interbedded on a large scale with greenschists, which may be equivalents of the greenschists of the Gambier Bay formation (Lathram and others, 1960; personal observation).

Permian system

Cannery formation

The name Cannery formation is proposed for thinly interbedded chert, argillite, and graywacke exposed in and around the mouth of Cannery Cove on the southwest shore of Pybus Bay. The formation crops out almost continuously along this shore from a point about three and one-half miles southeast of Cannery Cove northwestward to the north shore of Donkey Bay. Similar strata underlie a large area north of Pybus Bay, extending as far as the south shore of Gambier Bay.

Throughout most of the Pybus-Gambier area, the Cannery formation consists of thin-bedded siliceous argillite, graywacke, and chert (fig. 4), and local intercalations of thick-bedded, calcareous, volcanic graywacke and altered pillow lavas and breccias. In contrast to the Hood Bay formation, the color of the thin-bedded chert, argillite, and graywacke is highly variable with shades of green and gray dominating. Radiolarian tests occur only sparsely in some of the cherts.

At Gambier Bay in the vicinity of Church Point and Gain Island, the color of the cherts and argillite in the Cannery formation changes to bright greens and reds, and the chert acquires a coarser crystalline, surgary texture suggestive of metamorphic recrystallization. The overlying basal breccia of the Hyd formation contains fragments of these metacherts on the island north of Gain Island and on the north shore of Gambier Bay where the Cannery formation is missing. The matrix of this breccia is also recrystallized, indicating that the metamorphism of both the breccia and the chert of the Cannery formation occurred after the deposition of the breccia. The metamorphism may be related to the intrusion and extrusion of younger volcanic rocks in the Hyd formation that overlie the breccia.

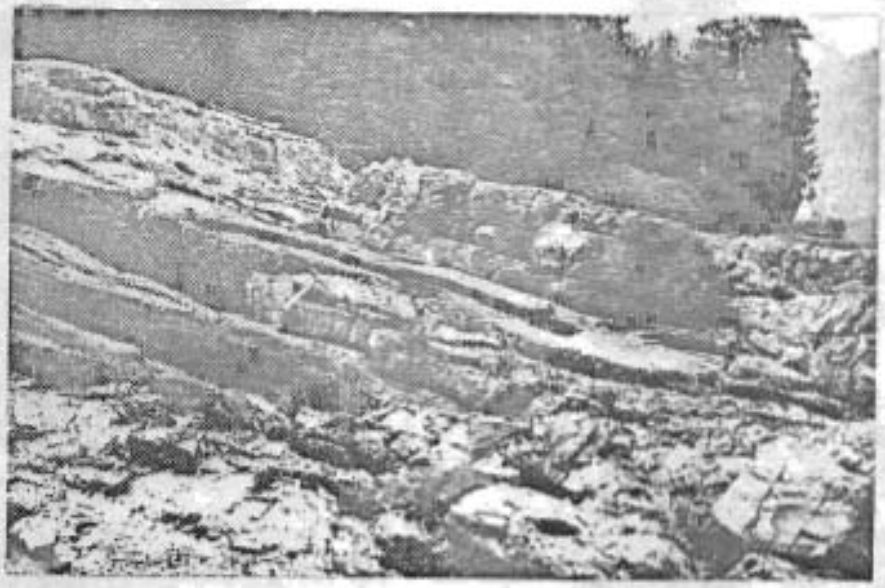


Figure 4.--Thin-bedded chert and argillite of the Cannery formation at Cannery Cove, Pybus Bay.

Among the larger clasts in the graywacke, quartz is rare and both feldspar and volcanic rock fragments are abundant. The feldspar consists of both andesine and albite grains, the latter being cloudy, and generally sericitized, as is commonly the habit of grains that have been albitized (Coombs, 1954). The presence of albite veins and of scattered albite and analcime crystals in the graywacke matrix and in the argillite suggest that the albite in these rocks is not detrital but has developed by diagenetic alteration of these strata. Other diagenetic minerals occurring in these rocks are quartz, chlorite, sericite, calcite, and probably various clay minerals (see Appendix for details).

Fossil evidence indicates that the Cannery formation is of Permian age, so that an interval of time at least equal to the Mississippian and Pennsylvanian periods elapsed between the deposition of the Gambier Bay and Hood Bay formations and the subsequent deposition of the Cannery formation. The Cannery formation must directly overlie the Hood Bay formation to the south and to the north the Gambier Bay formation, but the field evidence for the character of this unconformity is inconclusive because the lower contact of the Cannery formation is largely covered. Along the southeast shore of Snug Cove in Gambier Bay it appears to be a fault zone.

The Pybus dolomite, also of Permian age, generally overlies the Cannery formation, but the contact between them is poorly exposed. Fossil evidence is not sufficient to indicate whether or not a hiatus separates the two formations. Bedding attitudes in the Cannery formation close to this contact commonly diverge from those of the Pybus dolomite, a feature that may be tectonic. The two formations are so different in competence that slip along their contacts during intense folding would be expected; in the field the two formations are commonly separated by strike fault zones.

Southwest of Pybus Bay, the Cannery formation is buried unconformably beneath nonmarine sedimentary and volcanic rocks of Tertiary age. In places near Gambier Bay to the north, the Hyd formation of Triassic age lies unconformably upon the Cannery formation, as at Church Point and on Gain Island. Here the contact between the two formations is an erosion surface, having a local relief of about two feet. South and west of Gambier Bay, the exact distribution of the Cannery formation cannot be mapped because of the similarity of the thinly bedded rocks of the Hyd and Cannery formations, which, when the Pybus dolomite is absent, are difficult to distinguish from one another.

A few thousand feet of strata is probably sufficient to account for the total thickness of the Cannery formation north of Pybus Bay. Despite the large area of outcrop, the formation has been very tightly folded and stratigraphic repetition is probably frequent. In the absence of distinctive members, the thickness cannot be accurately measured in an area of poor exposures such as this. The reason for the thinning of the outcrop of the Cannery formation southwest of Gambier Bay is unknown, but it may be tectonic. Furthermore, the contact of the Cannery formation and the Gambier Bay formation may not be a simple sedimentary contact, for, as described on page 12, the Gambier Bay formation is distinguished on the basis of its metamorphic characteristics and hence may include in places parts of the original lithogenetic Cannery formation.

Bryozoan and coral fossil debris, identified by Helen Duncan (written communication, 1959; 1960) as probable Permian in age, were found in massive graywackes of the Cannery formation (see Appendix for fossil lists and localities). Rocks that may be correlative with the Cannery formation have been reported in a series of outcrops along the eastern side of Admiralty Island (Lathram and others, 1960). Like the Cannery formation,

they consist principally of thinly bedded argillite, graywacke, and chert, and Permian fossils have been found in them at Windfall Harbor and in the mountains south of Point Young. Permian fossils in similar lithology have also been found on the mainland about 100 miles northwest of the Pybus-Gambier area in the vicinity of William Henry Bay along the east flank of the Chilkat Mountains (Lathram and others, 1959). However, the poor quality of the collections from the Cannery formation in the Pybus-Gambier area does not afford the basis for precise biostratigraphic correlation with the above localities.

Permian fossils have also been reported (Buddington and Chapin, 1929, p. 119; p. 122-127) from marbles in a sequence of phyllites, mica-schists, chert, and slate on the mainland east of Admiralty Island at Taku Harbor and on the Snettisham Peninsula, and also from a dominantly clastic section on Kuiu Island and the Keku Islets south of Admiralty Island. These rocks were assigned to the "lower division of the Permian".

Pybus dolomite

The name Pybus dolomite is proposed for light brownish-gray, fossiliferous, cherty dolomite that crops out prominently at several localities along the shores of Pybus Bay. The best sections of this formation are on the peninsula about 1.2 miles west of Long Island on the southwest shore of Pybus Bay, at several localities along the northeast shore of the main arm of the bay, and in the vicinity of False Point Pybus.

The lower contact with the Cannery formation, as previously stated (p. 22), is not exposed, and its character is uncertain. Strikes of bedding in the Cannery formation commonly diverge widely from those of the Pybus dolomite, even within a few feet from the contact. Differences in the style of folding between thin-bedded argillite and chert of the Cannery formation and the medium- to thick-bedded Pybus dolomite may produce these

divergences. Some of the divergences could also be caused by faulting, since the contact commonly lies along fault zones, as for example on the peninsula between the two arms of Pybus Bay.

In contrast, the upper contact with the Hyd formation of Triassic age is well exposed in several localities. The Hyd formation contains a basal breccia 25-30 feet thick composed largely of detritus from the Pybus dolomite, and it lies upon an erosion surface cut in the Pybus dolomite. The relief of this contact surface in any one outcrop is not more than a few feet. The beds above and below the contact are roughly parallel in most outcrops, but bedding in the basal breccia is ill-defined and accurate comparison is difficult. Near the head of the main arm of Pybus Bay, a limestone member of the Hyd formation above the basal breccia is slightly discordant with respect to the Pybus dolomite.

The thickness of the Pybus dolomite is about 1,000 feet near False Point Pybus, and this seems to be a maximum for the area. More precise measurement is not justified because of numerous strike faults that repeat small folded sections of the dolomite, commonly along with small slivers of the Hyd formation. From False Point Pybus northward along strike the thickness gradually decreases, and becomes zero immediately south of Church Point. A similar wedging-out occurs north of the north arm of Pybus Bay, but poor outcrops and structural complexity prevent the accurate location of the zero isopach.

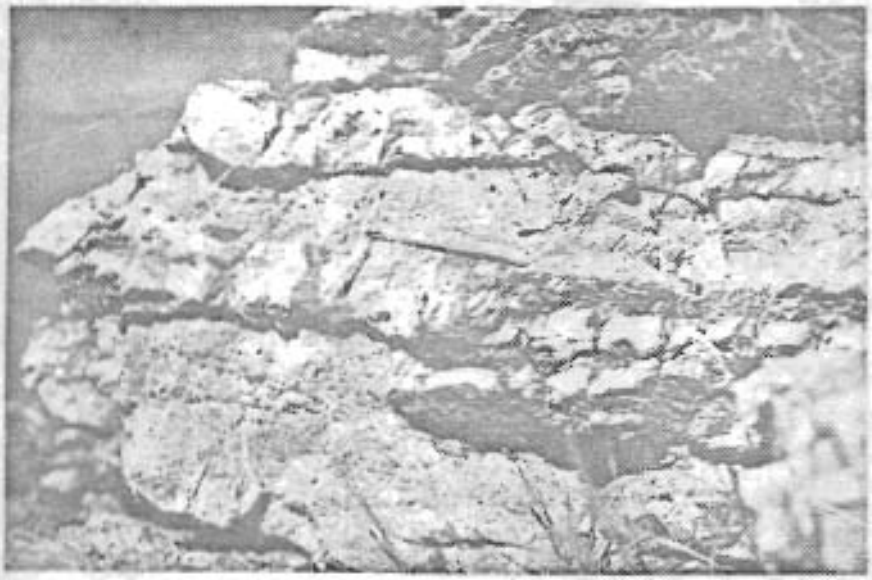
In general the zero isopach of the Pybus dolomite trends southwestward from the vicinity of Church Point around the south end of Gambier Bay, and thence northwestward to the northwestern limit of the dolomite west of Snug Cove. North of this line the Hyd formation lies directly upon the Cannery formation. The Pybus dolomite has not been reported from the belt of Permian rocks that extends along the eastern side of Admiralty

Island from a few miles north of Gambier Bay to the shores of Young Bay on the north coast (Lathram and others, 1960). These authors report a white, bedded chert at Windfall Harbor, which lies in this belt about 40 miles northwest of Gambier Bay, but this chert appears to be unfossiliferous and contains no interbeds of dolomite (personal observation).

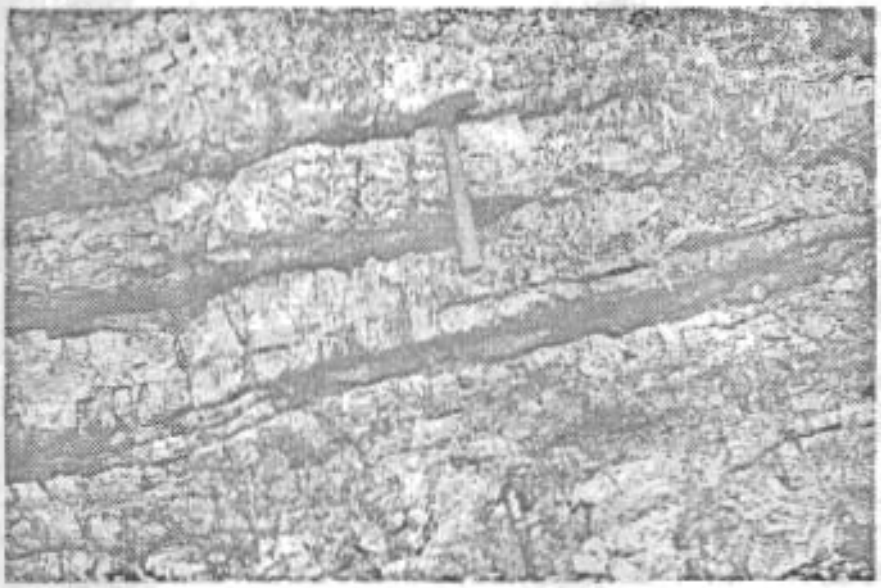
The erosion surface between the Pybus dolomite and the Hyd formation suggests that the disappearance of the dolomite results from truncation by erosion. However, the abrupt disappearance of Pybus dolomite fragments in the basal breccia of the Hyd formation when passing beyond the areal extent of the Pybus dolomite suggests that sedimentary thinning in about the same direction may also be a factor. West of Elliott Island near the south border of the area, the basal Hyd breccia lies in fault contact with the Cannery formation, and the Pybus dolomite appears to be faulted out. Here, however, the basal breccia contains only fragments of chert and argillite derived from the Cannery formation, suggesting removal of the dolomite by erosion or nondeposition rather than by faulting. If this is correct, the zero isopach of the Pybus dolomite also passes through the mouth of Pybus Bay.

Pybus dolomite ranges from dark gray to pale yellowish brown, and weathers to a finely pitted surface. The color of the weathered surface does not differ appreciably from that of the fresh rock. The texture is generally equigranular and sugary, ranging from fine to medium grained. Beds average about 1 foot in thickness but range from 1 inch to 10 feet.

Mottled, white and pale grayish-blue, translucent chert, both in the form of lenses and fragments, commonly occurs in the dolomite (fig. 5a). In a few places, the top few feet of the formation is composed of continuous chert beds ranging in thickness from 6.0 to 12.0 inches (fig. 5b). Both chert lenses and chert fragments contain well-preserved silicified fossils



a. Pybus dolomite at Pybus Bay showing transition of porous, rough-weathering chert into massive chert within a single bed.



b. Bedded chert forming uppermost unit of Pybus dolomite at False Point Pybus.

Figure 5

(fig. 6a, b). Other fossils not preserved in the chert have been nearly destroyed by dolomitization (see Appendix for petrographic details).

The lithology of the Pybus dolomite is represented by the following two incomplete sections both of which represent the upper part of the formation. In one, the uppermost unit is bedded chert and minor dolomite, and in the other, the uppermost unit is the more normal cherty dolomite. These are the two chief variants of the uppermost unit.

1. Section measured on small island along northeast shore of the main arm of Pybus Bay three miles northwest of triangulation station Dro.

	Feet
Hyd formation; basal breccia	
Disconformity	
Pybus dolomite:	
Chert and dolomite, interbedded; chert, mottled white and pale grayish blue, in beds 6-12 inches thick; 75 percent chert	7
Dolomite, mottled dark-gray and light brownish-gray becoming pale yellowish brown toward base, sugary, in beds 1 inch to 2 feet thick; contains pale grayish-blue chert in irregular, rough-weathering lenses 1-6 inches thick containing abundant silicified brachiopods, bryozoans, and cronoid debris, and scattered smooth-weathering chert fragments; chert lenses are closely spaced in some layers and widely spaced in others; 75 percent dolomite.	340
Dolomite, light brownish-gray, fine- to medium-sugary, in 1-4 foot beds contains sparsely scattered white and light bluish gray mottled chert fragments and a few	

a. Porous chert in Pybus dolomite at Pybus Bay.

b. Detail of bedding surface of figure 6a showing silicified fossils that form the porous chert.

Figure 6

Pybus dolomite--continued

	Feet
chert lenses composed of silicified fossils; 90 percent dolomite.	90
Covered	
Total	437

2. Section measured on northeast shore of main arm of Pybus Bay two and one-half miles N. 10° W. from triangulation station Dro.

Hyd formation; basal breccia

Slight angular unconformity

Pybus dolomite:

Dolomite, light brownish-gray, fine sugary, in 6 inch- to 2 foot-thick beds; contains light bluish-gray, weathering dark gray and yellowish-gray, chert lenses consisting of silicified brachiopods, bryozoa, and crinoid debris; chert lenses irregular, rough-weathering, 1 inch to 1 foot thick; 85 percent dolomite.	10
Dolomite, light-gray to light brownish-gray, weathers yellowish brown, sugary in beds 5-10 feet thick; contains bluish white chert lenses 1-3 inches thick, smooth-weathering, sparsely fossiliferous	25
Covered	50
Dolomite, light grayish-brown, fine sugary, in 2-6 inch beds contains chert lenses 1-2 inches thick both smooth and rough-weathering, fossiliferous, silicified brachiopods, bryozoa, crinoid debris	80

Pybus dolomite--continued

	Feet
Dolomite, light grayish-brown, fine sugary, in beds 1 inch to 2 feet thick contains slightly nodular pale blue, yellowish gray weathering, chert beds 1-6 inches thick; layers of close-spaced chert lenses alternate with layers of wide-spaced lenses; bedding gently undulatory; 85 percent dolomite.	50
Covered	
Total	215

A minor rock type not represented in the above sections, but useful as a marker high in the formation along the northeast shore of Pybus Bay, is medium-gray, clastic dolomite occurring in beds ranging in thickness from 1 to 3 feet. This rock consists of tightly packed layers of partially silicified brachiopods and other fossils embedded in a dolomite matrix; the brachiopods average less than one inch in diameter, considerably smaller on the average than those of the typical Pybus dolomite. The dolomite weathers to a distinctive, rough, reddish brown surface.

Two collections of fossils from the Pybus dolomite, including several genera of brachiopods such as Stenocisma, Neospirifer, Spiriferella, and Anidanthus, have been identified as Permian by J. Thomas Dutro, Jr. (written communication, 1960; see appendix for fossil lists and localities). Burchard (1920, p. 55) made a fossil collection from the Pybus dolomite on the peninsula west of Long Island in Pybus Bay that was identified by G. H. Girty as being of Artinskian age (Early Permian).

South of the Pybus-Gambier area on Admiralty Island, the Pybus dolomite crops out in a single locality on the north shore of Herring Bay (Lathram and others, 1960), where it appears to be similar to that at

Pybus Bay. Cherty dolomites or limestones of Permian age also crop out in the vicinity of northern Kuiu Island, south of Admiralty Island. F. E. and C. W. Wright (1908, p. 54-55) report "Beds of white cherty limestone 450 feet or more in thickness..." at Halleck Harbor on Kuiu Island. Buddington and Chapin (1929, p. 127-129) placed these beds in their "upper division of the Permian" of which the Pybus dolomite is also a member. Similar white cherty limestones of Permian age have been reported from the Keku Islets, Kupreanof Island near Keke, and from Suemez Island (Buddington and Chapin, 1929, p. 129-130).

Triassic system

Hyd formation

Strata of late Triassic age occur in a relatively thin, discontinuous belt between Permian and Jurassic-Cretaceous strata from the shores of Pybus Bay to the north shore of Gambier Bay. These are here called the Hyd formation, from triangulation station Hyd on the northeast shore of Pybus Bay where the formation is well exposed.

The formation as a whole contains four distinct members, namely: 1) basal breccia, consisting chiefly of chert fragments derived from underlying Permian strata; 2) limestone member; 3) thin-bedded argillite member, also including thinly interbedded chert, graywacke, and limestone; 4) spilitic flows, commonly including pillow lavas. Except for the spilitic flows which occur at several stratigraphic levels, the members are listed in ascending stratigraphic order, but they do not all occur together in any one section. The basal breccia and thin-bedded argillite member are widespread and occur throughout most of the mapped area. The limestone is absent to the south, west of Elliott Island, where the argillite member rests directly on the basal breccia, and it has a spotty

distribution and variable thickness farther north. The volcanic rocks are an increasingly prominent part of the formation to the north. Their southernmost outcrops are at the head of Pybus Bay and on Gain Island in Gambier Bay; north of Gambier Bay they predominate over the associated sedimentary strata.

Volcanic rocks seem to occur at several stratigraphic levels in the Hyd formation. At the head of Pybus Bay, altered flows directly overlie the limestone member, and the thin-bedded argillite member is absent. At Gain Island, volcanic flows overlie the basal breccia and contain units of the breccia interbedded in them. Pillow lava near the cove east of the triangulation station "Kan" on the north shore of Gambier Bay contains a thin unit of the limestone member in its lower part. On the peninsula northwest of Good Island pillow lava lies within the upper part of the thin-bedded argillite member. The variable stratigraphic position of the volcanic rocks, together with their thickening to the north, suggests that the rocks of the Hyd formation were laid down during an episode of contemporaneous volcanism and sedimentation, and that the volcanic member iscomposed of tongues of volcanic rock, extending southward into the sedimentary section at different levels from a center of volcanism north of Gambier Bay (see Lathram and others, 1960, for areal extent of probable Triassic volcanic rocks north of the Pybus-Gambier area).

Basal breccia.--This member occurs in two phases: a white chert phase, and a green and red chert phase. The white chert phase consists largely of a massive breccia composed of angular to subrounded fragments of mottled white and grayish blue chert and a lesser amount of light brown dolomite derived from the Pybus dolomite, embedded in a dolomite or limestone matrix that generally makes up about 10 percent of the rock (fig. 7). The fragments range in length from less than 1.0 inch to 1.0 foot, and

average about 2.0 inches. Locally the breccia is distinctly bedded, and shows a sorting of the fragments into coarser and finer layers; where this occurs the fragments are more rounded than in the more typical massive breccia. The contact relations with the overlying limestone member are variable. In one locality this contact is sharp and irregular, and appears to be an erosion surface; whereas in another the breccia grades upward by an increase in matrix into the limestone above. The distribution of the white chert phase is identical to that of the Pybus dolomite upon which it rests. It reaches a maximum thickness of 30 feet at False Point Pybus (see stratigraphic sections, p. 35b).

The green and red chert phase consists of a breccia composed chiefly of angular fragments of bedded chert and argillite derived from the Cannery formation, embedded in a calcareous argillite matrix forming generally less than 10 percent of the rock. The fragments range in size from coarse sand to small cobbles, commonly showing moderate hues of green, gray, red, and purple. In localities near the zero isopach of the Pybus dolomite, such as Church Point, a few scattered fragments of white chert and dolomite characteristic of the Pybus dolomite occur in the breccia. Also, near Church Point and Gain Island the chert and argillite fragments are recrystallized to a sugary texture, and have taken on brighter hues of green and red; here the matrix is also recrystallized, and consists of a yellowish brown-weathering, iron-rich dolomite. In this area the breccia is overlain and in places interbedded with volcanic flows of the Hyd formation. Perhaps the heating of the pore fluids during the volcanic eruption caused the recrystallization and oxidation of the breccia. The green and red chert phase occurs wherever the Pybus dolomite is absent and the Hyd formation rests directly upon the Cannery formation. It attains a maximum thickness of 350 feet in the island north of Gain Island (see Appendix for petrography).

Figure 7.--Massive, white chert phase of the basal breccia of the Hyd formation near the head of the main arm of Pybus Bay.

Limestone member.--This member, which attains a maximum thickness of more than 500 feet near False Point Pybus, consists of two types of limestone that do not crop out together: 1) A more widespread, medium-dark brown to dark-brown, light gray-weathering, very sparsely fossiliferous, very fine grained limestone. It occurs in beds ranging in thickness from 0.5 to 10 feet and averaging about 2.0 feet, which are separated by dark brown, undulating, stylolitic contacts (fig. 8a; see stratigraphic sections). 2) A medium dark gray, yellowish brown- to reddish brown-weahtering, fossiliferous, fine-grained limestone that is known only from the sea cliffs near False Point Pybus (fig. 8b). In this limestone the bedding is indicated on the weathered surface by irregular resistant layers, averaging about 0.5 feet in thickness, alternating with non-resistant layers that form lensatic pits and troughs, and give the outcrop a rough, pock-marked appearance.

Sections illustrating the white chert phase of the basal breccia and the light gray-weathering phase of the limestone member of the Hyd formation.

Section measured on northeastern shore of the main arm of Pybus Bay 2.5 miles N. 10° W. of triangulation station Dro.

	Feet
Covered	
Hyd formation:	
Limestone member:	
Limestone, dark brownish-gray, fine-grained to sublithographic in beds 6 inches to 3 feet thick; weathers light-gray to light brownish gray; bed contacts wavy, stylolitic, unfossiliferous.	10

Section measured on northeastern shore of the main arm of Pybus Bay 2.5 miles N. 10° W. of triangulation station Dro--continued

	Feet
Hyd formation--continued	
Basal breccia:	
Breccia, massive; composed of mottled white and grayish-blue chert and yellowish gray, sugary dolomite fragments, subrounded to angular in brownish-gray, dolomitic matrix; matrix less than 15 percent; sharp irregular contact with limestone above.	15
Total	25

Slight angular unconformity

Pybus dolomite

Section measured on shore 1.0 mile north of False Point Pybus

Covered	
Hyd formation:	
Limestone:	
Limestone, medium brownish-gray to dark-gray, very fine grained; in beds 1-8 feet thick, averaging 2 feet thick; dark brown, stylolitic, undulating seams between beds; limestone weathers light gray; lighter beds may be dolomitic (occur near base); contains dark brown, siliceous, resistant masses near top.	500

Section measured on shore 1.0 mile north of False Point Pybus--continued

	Feet
Hyd formation--continued	
Basal breccia:	
Breccia, massive to medium-bedded; composed largely of mottled light and dark gray, yellowish brown-weathering, subangular chert fragments in light-brown, sugary dolomite matrix near base and dark-brown, fine-grained limestone matrix near top; grades upward into overlying limestone by increase in matrix.	30
Total	530

Disconformity

Pybus dolomite

Thin-bedded argillite member.--This member consists of thinly interbedded, predominantly dark gray, argillite, chert, limestone, and graywacke, and attains a thickness of more than 280 feet west of Elliott Island in southern Pybus Bay (fig. 9a, b). The relative proportion of the four rock types is variable, but argillite is generally the most abundant and the most widespread. The beds range in thickness from 0.25 to 6.0 inches, and average about 1.0 inch. Siliceous and calcareous

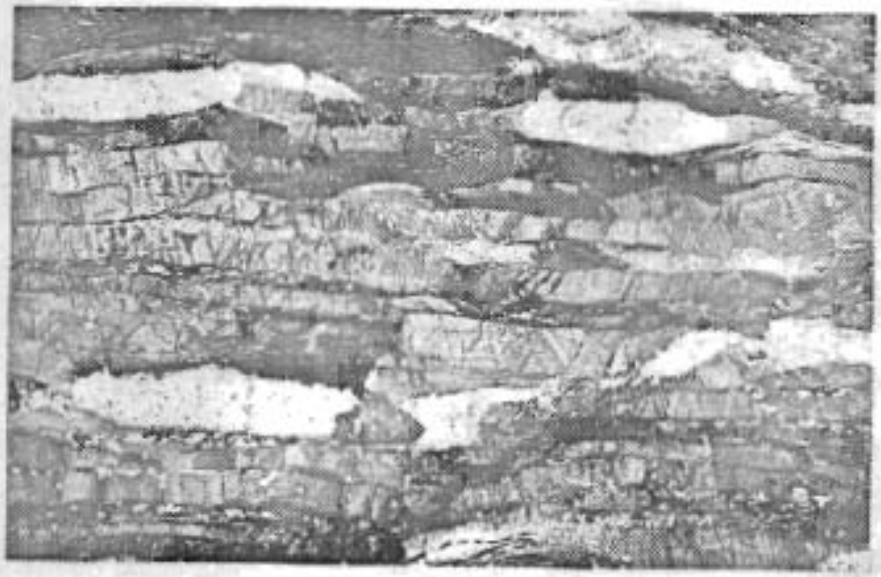
p. 36 follows

a. Light gray-weathering limestone of the limestone member, Hyd formation, near False Point Pybus.

b. Fossiliferous, brown-weathering limestone of the limestone member, Hyd formation, south of False Point Pybus.

Figure 8

a. Steeply dipping strata of the thin-bedded argillite member of the Hyd formation in tidal outcrop on southwest shore of Pybus Bay, west of Elliott Island; the strata lie unconformably beneath gently dipping Tertiary strata (composed conglomerate and sandstone) at the line of trees; ; the gentle dip of the Tertiary strata (Admiralty Island volcanics) is indicated by the topography and snow lines in the background.



b. Detail of strata in figure 9a; chiefly argillite chert, and limestone (light gray), showing boudinage structure in limestone.

Figure 9

argillite occur in about equal amounts; both are homogeneous rocks, generally lacking slaty cleavage. The siliceous argillite weathers to a minutely fractured, brownish gray surface, and grades into Radiolarian chert having a chonchoidal or sharply angular fracture. Calcareous argillite weathers to a slightly rough, brown surface.

The limestone is dark brown, light gray weathering, and very fine grained; it resembles closely the light gray-weathering phase of the limestone member. The graywacke is calcareous and very fine grained; it is commonly graded and crossbedded on a small scale (see Appendix for petrographic details).

Volcanic member.--This member, which attains a maximum thickness of 500 feet along the north shore of Garbier Bay, consists chiefly of greenish gray, altered, spilitic volcanic flows, commonly showing well-developed pillow structure (fig. 10). The flows weather to shades of yellowish green, grayish olive green, and grayish red, and are veined with white calcite. The pillows of the pillow lava range in diameter from 1 to 3 feet; they consist of a coarser crystalline core with a border zone rich in amygdules, and an aphanitic rim. The amygdules are most commonly composed of calcite, chalcedony, and chlorite. The matrix between the pillows is a mixture of calcite and fine fragments of volcanic rock. Phenocrysts are not conspicuous in the pillow lava, but phenocrysts of hornblende and augite are common in non-pillow flows. Albite (An_3 to An_7) is the plagioclase of most flow rocks, occurring both in the groundmass and as ragged, sericitic phenocrysts. In addition to albite, the groundmass consists generally of chlorite, epidote, calcite, and opaque minerals. One pillow lava contains potassic feldspar instead of albite; chemical analysis of this rock shows a predominance of K_2O over Na_2O (see Appendix).

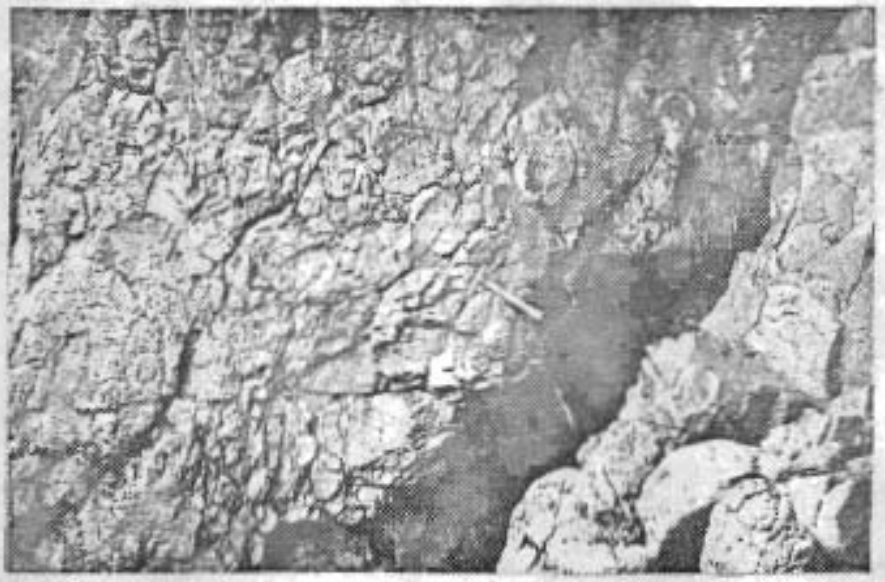


Figure 10.--Subvertically dipping pillow lava in Ryd formation, near Good Island, Gambier Bay; top is to the left.

The Hyd formation lies unconformably upon the Pybus dolomite in some places and upon the Cannery formation in others. This contact is a disconformity or a slight angular unconformity and represents an interval of time extending from possible Early Permian to Late Triassic.

The overlying Seymour Canal formation seems to be structurally conformable with the Hyd formation, but paleontological evidence indicates that a hiatus extending from Late Triassic toLate Jurassic separates the two formation. The contact between them must be a disconformity, but it has not been certainly identified in the field because of the similarity of the thin-bedded argillite member, which commonly forms the uppermost strata of the Hyd formation, to the argillite and graywacke of the overlying Seymour Canal formation.

No single section of the Hyd formation could be found in which both the upper and lower contacts are exposed, hence no accurate thickness could be measured. A composite thickness of 1,310 feet is obtained by totalling the greatest measured thicknesses of the various members. The general width of outcrop indicates that this total thickness is approximately correct in most places, despite variation in the thickness of the individual members.

Both the thin-bedded argillite and limestone members of the Hyd formation have produced fossils indicative of a Late Triassic age. Ammonites (especially Tropites) are prominent in the assemblage collected from the limestone, and are considered to be late Karnian (medial Late Triassic) in age, whereas the collections from the thin-bedded argillite are dominated by Monotis subcircularis Gabb, indicative of a middle or late Norian (late Late Triassic) age. The identifications and age correlations of fossils were made by N. L. Silberling (written communication, 1959; see Appendix for fossil lists and localities).

Rocks of Late Triassic age crop out almost continuously along the east side of Admiralty Island from Gambier Bay northward to the Mansfield Peninsula (Lathram and others, 1960; see fig. 1). According to these authors the dominant rocks in this belt are basic volcanic flows, commonly pillow lavas, and thin-bedded, grayish-black chert, calcareous argillite, and limestone. Rocks comparable to the basal breccia and the limestone member have not been reported north of the Pybus-Gambier area.

In contrast the volcanic member has not been reported from Admiralty Island south of the Pybus-Gambier area (Martin, 1926, p. 89-92; Lathram and others, 1960), and sedimentary members of the Hyd formation have been observed in only two isolated outcrops south of Pybus Bay. The basal breccia, the limestone member, and the thin-bedded argillite member crop out in the Chapin and Herring Bays area (H. C. Berg, oral communication, 1960), and the thin-bedded argillite member containing conglomerate beds crops out near Carroll Island (E. H. Lathram, oral communication, 1960).

Elsewhere in southeastern Alaska rocks of Late Triassic age crop out in the Juneau area, Kupreanof Island near Hamilton Bay, Keku Islets, Kuiu Island, Screen Island, and Gravina Island (Martin, 1926, p. 65-95). In addition, marble and schist on the west coast of Chichagof Island have been tentatively assigned to the Triassic, possibly Late Triassic, by Reed and Coats (1941, p. 29-30). The details of the stratigraphy of the Hyd formation cannot be correlated with the Upper Triassic in other parts of southeastern Alaska on the basis of the published descriptions. These descriptions do indicate, however, that dark-hued limestone, chert, calcareous argillite, and conglomerate or breccia similar to those of the Hyd formation are widespread sedimentary rock types in the Upper Triassic of this region.

Martin (1926, p. 81; 91-94) reported volcanic rocks, including pillow

lavas, associated with sedimentary rocks of Karnian age in the Juneau area and of Norian age in the Keku Strait area. If these age correlations are valid, they substantiate the evidence in the Pybus-Gambier area that volcanic rocks occur at different stratigraphic levels, and erupted contemporaneously with the Late Triassic sedimentary deposition.

Jurassic and Cretaceous systems

Seymour Canal formation

The name Seymour Canal formation is proposed forthe thick sequence of argillite, graywacke, and conglomerate exposed at the mouth of Seymour Canal in the northeast part of the Pybus-Gambier area (see index map, fig. 1). Typical sections are also exposed along the northern and northwestern shore of Pybus Bay, and in the islands near the mouth of the bay. In general, rocks of the Seymour Canal formation form the eastern and southeastern border of the Pybus-Gambier area. They crop out in a broad belt which bends sinuously through Pybus Bay from Elliott Island northeastward to Point Pybus, and thence beneath the waters of Stephens Passage. They reappear in eastern Gambier Bay where they form a nearly rectilinear belt of outcrops trending north-northwest and extending almost continuously along the shores of Seymour Canal for a distance of about forty miles north of Gambier Bay (Lathram and others, 1960; see also fig. 1). The terrain underlain by the Seymour Canal formation is low and featureless, except for a few rounded hills underlain by conglomerate. Fossil evidence indicates that the stratigraphic interval from Upper Triassic to Upper Jurassic is missing between the Seymour Canal formation and the underlying Hyd formation. Since no structural discordance could be detected between them, the contact is considered to be a disconformity.

Overlying the Seymour Canal formation are the Brothers volcanics.

The contact between the two, as seen on the western shore of West Brother Island, is conformable. Angular fragments of the overlying volcanic rocks occur in the argillite for as much as a foot or two below the contact, suggesting that the underlying mud was soft at the time of volcanic extrusion and sedimentation was probably taking place when volcanism begun (fig. 11). The exact stratigraphic position of the Brothers volcanics with respect to the entire Seymour Canal formation is unknown, as the upper contact of the volcanics is not exposed. The Brothers volcanics crop out within the general outcrop area of the Seymour Canal formation, as indicated by outcrops on scattered islands in Stephens Passage, and it may be that they are actually interbedded in the upper part of the formation.

The Seymour Canal formation consists largely of dark gray, slaty argillite and thin-bedded graywacke, which locally contain thick lensatic bodies of conglomerate and massive graywacke. The thin-bedded graywacke occurs throughout the argillite section in variable abundance from place to place, whereas the conglomerate and massive graywacke units are more local and appear to be confined to the upper part of the formation throughout the area. A minimum thickness of 4,000 feet was estimated for the lower part of the formation as exposed on the northeastern shore of the main arm of Pybus Bay. This section, however, does not include the conglomerate facies, which appears from its position in the outcrop belt to characterize the upper half of the formation. The actual thickness of the formation is probably as much as 8,000 feet. These figures can be regarded as no more than estimates because intense folding and the lack of marker beds in the Seymour Canal formation precludes reliable measurement of stratigraphic thickness.

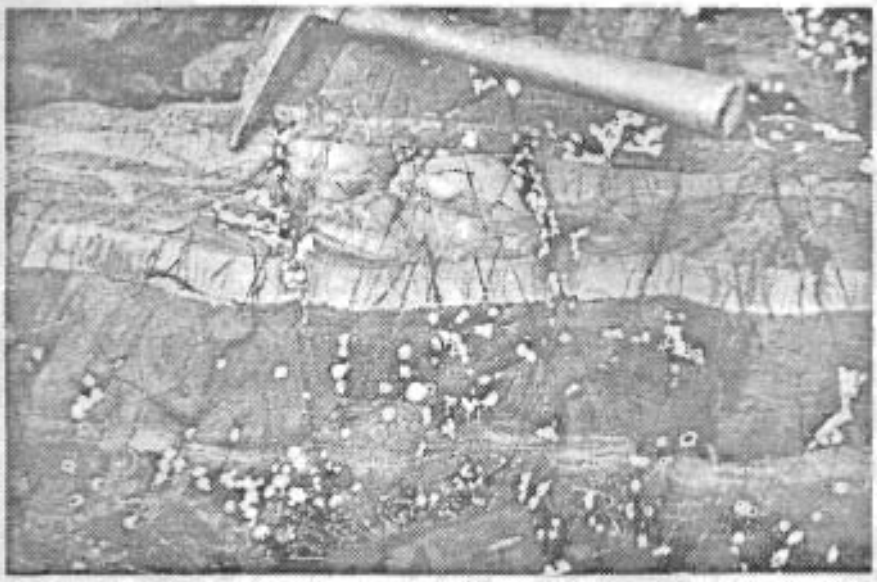
The argillite and thin-bedded graywacke, which characterize the Seymour Canal formation throughout its visible extent, have the general

Figure 11.--Contact between slaty argillite of Seymour Canal formation (below) and flows of the Brothers volcanics, West Brother Island; note angular fragment of volcanic rock (circle) embedded in argillite; bedding in argillite about parallel to contact, whereas fracture cleavage dips steeply to right.

characteristics of flysch deposits in many parts of the world (fig. 12a, b). The argillite itself is rather massive, dark gray, and non-calcareous, but it contains scattered concretions of yellowish-weathering limestone and relatively fewer exotic inclusions of older limestone (fig. 13a, b). The intercalated thin-bedded graywacke layers are dark gray indurated rocks that weather to light gray. Individual graywacke beds range from a quarter inch to two feet in thickness, but most are about one inch thick. They are usually continuous within any outcrop, but may vary noticeably in thickness. Graded bedded, small scale crossbedding, convolute laminations, and various sole markings, which are characteristic of turbidite deposits as described by Kuenen (1957), are typical of the Seymour Canal graywackes. In a few layers, as much as 20 feet thick, the thin graywacke beds have been broken and the fragments more or less scattered through the argillite in a manner suggesting submarine slumping. Petrographically they are volcanic graywackes, noteworthy for their low quartz content (see Appendix).

Conglomerate and massive graywacke occur together as thick lensatic masses in the upper part of the Seymour Canal formation. The largest of these are shown on the geologic map (pl. 1). In these masses, the largest of which on Elliott Island is 2,000 feet thick, conglomerate beds commonly thin along the strike and intertongue with massive graywacke, which in turn intertongues with argillite and thin-bedded graywacke. Such orderly facies change, although it seems broadly characteristic, is disturbed in detail by intrusions of conglomerate and massive graywacke into the argillite and thin-bedded graywacke (fig. 14a, b). Furthermore, large angular blocks of thin-bedded graywacke and argillite as much as 30 feet across occur here and there within the conglomerates. Both conglomerate and massive graywacke layers lack internal bedding structure and appear unsorted (fig. 15a, b). They are thought to be the products of submarine

a. Thinbedded graywacke and argillite, Seymour Canal formation, north of Point Pybus, top is to the right.



b. Convolute bedding in a thicker-than-average (about 8 in.) graywacke bed, Seymour Canal formation, north arm of Pybus Bay.

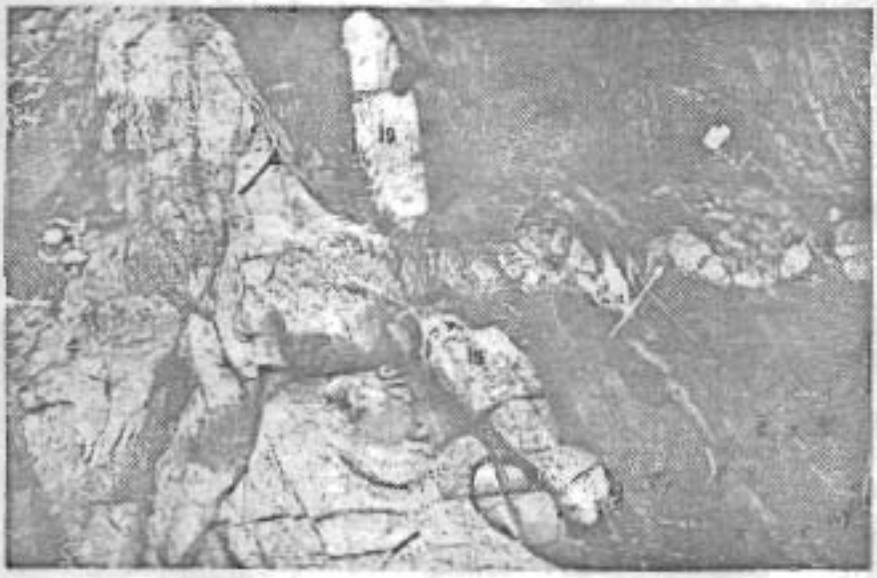
Figure 12

a. Limestone concretion in argillite of Seymour Canal formation, Pybus Bay.

b. Exotic inclusion of older limestone in argillite and thin-bedded graywacke of Seymour Canal formation, Gambier Bay.

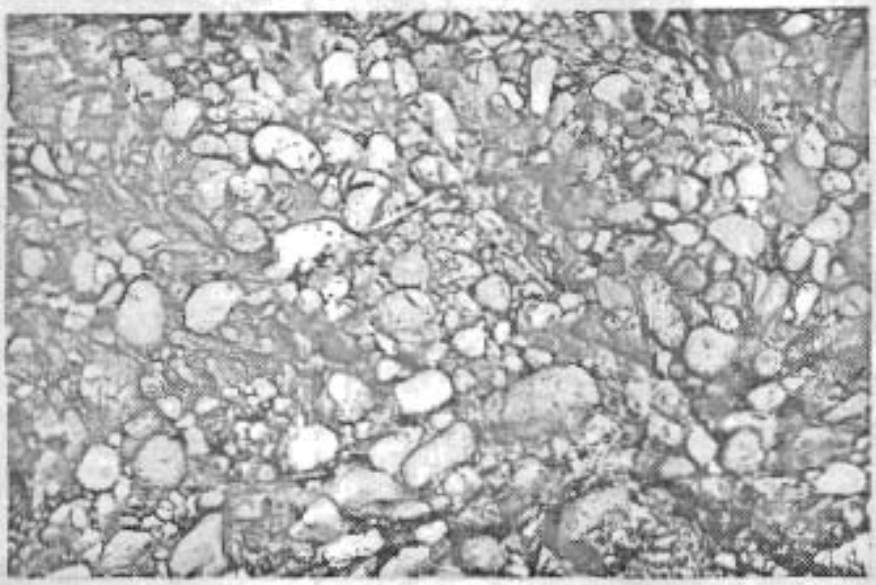
Figure 13

a. Intrusion of conglomerate into argillite and thin-bedded graywacke, Seymour Canal formation, Gambier Island (horizontal surface).



b. Intrusion of graywacke dike from massive graywacke bed on left into slaty argillite and thin-bedded graywacke; note disrupted limestone concretion (ls); Seymour Canal formation (horizontal surface).

Figure 14



a. Cobble conglomerate, Seymour Canal formation, Elliott Island, Pybus Bay; less than 10 percent graywacke matrix.

b. Conglomeratic argillite, Seymour Canal formation, Romp Island, Gambier Bay; more than 90 percent slaty argillite matrix.

Figure 15

slide downslope into a basin floor where the argillite and thin-bedded graywacke were accumulated in more regular fashion.

Fossil collections from the argillite of the Seymour Canal formation indicate ages ranging from Late Jurassic to Early Cretaceous. The two most diagnostic forms collected are Buchia rugosa (Fischer) and Buchia cf. B. volgensis (Lahusen). Collections containing Buchia rugosa (Fischer) are considered by R. W. Imlay (written communication, 1959) to be middle Kimmeridgian to early Portlandian in age; other collections containing Buchia cf. B. volgensis (Lahusen) are considered by Imlay to be probably Barriasian in age. Because of the intense folding and the lack of marker beds, the relative stratigraphic position of beds containing the two fossils cannot be determined, but in general beds containing Buchia rugosa (Fischer) tend to crop out nearer to the lower contact of the formation than do those containing Buchia cf. B. volgensis (Lahusen). A complete list of fossil localities and fossils is recorded in the Appendix.

The Seymour Canal formation crops out on the small islands and reefs in southern Pybus Bay, and then disappears beneath the waters of Frederick Sound and the Tertiaryrocks. It reappears farther south on Admiralty Island in a single locality between Herring and Chapin Bays, where fossils of Early Cretaceous age have been collected (E. H.Lathram, oral communication, 1960; see also Lathram and others, 1960).

North of Gambier Bay the Seymour Canal formation crops out for the entire length of Seymour Canal and northwestward as far as the eastern shore of Mansfield Peninsula (Lathram and others, 1960). According to these authors, no fossils have been found in the formation on Admiralty Island north of the Pybus-Gambier area. These rocks on Mansfield Peninsula andon the neighboring islands to the east have been grouped by

Barker (1957) into two formations: 1) a lower unit, Symonds formation, consisting of slate and graywacke, and 2) an upper unit, Shelter formation, consisting of conglomerate, slate, and greenstone. Barker considered both formations to be of possible Early Cretaceous age, because they appear to be the northern extension of the rocks containing Aucella /Buchia/ at Pybus Bay. The Symonds formation by definition includes only the slate and graywacke below the conglomeratic Shelter formation, and hence may be equivalent only to the lower part of the Seymour Canal formation. The conglomeratic units in the Seymour Canal formation may correlate with the Shelter formation, but their lenticular form and the distance (65 miles) separating the Pybus-Gambier area from Mansfield Peninsula does not justify the use of the same name.

On the mainland northwest of Juneau, Knopf (1911, p. 14-17; 1912, p. 15-18) gave the name Berners formation to the slate, graywacke, and greenstone at Berners Bay, and on the basis of plant fossils he considered them to be Upper Jurassic or Lower Cretaceous. The rocks of the Berners formation extend southeastward to the vicinity of Auke Lake, north of Juneau, where they were called the Treadwell formation by Barker (1957). Knopf correlated the Berners formation with the slates and graywackes at Point Young in northern Admiralty Island and with rocks of the same lithology containing Aucella/Buchia/ at Pybus Bay, that is the Seymour Canal formation.

In general, slates or argillites, graywackes, and conglomerates containing Buchia occur in two broad belts in southeastern Alaska: 1) an eastern belt along the west flank of the Coast Range batholith extending from the vicinity of Ketchikan on the south to the vicinity of Skagway on the north, and extending westward as far as the Pybus-Gambier area; 2) a western belt extending along the west coasts of Baranof and Chichagof

Islands and northwestward along the west flank of the Fairweather Range (see Dutro and Payne, 1960; Reed and Coats, 1941). Other than the correlations discussed in the previous paragraphs, detailed correlations with the Seymour Canal formation and other strata of Jurassic and Cretaceous age in these two belts are not justified by present knowledge.

Brothers volcanics

The name Brothers volcanics is proposed for the sequence of andesitic volcanic flows, breccias, and associated volcanic sedimentary rocks at least 2,000 feet thick on the Brothers Islands in the southeastern part of the Pybus-Gambier area. These islands were previously mapped as diorite by Buddington and Chapin (1929, pl. 1), and as Cretaceous and Jurassic intrusive igneous rocks by Dutro and Payne (1957).

The Brothers volcanics seem to lie conformably on the Seymour Canal formation, as shown by the contact exposed on West Brother Island (p. 43) and by the general structural conformity of the two formations. The Brothers volcanics may lie either partly or wholly within the uppermost part of the Seymour Canal formation, as suggested by the location of their outcrops within the eastern and possibly younger part of the outcrop belt of the Seymour Canal formation, or they may lie wholly above the Seymour Canal sedimentary rocks.

The Brothers volcanics are composed of about equal amounts of massive andesitic flows (fig. 11) and flow breccias, and minor intercalated volcanic graywacke. The flows are chiefly dark gray, purplish gray, dark greenish gray, and rarely medium gray in color, and weather light green, dark green, and yellowish olive. They range from fine grained to aphanitic in texture, and in places contain euhedral phenocrysts averaging about 2.0 mm in length of plagioclase, pyroxene, and less commonly

hornblende. The flows grade into flow breccias containing angular fragments of the above rock types ranging in length from 0.5 inch to 3.0 feet, embedded in a matrix of the same composition. The rocks commonly contain scattered calcite amygdales averaging about 3.0 mm in diameter. The typical flow rock is slightly altered, and is largely composed of sericitic plagioclase (An_{25} to An_{48}), clinopyroxene, hornblende, chlorite, calcite, and opaque minerals (see Appendix).

Detrital rock a few hundred feet in thickness and composed entirely of volcanic material is intercalated in the flows and breccias. Some of these rocks may be tuffs, but most are certainly poorly sorted, water-laid sedimentary rocks and are classed as volcanic graywackes (Williams, Turner, and Gilbert, p. 304). Volcanic rock fragments in the graywacke appear similar to the flows and breccias described above, and they are embedded in either a calcite cement or a chloritic matrix. The calcareous graywacke generally forms slightly irregular, lensatic masses parallel to the bedding ranging in thickness from 0.5 inch to 3.0 feet within the chloritic graywacke. The calcareous masses weather to a rough, olive gray surface that contrasts sharply with the smooth-weathering surface of the chloritic rock (fig. 16). In both varieties the grains form about 60 percent of the rock, and range in size from medium sand to coarse pebbles; the average is very coarse sand. Bedding is commonly shown by slight variations in the grain size of adjacent layers. An important difference between the grains and the flow rocks examined is the presence of large (as much as 2.0 mm in length), cloudy, somewhat mottled, untwinned and simply twinned feldspar phenocrysts which have been shown by sodium cobaltinitrite stain to be potassic feldspar. Perhaps this difference indicates an introduction of potassium during or following sedimentation, but sampling was not extensive enough to be certain. The rock fragments

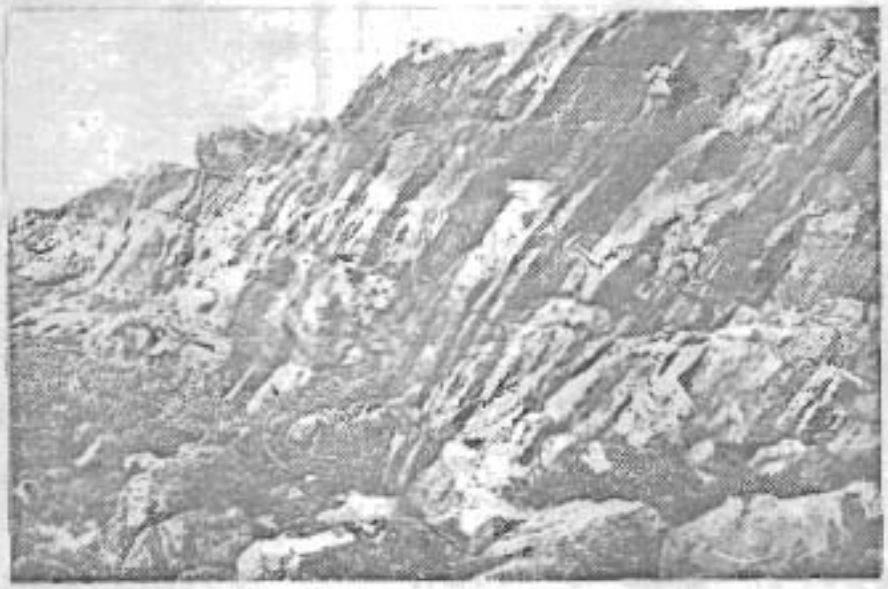


Figure 16.--Steeply dipping volcanic graywacke, Brothers volcanics, south shore of East Brother; shows rough-weathering calcareous lenses in smooth-weathering non-calcareous rock.

tend to have borders of fine opaque grains which include both pyrite and leucoxene; a few fragments are nearly opaque because of abundant pyrite inclusions. A few rounded grains of colorless clinopyroxene and greenish brown hornblende having rims of chlorite and magnetite-ilmenite were observed.

Although no fossils were found in the Brothers volcanics, they are regarded here to be of Late Jurassic or Early Cretaceous age similar to that of the Seymour Canal formation. This correlation is based on the general structural conformity of the two formations, and the previously described features of their contact (p.43). C. W. Wright (1906, pl. 33) mapped the volcanic rocks of the Brothers as "surface lavas and tuffs", and correlated them with the Tertiary volcanic rocks of southern Admiralty Island (Admiralty Island volcanics of this paper). However, the steep attitudes of the Brothers volcanics (pl. 1) are in general conformable with those of the Seymour Canal formation, whereas the attitudes of all known Tertiary rocks in the region are very gentle.

Volcanic rocks possibly correlative with the Brothers volcanics form the Glass Peninsula in northeastern Admiralty Island (Lathram, and others, 1960). This belt consisting of altered, augite-bearing, volcanic breccia and tuff, and minor slate lies in contact on the west with the argillite and graywacke cropping out along the shores of Seymour Canal considered here to be an extension of the Seymour Canal formation. The volcanic rocks of the Glass Peninsula were considered by Buddington and Chapin (1929, p. 158-159) to be Jurassic or Cretaceous in age. Northwestward along the trend of the Glass Peninsula, similar volcanic rocks crop out on Douglas Island in the vicinity of Juneau. Martin (1926, p. 255-256) called these rocks the Douglas Island volcanic group, and considered them to be of probable Late Jurassic age. In general, then, the belt of volcanic rocks

extending from Douglas Island southeastward to the tip of the Glass Peninsula may be represented in the Pybus-Gambier area by the Brothers volcanics.

Rocks correlative with the Brothers volcanics do not crop out on Admiralty Island south of the Pybus-Gambier area (Lathram, and others, 1960). Buddington and Chapin (1929, p. 165-167) stated that southeast of Admiralty Island greenstone volcanic rocks occur throughout the belt of Jurassic and Cretaceous rocks which lies along western flank of the Coast Range batholith. Reed and Coats (1941, p. 34-35), on the west coast of Chichagof Island in the western belt of Jurassic and Cretaceous rocks, reported "greenstone schist" intercalated in their graywacke formation which they considered to be Late Jurassic and Early Cretaceous in age.

Tertiary system

Unnamed conglomerate and sandstone

A gently dipping sequence of interbedded conglomerate, lithic sandstone, and minor amounts of shale, probably of nonmarine origin, crops out on the west shore of Pybus Bay west of Elliott Island and in eastern Little Pybus Bay. This unit has been previously mapped by Buddington and Chapin (1929, pl. 1) as Cretaceous, and by Dutro and Payne (1957) as Cretaceous.

This gently dipping sequence overlies the strongly deformed strata of the Cannery, ~~Hyd,~~ and Seymour Canal formations with pronounced angular discordance. The contact is visible on the west shore of Pybus Bay near the south border of the map (pl. 1; fig.17a). The conglomerate and sandstone unit is conformably overlain by the Admiralty Island volcanics, as seen on the islands and reefs in Little Pybus Bay (fig. 17b). The dominance of cobbles of rock types similar to those of the Admiralty Island volcanics in the top few feet of the conglomerate indicates that volcanism

a. Unconformable contact between unnamed conglomerate (Eocene) and argillite of Seymour Canal formation (below); note slabs of argillite in conglomerate; southern Pybus Bay.

b. Conformable contact between Admiralty Island volcanics above and unnamed conglomerate (Eocene) below; conglomerate composed largely of volcanic fragments in top few feet; Little Pybus Bay.

Figure 17

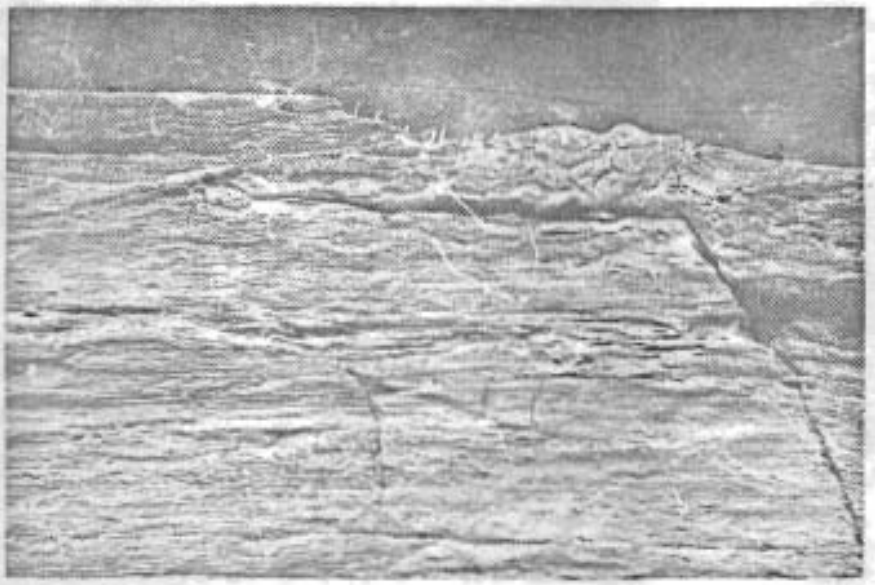
began before the end of conglomerate deposition.

The outcrop of the conglomerate and sandstone unit in the Pybus-Gambier area is confined to a triangular area bounded on the west by the Admiralty Island volcanics, on the south by the boundary of the area, and on the east by older rocks cropping out along the west coast of Pybus Bay. The unit is about 2,000 feet thick near the south border of the area, but thins northward and pinches out immediately south of Cannery Cove.

The conglomerate and sandstone occur in highly lensatic beds that in part represent stream channels and in part alluvial fans. Conglomerate predominates over sandstone by a ratio of about 3:1, and consists chiefly of rounded cobbles of a wide variety of rock types (see Appendix) in which acid plutonic rocks and argillite dominate in the unit as a whole, but volcanic rocks dominate in the top few feet. These clasts are embedded in medium to light gray, coarse-grained, lithic sandstone matrix that is similar to the sandstone of the sandstone beds. The sandstone is characterized by an abundance of lustrous, dark gray phyllite fragments, and generally less than 15 percent quartz; it contains both calcareous and argillaceous matrix generally in excess of 10 percent, and may be classified as lithic wacke (William, Turner, and Gilbert, 1954, p. 297). The coarse-grained sandstone beds commonly show large scale crossbedding (fig. 18a), but the much less abundant fine-grained sandstone and siltstone beds generally show both ripple marks and small scale crossbedding (fig. 18b), and in places contain thin (less than 5 mm thick) coaly seams.

The conglomerate and sandstone unit is considered to be of Eocene age because of its close resemblance to the conglomerate, sandstone, and shale of the Kootznahoo Inlet area in western Admiralty Island, whose age is based on plant fossils (C. W. Wright, 1906, p. 144-147). The only organic remains found in the unit within the Pybus-Gambier area are carbonized plant stems not indicative of age (R. W. Brown, written communication, 1959).

a. Coarse sandstone of conglomerate and sandstone unit at Little Pybus Bay; note scattered pebbles, and large-scale crossbedding in layer below Brunton compass.



b. Fine-grained sandstone of the conglomerate and sandstone unit at Little Pybus Bay; note symmetrical ripple bedding at top, and small-scale (0.5-1.0 in.) crossbedding sets near middle of bed.

Figure 18

Although coal is much more abundant in the Kootznahoo area than at Little Pybus Bay, the sandstones of the two areas are quite similar and contain an abundance of dark-gray, lustrous phyllite grains (personal observation). Furthermore, both sequences are only slightly deformed, and overlie intensely deformed older strata. The beds at Kootznahoo, however, are not overlain by theAdmiralty Island volcanics as are the beds at Little Pybus Bay, but, in view of the similar relation of the two formations to older strata and their similar lithology, it seems likely that they are roughly contemporaneous deposits formed under similar continental environments.

To the south on Admiralty Island, near Murder Cove, coal beds, volcanic sandstones and conglomerate of probable Eocene age areintercalated in volcanic flows and breccias of the Admiralty Island volcanics (C. W. Wright, 1906, p. 152; Lathram and others, 1960).

According to Buddington and Chapin (1929, p. 260-267), more than 1,350 feet of sandstone and intercalated conglomerate containing plant fossils of Eocene age underlie rhyolitic and basaltic volcanic rocks at Port Camden, Kuiu Island, and at Hamilton Bay, Kupreanof Island. These rocks were considered by these authors to be part of a once continuous belt of Tertiary continental deposits extending northward and including the similar deposits on Admiralty Island. This early Tertiary basin of deposition, which also includes the Admiralty Island volcanics, has been called the Admiralty trough by Payne (1955; see also Miller and others, 1959, p. 22).

Section of lower part of the conglomerate and sandstone unit measured on the shores of the peninsula between Little Pybus and Pybus Bays.

	Feet
Covered	
Conglomerate and sandstone unit:	
Conglomerate, pebble and cobble; rounded clasts of granite, gneiss, black slate, phyllite, white chert in a light-grey, coarse-grained, slightly calcareous, lithic sandstone matrix; matrix less than 10 percent. .	25
Sandstone, light-gray, medium- to coarse-grained, slightly calcareous, slabby, crossbedded; contains scattered dark gray, lustrous phyllite grains; very sparse rounded pebbles scattered throughout; crossbedding sets 0.5-2.0 feet thick.	15
Conglomerate, as above; contains boulders 1.0-4.0 feet in length.	4
Sandstone, as above	12
Covered	15
Conglomerate, boulder and cobble; similar to conglomerate above; contains abundant fragments of medium-gray, fine-grained, volcanic breccia and porphyritic diorite.	110
Sandstone, as above	3
Covered	45

Section of lower part of the conglomerate and sandstone unit measured on the shores of the peninsula between Little Pybus and Pybus Bays.--continued

	Feet
Conglomerate and sandstone unit--continued	
Conglomerate, pebble and cobble, rounded clasts of types given above in medium dark-gray, coarse-grained, lithic sandstone matrix; matrix about 40 percent contains abundant grains of dark-gray, lustrous phyllite; lenses of medium dark-gray, slightly bluish, coarse-grained, lithic sandstone; sandstone lenses are crossbedded in sets 0.5-2.0 feet thick; contains slightly rounded slabs of slaty argillite near base.	145
Total	374

Angular unconformity

Seymour Canal formation:

Argillite, dark-gray, slaty, fractured; contains sparse 1.0-2.0 inch thick medium dark-gray, fine-grained graywacke beds.

Section of upper part of the conglomerate and sandstone unit in northern Little Pybus Bay.

	Feet
Admiralty Island volcanics:	
Conformable contact	
Conglomerate and sandstone unit:	
Conglomerate, cobble, medium dark-gray; subrounded cobbles averaging 3 inches in length, 20 percent coarse sandstone matrix; cobbles chiefly dark gray,	

Section of upper part of the conglomerate and sandstone unit in northern Little Pybus Bay--continued

	Feet
Conglomerate andsandstone unit--continued	
fine crystalline, vesicular volcanic rocks, and a few black chert and white quartz pebbles; about 20 percent matrix.	10
Conglomerate, pebble-to-cobble, medium light-gray, massive; rounded clasts of granite, gneiss, quartz, felsite, black slate in medium-gray, coarse-grained, lithic sandstone matrix; matrix about 40 percent; clasts average about 3 inches in length; unit includes a few 1-3 foot thick lenses of medium light-gray, medium- to coarse-grained, sparsely pebbly, lithic sandstone.	65
Sandstone, medium light-gray, weathers reddish yellow, fine-grained, micaceous (muscovite), slabby, crossbedded; crossbedding sets average 1.0 inch in thickness; symmetrical ripple marks; scattered brown, iron-rich concretions 1-2 inches in diameter.	10
Shale, medium-gray, fissile	20
Sandstone, medium dark-gray with slight bluish cast, coarse-grained, lithic, crossbedded, slightly calcareous, massive; contains abundant slab-like grains of dark-gray, lustrous phyllite; crossbedded sets average about 1.0 foot in thickness.	10
Covered	
Total	115

p. 61 follows

Admiralty Island volcanics

The name Admiralty Island volcanics is here proposed for the thick sequence of gently dipping, andesitic and basaltic flows and minor rhyolitic breccia and tuff that crops out in the southwestern part of the Pybus-Gambier area, and is typically exposed west and north of Little Pybus Bay. The volcanics rest conformably upon the unnamed conglomerate and sandstone unit in the Little Pybus Bay area (p. 56; see also fig. 17b), but from Cannery Cove northwestward the volcanics overlie strongly deformed rocks of pre-Tertiary age with a marked angular unconformity. The Admiralty Island volcanics are overlain by scattered unconsolidated deposits of Quaternary age.

The formation attains a thickness of at least 9,500 feet west of Cannery Cove, but thins southward to less than 5,000 feet near Little Pybus Bay. Individual flows range in thickness from 10 to 50 feet, and form a regularly layered sequence in which some flows seem to persist for miles. Rugged topography underlain by the volcanics consists of alternating cliffs and gentle dip-slopes that reflect the thick layering and gentle dips of the flows (fig. 19a). Fresh, unaltered flow rock is dark gray to grayish black, and weathers yellowish brown, reddish brown, greenish gray, and black. The most common type contains plagioclase phenocrysts set in a fine-grained or aphanitic groundmass. The flows commonly contain anygdales composed of chalcedony, calcite, or chlorite in their upper parts. The flows are generally massive and irregularly fractured (fig. 17b), but in a few places they display crude columnar jointing (fig. 19b). The rock is composed largely of plagioclase (An_{54} to An_{88}), clinopyroxene, magnetite-ilmenite; locally glass is an important constituent (see Appendix).

The Admiralty Island volcanics are cut by numerous dikes, ranging in thickness from 0.25 inch to 20 feet, having compositions similar to those of the flows. The dikes are also abundant in the older rocks

a. Terrain west of Cannery Cove showing gently dipping flows of the Admiralty Island volcanics.

b. Crude columnar jointing in flows of the Admiralty Island volcanics, Little Pybus Bay.

Figure 19

in a zone about one mile wide bordering the outcrop of the volcanics, but beyond this zone dikes are scarce. This fact suggests that the Tertiary volcanism did not extend far beyond the present areal extent of the Admiralty Island volcanics. Figure 20 shows the orientation of dikes in the pre-volcanic rocks in the above zone. The average dike orientation, striking N. 32° E. and dipping 75° to the south, is about normal to the axial planes of the second folds in the Pybus structural province (p.).

Alteration resembling the propylization of Wilshire (1957, p. 244-245), is widespread in both flows and dikes of the Admiralty Island volcanics. The chief products of this alteration are chlorite, calcite, sericite, epidote, and albite, whose presence imparts a greenish gray color to the altered rocks (see Appendix for details). The relation of the altered rocks to the unaltered rocks is unclear because of the difficulty of tracing out individual flows or dikes in the rugged terrain. However, all transitions from unaltered to completely altered rocks occur in different localities, suggesting that zones of altered rock grade into unaltered rock. Altered and unaltered dikes have the same general orientation (fig. 20), and thus probably belong to the same episode of intrusion.

Because of the variability of the plagioclase composition, the classification of the rocks of the Admiralty Island volcanics is based on their chemical composition. Four rapid rock analyses were made of unaltered or slightly altered rocks; the slightly altered rocks contain small amounts of chlorite, sericite, and calcite (fig. 21, nos. 1, 2, 3, 4). In addition, three analyses of almost completely altered rocks were made (fig. 21, nos. 5, 6, 7). The analyses of the unaltered rocks show a range in SiO_2 composition from 47.4 to 57.9 percent with most containing 53.9 to 55.9 percent SiO_2. Williams (1950, p. 234-235) calls those rocks containing less than 54 percent SiO_2 basalts, and those containing more than 54 percent

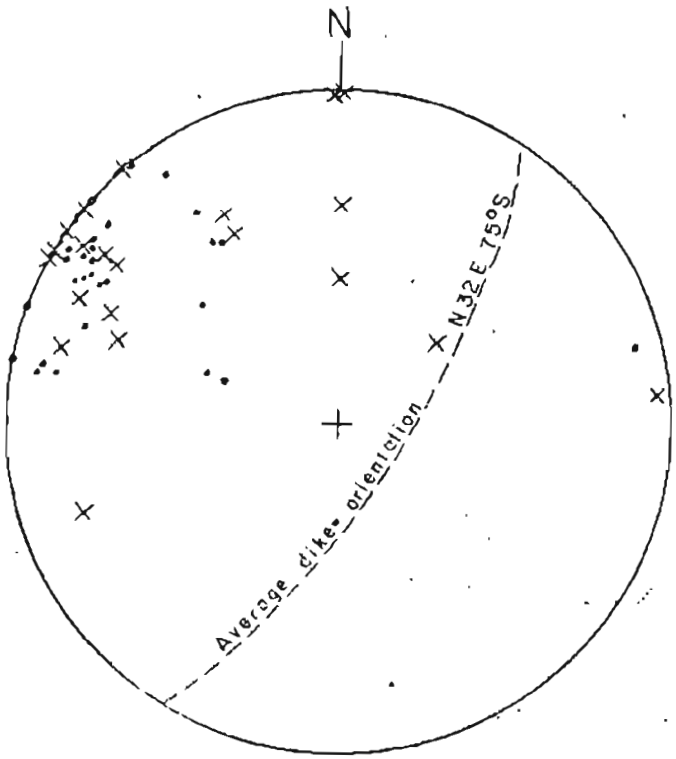


Figure 20.--Equal area, lower hemisphere plot of poles to 50 dikes associated with the Admiralty Island volcanics; • --unaltered dike, X--altered dike.

SiO_2 andesites. On this basis specimen 1 with 47.4 percent SiO_2 is a basalt, and specimen 4 is an andesite; the rest range from andesitic basalts to basaltic andesites. The most basic of these, number 1, was collected from a flow near the base of the formation, wheress the rest were collected at higher stratigraphic levels.

According to Wilshire (1957, p. 257), the propylitized andesites at Ebbet Pass, California, show a decrease in Al_2O_3, K_2O, and Na_2O in comparison to unaltered andesites. He attributed the loss of Al_2O_3 and Na_2O in large part to the replacement of plagioclase by calcite. These changes in composition cannot be followed closely in the present analyses because, unlike Wilshire's work, analyses could not be made of unaltered and altered parts of the same rock body. In the analyses of figure 21 K_2O and Na_2O show no constant sense of change between altered and unaltered rocks, however, Al_2O_3 is distinctly lower in the altered rocks. The intermediate Al_2O_3 percentages of specimens 2 and 4 may reflect the degree to which alteration has progressed in these rocks.

No fossils were found in the Admiralty Island volcanics, however, they are considered here to be Eocene because of their general structural conformity with the underlying conglomerate and sandstone unit, and because of the concentration of volcanic fragments of types common in the volcanics in the uppermost layers of the conglomerate (p. 56; fig. 17b). The latter evidence suggests that the volcanism had begun before the end of conglomerate deposition.

The Admiralty Island volcanics within the Pybus-Cambier area represent only the northeastern part of the total extent of these volcanic rocks. They cover most of the southern end of Admiralty Island, an area of about 300 square miles (Lathram and others, 1960). Coal-bearing beds are intercalated between volcanic breccia near Murder Cove at the south tip of

Figure 21. Analyses of rocks from the Admiralty Island volcanics. (Rapid rock analyses by Paul L. D. Elmore, Ivan H. Barlow, Samuel D. Botts, and Gillison Chloe, U. S. Geological Survey.)

	1	2	3	4	5	6	7
SiO_2	47.4	55.9	55.9	57.9	44.1	55.2	58.9
Al_2O_3	18.0	16.6	18.3	17.8	15.4	15.8	15.1
Fe_2O_3	2.2	1.6	1.1	1.1	1.6	3.2	10.9
FeO	7.9	5.6	5.0	4.9	7.8	6.6	4.0
MgO	5.5	4.4	2.7	3.8	5.2	3.3	2.4
CaO	10.5	7.7	7.7	7.3	9.0	6.0	4.4
Na_2O	2.5	3.5	3.6	3.6	2.9	4.6	3.9
K_2O	.20	.48	.98	1.4	2.0	1.2	1.8
H_2O	2.6	1.7	2.5	.92	4.3	1.8	2.7
TiO_2	1.6	1.1	1.1	.91	2.0	1.8	.82
P_2O_5	.20	.22	.24	.18	.68	.40	.18
MnO	.14	.14	.10	.10	.15	.14	.08
CO_2	1.4	2.6	.26	.05	4.5	.05	4.8
Sum	100.	100.	99.	100.	100.	100.	100.
Powder Sp. Gr.	2.80	2.77	2.70	2.82	2.80	2.85	2.74

1. Unaltered porphyritic basalt from near base of section on west shore of Little Pybus Bay.
2. Slightly chloritized, nonporphyritic andesitic basalt from north side of ridge top 1.3 miles east of head of south arm of Hood Bay.
3. Unaltered, glassy, porphyritic basaltic andesite from ridge top near altitude 2,627 feet, 1.6 mile N. 30° W. from head of Eliza Harbor.
4. Slightly chloritized, porphyritic andesite from east shore at head of Eliza Harbor.
5. Altered lava from top of peak 3,626 feet altitude, 2.7 miles east of head of Eliza Harbor.
6. Altered lava from north side of ridge top 0.8 mile south of south arm of Hood Bay.
7. Altered dike from shore north of Cannery Cove 0.5 mile west of triangulation station Dove.

Admiralty Island (C. W. Wright, 1906, p. 145, 152-153).

Buddington and Chapin (1929, p. 266-267) described basaltic and andesitic lava flows underlain by sandstones and conglomerates of Eocene age south of Admiralty Island on Kupreanof, Kuiu, and Zarembo islands. In addition, they found small outcrops of similar volcanic rocks on the Castle Islands in Duncan Canal, and on small islands near Onslow Island in the Ketchikan district. Northwest of Admiralty Island volcanic flows and tuffs of possible Tertiary age occur on Pleasant Island, and on the Sisters in Icy Strait (Lathram and others, 1959).

Miller and others (1959, p. 22) considered the nonmarine sedimentary rocks of Eocene age, and overlying volcanic rocks cropping out on Admiralty, Kupreanof, and Kuiu islands to be remnants of deposits in their Tertiary Admiralty trough.

Quaternary deposits

Unconsolidated deposits of glacial clay and gravel, and recent alluvial gravel, all of which are too small to show on the geologic map, are scattered along the floors of most stream valleys. Fossils of marine invertebrates were found in glacial clay at two localities. One of these, containing mollusc shells, is located at an altitude of 150 feet in the channel of a stream flowing northeastward into southeastern Gambier Bay (loc. 36, fig_{56}). The other locality, containing Foraminifera tests, occurs at an altitude of 475 feet in the channel of a stream lying west of False Point Pybus that flows east and south into Stephens Passage (loc. 37, fig_{56}). Thus sea level in glacial times reached a level at least 475 feet higher than at present.

Northwestern Pybus-Gambier area

The northwestern part of the Pybus-Gambier area lying west of Gambier Bay and northwest of the Gambier fault is poorly known, and has been mapped on a reconnaissance scale only (pl. 1) in order to complete the geologic mapping of the Sitka B-1 quadrangle. In general it is a poorly exposed area of plutonism and contact metamorphism. Because of the metamorphism and the lack of exposures in this area, the rock units mapped elsewhere in the Pybus-Gambier area could not be recognized with certainty. The structure is, therefore, poorly known; the rocks are in general layered, but in most places bedding and foliation could not be distinguished from one another. For this reason a special map symbol is used here for the attitudes of the dominant planar structure present which does not distinguish between the different types of planar structures.

The southeastern boundary is taken at the Gambier fault; although this fault appears to bring metamorphic rocks on the north against nonmetamorphic rocks on the south, the country along the fault is poorly exposed and the relations are by no means clear. To the east the metamorphic rocks of the Gambier Bay formation appear to grade westward into coarser grained, but similar varieties in the contact zones of the plutons. Four generalized units are mapped as follows:

Hornfels

Mostly thinly layered, dark green, amphibole-bearing hornfels containing scattered minor units of dark gray, thin-bedded, finely sugary quartzite that is probably a metachert. The rocks in general are not obviously foliated, but in a few places become schistose and indistinguishable from the greenschist unit. Tight, small-scale folds are common. The unit may include metamorphic equivalents of the Hood Bay, Cannery, and Hyd

formations.

Greenschist

Complexly folded greenschist and subordinate amounts of fine-grained mica-schist. These rock types are in general similar to the greenschists of the Gambier Bay formation, but are more coarsely crystalline; the coarser grain size is at least in part due to contact metamorphism. The unit may be roughly equivalent to the noncalcareous parts of the Gambier Bay formation.

Marble

Light-gray to white, thick-bedded, medium- to coarse-crystalline marble containing minor units of medium-gray, thinly platy, fine- to medium-crystalline marble and greenschist. The marble locally contains abundant needles which in some places are wollastonite and in others are tremolite. A coarse foliation is commonly present, but its relation to bedding is not known. The dip slope of the thick-bedded marble weathers to a rough, Karst topography. The marble occupies topographically high positions, and may overlie part of the greenschist. It may be equivalent to the marble member of the Gambier Bay formation.

Diorite

Only the border zones of the two plutonic bodies have been sampled. The most common rock type seen is a porphyritic hornblende-andesine diorite containing abundant phenocrysts of andesine ranging from 5 to 10 mm in length. Samples from the contact zone of the northernmost pluton are rich in magnetite and pyroxene. The plutons in places intrude rocks of all three of the above metamorphic units generally with an increase in grain size of the metamorphic rocks toward the contact. The country rocks of

the contact zones are commonly cut by a complex of veins of the diorite. Such effects appear to be limited to zones ranging in width from 50 to 100 feet beyond which the only contact effects seen are those of crystallization.

STRUCTURE

General discussion

Structural provinces

The Pybus-Gambier area may be divided into three provinces based on structural style (fig. 22); 1) the Gambier structural province, composed of the Gambier Bay formation and characterized by intense, metamorphic deformation in which folding has dominated; 2) the Pybus structural province, composed of the rocks of the Hood Bay, Cannery, Eyd, and Seymour Canal formations and also characterized by intense deformation in which folding has dominated, but without regional metamorphism; 3) the Southwest structural province, composed of rocks of Tertiary age and characterized by mild deformation in which faulting has dominated. The following structural analysis is chiefly a study of the folds in the Gambier and Pybus structural provinces. Faults are important features of all provinces; however, because they are commonly shared by more than one province, faults are discussed in a separate section rather than under the province in which they occur.

Discussion of structural analysis

A method of structural analysis employing equal area projections was used, in addition to conventional methods, to study the geometry of the rocks of the Gambier and Pybus provinces. This method was used because it permits the representation of the orientation of structural elements so as to show the three-dimensional relations between them. Furthermore,

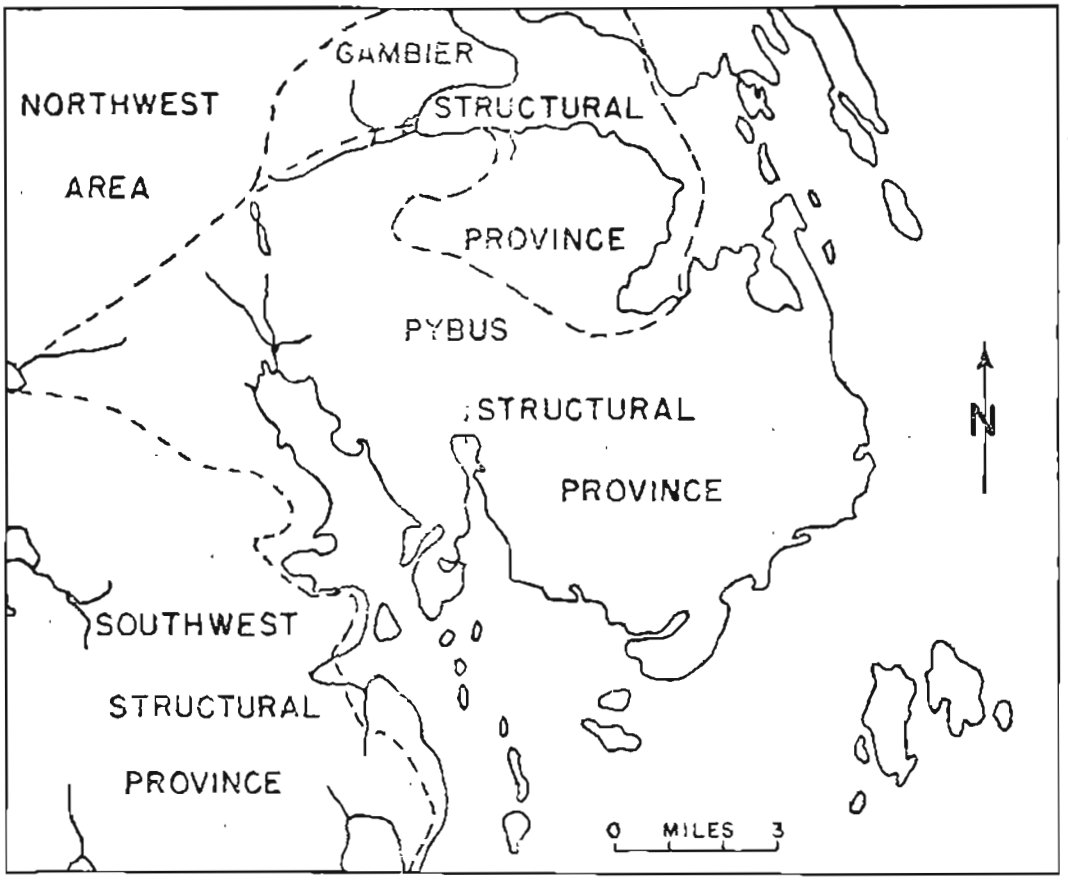


Figure 22.--Index map of structural provinces.

conventional geologic sections are not satisfactory in these provinces because fold axes change orientation within short distances preventing the prediction of their orientation below the surface. The scarcity of marker beds adds further difficulty to the construction of significant sections. Because of these difficulties, conventional geologic sections are used only in a highly diagrammatic and distorted form in the isometric block diagram (pl. 5) in order to give a generalized view of my interpretation of the geology of the Pybus-Gambier area.

The method of analysis is based on Sander (1948, p. 132-148), and is described in detail by Weiss (1959a, p. 12-24; see also Weiss and McIntyre, 1957). It consists of three parts: 1) study of mesoscopic[1/] structures; 2) study of macroscopic structures; 3) correlation of mesoscopic and macroscopic structures.

[1/] In this paper the use of the terms mesoscopic and macroscopic follows that of Weiss and McIntyre (1957, p. 577): mesoscopic structures are those whose features can be determined directly in single, continuous outcrop; macroscopic structures are those whose features must be determined from isolated observations.

The study of mesoscopic structures consists of the measurement of their orientation and the grouping of them into syngenetic groups called generations. The establishment of the generations is based on the overprinting (Überprägung of Sander, 1948, p. 81) or superposition of later structures on earlier ones. The structures grouped in a generation must show consistent relations to those of the other generations. A generation of structures (excluding primary structures) may consist of folds, lineation, and axial plane foliation that formed together in response to the same stress field.

Where order of overprinting is unclear, the physical characteristic of the structures of a generation may sometimes be used in correlation. However, physical characteristics must be used with caution because they commonly vary with rock type and even where constant may resemble those of structures belonging to other generations. Certain fundamental characteristics such as the general form of folds (for example, similar or parallel) may prove to be constant in one rock type.

The orientation of structures of one generation in terranes of superposed folding may be highly variable, and is not a good basis for correlation. Field evidence in the Rybus-Gambier area and in the Scottish Highlands (Weiss and McIntyre, 1957, p. 283, 297; Ramsay, 1958a, p. 291) indicates that the axial surfaces of folds tend to have a more regular preferred orientation than do their axes. Axial surfaces of folds tend to be initially planar in spite of pre-existing variations in the orientation of the structural surface being folded, whereas the orientation of fold axes for a given stress field is controlled in part by the pre-existing orientation of the surface being folded (Weiss and McIntyre, 1957, p. 597-598; Weiss, 1959b, p. 95-98). Thus, for example, the orientation of axes of later folds superposed on previously folded bedding is not constant. Furthermore the earlier fold axes would be curved owing to deformation by the later folding; for discussions of the deformation of earlier linear structures by later folding see Sander (1948, p. 171-172), Weiss (1959b, p. 98-102), and Ramsay (1960). In contrast, later folding of axial surfaces, because of their initial subplanar form may result in structurally homogeneous domains[1] large enough to map.

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[1] Domains are considered structurally homogeneous if the structural surface is either planar or is folded about a single, rectilinear, statistically defined fold axis; the term cylindroidal is also applied to such a fold (Weiss, 1959b, p. 92-93).

The study of the macroscopic structures uses the β-axis method originated by Sander (1948, p. 132-146) and further developed by Weiss (1959a, p. 12-24; see also Weiss and McIntyre, 1957, p. 587-595). The macroscopic folding in a selected structural surface (bedding, foliation, etc.) is studied by subdividing the area of study into structurally homogeneous domains. In the present work, β-axes were constructed by plotting attitudes of the structural surface on the lower hemisphere of equal area projections either as arcs of great circles (S-diagrams) in domains where data are scarce or as poles of the surface (S-pole diagrams) in domains where data are abundant.

The third part of the structural analysis involves the correlation of the macroscopic fold axes, determined as β, of the various domains with associated mesoscopic folds and lineations. This is accomplished by plotting the attitudes of these mesoscopic linear structures measured in a domain on a projection together with the β-axis of that domain. The macroscopic fold represented by the β-axis is considered to belong to a certain generation if mesoscopic folds and associated lineations of that generation are subparallel to β.

In the Pybus-Gambier area one additional process was necessary: namely, correlation of events between structural provinces in order to construct the tectonic history of the area as a whole.

Gambier structural province

Mesoscopic structures

General statement.--Fissile greenschists and phyllite commonly show an abundance of fine structural detail consisting of several types of interfering small folds and lineations, whereas the massive-appearing greenschists, marbles, and metacherts generally show only crude layering. Microscopically

all these rocks show a prominent foliation or schistosity. The interfering structures have been grouped into three generations based on criteria previously discussed (p. 72).

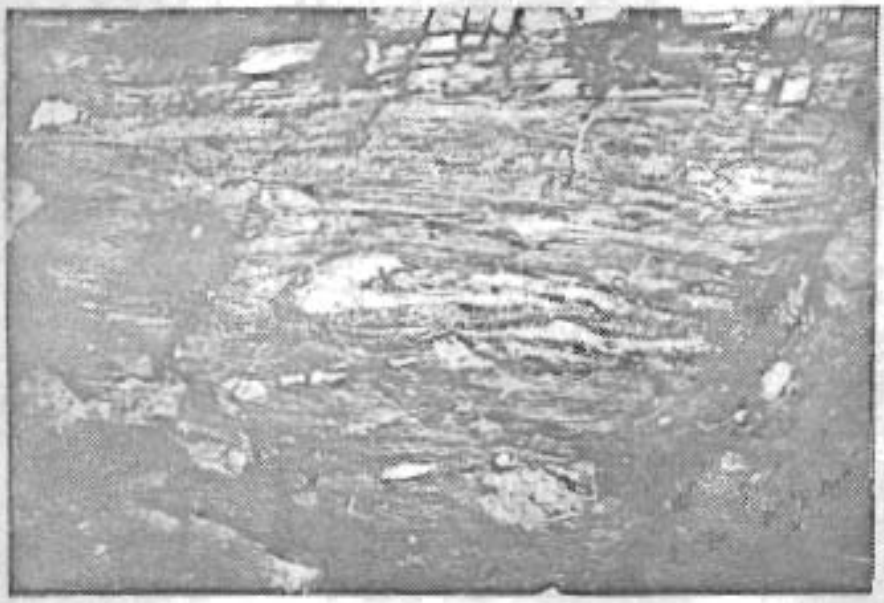
Bedding.--Bedding survives clearly only in a few places as thin metagraywacke beds in dark phyllite. In most outcrops only a prominent secondary foliation can be seen; in a few places this foliation is seen to intersect the bedding at various angles. Thick, massive-appearing marble and metachert units must also represent bedding, but the attitude of these units is generally unknown because their contacts with the other rocks are obscure.

The scarcity of visible bedding seems to have been caused by a combination of the following two factors: 1) rocks were initially largely thick-bedded or massive volcanic rocks; 2) bedding is largely disrupted and transposed by formation of a secondary foliation, resulting in disrupted fragments of beds lying subparallel to the foliation (fig. 23a; for discussion of transposition see E. Knopf, 1931, p. 15).

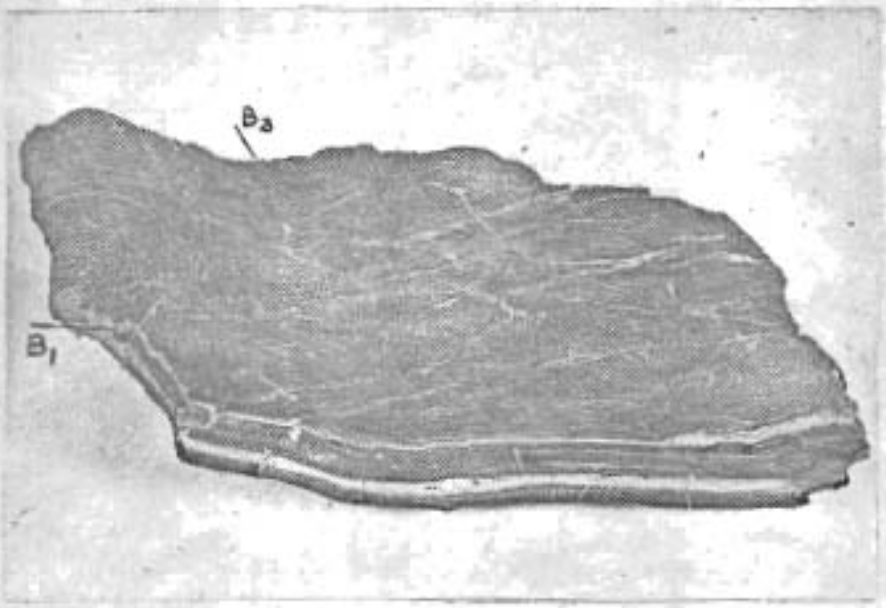
First generation of structures.--This generation consists of folds, lineation, and foliation upon which have been superposed the structures of the other two generations; it is therefore considered to be the earliest of the three.

The folds of the first generation will be called the "first folds" for brevity; they differ from the folds of all other generations in that they are formed only in the bedding. The first folds are tightly appressed or nearly isoclinal with thickened hinges and thinned limbs (figs. 23a, b). As a rule they are visible only in thinly bedded phyllite, but occasionally detached fold hinges are seen in thin marble beds within the greenschist (fig. 23a).

All first folds have a pronounced foliation subparallel to their axial surfaces, however, as mentioned above, slip movement along the foliation



a. Detached hinges of first folds and elongate fragments in greenschist, Gambier Bay formation, Gambier structural province.



b. First fold hinge in thin-bedded phyllite; B_1--axis of first fold; B_3--axis of third fold; bedding and foliation about parallel except in hinge.

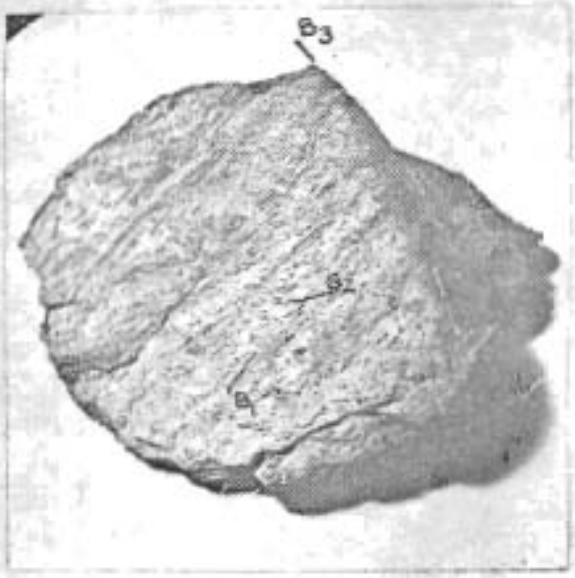
Figure 23

surfaces has generally disrupted and transposed these folds. Such a foliation (or cleavage) subparallel to the axial surface of a fold is considered by many geologists to be syngenetic with the fold (Hills, 1955, p. 110-113; Wilson, 1946, p. 264-273; Billings, 1954, p. 350). Therefore, the foliation is grouped with the first folds as a structure of the first generation, and will be called "the foliation".

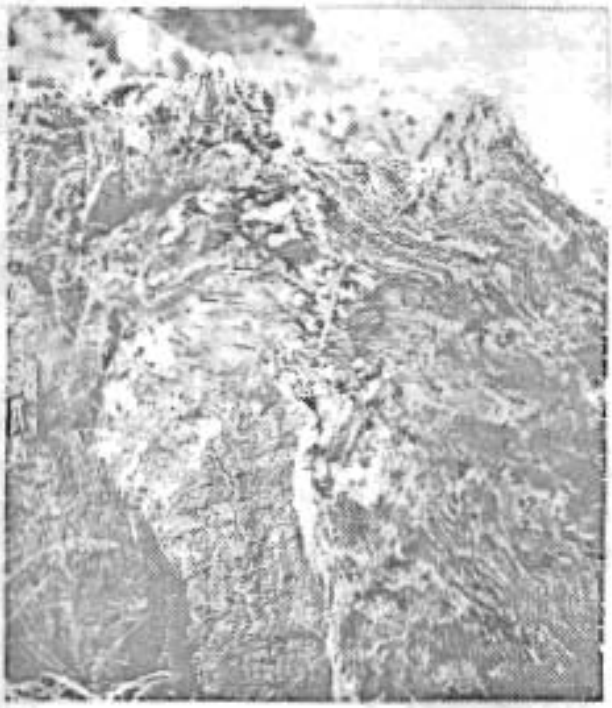
In phyllite, the foliation is a lustrous slaty cleavage; the silvery sheen is due to the crystallization of sericite along the foliation surfaces. The phyllite in places grades into fine-grained sericite schist in which the foliation takes on the aspect of a schistosity. The field appearance of the foliation in greenschist depends upon the composition of the rock. In fissile schists rich in chlorite and sericite it is represented by lustrous, paper-thin sheets, whereas in the massive-appearing, calcareous greenschists the foliation appears as crude layering parallel to which are scattered elongate coarse fragments of marble and altered volcanic rock. But regardless of appearances in outcrop, the foliation in all these rocks is defined microscopically by parallel preferred orientation of platy minerals or by very thin layers of mechanically comminuted material (see fig. 42 in Appendix).

Thin streaks or ridges on the foliation surfaces, generally contrasting in color and composition with the rest of the rock, occur abundantly throughout the Gambier province (fig. 24a). They represent the trace of the intersection of bedding and foliation, and are subparallel to the axes of the first folds. Thus the streaks provide a means of measuring the axial orientation of the first folds where the folds themselves are not seen.

Second and third generations of structure.--The structures of the second and third generations affect both bedding and foliation, and are thus readily distinguished from those of the first generation which affect the



a. Hand specimen of phyllite showing single third kink fold (B_3) in foliation, first streak lineation (B_1), and second lineation (B_2), specimen about 8 inches across.



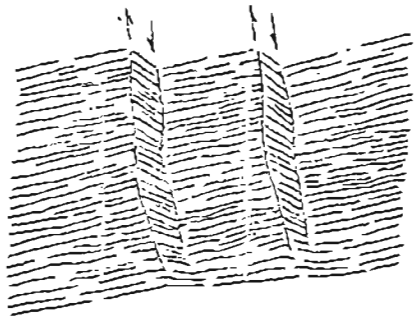
b. Second folds in greenschist, Gambier province; folds above and below pencil show common sharp crests and rounded troughs.

Figure 24

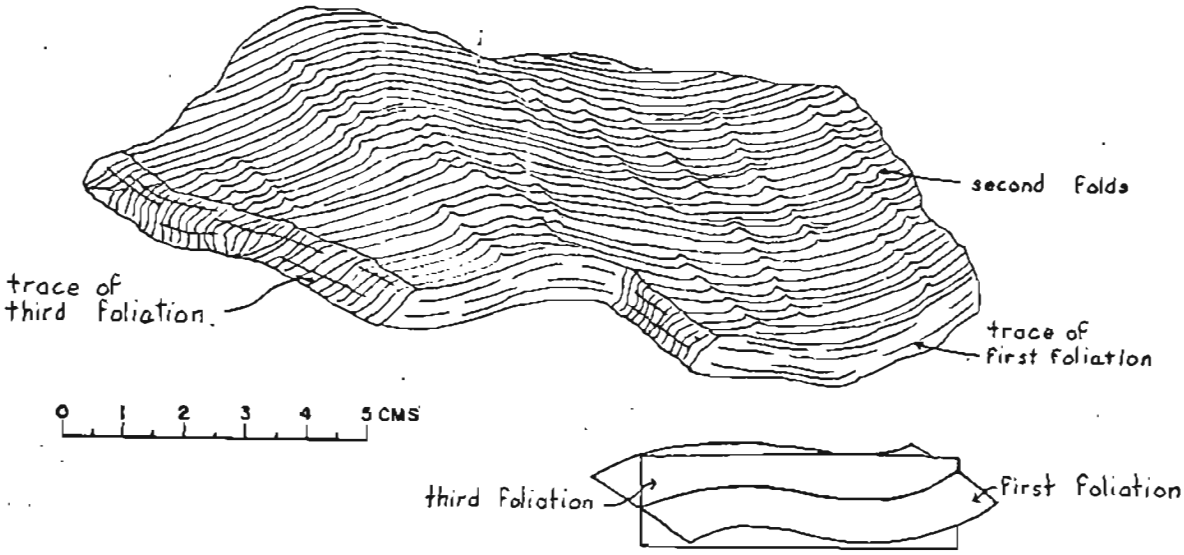
bedding only. Where third generation structures are overprinted upon the second the two are easily distinguished, but where only one is present their separation is often uncertain because the smaller linear structures of the two generations such as crenulations and striations, are similar in form. The larger mesoscopic folds of each generation, however, have characteristic differences both in physical aspect and in orientation that remain constant throughout large areas, and are useful in correlating the generations.

The second generation consists largely of folds ranging in size from crenulations a millimeter in wave length to folds several tens of feet in wave length in which axial surface foliation is generally lacking. The style of the second folds is variable, but it most commonly consists of sharp-hinged anticlines alternating with rounded-hinged synclines (fig. 24b). The axial surfaces of the second folds dip moderately southward in most of the Gambier province.

The third generation consists largely of kink folds with generally subvertical axial surfaces. This orientation contrasts with the moderate dip of the axial surfaces of the second folds greatly facilitating the separation of the two generations of folds. The term "kink fold" is used here for folds formed by the rotation of foliation surfaces in a thin zone of rock with respect to the surfaces on each side of the zone (fig. 25a). The rotated zone is bounded by surfaces of kinking that roughly parallel the axial surfaces of the kink folds. The rotation is accomplished by the slip of the foliation surfaces over one another. In general the rotated zones range in width from a few millimeters to a few inches, but in a few places they are very thin (average width less than 0.06 mm) and closely spaced. Such closely spaced kinking surfaces resemble foliation surfaces, and the rotation of the first foliation is not readily visible in hand specimen (fig. 25b).



a. Sketch of kink folds.



b. Sketch of phyllite specimen, Gambier province, showing penetration of structures of the first and second generations by planar third foliation.

Figure 25

The kink folds resemble closely the Knickzonen and Flexuren of Koeppener (1955, p. 34-37; 1956, p. 263). Their general form is also similar to that of kink bands in deformed metals (Orowan, 1942, p. 643).

The kink folds are superposed upon the structures of the first and second generations, and they in turn do not appear to have any later mesoscopic structures superposed upon them. These relations are illustrated by the following examples: 1) Figure 24a shows a single third kink fold superposed upon the first foliation, first lineation (streaks), and second lineation (crenulations). 2) Figure 25b is a sketch of a hand specimen in which the third foliation penetrates the first foliation and second folds without distortion. 3) Figure 26 shows steeply plunging kink folds superposed upon the first foliation and gently plunging second folds and lineation.

Macroscopic structures

General statement.--Because the first foliation is the only prominent, widespread structural surface in the Gambier province (p.75), it is the only surface whose macroscopic form could be studied. The foliation is subparallel to the axial surfaces of the first folds, and was probably approximately planar at the end of the first folding (p.75). It is assumed, therefore, that its present complex form (fig. 27a) is largely the result of later deformation. Figure 27a contains no plane of symmetry and no single girdle of foliation poles, thus no single, rectilinear axis of folding exists for the entire province. The complex pattern suggests noncylindroidal folding (see Weiss, 1959a, p. 18-19).

In order to test for the presence of cylindroidal folding on a smaller scale, the province was subdivided into structurally homogeneous domains (p.73) in plate 2. The diagrams of certain domains of this plate show no

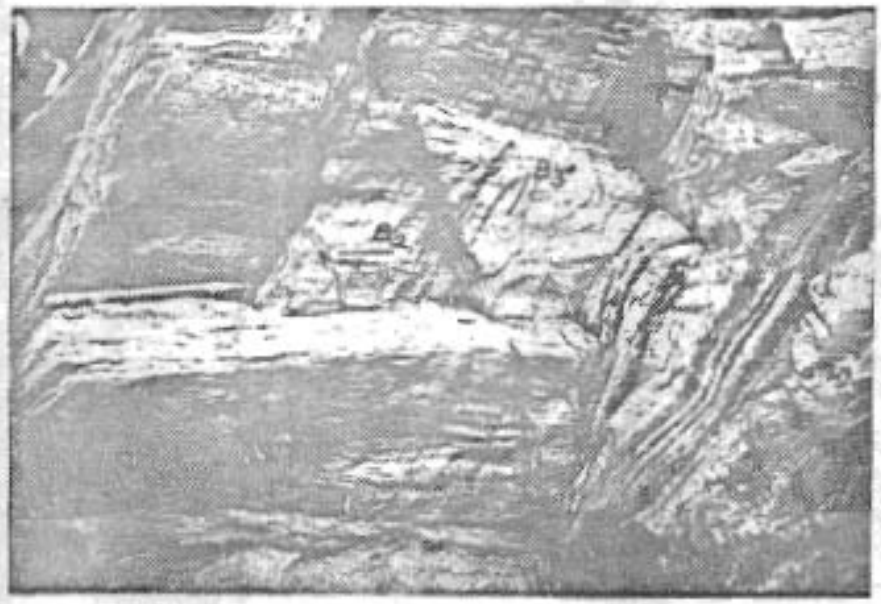


Figure 26.--Steeply plunging third kink folds (B_3) superposed on foliation and shallowly plunging second folds and lineations (B_2), Gambier structural province.

a. Collective diagram of 300 foliation poles, Gambier province; (1/3)-1-2½-5 percent per 1 percent area.

b. Collective diagram of 85 mesoscopic first fold axes and lineations, Gambier province; (1)-5-10-15 percent per 1 percent area.

Figure 27

distinct β-axes; in some too few data were available to establish a β-axis, and in others the foliation is subplanar, i.e., either unfolded, or more likely, isoclinally folded. Plate 2 shows also form lines that are the generalized traces of the foliation on the topographic surface.

First generation.--The macroscopic form of the bedding is virtually unknown, hence what little is known about the first folds is derivedd from the orientation of the mesoscopic first fold axes and their relation to later folds. Information of this kind is chiefly in terms of preferred orientation and tells little about the size of the macroscopic first folds and the location of their hinges.

The axes of the first folds plunge gently eastward or westward (fig. 27b). Those plunging to the west are most abundant, and form in the projection in a strong maximum trending west-northwest; whereas those plunging to the east are much less abundant and have trends ranging from southeast to north-northeast. The areal variations in the orientation of the first axes is shown in plate 3, which was made by subdividing the province into domains of approximately uniform preferred orientation of second fold axes. The data used in this plate were taken only from localities in which the second linear structures were clearly superposed upon those of the first generation.

A correlation exists between the orientation of the first fold axes and the attitude of the foliation in the domains in which the folds occur. This is to be expected from the mesoscopic evidence that the foliation is subparallel to the axial surfaces of the first folds (p. 75). Plate 3 shows that first axes plunging to the west-northwest or east-southeast (i.e., west-northwest-trending) occur chiefly in domains in which the strike of the foliation ranges from west to northwest (domains II, III, IV, pl. 3), whereas those plunging to the northeast occur chiefly in

domain I in which the foliation strikes north. Where the foliation bends around the hinges of macroscopic folds, the first fold axes show a corresponding change in orientation (fig. 28).

Plate 3 (see also fig. 28) shows that the angle between the first and second fold axes is small in the northern part of the province (domains II, III, and IV) and large in the southeastern part (domain I).

Second generation.--The form lines of plate 2 describe a series of straight-limbed folds in the foliation whose axial planes strike northwest. These folds belong to the second generation, and are the largest in the province, having southeast-plunging rectilinear axes.

Two folds are described by the form lines south and west of Snug Cove: a northern fold, convex to the northwest, and a southern one, convex to the southeast. The northern fold belongs to the Snug Cove synform[1] whose

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[1]. Antiform and synform are purely descriptive terms introduced by E. B. Bailey (in Bailey, Weir, and McCallien, 1939, p. 120-121) for folds whose hinges are respectively convex upward and convex downward. They do not imply that the folded strata become either older or younger toward the cores of folds, and are used in this paper for folds in complexly layered rocks to avoid the stratigraphic connotation of the terms anticline and syncline.

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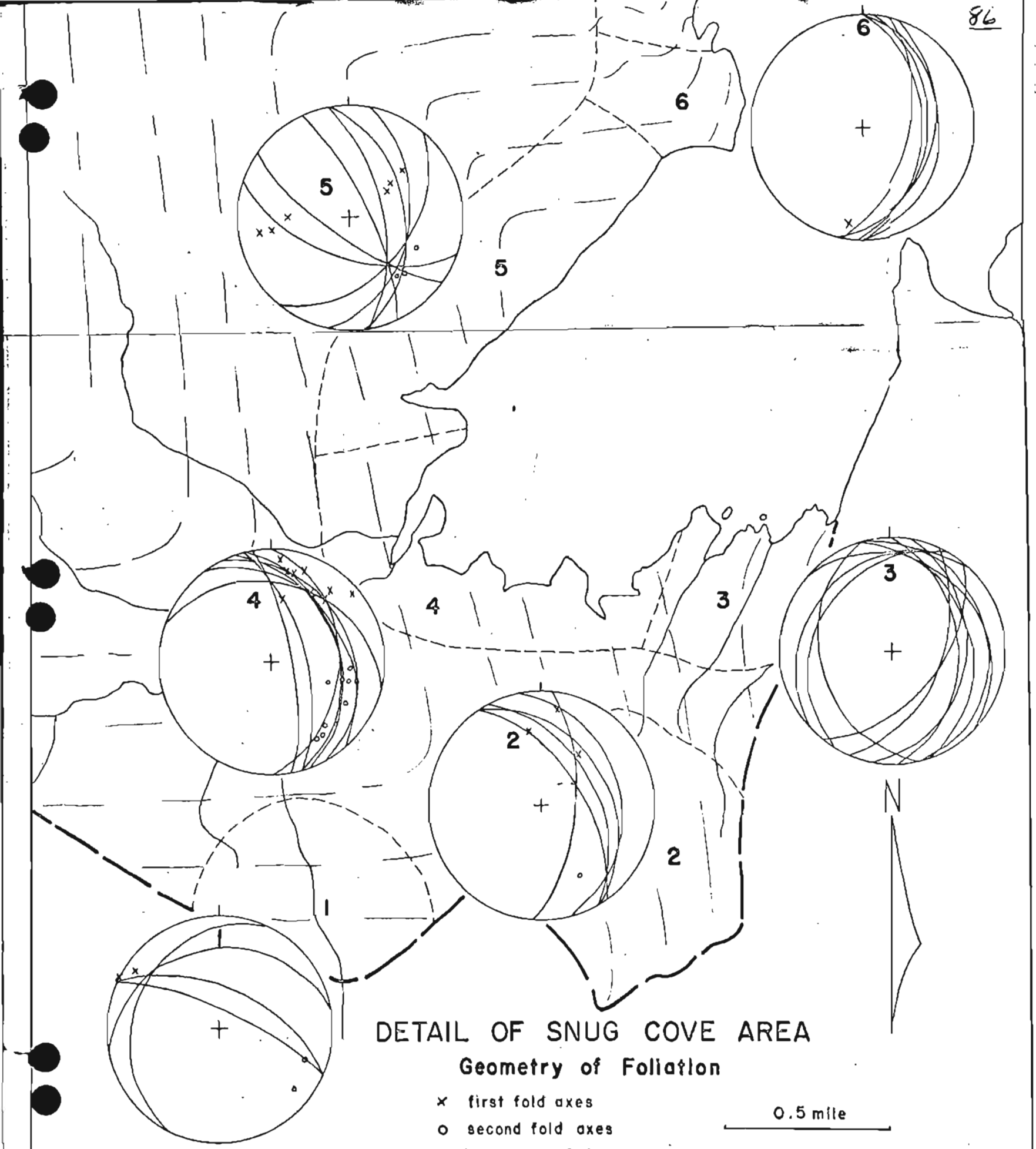
northern limb strikes west and dips moderately to the south, and whose southern limb strikes north and generally dips moderately to steeply to the east, and locally to the west. The asymmetry of the synform requires that its axial surface dip to the south. An axial plunge to the southeast is indicated both by the northwestward convexity of the fold, and by the plunge of the β-axes of domains 5 and 13 (pl. 2) located on the hinge. The



DETAIL OF SNUG COVE AREA

Geometry of Foliation

× first fold axes

o second fold axes

(see Plate 2 for other symbols)

correlation of the synform with the second generation is based upon the clustering of mesoscopic, second fold axes in domains 5 (fig. 28) and 13 (fig. 29) about the β-axes of these domains.

A fold, occurring northwest of the west arm of Gambier Bay, is similar in form and in direction of convexity to that ofthe Snug Cove synform, and may be the extension of it. However, the two hinges are not exactly aligned, and the northwest hinge is displaced westward with respect to the hinge of the Snug Cove synform. Little is known about this fold, but its similarity to the Snug Cove synform suggests that it is also a southeast-plunging synform.

The southern fold flanks the Snug Cove synform on the southwest. The north-striking limb of the fold, which it shares with the Snug Cove synform, dips generally eastward, and the poorly exposed west-northwest-striking limb also seems to dip to the east. Hence, the axial surface dips to the northeast in an opposite direction to that of the Snug Cove synform, and the fold is overturned to the southwest. The relation of this fold to the Snug Cove synform indicates that it is an antiform probably plunging to the southeast. However, the hinge of this fold is poorly exposed and its axial orientation could not be determined.

Another fold comparable in size to the two described above occurs in the northwestern part of the province. The hinge is covered by the waters of Gambier Bay, and is not defined by the form lines of plate 2. The evidence for its existence is therefore indirect, and may be summarized as follows: 1) The change in attitude of the foliation from one side of the northwest arm to the other suggests the presence of two limbs of an overturned antiform whose axial surface strikes northwest along the center line of the arm. The normal, southwestern limb of this possible antiform strikes west-northwest and dips 30° to 40° to the south, whereas the over-

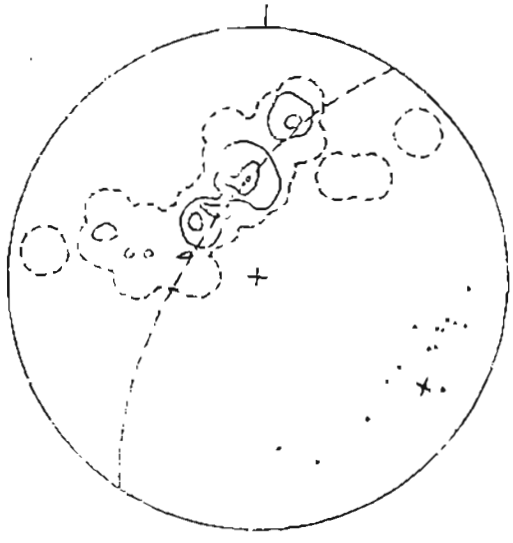


Figure 29.--S-pole diagram of foliation in domain 13 (pl. 2), showing relation of β axis (X) to axes of mesoscopic second folds (dots); in domain contours (2)-5-10-15-20 percent per 1 percent area, 55 measurements.

turned, northeast limb strikes northwest and dips about 60° also to the south. The convergence of the two limbs both upward and to the southeast suggests a southeast-plunging antiform. An antiform is to be expected here, since the southwest limb of this fold is also the northeast limb of the probable extension of the Snug Cove synform.

2) First generation fold axes and lineation seem to have been bent by this fold. These structures plunge chiefly to the southeast on the southwest shore of the arm (domain III, pl. 3) and chiefly to the northwest on the northeast shore (domain IV, pl. 3), whereas near the center line of the arm at the north border of the area they are subhorizontal. The opposing plunges of the first axes suggest the presence of two divergent fold limbs, and the horizontal first axes suggest the presence of a hinge near the center line of the arm in the manner illustrated by figure 30.

3) The stratigraphic sequence, as defined by the fossiliferous, marble unit, seems to be repeated north and south of the northwest arm.

4) The diagram of domain 28 (pl. 2) shows that the foliation in the vicinity of the northwest arm has been folded about a single axis (β) that plunges moderately to the southeast consistent with the direction of plunge obtained from other evidence above. The β-axis of domain 28 (fig. 31) lies in the field of second fold axes and lineation in the domain, and thus the antiform is correlated with the second generation.

Two orientations of mesoscopic second folds and lineations dominate: one plunging moderately to the west-southwest, and the other plunging moderately to the southeast (fig. 32). These two orientations are represented in figure 32 by two maxima each of which are contained in a partial girdle. The partial girdles do not lie in the same plane suggesting that for the province as a whole the axes of the second folds do not lie in parallel planar axial surfaces.

Plate 3 shows a subdivision of the province into domains structurally

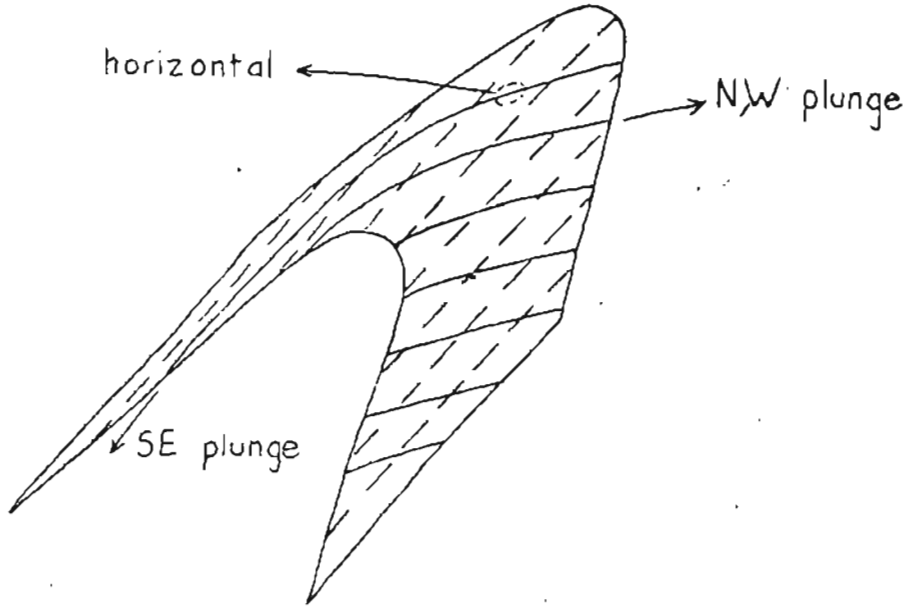


Figure 30.--Diagram showing relation of first (solid lines) and second (broken lines) lineations to overturned, macroscopic second fold in foliation (see text).

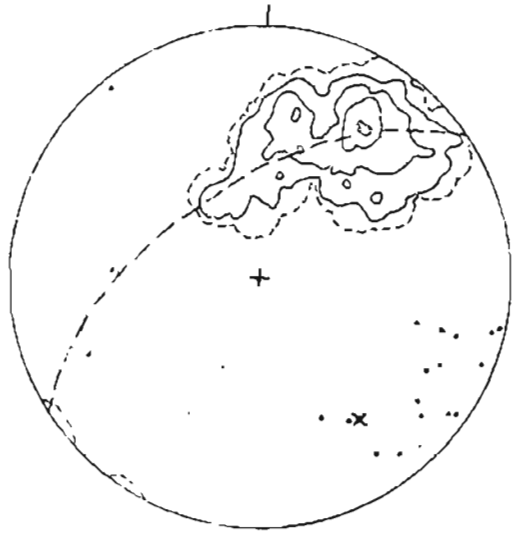


Figure 31.--S-pole diagram of domain 28 (pl. 2), showing relation of β axis (X) to mesoscopic second fold axes and lineations (dots) in domain; contours (2)-5-10-15-20 percent per 1 percent area, 33 measurements.

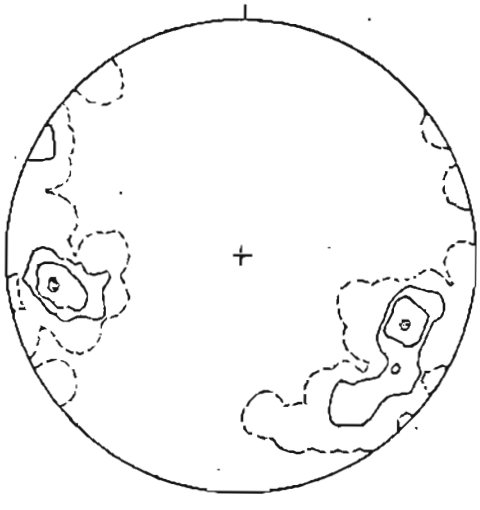


Figure 32.--Collective diagram showing preferred orientation of 70 mesoscopic second fold axes and lineations, Gambier province; contours (1)-5-10-15 percent per 1 percent area.

homogeneous with respect to the second fold axes. The scarcity of data for domain IV prevented its further subdivision into homogeneous domains. In general, the domains lying along the largest macroscopic fold hinges show a moderate plunge to the southeast (domains I and III, pl. 3), whereas the southwest-plunging second fold axes occur largely on the limbs of these macroscopic folds (domain II, pl. 3). The occurrence of both orientations of second axes in domain IV may reflect its location partly on the hinge and partly on the limb of a macroscopic second fold. Similarly, the β-axes of the domains of plate 2, such as 7, 8, 10, 11, and 12, located on the limbs of the largest macroscopic folds show no consistent β-axis orientation in contrast to the consistent plunge to the southeast shown by those on the hinges. According to this evidence, the limbs of the largest second folds, and hence also the smaller second folds located in them, no longer have the original relation to the axes of these largest folds. That is, neither β-axes of domains nor mesoscopic second fold axes in the limbs parallel the axes of the largest second folds.

Third generation.--The macroscopic folds of this generation are poorly known. The hingesof the largest macroscopic second folds do not seem to have been noticeably deformed by the third folding. A similar resistance of hinges of larger earlier folds to later deformation has been reported by Ramsay (1958a, p. 304) at Loch Monar in the Scottish Highlands. However, this folding may have bent the axes of the mesoscopic second folds and the β-axes of domains (pl. 2) in the limbs of the macroscopic second folds from their original orientation which is assumed to have been subparallel to the axes of macroscopic second folds. The third folding may also have caused the nonplanar form for the province as a whole of the axial surfaces of the mesoscopic second folds (p. 89).

Of the domains of plate 2 located on the limbs, only 12 shows a β-axis

having a southward plunge possibly parallel to that of the mesoscopic third folds (fig. 33a), but the lack of orientation data of mesoscopic third axes in this domain precludes certain correlation. The relative small size of these domains (pl. 2) indicates that the largest macroscopic third folds, if present, are considerably smaller than the largest macroscopic second folds. This size relation tends to substantiate the general rule of Weiss (1959b, p. 98) that the largest cylindroidal folds of a later generation must be smaller than those of an earlier generation.

The axes of mesoscopic third folds plunge dominantly to the south (fig. 33a). Although distributed in a broad maximum in figure 33a, they tend to fall into two groups represented by the two submaxima. The stronger submaxima represents a plunge of about 30° to the south-southeast, and the weaker one represents a plunge of about 45° to the south-southwest. A few third axes plunge northward. The orientation of the third fold axes is related to the orientation of the foliation in which they occur. Most of the southward-plunging axes occur in southward-dipping foliation; this dip is predominant in the northern two-thirds of the province, and the bulk of the field data were obtained in this area. Both north- and south-plunging third fold axes occur in the north-striking limb in the vicinity of Snug Cove, but many fewer field data were obtained here than in the north because exposures are few.

The axial planes of the mesoscopic third folds also tend to occur in two groups; each group of planes lies near a corresponding group of axes (fig. 33; see dashed lines in 33a). The axial planes have a consistent subvertical dip, although their strike varies widely. The average strike is slightly east of north.

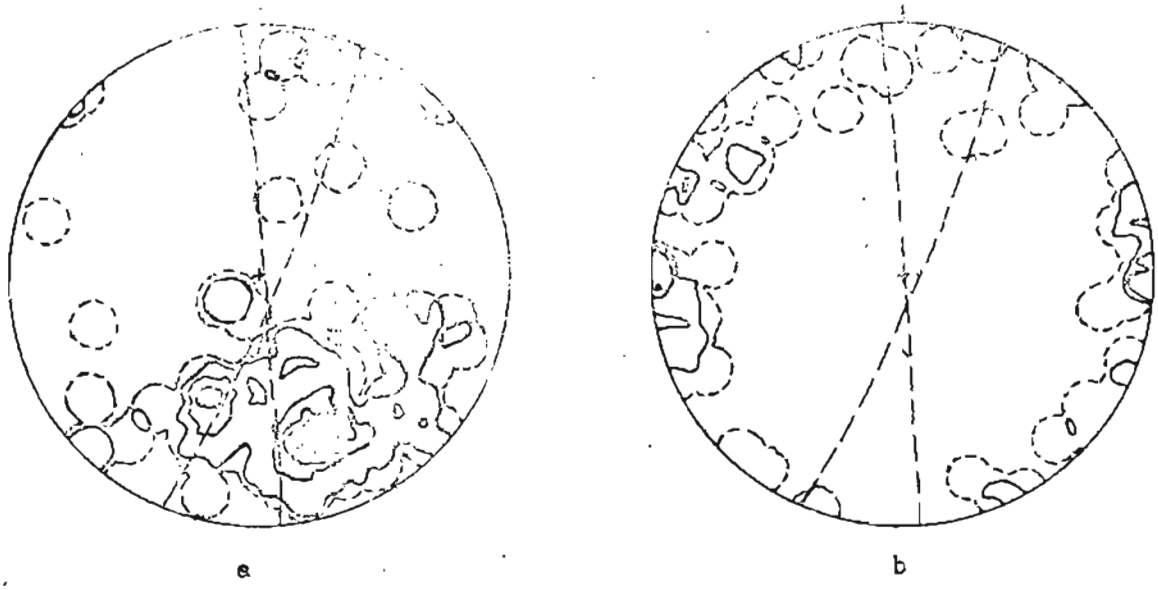


Figure 33.--Collective diagrams showing the preferred orientation of mesoscopic third structures, Gambier province: a, 100 axes of thrid folds; contours (1)-2½-5-7½-10 percent per 1 percent area. b, 65 axial planes of third folds; contours (2)-5-10-15 percent per 1 percent area; dashed lines show average axial plane orientations.

Interpretation of structure

The geometrical relation of the first fold axes to the second suggests both the mechanism of second folding and the initial geometry of the macroscopic first folds. In spite of deformation by the second folding, the mesoscopic first folds maintain a gentle plunge either to the northwest or to the southeast in the northern half of the province (domains II, III, IV, pl. 3). In this area the angle between the first and second fold axes is consistently small. Hence, during the second folding the first axes seem to have been rotated in a narrow cone about the second fold axes. This relation suggests that the second folding was accomplished largely by flexural slip of the foliation surfaces (Sander, 1948, p. 171-172; see also Weiss, 1959b, p. 90-100; Ramsey, 1960, p. 76).

In contrast, if the second folding had been accomplished largely by slip along an oblique set of surfaces (slip or shear folding), the first linear structures would have been rotated through a path in which the angle between them and the second fold axes would have changed continuously, causing a wide variation in observed angles (Weiss, 1959b, p. 100-102; Ramsey, 1960).

The angle between axes of first and second folds increases to about 90° in the southern part of the province near Snug Cove (domain I, pl. 3; fig. 28). Two possible explanations for this increase in angle are: 1) the orientation of the first fold axes was originally constant throughout the province, but the mechanism of second folding varied from flexural slip in the north to slip (shear) in the south; 2) the secondfolding was due to flexural slip throughout, but the original orientation of the first fold axes varied and they described a broad arc one limb of which lay in the north and the other in the south. Explanation 2) seems much more probable, and could have been brought about by the superposition of the first folds

upon bedding that has been previously folded into a broad, open fold. According to the concepts of superposed folding (Weiss, 1959b, p. 95-98), a different first axis orientation would have formed in each limb of the fold. The greater scattering of first fold axis orientations in the south where the angle between the first and second axes is large would then be caused by their rotation through broader cones about the second axes. It is also possible that heterogeneous deformation could have produced first folds with initially curved axes.

In contrast to the initial geometry of the axes of the macroscopic first folds, the hinges of the macroscopic second folds extend nearly rectilinearly across the province. According to Weiss, (1959b, p. 95-98) this must mean that the foliation (hence also the axial planes of the first folds) in which they wete formed were initially subplanar throughout the province. The macroscopic second folds as a whole are not cdylindroidal, however, because of later folding of their limbs. The geometry of the macroscopic second folds in bedding, which is unknown, must be complicated because of the existence of the first folds in the bedding at the time of the second folding.

The range in orientation of the axial surfaces of the third kink folds (fig. 33b) suggests an intersecting fan of planes about a subvertical axis similar to that suggested by Weiss (1959b, p. 103) at Loch Leven. Weiss's alternate suggestion that such a range of axial surface orientations could also have been produced by the change from slip along slip surfaces parallel to the axial planes of slip folds to flexural slip during the folding does not seem likely here, since kink folding does not involve actual slip along slip surfaces (p. 79, fig. 25a).

The orientation and character of the kink folds also suggest that the above fan of planes is composed of two sets of a conjugate system. Both

the axial planes and the axes tend to form two groups in which each group of axes lies near a corresponding group of planes (fig. 33). According to Hoeppener (1956, p. 268-270), kink folds (Flexuren) represent in thinly layered rocks the slip or shear fracture of more homogeneous rocks. In kink folds the slip is represented by the flexural kinking of the foliation surfaces without actual rupture and slip (fig. 25a). Thus, according to Hoeppener, the kink folds may occur in conjugate systems, similar to those of slip fractures, composed of two intersecting sets having opposite senses of kinking. It seems possible that sets of kink folds, like the sets of conjugate slip fracture systems, may rotate during compression about their line of intersection toward the plane normal to the direction of compression (Weiss and McIntyre, 1957, p. 599);(Hoeppener, 1956, p. 250-253). Thus kink folds may occur whose axial plane orientations lie anywhere within the range of rotation. Unfortunately, the sense of kinking was not recorded in the field, and hence a conjugate system cannot be proved.

However, the orientation of the axes of the kink folds (fig. 33a) and their relation to the orientation of the foliation in which they occur can be explained by assuming that the range in orientation of their axial planes (fig. 33b) represents a fan of intersecting planes. Figure 34 shows diagrammatically the relation of the fan of axial planes to the two most common orientations of the foliation. These orientations represent the limbs of the macroscopic second folds, and intersect in the second fold axis. The third fold axes seem to have formed parallel to the intersections of the planes of the fan and the foliation. The abundance of southward-plunging third folds reflects the abundance of south-dipping foliation in the province. Similarly, the sparsity of north-plunging axes reflects the lesser abundance of north-striking foliation whose

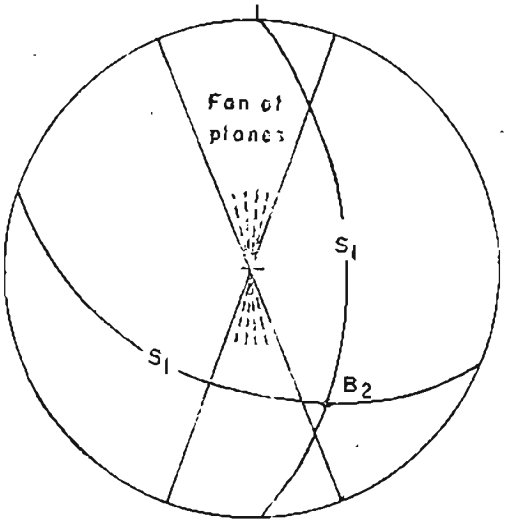


Figure 34.--Diagram showing relation of fan of third axial planes to the dominant foliation, Gambier province orientations (S1); B_2 is average macroscopic second fold axis orientation.

intersections with the fan of planes plunge either to the north or to the south.

In summary, the dominant macroscopic second folds--the major structures of the Gambier province--may be thought of as folds in two distinct but subparallel sets of surfaces: 1) the first axial plane foliation, and 2) the subparallel limbs of the isoclinal first folds. During the second folding the rock body seems to have behaved structurally as a uniformly layered mass.

The second folds formed in this complexly layered body and can have no simple relation to the original stratigraphic sequence. Similar examples of an earlier isoclinally folded sequence behaving effectively as a uniformly stratified mass during later folding have been described by Reynolds and Holmes (1954, p. 418-444) in Donegal, northern Ireland and by Ramsay (1958b p. 418-520) at Glenelg in the Scottish Highlands.

The sequence of structural events in the Gambier structural province may be summarized as follows:

1) The possible folding of the bedding into broad open folds prior to the first strong folding.

2) Strong deformation of the province with the formation of the isoclinal first folds in the previously warped bedding, and the development of a pronounced, widespread, uniformly oriented, axial plane foliation. During this deformation slip movement along foliation surfaces seems to have partially transposed and disrupted the bedding. The original orientation of the first folds is not known, but the southeastward plunge of the second folds formed in the axial plane foliation suggests that the initial dip of the axial planes of the first folds had a southeasterly component; vertical and northward dips are, therefore, ruled out.

3) Renewed strong deformation of the subparallel foliation and bed-

ding, and formation, possibly largely by flexural slip along the first foliation surfaces, of the largest folds in the province. The axes of these macroscopic second folds plunge moderately to the southeast, and are accompanied by numerous smaller folds but virtually no secondary foliation. If these folds formed largely by flexured slip of the foliation surfaces, then the bedding must have been further disrupted during this folding.

4) Deformation resulting in the formation of the third folds which consist largely of kink folds. The third folding may have produced no large macroscopic folds. The only macroscopic folds tentatively related to this deformation occur in the limbs of the largest second folds; the hinges of these second folds are not noticeably affected by the third deformation. The mesoscopic third folds may have formed with axial planes in two intersecting conjugate sets.

Pybus structural province

General statement

The rocks of this province are chiefly nontectonites in which sedimentary structures are well preserved. In contrast to the Gambier structural province, primary sedimentary bedding is seen in almost every outcrop, and mesoscopic folds and lineation are rarely seen. Fractures and faults are the most abundant mesoscopic structures; of these only the fracture cleavage of Seymour Canal formation displays a regularity that is useful in structural analysis.

Two generations of structures are distinguished in the province: the first generation, which occurs both on a mesoscopic and a macroscopic scale, and the second generation which occurs only on a macroscopic scale. The evidence for distinguishing the two generations is based on their macroscopic geometry.

Unconformities occur between almost every formation in the Pybus province (fig. 3) Movements causing these unconformities seem to have formed no fold systems, and were probably restricted to mild warpings and uplifts. The superposition of successive warpings, however mild, will result in increasingly complex structure in the rocks of successively older formations. The structure of the Seymour Canal formation (the youngest in the province) is therefore probably the simplest, and is also best known because of the extensive and excellent shoreline exposures of this formation. It is presented in greater detail than that of the older formations.

Mesoscopic structures

Bedding.--The orientation of primary sedimentary bedding can generally be determined throughout the province. However, it is commonly not possible to determine the stratigraphic top of a bed or a sequence of beds. Position of a bed in stratigraphic sequence can sometimes be used for determining the top of a sequence where thinner units such as the Pybus dolomite and the Hyd formation are present, but where these are absent, lack of marker beds and subvertical dips make it necessary to rely on graded bedding, cross-bedding, and, where possible, bedding-cleavage relations to determine the top of a stratigraphic sequence. Graded bedding and crossbedding are developed chiefly in thin graywacke beds, which are most common in the Seymour Canal formation.

First generation.--Folds of this generation are the common mesoscopic folds of the Pybus province. They are characterized by straight limbs and small, rounded hinges (fig. 35a, b). In general, the first folds have one moderately dipping normal limb and one subvertical limb which is commonly overturned. The axial planes are generally subvertical, and the axes show

a. Hinge of typical mesoscopic first fold in argillite and thin-bedded graywacke in Seymour Canal formation, Pybus province near Gambier Island; note subvertical axial plane cleavage.

b. Mesoscopic first fold in argillite and thin-bedded graywacke in Seymour Canal formation, Pybus province near Gambier Island; note subvertical axial plane cleavage.

Figure 35

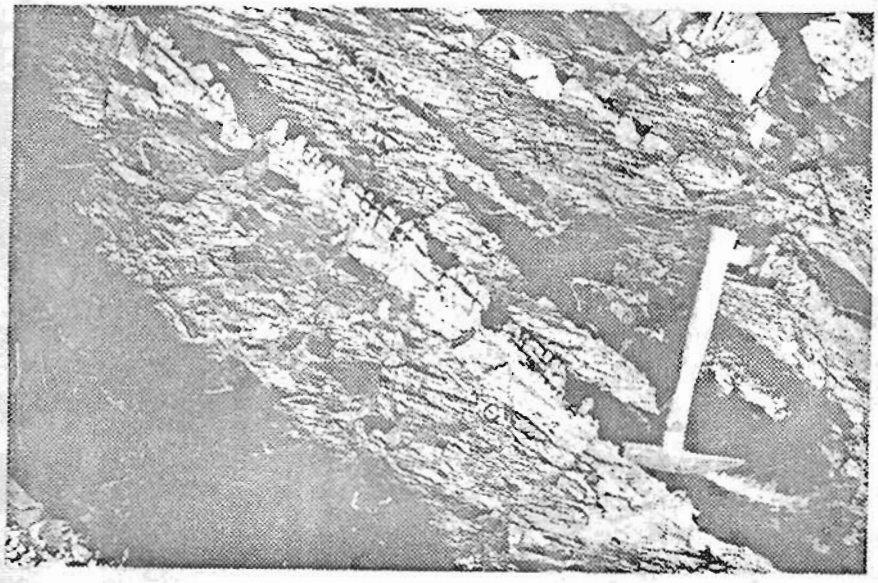
a gentle to moderate plunge. Folds having a wave length of less than 10 feet are seldom seen, and fold hinges are not commonly visible. Thus, folds must often be mapped by indirect evidence such as reversals in dip and in direction of the stratigraphic top of beds.

The first folds in the argillite of the Seymour Canal formation generally show a fracture cleavage subparallel to their axial surfaces (fig. 36a, b). The cleavage is largely confined to homogeneous argillite of the type that forms most of the Seymour Canal formation, and is generally lacking in the interbedded siliceous and calcareous argillites, chert, graywacke, limestone, and dolomite that make up the older formations in the province.

The cleavage consists of roughly parallel fractures whose spacing ranges from about 1 inch to microscopic dimensions (fig. 36a, b). As a rule the rock slices between the cleavage fractures seem to be undeformed, and no newly formed micaceous minerals can be seen along the fracture surfaces. In a few places where the fractures become more closely spaced and uniform, incipient crystallization of micaceous minerals subparallel to the fractures has been observed, and the fracture cleavage grades into true slaty cleavage in which the cleavage surfaces penetrate the rock on an intergranular scale. In general, the cleavage ranges from slaty cleavage in eastern Gambier Bay to irregular, wide-spaced fractures in southwestern Pybus Bay. In the latter locality they could not be distinguished from joints and other fractures, and hence could not be used in the structural analysis.

Generally the cleavage extends only into the very fine grained parts of the graywacke beds. The common fractures of the graywacke beds tend to be normal to the bedding (fig. 36b), and are not continuous with the cleavage.

a



b

Figure 36.--Fracture cleavage (cl) in argillite of Seymour Canal formation, Pybus structural province; note angle between graywacke beds and cleavage.

Macroscopic structure

First generation.--A few possible first fold hinges can be seen on the geologic map (pl. 1) near False Point Pybus and at the head of the main arm of Pybus Bay. These hinges represent tightly appressed folds involving the Pybus dolomite and the Hyd formation, and have axial planes which strike about northwest. The folds are faulted and have complicated forms suggesting repeated episodes of deformation. In spite of the lack of marker beds, the macroscopic first folds in the rocks of the Seymour formation, are better known, and the following discussion is chiefly about them.

East of the False Point Pybus fault zone the first folds trend uniformly to the north-northwest. This uniformity of trend is expressed by the pattern of the poles of bedding in this area (fig. 37b). The strong maximum in this diagram represents an average strike of N. 30° W., and dips ranging from 60° to 90°. This geometry suggests that the macroscopic folds have the same style as the mesoscopic folds in which one limb is subvertical and the other has a dip of from 60° to 70°. The scarcity of gentle dips near the center of the diagram and the abundance of steep dips also suggest that the macroscopic folds have small hinges and long, straight limbs similar to those of the mesoscopic folds.

Figure 37b has no single β-axis, but the scattering of points near the center of the diagram suggests steep-dipping to subvertical incipient girdles whose β-axes plunge gently to moderately either to the northwest or to the southeast. This trend and plunge corresponds to those of the mesoscopic first folds.

Figure 37d shows that the orientation of the cleavage east of False Point Pybus has a regularity similar to that of the bedding. The strong maximum represents an average strike of N. 30° W. and an average dip of 82° to the east corresponding closely with the average bedding attitude.

a

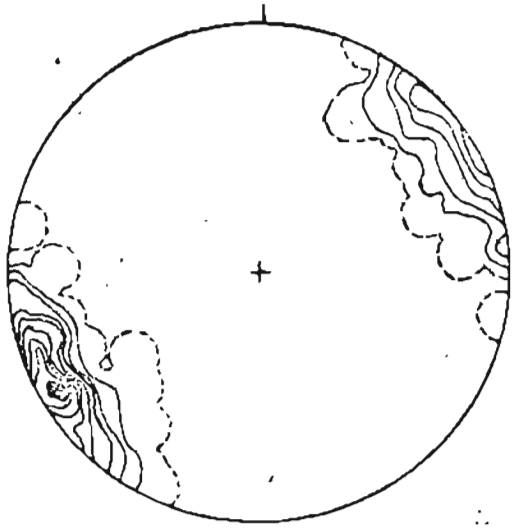
a. Collective diagram of 275 poles of bedding, Seymour Canal formation, western Pybus province; contours (1/3)-1-2½ percent per 1 percent area.

b

b. Collective diagram of 200 poles of bedding, Seymour Canal formation, eastern Pybus province; contours (½)-1-2½-5-7½-10 percent per 1 percent area; dashed great circle is average cleavage orientation.

c

c. Collective diagram of 145 poles of cleavage, Seymour Canal formation, western Pybus province; contours (2/3)-2½-5-7½-10-12½ percent per 1 percent area.



d

d. Collective diagram of 150 poles of cleavage, Seymour Canal formation eastern Pybus province; contours (2/3)-2½-5-7½-10-12½-15-17½-20 percent per 1 percent area.

Figure 37

This attitude when plotted on figure 37b (dashed great circle) approximately bisects the angle between the two maxima, which represent the two dominant orientations of the limbs of first folds, and substantiates the field observations that the cleavage is subparallel to the axial surfaces of the first folds.

Because of the lack of marker beds, the relative size and position of macroscopic first folds is difficult to determine within the Seymour Canal formation. However, two large macroscopic folds are thought to exist east of False Point Pybus based on a study of the stratigraphic tops and the areal distribution of units. The outcrop of the Pybus dolomite and Hyd formation at False Point Pybus probably represents the western, normal limb of an overturned syncline whose axial plane strikes north-northwest through Price Island. To the east near Good Island, the Hyd formation is brought up in the core of an anticline of similar amplitude.

In contrast to the regularity of trend of the macroscopic first folds east of the False Point Pybus fault zone, the first folds to the west show a diversity of trend. The trend of mesoscopic first folds follows the sinuous outcrop of the Pybus dolomite through Pybus Bay (pl. 1). This bending of first folds is reflected in the nearly random pattern of figure 37, a, and contrasts sharply with the regularity of figure 37b. The form of the cleavage in the western area represented by a subhorizontal girdle in figure 37c clearly reflects the bending of the first folds and the cleavage (compare with 37d).

In order to study the bending of the first fold in greater detail the Pybus Bay area was subdivided into structurally homogeneous domains (pl. 4). The abrupt change in the orientation of β and the scarcity of outcrops in domain IV prevented the establishment of a homogeneous domain. Plate 4 shows that the trend of the β-axes of the domains describe the same bends

as do the strike of the bedding and the trends of mesoscopic folds. It also shows that the axes of the mesoscopic first folds in the domains are subparallel to the β-axes of the domains, permitting correlation of the macroscopic folds with the mesoscopic first folds. The average orientation of cleavage (solid great circle, pl. 4) in each domain tends to be subparallel to the β-axis and to bisect the limbs of the macroscopic fold represented by the maxima, further demonstrating that it is subparallel to the axial planes of the first folds.

Second generation.--East of the False Point Pybus fault zone the first folds appear to be unaffected by a second generation of folds. However west of the fault zone, at Pybus Bay, the axial plane cleavage of the first folds and the bedding have been folded into a series of rather broad folds whose axial planes strike northwest(traces shown by antiform and synform symbols in pl. 1). The axes of these folds in the cleavage of the first generation plunge about 80° to the south as shown by the orientation of the β-axis of figure 37c. In order to contain these subvertical axes, the axial planes of the second folds must also be subvertical. The second fold axes in the bedding, however, have a complicated geometry because the bedding, unlike the cleavage, was tightly folded prior to the second folding. Thus, a different fold axis exists for each orientation of the bedding (Weiss, 1959b, p. 95-98); thepattern of figure 37a reflects this complexity.

Interpretation of structure

Although probably subjected to the same regional compression during the second folding, the axial planes of the first folds west of the False Point Pybus fault zone were folded, while those to the east were not. Therefore, the first axial planes east of the fault zone must have been oriented about normal to the direction of compression and those west of

the fault must have deviated sufficiently from this orientation to have been folded. The axial planes of the first folds in the east now strike north-northwest and are subvertical (fig. 37c); the axial planes of the second folds in the west strike northwest and are also subvertical. Therefore, the direction of compression during the second folding was probably about normal to these axial planes, that is, about northeast-southwest and subhorizontal.

The amount by which the axial planes of the first folds west of the fault zone deviated from the plane normal to the second compression is unknown, but a subvertical dip is indicated for these planes by the subvertical orientation of the axes of the second folds formed in them. It is implicit in the concept of superposed folding (Weiss, 1959b, p. 95-98), that a fold cannot have an angle of plunge greater than the angle of dip of the surface in which it is formed. Allowing for departures from this simplified ideal in nature, it seems generally true that steeply plunging axes must have formed in steeply dipping surfaces.

The second folds, in the axial planes of the first folds then, seem to have formed parallel to the intersection of two subvertical planes; the plane normal to the compression, and the axial planes of the first folds. The strike of the plane normal to compression is approximately known (northwest), but the strike of the axial planes of the first folds at the start of the second folding cannot be determined within wide limits because the intersection of two subvertical planes would have a steep plunge for a wide range of angles of intersection. However, it is probable that the axial planes of first folds prior to the second folding had a general northeasterly strike about normal to present axial planes of the second folds.

The divergence of the first folds axes east and west of the False Point

Pybus fault zone may have developed at a late stage in the first folding. It is possible that the axial planes and cleavage of the first folds in both areas were formed initially subparallel in response to the same stress and that later in the first folding the folds in the two areas became divergent because of inhomogeneous yielding (see p.119 for further discussion).

In general, the Pybus structural province may have been divided into three domains bounded by northwest-striking fault zones, as follows: the domain east of the False Point Pybus fault zone which contains no second folds; the domain lying west of the False Point Pybusfault zone which contains second folds, and the domain west of the Pybus fault zone about which little is known, but which resembles in structural trend the domain east of False Point Pybus. These fault zones seem to represent zones of rupture between domains that have responded differently to the second compression.

Southwest structural province

The slightly deformed sedimentary and volcanic rocks of this province are disposed in an irregular, north-trending, troughlike structure whose axis seems to coincide with the Eliza fault in the western part of the province. West of this fault the beds dip gently eastward, whereas to the east of it they dip gently southwest and west.

Flexures are rare in the province, and rocks having different attitudes are commonly separated by faults instead of fold hinges. Faults are abundant and generally have steep dips. Most seem to have had largely vertical movement but the scarcity of marker beds generally prevents accurate determination of displacement (see section on Faults for further discussion). North-striking faults predominate, but northwest- and northeast-striking faults are also present. All fault traces are expressed on the ground by linear topographic features, which are clearly shown on aerial photo-

graphs. Only the largest faults are shown on the geologic map (pl. 1).

Faults

General statement

The Pybus-Gambier area is cut by numerous faults many of which are shared by more than one structural province. The faults generally could not be correlated with the generations of structures described in the foregoing pages because faults may originate early in the tectonic history and continue to act as zones of movement during later episodes of deformation. Therefore, only a few faults are tentatively correlated with generations where evidence permits.

Poor exposures inland and the lack of marker beds in many of the formations prevent the determination of the character of a large number of faults. Some prominent and persistent lineaments shown on the aerial photographs could not be proved by field evidence to be fault traces; these lineaments have been omitted from the geologic map (pl. 1) and from the consideration here. The failure to find field evidence of faulting was often due to poor exposure, and hence the omission of these lineaments does not rule out the possibility that they may represent fault traces.

The faults in the following discussion are arbitrarily grouped according to strike, and, where possible, according to movement. Unless so stated, no implication of common origin is intended.

Northwest-striking faults

False Point Pybus fault zone.--The faults of this strike are best displayed immediately west of False Point Pybus. The faults strike from N. 10° W. to N. 30° W. and are characterized by rather straight traces which show a slight tendency to bend westward with higher altitude. A steep eastward

dip is, therefore, suggested, but the position of the fault traces is not known with sufficient accuracy to warrant the assigning of a numerical value to the dip.

The larger faults in this zone occur in the inverted limbs of a series of overturned anticlines. The anticlines appear to be thrust over the adjacent synclines to the west; an interpretation of this structure is given in plate 5.

The faults along the western margin of the fault zone appear to truncate the second folds to the west suggesting that the faulting is either later than the second folds or that it occurred late in the second folding.

Other northwest-striking faults.--Four localities are described below which are thought to contain north-northwest-striking faults similar to the thrusts of the False Point Pybus fault zone. However, poor exposures have prevented the obtaining of enough reliable data to definitely establish the true nature of these faults. The proposed fault zones, lying to the west of the False Point Pybus fault zone, are briefly summarized below:

1) A persistent fault trace lies along the valley east of the prominent northwest-trending ridge formed by the Pybus dolomite east of the north arm of Pybus Bay. This fault appears to lie in the core of a syncline whose limbs are nearly vertical. The type of movement on this fault is uncertain because of the difficulty of mapping units on both sides of the fault zone. The right lateral displacement of the Pybus dolomite across the fault at the hinge of the syncline is believed to be of the correct order of magnitude although accurate mapping here is impossible. The right lateral displacement may be explained either by a dominantly strike-slip movement or by a dominantly dip-slip movement. The latter movement involving the relative upward movement of the eastern block seems more likely in view of the evidence for similar movement on roughly parallel faults in the False Point Pybus area.

2) A fault trace appears to lie along the straight, northwestward-trending creek and ridge saddle about three-quarters of a mile to the east of fault 1). The field data on this fault are very sparse, but it appears to lie in the core of a sharp hinged anticline in a manner similar to fault 1). The Pybus dolomite is cut off at the fault when traced to the north; its position on the east side of the fault trace could not be located, but marker beds in the overlying Hyd formation were found in a position strongly suggesting right lateral displacement. As in fault 1), this displacement could have been accomplished by the relative upward movement of the eastern block.

3) A fault lies parallel to the axis of the north arm of Pybus Bay and its trace probably trends northwestward along the prominent lineament in the axis of the valley at the head of the arm. The Pybus dolomite appears to have been displaced right laterally about one-quarter mile across this fault. This lateral displacement could again be explained by the relative upward dip-slip movement of the eastern block.

4) Another north-northwest-striking fault zone lies along the axis of the main arm of Pybus Bay and probably continues southeastward through West Channel and northwestward through the valley at the head of the arm. The complex structure along this arm of the bay suggests a wide zone of faulting similar to that at False Point Pybus rather than as single fault as in the north arm of Pybus Bay. The complicated faulted folds along the main arm of Pybus Bay are shown by the scattered outcrops of the Pybus dolomite, and are suggestive of those found at False Point Pybus. However, the bay covers much of the critical area and prevents a definite solution to the structure here. In general the structure of the area in and around the main arm of Pybus Bay is thought to be that of a complexly faulted antiform the hinge of which is delineated by sharply bent

overturned syncline at the head of the arm (see pl. 5). The strike of the axial plane of this antiform is northwest, roughly parallel to that of the macroscopic second fold to which it may be related.

Minor faults.--Numerous minor faults occur in the vicinity of the major fault zones described above. Two sets of an apparent conjugate fault system having horizontal displacements ranging from 10 to 100 feet have been mapped in the Pybus dolomite and overlying Hyd formation in the north arm of Pybus Bay. The right lateral set strikes about N. 20° E. and the left lateral set strikes about N. 70° E.; the strike of the major north-northwest fault while not accurately known tends to bisect the obtuse angle (130°) between the two sets of faults, thus approaching the relationship proposed by Anderson (1951) for conjugate sets of wrench faults to related thrust faults. The greatest principal stress direction should bisect the acute angle between the two sets of wrench faults according to Moody and Hill (1956, p. 1209); these writers quote Hubbert (1951) to the effect that a value of 31° is a good average for the angle between the greatest principal stress axis and planes of actual shear fracture in rocks. This angle here is about 25°.

The sense of movement of other minor faults was determined in the vicinity of Church Point and Gain Island in eastern Gambier Bay. These faults may be related to the False Point Pybus fault zone which probably continues northward under the waters of the bay immediately to the west of Gain Island. No constancy of strike for faults of like sense of movement can be seen here. Two larger faults striking about N. 60° W., one at Church Point and one to the south, appear to have moved right laterally in contrast to the left lateral displacement on faults of the same strike along the north arm of Pybus Bay. Between the two larger faults are several smaller ones, three of which are mapped on plate 1. In contrast

to the right lateral movement of the large faults, the smaller faults striking roughly parallel to them have left lateral displacement, whereas those striking about N. 85° W. are right lateral faults. Other small faults in the vicinity of the north end of Gain Island have still other strikes. The apparent lack of constancy of the strike of faults with similar senses of displacement may be due to the presence of different orders of wrench faults which, according to Moody and Hill (1956, p. 1213), may form in response to a single compression. I consider the data to be insufficient to attempt an analysis of the type proposed by the above writers. More probable explanations, in view of the different episodes of deformation believed to have occurred here, are that the above faults may belong to different generations of structures, or that if all of the same generation, they have been deformed to varying degrees by later deformation.

North-striking faults

A persistent group of faults strike northward in the southwestern part of the Pybus-Gambier area. Their rather straight traces extend from the Southwest structural province northward into the Pybus structural province where they eventually are lost.. These faults may represent a late group of high-angle faults of largely dip-slip movement.

Little Pybus fault.--This fault extends north from Little Pybus Bay to Cannery Cove through a well-defined lineament. The contact between the Admiralty Island basalt and underlying Eocene sedimentary rocks has been displaced left laterally across the fault. A field study of the relation of lava flows on opposite sides of the fault suggests that the left lateral displacement was largely accomplished by the relative downward movement of the east block. This fault is in line with another north-striking fault truncating the Pybus dolomite on the northeast shore of the main arm

of Pybus Bay, but the complex structure the latter locality makes further conclusions as to the fault displacement impossible.

Eliza fault.--This fault lies along the strong lineament extending northward from Eliza Harbor along series of straight creeks to the country about 2 miles east of the North Arm of Hood Bay where the lineament is lost. In the latter area, the contact of the Admiralty Island basalt and the underlying Hood formation is displaced right laterally about half a mile across the fault trace. From the eastward-bending of the fault trace with increase in altitude of topography south of the above contact, the dip of the fault has been estimated to be about 40° to the west. The right lateral displacement could be accomplished either by strike-slip movement or by the relative downward, dip-slip of the west block. More probable is a dip-slip movement along a curved fault surface, accompanied by rotation to account for the change in dip across the fault (see pl. 5).

Other north-striking faults.--Other north-striking faults are mapped in the country between the Little Pybus and the Eliza Harbor faults. These faults do not clearly effect marker beds, and hence their sense of displacement is unknown. Brecciated fault zones have been observed in places along the trace of these faults indicating fault movement. The straight traces of these faults indicates subvertical dips.

Northeast-striking faults

Gambier fault.--Field evidence suggests that a major fault may lie in the important northeast-trending valley extending from the north arm of Hood Bay to the west arm of Gambier Bay. The field evidence for this fault is summarized as follows:

1) Along the south shore of the west arm of Gambier Bay the east-trending synformal hinge in the Permian and Triassic rocks appears to be

truncated along its northern boundary.

2) The Snug Cove synform in the rocks of the Gambier Bay formation appears to be displaced about 1 mile left laterally across the west arm of Gambier Bay.

3) Structural trends southeast of the major valley in the region southwest of Gambier Bay change abruptly from northwest to northeast as they are traced northward to the valley. Whether or not this abrupt change in trend is related to faulting could not be determined.

4) The contact metamorphism, widespread in the northwest part of the Pybus-Gambier area, is restricted to the northwest side of the above valley from the area north of the mouth of the outlet of Pybus Lake south to Hood Bay.

In general, along its eastern extension the Gambier fault appears to separate theolder rocks of the Gambier Bay formation to the north from the younger rocks of the Hyd and Cannery formations to the south indicating a relative upwacd movement of the north block. The left lateral displacement of the Snug Cove synform could be produced by such a dip-slip movement, since the axial plane of the synform dips southwest.

Fault near Snug Cove.--This fault lies southeast of Snug Cove along a northeast-flowing creek. The position of this fault along the northwest side of the creek valley is suggested by the fact that the units exposed in the creek do not extend to the county immediately to the north even though the prevailing strike appears to be northward. Exposures outside the creek gorge itself are poor, and the fault position is only inferred. The fault appears to have a left lateral displacement of about a mile, but the location of marker beds on opposite sides is not accurately known. In general, the fault separates older rocks to the north from younger to thesouth suggesting the relative upward movement of the north block.

Faults in northwest Pybus Bay.--Two faults of similar northeast strike,

but opposite apparent displacements, are indicated by the truncation of the Pybus dolomite at two localities on the shore of the main arm. The trace of one of these trends along a small creek on the northeast shore near the head of the arm. Here the nose of an overturned syncline outlined by the Pybus dolomite appears to be displaced left laterally. The structure in this fault zone is so chaotic that the sense of displacement is uncertain and is only suggested. The other northeast-striking fault occurs on the southwest shore of the main arm, north of Donkey Bay; here a syncline in the Pybus dolomite and the Hyd formation appears to be faulted against the Hood Bay formation. The Pybus dolomite cannot be found on the northwest side of the fault and may have been displaced right laterally to a position under the waters of the main arm. If so, a displacement of more than one mile is indicated; the apparent displacement can be explained by the relative upward, dip-slip movement of the northwest block.

Strike faults in Pybus dolomite

The outcrops of the Pybus dolomite in Pybus Bay are characterized by small faults, striking about parallel to the strike of the beds that cause a repetition of beds. The largest faults of this type observed occur on the peninsula on the northwest shore of the main arm of Pybus Bay due east of Donkey Bay. These faults are involved with a series of folds in the Pybus dolomite which are overturned toward the east in opposition to the overturning in the Seymour Canal formation southeast in the vicinity of the Midway Islands. Plate 5 shows an interpretation of the faults as northwest-dipping thrust faults closely associated with the folding. The same type of faulting, again striking parallel the strike of the bedding, is seen on a smaller scale in the outcrops of the Pybus limestone in the north arm of Pybus Bay. These faults are generally too

small to show on the map, but show in the field as a complex of repeated beds and small faulted folds. The section along the west shore of the north arm both above and below the Pybus dolomite is overturned to the southeast in a direction similar to that described above for the main arm. The section on the east shore of the north arm is normal except for local overturning. The origin of the strike faults is not clear, but they may have formed as surfaces of slip movement during the folding of the Pybus dolomite. Their present cross-cutting character may have been the result of movement during a later deformation.

Correlation of episodes of deformation

A suggested correlation of generations of structures between the three structural provinces is shown in figure 38. The correlation is based chiefly on the similarity of the first and second generations in the Pybus and Gambier provinces, and the fact that some of the principal differences between these generations in the two provinces can be explained by the concept of superposed folding. The similarities of the two provinces may be summarized as follows:

1) Both provinces have gently plunging, isoclinal or nearly isoclinal first folds developed only in bedding and accompanied by axial plane foliation.

2) In both provinces these first folds and the axial plane foliation have been deformed by second folds having northwest-striking, steeply dipping axial planes; this parallism of axial planes suggests that the second folds in both were formed in response to the same general northeast-trending, horizontal compression.

The lack of second folds east of the False Point Pybus fault zone suggests that the ~~axial~~ planes and limbs of the first folds there were oriented

Figure 38.--Correlation of generations of structures.

	Gambier province	Pybus province	Southwest province
pre-Cretaceous Structure	broad, open folds in bedding	broad, open folds in bedding	not present
First Generation	gently plunging, isoclinal folds in bedding having initial subvertical? axial planes and axial plane foliation; streak lineation.	gently plunging, tight folds having subvertical axial planes and axial plane cleavage in Seymour Canal formation.	not present
Second Generation	tight folds having moderately plunging axes in first foliation and northwest-striking axial planes; crenulation lineations.	macroscopic folds having subvertically plunging axes in first cleavage, and northwest-striking axial planes; occur only west of False Point Pybus fault zone.	not present
Third Generation	kink folds having subvertical axial planes and a variable but general northward strike; plunge generally southward.	not recognized; may be represented by slip fractures	not present
Post-Orogenic	subvertical, dip slip faults	subvertical, dip slip faults	subvertical, dip slip faults and possible broad warps

about normal to the compression at the onset of the second folding. This orientation is further suggested by the fact that the axial planes of these first folds are today nearly parallel to the axial planes of the second folds to the west. Thus, the axial planes of the first folds west of the fault zone in both Pybus and Gambier provinces must have diverged significantly from those to the east prior to the second compression.

This divergence may have been brought about by the crowding of first folds west of the fault zone, both in Pybus and Gambier provinces, against an abrupt westward bend in the western margin of the depositional trough (fig. 39a). The existence of such a bend is indicated by the abrupt westward bend of the Mesozoic rocks in the Pybus-Gambier area. This westward bend is the northern flank of a regional westward salient in an otherwise dominantly north-northwest-trending belt of Mesozoic rocks (the Seymour geosyncline; fig. 40). The salient attains its maximum westward extension near the south end of Admiralty Island (Lathram and others, 1960), and then swings eastward again to the south in northern Kuiu and Kupreanof islands (Dutro and Payne, 1957).

Thus at the end of the first folding the axial planes of the first folds west of False Point Pybus fault zone may have been bent into broad warps that in general conformed to the western margin of the trough (fig. 39a). These warps probably died out eastward away from the margin of the trough, and were not present in eastern Gambier Bay. It is probable that the axial planes of the first folds in these warps were not uniformly oriented, and varied in both strike and dip.

Renewed or continued compression, oriented subhorizontally northeast-southwest as before, folded the axial planes of the first folds where they were favorably oriented. East of False Point Pybus fault zone the axial planes of the first folds were about normal to the compression and were

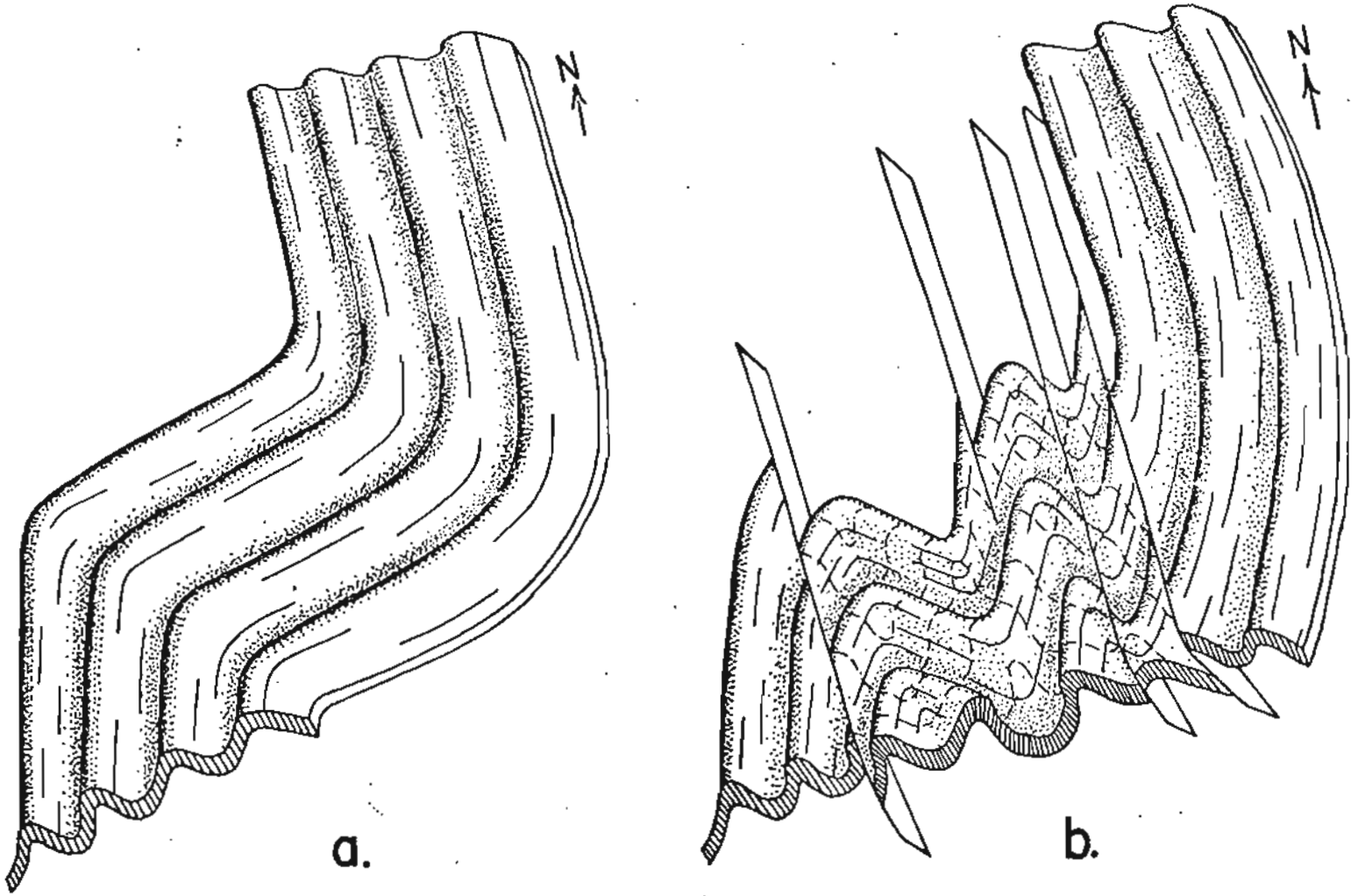


Figure 39.--a, diagram showing possible disposition of first folds, Pybus structural province, at end of first deformation. b, disposition of same first folds after the second deformation (see text).

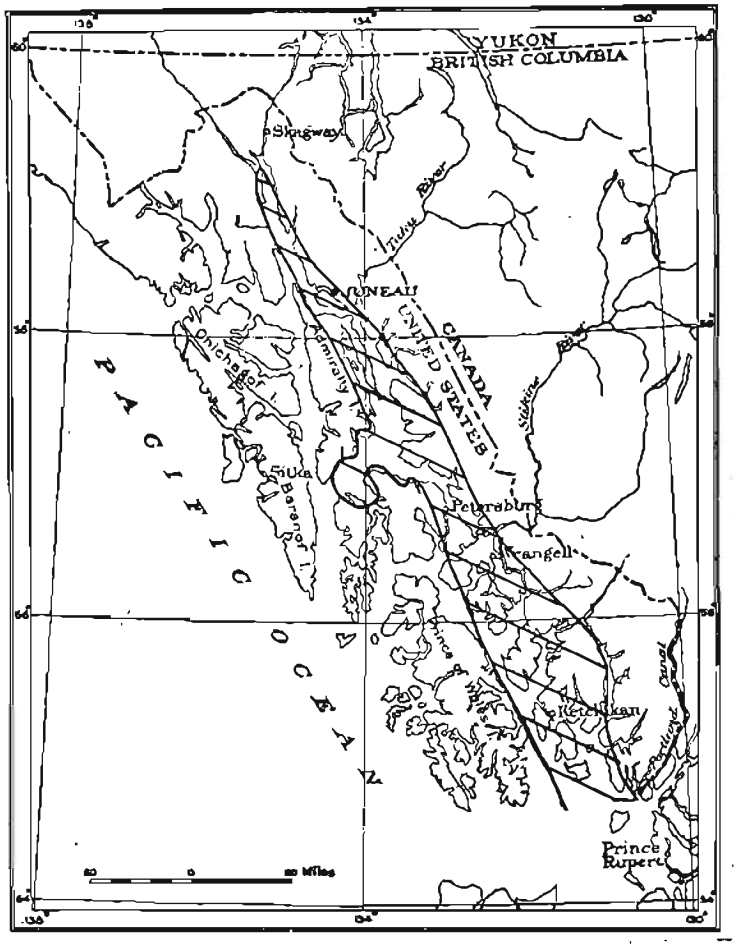
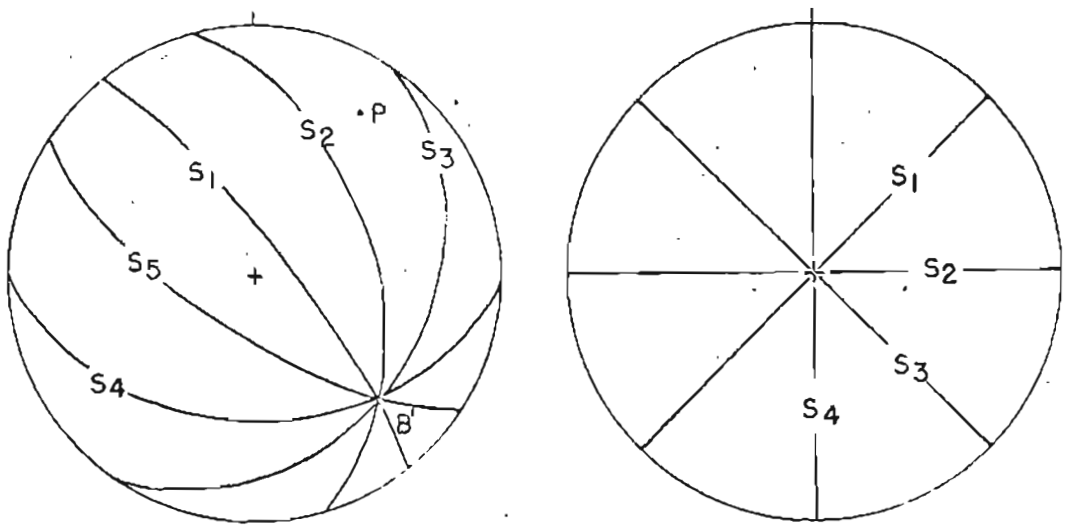


Figure 40.--Sketch map of southeastern Alaska showing the general location of the eastern belt of Mesozoic rocks (Seymour geosyncline).

not folded, but to the west these planes were more nearly parallel to the compression and folding occurred (fig. 39b). The orientation of the axes of the second folds resulting from this compression probably depended upon the orientation of the first axial plane being folded. According to Weiss (1959b, p. 98; see also McBirney and Best, 1961, p. 495-497) folds superposed upon such a folded surface (bent first axial planes) would form with their axes parallel to the intersection of the surface and the plane normal to the compression.. Hence, this intersection was subvertical in western Pybus province because both the plane normal to the compression and the axial planes of first folds there were subvertical. Similarly, the moderately plunging axes of the second folds in the Gambier province indicate that the intersection was moderately plunging in this locality. It is likely that the plane normal to the compression was also subvertical here, but that the axial planes of the first folds had some orientation that resulted in a moderately plunging intersection. Here, however, the folding about moderately plunging axes changed both the strike and the dip of the first axial planes (fig. 41a), unlike western Pybus province where the second folding about subvertical axes greatly changed the strike but not the original subvertical dip of the first axial planes (fig. 41b). Thus the original orientation of the axial planes in the Gambier province cannot be determined because they could have had any of the wide range of orientations shown in figure 41a, except perhaps those about normal to the second compression, and intersect the plane normal to the compression in moderately plunging axes.

The third generation of structures in the Gambier province, the kink folds, appears to have no recognizable counterpart in the Pybus province; the kink folds are generally confined to the more thinly fissile rocks of the Gambier province, and the lack of these folds in



a b

Figure 41.--a, projection showing folding of foliation in Gambier province about a moderately plunging, macroscopic second fold axis (B_2); S_5 is normal to the second compression at P. b, Projection showing rotation of planes about a vertical axis.

the Pybus province may be due to the absence of such rocks. Possibly the Pybus province yielded to the third deformation by fracture and faulting instead.

The above correlation requires that the metamorphism and penetrative deformation of the Gambier province was contemporaneous with the less intense deformation of the Pybus province. If this is correct, the effects of this metamorphism must die out both upward and laterally, since parts of the nonmetamorphic Pybus province are younger than the Gambier Bay formation and other parts are either coeval or older (Hood Bay formation, see p. 18). The lateral dying out of the effects of metamorphism conforms to the general southward dying out of regional metamorphism in both Paleozoic and Mesozoic rocks in southern Admiralty Island, and suggests that the metamorphism of these rocks occurred during the same episode.

The effects of metamorphism extend farther south in the older rocks than in the younger ones. Thus nearly all signs of metamorphic deformation in Devonian rocks die out between Gambier Bay and the outcrop of the Hood Bay formation to the southwest. Whereas, in the Seymour Canal formation the effects of metamorphism, which are pronounced in Seymour Canal (phyllitic slate and semischist), are nearly lacking to the south in eastern Gambier Bay. Perhaps the metamorphism of the older rocks was more extensive because of their deeper burial.

The above episodes of strong deformation are completely absent in the Southwest structural province, hence, the high-angle faults and mild warps there are records of later structural events in the tectonic history of the Pybus-Gambier area.

GEOLOGIC HISTORY

Silurian(?) and Devonian deposition

The known history of the Pybus-Gambier area began with the deposition of the Gambier Bay and the Hood Bay formations. These two formations may have been deposited contemporaneously with an interfingering of their deposits. A subsiding marine trough occupied the area receiving in the Gambier Bay area alternate layers of mafic volcanic rocks and fine-grained muddy sediments; siliceous types were common among the latter. Shallow mafic and ultramafic dikes and sills intruded the layered rocks. In middle Devonian time, possibly toward the end of the deposition, the deposition of calcareous mud prevailed, and other types of deposits were temporarily diminished. After several hundreds of feet of calcareous mud was deposited, normal, more argillaceous, sedimentation resumed.

Fine-grained, muddy sediments not too unlike those of the Gambier Bay formation, but lacking mafic volcanic rocks characterized the deposition of the Hood Bay formation in western Pybus-Gambier area. Thousands of feet of thin-bedded, siliceous and non-siliceous muds rich in organic material accumulated in an anaerobic environment below the wave base. Occasionally turbidity currents brought in muddy sand layers; locally thick lenses of impure, calcareous mud rich in organic material accumulated.

Both the Gambier Bay formation and the Hood Bay formation are composed in their sedimentary phases of fine-grained, clastic sediments indicating that no nearby source of coarse clastic material was available. Therefore, the volcanism of the Gambier Bay formation must have been submarine, and the volcanic rocks were not undergoing subaerial erosion locally.

Post-Gambier Bay-Hood Bay and pre-Cannery deformation

Sometime after the deposition of the Gambier formation in middle Devonian time and before the deposition of the Cannery formation in Permian time, the area was folded into broad, open warps, and uplifted into the zone of erosion.

Permian deposition

A subsiding marine trough again occupied the area, and several thousands of feet of thinly bedded, siliceous and non-siliceous, fine-grained sediments forming the Cannery formation were deposited. Occasional turbidity currents deposited muddy volcanic sand in thin layers; a few more viscous types of currents deposited massive, chaotic coarser deposits of sand which contain scattered limestone fragments. Submarine volcanism, possibly located to the northeast, extruded a few layers of pillow lava in the Gambier Bay area. The fine-grained volcanic detritus must have been derived from a more distant source; perhaps the local volcanism was entirely submarine. The silica of the abundant, Radiolarian-bearing, siliceous sediments may have been derived from submarine eruptions and hot springs.

An episode of comparative stability followed the Cannery deposition in which clear water conditions prevailed, and very little detrital material reached the area. During this time about a thousand feet of calcareous mud and limestone debris accumulated; brachiopods and bryozoans flourished. Before consolidation the silica in this deposit was concentrated into layers and nodules; numerous calcite shells were silicified during or following this process. Following the concentration of the silica, but preceding lithification, the calcite of the deposit was replaced by dolomite.

Calcareous fossils were largely destroyed by the dolomitization, but those that had been previously replaced by silica were preserved. This deposit, the Pybus dolomite, may not have extended north to the Gambier Bay area, and may have pinched out again to the south in near Little Pybus Bay.

Post-Pybus and pre-Hyd uplift

The deposition of Pybus dolomite was followed by emergence and erosion; a slight warping appears to have accompanied the uplift. The Pybus dolomite, now lithified, was stripped from part of the area by erosion which also bevelled the slightly tilted beds of the Cannery formation.

Triassic deposition

The Hyd deposition began with the accumulation of the coarse detritus upon the slightly irregular erosion surface; chert and dolomite debris collected upon the Pybus dolomite, and bedded chert and argillite debris collected upon the Cannery formation. This close correlation between deposit and the underlying terrane suggests land-laid deposition in an arid region having inadequate water available to remove the erosional debris. Before the close of the coarse clastic deposition, volcanism, centered north of the area, laid down thick flows of mafic volcanic rock. The latter part of the breccia deposition may have been marine as the late Triassic seas transgressed the area. Carbonate deposition followed that of the coarse clastics which apparently ceased when the area and the surrounding country was completely inundated. After a few hundreds of feet of dark calcareous mud was deposited, an interbedded sequence of fine-grained, muddy sediments began accumulating, and a few hundreds of feet of thinly bedded, dark-colored, siliceous, calcareous, and argillaceous mud was deposited. Occasional turbidity currents deposited thin beds of fine-grained, muddy

sand in the quiet, slightly reducing environment. Submarine volcanism continued throughout the interval of sedimentation sending out pillow lavas from centers to the north of the area. The detritus is largely composed of andesitic volcanic debris, but its general fine-grained character suggests that it was derived from a distant volcanic source, and that the local centers of volcanism were largely submarine.

Post-Hyd and pre-Seymour Canal uplift

After the deposition of the Hyd formation the area was brought into the zone of erosion by uplift. Any warping accompanying this uplift must have been very mild, as it has not been detected in the field.

Jurassic and Cretaceous deposition

The sea again transgressed the area in late Jurassic time initiating the deposition of the Seymour Canal formation. The subsiding marine trough in which this formation was deposited may have been confined to the eastern part of the area. Chiefly fine-grained muds accumulated in the part of the trough in the Pybus-Gambier area which must have been located some distance offshore from a dominantly andesitic volcanic source area. At frequent intervals, however, turbidity currents swept down the sides of the trough and deposited thin layers of muddy sand. At less frequent intervals, possibly confined to the later part of the deposition, submarine landslides came down the sides of the trough and deposited large masses of chaotic coarse detritus at the break in slope. Parts of these landslides may have continued slightly farther into the trough as extremely viscous currents, and deposited thick chaotic beds of coarse, muddy sand. The landslide deposits disrupted and intruded the fine-grained sediments already deposited.

At or near the close of the deposition, volcanism in the eastern part of the area extruded the andesitic flows and breccias of the Brothers volcanics. The detritus of the Seymour Canal formation is in general volcanic, and it is possible that part of this may have been derived from contemporaneous volcanism to the east, of which the Brothers volcanics may be a part. The deposition ended in early Cretaceous time after possibly 10,000 feet of sediment had been deposited.

Post-Seymour Canal and pre-Eocene deformation

The deposition of the Seymour Canal formation was followed, or perhaps was brought to a close by the strong deformation in Cretaceous time. The conglomerates of the Seymour Canal formation may relate to early stages of this deformation.

During the first deformation the rocks of the Pybus-Gambier area were compressed into gently plunging, nearly isoclinal folds having subvertical, north-northwest-striking axial planes. Axial planes foliation developed in the rocks of the Gambier Bay and Seymour Canal formations. During the late stages of this folding the folds were crowded against the western margin of the trough, causing the folds in the west to diverge from those in the east, which were less affected by the crowding.

During the second deformation renewed compression, oriented about northeast-southwest as during the first, broke the area into elongate blocks by northwest-striking thrust faults. These faults formed between domains in which the first folds had contrasting orientations at the end of the first deformation. The axial planes of the first folds in the eastern domain, which were oriented about normal to the second compression were not folded, but those in the western domain, which had various orientations as a result of the crowding of folds during the first

deformation, were folded about various axes depending upon the relation of their orientation to the compression.

The third deformation, involving renewed compression oriented about east-west, resulted in the formation of kink folds in the Gambier formation, and possibly the formation of fractures and faults in the nonmetamorphic rocks.

Plutonism

The above deformation may have been closely followed by plutonic intrusion and contact metamorphism in the northwestern part of the Pybus-Gambier area.

Tertiary deposition

The post-Seymour Canal deformation left the area emergent and undergoing erosion. In Eocene time a subaerial basin formed in the southwestern part of the area perhaps by faulting. The rugged mountains cut in the folded Mesozoic and Paleozoic rocks adjacent to this basin poured down coarse detritus into it probably forming steep alluvial fans through which cut steep-gradient streams. The climate was probably humid, and lakes and swamps, in which plant life flourished, formed in the central parts of the basin. After about 2,000 feet of coarse gravel had accumulated, volcanic fissure eruptions began to flood the southwestern country with flows of basalt and andesite. The flows may not have extended to the northeastern shore of Pybus Bay. At least 9,000 feet of flows accumulated, forming the Admiralty Island volcanics.

Post-Admiralty Island uplift

The Pybus-Gambier area was subjected to high-angle faulting and mild warping after or in the final stages of the volcanic eruption. Perhaps subsidence in the region of greatest thickness, near the southwest corner of the area, may be in part responsible for the deformationcof the Admiralty Island volcanics themselves. The area remained largely dry land throughout the remainder of Tertiary time.

Pleistocene deposition

A rise in sea level in glacial times resulted in the deposition of fossil-bearing, marine, glacial clay in stream valleys at various levels up to 475 feet. The sea then retreated to its present level.

APPENDIX

Petrography

Gambier Bay formation

The rocks of the Gambier Bay formation have been divided into several categories within each of which considerable variation occurs. Both massive-appearing and fissile rock types occur interlayered with one another, however, both types microscopically possess the same intergranular foliation. In general, the more micaceous mineral constituents a rock contains, the more fissile is its aspect. In the field, massive-appearing chlorite-epidote-calcite phyllites and schists appear to be the most abundant rock types, whereas, fissile rocks are less prominent. However, the more fissile rocks may not crop out with a frequency commensurate with their true abundance and they may be at least as abundant as the more massive-appearing rocks. Almost every beach contains poorly exposed stretches in which only scattered outcrops of the more massive-appearing rocks occur, and these stretches appear to be largely underlain by more fissile rocks.

The presence of the mineral assemblages quartz-muscovite-chlorite-albite, quartz-talc-calcite, talc-dolomite, and chlorite-calcite indicates that the rocks of the Gambier Bay formation belong to the quartz-albite-muscovite-chlorite subfacies of the greenschist facies (Fyfe and others, 1958, p. 219-223). The common occurrence of relict pyroxene, hornblende, and calcic plagioclase grains, however, indicates that equilibrium was seldom attained in these rocks.

Chlorite-epidote-calcite phyllites.--These rocks are among the most abundant in the Gambier Bay formation. In outcrop the rocks are massive appearing, homogeneous, medium bluish gray to dark greenish gray in color. The weathered surface is roughly granular, and euhedral pyroxene crystals ranging in length from 0.5 mm to 2 mm can sometimes be seen projecting

from it. Compared to the more fissile rocks, the phyllites lack structural detail. These rocks are phyllonites which contain an abundance of relict pyroxene and, in places, hornblende. These relict grains make up as much as 60 percent of the total rock and are several times the size of the metamorphic grains. Thus the pyroxene and hornblende grains appear to be the remnants of a coarser grained igneous rock, possibly a pyroxenite, which has been to varying degrees reduced in grain size by metamorphic deformation. The resulting rock is phyllitic in appearance, but results from a process of reduction rather than increase of grain size (Turner, in Williams and others, 1954, p. 206-208). In some specimens metamorphic crystallization has been so slight that the rocks resemble mylonites.

Microscopically these phyllonites consist of abundant relict grains of yellowish clinopyroxene and, in some specimens, hornblende, in a strongly foliated matrix consisting of chlorite, epidote, calcite, talc, and fine mylonitic material; the foliated matrix bends around the relict grains (fig. 42).

Pyroxene grains are generally yellow and nonpleochroic. They are commonly fractured and trails of smaller pyroxene fragments form streaks parallel to the foliation. The grains have overgrowths of amphibole which project in sawtooth fashion from surfaces of the pyroxene grains, commonly across the foliation, and in a few places the amphibole fills fractures within the pyroxene grains. The amphibole overgrowths are colorless except for the part in contact with the pyroxene grains which is strongly pleochroic as follows: X = deep blue, Y = bluish green, and Z = pale yellow. The colorless amphibole is tremolite, and the bluish amphibole is a sodic variety. Turner (1935, p. 340-341) has also reported tremolite or actinolite and blue amphibole occurring as overgrowths on relict augite from the greenschists of New Zealand.

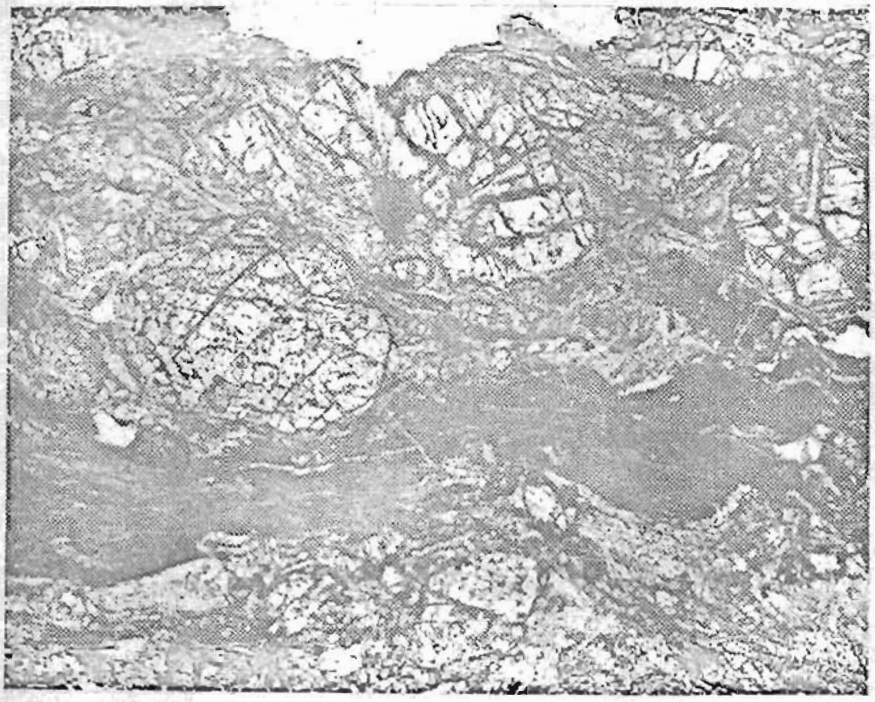


Figure 42.--Photomicrograph of phyllonite showing foliated matrix, chiefly of chlorite, epidote, and mylonitic material, bending around relict clinopyroxene crystals (plain light, 35 X).

Universal stage measurements indicate that the yellow pyroxene is augite with the angle $Z \wedge c$ in the range 40°-45°, and $2V_z$ in the range 56°-68°. The cause of the yellow color is unknown.

Chlorite is faintly pleochroic pale yellowish green, and shows an anomalous low brownish birefringence.

Epidote occurs both as stubby euhedral crystals and as anhedral grains; both types tend to form clots slightly elongate parallel to the foliation around the margins of the pyroxene grains. The pleochroism is Z = yellow, Y = greenish yellow, and X = pale yellow.

Calcite occurs interstitially and in equant patches scattered throughout the matrix. Minor amounts of albite and quartz occur as fine mosaic patches and rare veins in all specimens examined.

Quartz-albite-muscovite (sericite)-chlorite phyllites.--Rocks of this category are thinly fissile and range from sericitic phyllites to chloritic greenschists with all gradations between. The color ranges from lustrous medium dark green to lustrous grayish green depending on whether sericite or chlorite dominates. The amount of quartz and albite varies but is minor in the most thinly foliated types. These rocks possess a thin, regular foliation, and commonly show an abundance of fine structural detail such as small folds and lineations. As pointed out above, they may be one of the most abundant rock types in the Gambier Bay formation, but because of their nonresistant character they do not crop out prominently in the field.

Only the coarsest grained specimens have been examined in thin section. These consist of thin lenticular layers of slightly undulose mosaic quartz ranging from 0.018 mm to 0.3 mm in thickness separated by layers of muscovite and chlorite showing a strong preferred orientation. An unknown amount of albite, mostly untwinned, is scattered through the quartz-rich

layers. Minor amounts of calcite and magnetite occur in all the sections examined. In addition, angular quartz and lesser amounts of twinned plagioclase grains are scattered along the foliation in all sections; these grains may be relict clasts.

Microfolds involving all the above minerals deform the foliation in all thin sections studied. In hand specimen crenulations and striations parallel to the axes of these microfolds can be seen crossing the foliation surfaces.

Muscovite, much of which can be termed sericite, occurs as fine, irregular, elongate crystals which average about 0.04 mm in length. It ranges from colorless to pale green and is commonly interlayered with chlorite. In general, chlorite does not have the strong preferred orientation of muscovite but tends to form feathery aggregates parts of which diverge from the foliation. The chlorite is pale yellowish green in color and slightly pleochroic, but in one specimen more strongly pleochroic crystals are common in which X and Y = green and Z = pale yellowish green.

Quartz-albite-talc-chlorite quartzites and phyllites.--These are fine-grained, highly quartzose rocks ranging in color from greenish gray to grayish yellow. In outcrop they appear slightly translucent and irregularly foliated. The rocks of this category are generally composed of light-colored lenses ranging from a few millimeters to a few centimeters in length separated by a darker strongly foliated matrix. Locally, the lenses weather out in splintery, pencil-like forms.

The light-colored lenses consist largely of microcrystalline quartz and contain variable amounts of albite. Because albite is mostly untwinned, accurate estimates of its relative amount couldnot be made. The darker foliated layers are rich in talc and chlorite, both showing a strong preferred orientation. The relative proportions of these two

minerals varies; in some rocks talc predominates over chlorite, and in other chlorite over talc. Both minerals occur also in the quartz-rich lenses within and also between the quartz grains. The chlorite is generally pleochroic pale yellowish green in color, and has a very low anomalous blue birefringence. Less abundant minerals commonly present are sphene, epidote, calcite, tremolite, and pyrite.

Quartz ranges from 40 to 90 percent of the rock, depending upon what percentage of the rock is made up of the quartz-rich lenses. Quartz grains range from less than 0.018 mm to 0.1 mm in diameter, the small grain size suggesting that the rocks may have been originally cherts. The few larger angular quartz grains scattered through the quartz-rich layers suggest relict clasts.

One specimen contains abundant larger grains of slightly sericitized, complexly twinned plagioclase ranging from 0.07 mm to 1 mm in diameter. Universal stage measurements indicate that the composition of the plagioclase lies in the range An 10-15. The margins of the grains are granulated, and are surrounded by fine mosaics of quartz and albite. The chlorite and talc appears to have replaced and embayed the plagioclase along its margins. This rock is not so clearly divided into lenselike masses as are the other rocks in this category, and the foliated zones are more closely spaced and regular. It appears to have been derived either from an igneous rock or a feldspathic sedimentary rock.

Marble.--Prominent in the Gambier Bay Formation is a dark, slightly mottled with white, finely crystalline marble. Marble beds are very rare, and it is possible that only one marble unit is present in the formation. However, structural complexity prevents being certain of the number of units present.

The marble consists of nearly 99 percent calcite in an irregular

mosaic of grains having irregularly sutured borders. Most grains average about 1.0 mm in length and 0.09 mm in width, and are elongate parallel to a clearly defined foliation. Small grains cluster along the borders of the larger grains, especially along the borders parallel to the foliation surfaces, suggesting granulation and recrystallization. Patches of equant grains break up the foliated pattern in places. The borders of the grains have a thin coating of opaque, carbonaceous dust probably accounting for the dark color of the marble.

The calcite grains themselves show abundant, broad lamellae which are commonly bent and lensoidal (fig. 43). The form of the lamellae resembles that in the calcite grains of the Yule marble artificially deformed by extension at 800° C, 5 kilobars (Griggs and others, 1960, pl. 11).

Minor amounts of quartz and albite occur in small patches of equant grains. Sparse tremolite needles are scattered through one specimen.

Calc-schists.--These are lustrous, fine-grained, pale olive, foliated rocks containing dots and streaks of light-gray marble, and they occur chiefly but not entirely as layers in marble. Poorly preserved fossils have been observed in the thicker marble streaks.

The calc-schists consist of lenticular layers of calcite, quartz, and albite separated by strongly foliated cloudy talc-rich layers, in which the talc forms indistinct, feathery masses containing much fine unresolvable material. In most specimens, calcite is the dominant constituent amounting to as much as 50 percent of the total rock, but in one specimen at least the carbonate is dolomite. Talc, quartz, albite, and chlorite in varying proportions make up the remainder of the rocks, and pyrite cubes partly altered to limonite are minor constituents in all of them.

Figure 43.--Photomicrograph of marble, Gambier Bay formation showing bent and lensoidal lamellae; note grains near center and near upper left corner (crossed nicols, 35 X).

The calcite generally occurs as anhedral aggregates in layers and lenses ranging in thickness from 1.0 mm to 25.0 mm. Grain size of the calcite aggregates is extremely variable.

Quartz and albite occur together as mosaics of anhedral grains, but, since the albite is largely untwinned, it is difficult to estimate the relative proportions of the two minerals. Universal stage determinations on twinned albite indicate compositions in the range An0-6. In one specimen quartz occurs as augen 2.0 to 4.0 mm in diameter in spherulitic, chalcedonic aggregates along with calcite and albite.

Chlorite is a minor constituent in all specimens examined except one in which it formed about 20 percent of the total rock. It occurs in all the specimens as nonpleochroic very pale green, irregular, elongate crystals oriented about parallel to the foliation; the birefringence of the chlorite is a low anomalous brown.

Albite-chlorite-calcite-quartz rocks.--Rocks of this category are uncommon but distinctive and are characterized by an abundance of closely packed, dusky yellow platelike laths of feldspar ranging from 4.0 mm to 25.0 mm in length. The laths are set in a fine-grained matrix which ranges in color from grayish olive to dark greenish gray. The lighter colored varieties are foliated, but darker varieties, which are the most common, show no visible foliation, and are completely massive. The large plagioclase grains set in a fine-grained metamorphic matrix indicate that the rock has undergone partial reduction in grain size, and hence one that is on the way to becoming a phyllonite.

The laths are composed of a cloudy mixture of chlorite, epidote, albite, calcite, and quartz. Most of this mixture is very fine grained ($<$0.02 mm in diameter), but in places albite anhedra as much as0.9 mm in diameter occur. The interstices between the laths are filled with a granular

mixture of quartz and albite containing much interstitial chlorite and patches of calcite. In one specimen anhedral grains of apatite are scattered throughout; in another sphene forms an important accessory.

In the rocks having a noticeable foliation, the minerals of the matrix show a preferred orientation parallel to the foliation surfaces; in the other specimens no preferred orientation could be seen.

Albite occurs both as small, largely untwinned, equant anhedra along with quartz of a similar form, and also as larger anhedra. The larger grains are irregular in outline, and show about an equal amount of twinned and untwinned types. The twinning is a fine polysynthetic type which has twinned according to the albite-ala law; universal stage measurements indicate compositions in the range An0-8. All albite grains contain abundant inclusions of chlorite, and also patches of calcite.

Chlorite occurs in irregular interstitial masses, and in fine plates in albite. The chlorite shows a pleochroism from Z = yellow green to Y and X = green and a low anomalous blue birefringence.

Calcite occurs interstitially as well as in larger patches which appear to have replaced and embayed the surrounding grains.

Hood Bay formation

Chert and siliceous argillite.--These are the most abundant rock types of the formation. They are generally grayish black, and are commonly thinly interbedded in beds ranging from 0.5 to 3.0 inches in thickness. The ratio of chert to argillite is generally about 1:1 but ranges locally from 3:1 to 1:3. Where siliceous argillite is predominant, it commonly occurs in homogeneous beds ranging from 0.5 to 1.0 feet in thickness containing thin units of thinly bedded chert averaging0.5 feet in thickness. In some localities, dark-gray limestone nodules ranging from 2 to 12 inches in

length are sparsely scattered through the massive argillite beds. All gradations between chert and non-siliceous argillite occur.

The cherts typically contain abundant quartz veinlets averaging about 1.0 mm in thickness which intersect the bedding at angles of about 90 degrees. On the weathered surfaces, these veinlets appear as ridges intersecting one another at various angles.

A common feature of the chert beds is illustrated by figure 44, which shows a fragment of a chert bed divided into segments in which the bedding has been rotated slightly with respect to one another. Small, subparallel cuestalike ridges bound the rotated fragments and the sense of rotation is commonly the same in anyone outcrop. The beds appear to have been broken, slightly rotated, and recemented. The zone of cementation is commonly not visible, and does not coincide as a rule with the prominent quartz veinlets. These features are less apparent in the siliceous argillite, because this rock tends to break irregularly with no surface parallel to the bedding.

The outcrops of thinly bedded chert and argillite are commonly stained reddish brown, particularly along shear zones that are common in the Hood Bay formation. This stain probably results from the oxidation of pyrite which is a common accessory mineral in the chert and argillite.

In thin section, the typical chert is seen to consist of abundant microcrystalline quartz, sparsely scattered patches of chlorite and euhedral pyrite, and abundant dark brown, unresolvable dust. Scattered sparsely along a few layers are masses of spherulitic and microgranular quartz which are circular or elliptical in outline and average about 0.02 mm in diameter, with the largest measuring as much as 0.2 mm in diameter. These masses are very similar to the Radiolarian tests in bedded cherts of California figured by Taliaferro and Hudson (1943, p. 251-256, figs. 12, 15, 17-22).

Quartz occurs both in spherulitic and granular forms. In both its

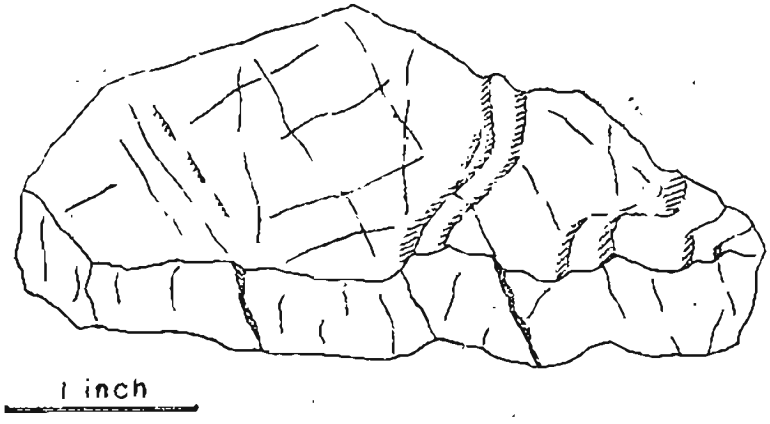


Figure 44.--Sketch of chert specimen showing displaced and re-cemented segments separated by cuestelike ridges; Hood Bay formation.

average grain size is extremely small (less than 0.002 mm in diameter). Clots of coarser grains, generally elongate parallel to bedding, occur sparsely throughout the rock.

Small colorless micalike flakes are sparsely scattered through the rock roughly parallel to the bedding, but show no strong preferred orientation. The flakes are length slow, and have a first order yellow birefrigence.

Veins seen in thin section are mosaics of anhedral quartz crystals containing small patches of calcite and chalcedonic quartz. In addition, numerous stylolitic seams containing dark brown material cut the rock at high angles to the bedding.

Limestone and calcareous argillites.--Dark-gray massive, gine-grained limestone is a prominent but minor constituent of the Hood Bay formation. It usually occurs in beds 30 to 40 feet in thickness which can be traced only a few hundred feet along strike, suggesting lenslike bodies. These massive limestone beds are commonly associated with thinly bedded dark-gray calcareous argillite and very thinly laminated dark-gray and grayish-black limestones. The entire calcareous section including the massive limestone beds are commonly less than 50 feet in thickness and is overlain and underlain by thin-bedded chert and siliceous argillite.

On weathered surfaces the massive limestone is medium gray mottled with dark gray and is commonly cut by numerous white calcite veins. A crude parting occurs parallel to the bedding, and freshly broken limestone has a distinct sulfurous odor. In one locality, the limestone contains scattered, small clots of black asphaltic material. Calcite is the chief carbonate mineral in the limestone, as indicated by the copper nitrate ($Cu(NO_3)_2$) stain method (Rodgers, 1940, p. 788-798). Solution of powdered limestone in warm, dilute hydrochloric acid yielded 15.0 percent by weight

insoluble residue consisting largely of extremely fine carbonaceous material.

Graywacke.--Graywacke is a minor constituent of the Hood Bay formation, but locally it is the dominant rock type. It occurs mostly as thin beds 1 to 2 inches in thickness in the thinly bedded chert and siliceous argillite sections. In the few localities where it is abundant, graywacke forms beds 0.5 to 2.0 feet in thickness interbedded with thinner beds of chert or argillite.

The graywacke ranges in color from medium gray to medium dark gray and in grain size from very fine sand to medium sand. Coarse-grained beds are extremely rare. The thinner beds of graywacke commonly show graded bedding. Thicker beds (1 to 2 feet in thickness) are generally homogeneous; some appear to grade laterally into argillite.

A typical graywacke is composed of subangular grains of quartz, plagioclase, argillite, chert, and calcite amounting to about 80 percent of the total rock, embedded in a dark brown, cloudy matric composed of sericite, chlorite, calcite, microgranular quartz and albite, and abundant fine opaque dust. Slight preferred orientation of the sericite and chlorite crystals in the matrix and the slight granulation and elongation of the larger clastic grains produce incipient foliation in the rock.

Quartz grains, composing about 45 percent of the rock, average about 0.15 mm in diameter, and generally show undulose extinction under crossed nicols. They have been corroded and penetrated along their margins by the micaceous matrix, and in addition many grains show overgrowths of clear quartz which tend to elongate the grains parallel to the incipient foliation.

Plagioclase grains (15 percent of the rock) are partly sericitized and commonly complexly twinned. Universal stage determinations indicate compositions in the range An_{28} to An_{38}.

Chert and argillite grains, about 15 percent of the rock, resemble in texture and composition the chert and siliceous argillite of the Hood Bay formation. They are elongated parallel to the foliation, and have frayed ends projecting along the foliation.

Calcite grains, forming about five percent of the rock, have irregular shapes and indistinct borders. A few show structures faintly suggestive of fossils.

Cannery formation

Thin-bedded chert and argillite.--These are the most abundant rock types in the Cannery formation making up about 60 percent of the total. The chert and argillite generally occur rhythmically interbedded in beds ranging from 0.25 to 3.0 inches in thickness. Very thin (1.0 inch) beds of graywacke, commonly green in color, are scattered sparsely through most sections of chert and argillite.

The chert occurs in a variety of colors the most common of which are dark gray, medium dark gray, greenish black, dark greenish gray, greenish gray, and grayish green. It weathers dark greenish gray and olive gray and is typically crossed by a network of fractures.

Under the microscope, most of the cherts examined consist of a cloudy mass of submicroscopic to microgranular quartz containing sparse lenticular clusters of coarser equigranular quartz and in places albite aligned parallel to bedding. Scattered sparsely through the rocks are angular clasts of quartz and plagioclase which average about 0.25 mm in diameter. Most specimens contain very small chlorite and sericite patches and flakes disseminated throughout the thin sections.

One-third of the specimens examined contain clear masses of microgranular quartz having ovoid or circular outlines similar to those described

on page 144 in the cherts of the Hood Bay formation, which probably represent recrystallized Radiolarian tests. The probable Radiolarian tests range from 0.06 to 0.18 mm in diameter. The bedding planes in the cherts are commonly marked by extremely thin dark-colored laminae. The layers between the dark laminae pinch and swell and impart a microscopic lenticic appearance to the rock. Clasts of quartz and plagioclase as well as Radiolarian tests commonly have indistinct margins which appear to merge into the matrix.

The brightly colored, sugary-textured cherts from the vicinity of Gain Island in Gambier Bay in thin section are seen to consist chiefly of a sutured mosaic of quartz averaging 0.03 mm in diameter mottled with scattered patches of mosaics having a larger grain size. The rock also contains sparsely scattered sericite flakes.

All the cherts contain abundant veinlets of mosaic quartz and albite; calcite veinlets are less common, although calcite commonly forms a minor constituent of the quartz-albite veinlets. In the vicinity of the calcite veinlets the chert commonly contains much interstitial calcite which appears to have replaced the minerals of the matrix. One specimen contained veinlets composed of a complex of calcite, quartz, albite, and analcime crystals.

In thin section all gradations are seen between chert, siliceous argillite, and argillite. The transition from chert to argillite appears to be brought about by a decrease in quartz and an increase in chlorite and sericite. The argillites tend to contain a greater amount of detrital quartz and plagioclase; as the detrital fraction increases the argillite passes into a graywacke.

Graywacke.--The graywacke of the Cannery formation occurs in two froms: 1) as thin, graded beds averaging less than one inch in thickness;

2) as thick, massive, calcareous beds ranging in thickness from 2 to 10 feet.

Both types contain more than 15 percent matrix (fig. 45b), and, therefore, according to Pettijohn (1957, p. 288-293) classify as graywackes deposited by a concentrated medium. The thin-bedded graywackes of type 1 display graded bedding and in places small scale crossbedding indicative of deposition by a medium fluid enough to allow mixing of grains and sorting. The massive graywackes of type 2 lack current structures and sorting features, and may have been deposited by a medium too viscous to allow free mixing of grains.

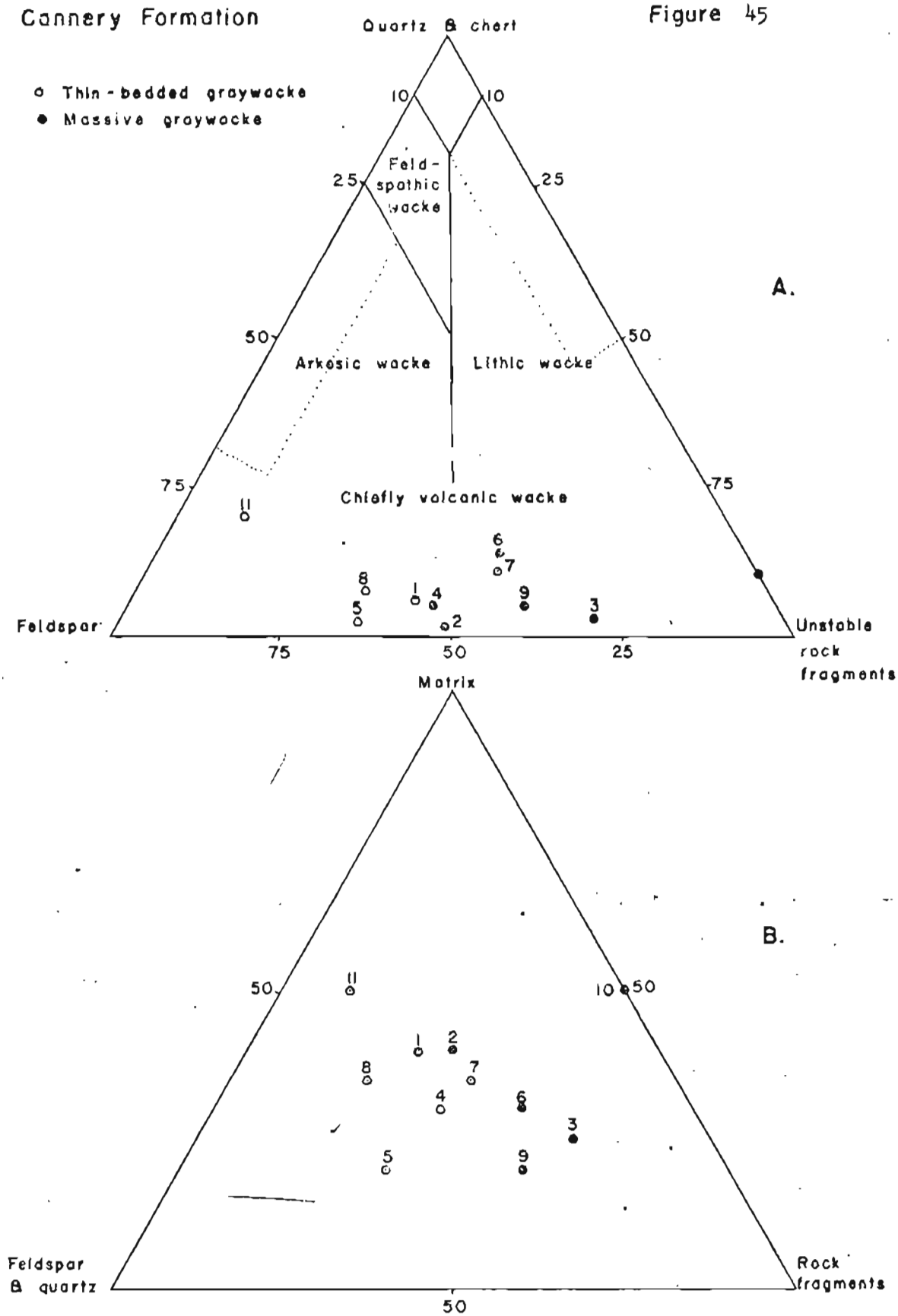
The graywacke of type 1 is most commonly dark greenish gray, but other colors such as dusky yellow green, medium dark gray, and medium bluish gray occur in places. The thin beds weather to a rough surface which contrasts sharply with the smooth-weathering argillites and cherts. The upper and finer part of these beds tends to develop a shaly parting.

The graywacke of the first type is composed of subangular to angular grains of plagioclase, quartz, and rock fragments embedded in a cloudy matrix consisting of an intimate mixture of chlorite, sericite, calcite, microgranular quartz, albite, and in places analcime. The matrix, which ranges from 20 to 50 percent of the rock (fig. 45b, white dots), contains much fine opaque dust, part of which is pyrite and limonite, but most is unresolvable. Much of the matrix was probably originally clastic, but most of the clastic constituents have been replaced by alteration products. The grains generally have indistinct, frayed borders which show signs of replacement by chlorite, sericite, and calcite of the matrix.

The grain size near the base of the graywacke beds averages about 2.0 mm in diameter, and grades upward to about 0.04 mm in diameter at the top. The upward decrease in size of grains is accompanied by an increase in the percentage of matrix; in a typical specimen the matrix increases

Cannery Formation

Figure 45



from about 30 percent near the base to about 90 percent near the top of the bed. The upper few millimeters of the graded bed is virtually indistinguishable from the overlying chert or argillite bed, but in general the average grain size of the clasts in the chert and argillite tends to be smaller (<.02 mm in diameter) than that of the uppermost parts of the graded beds. The decrease in grain size is also accompanied by an increase in quartz grains and a decrease in rock fragments.

Figure 45a shows the relative amounts of the chief grain types; in this diagram the white dots represent specimens of graywacke of type 1 studied in thin section. Feldspar (chiefly plagioclase) and unstable rock fragments (chiefly volcanic rocks, argillite, and limestone) greatly predominate over chert and quartz. Specimen 11 represents a thin section with an average grain size of about 0.04 mm in diameter cut near the top of a graded bed; the composition of its constituent grains illustrates the relative increase in quartz, and the relative decrease in rock fragments with decrease in grain size. The overprinting in the diagram is taken from Williams, Turner, and Gilbert (1954, fig. 96), and shows that these graywackes lie in the field of volcanic wackes.

The massive graywackes of type 2 are generally medium gray or medium dark green on a fresh surface, and weather to a yellowish brown or brownish olive gray surface which is generally smooth, but contains scattered pits a few millimeters in diameter. Individual grains are difficult to see on the weathered surface, and the general aspect is that of a weathered basic volcanic flow. The pits represent the casts of calcite fragments (largely fossil debris) which have been partially removed by weathering.

Although the beds of graywacke of this type are generally homogeneous, in a few places they contain lenses of black chert pebbles and recrystallized calcarenite.

The graywackes of type 2 differ from those of type 1 chiefly by the greater abundance of limestone rock fragments among the grains and by a greater proportion of calcite in the matrix. In other respects the compositions and textures of the two types are similar. Figure 45a shows the principal grain constituents of the graywackes of type 2 as black dots. This diagram shows the tendency for the graywackes of type 2 to contain a greater proportion of unstable rock fragments than those of type 1 (white dots), although the distribution of the dots of the two types overlap slightly. At least half of the unstable rock fragments of type 2 are limestone. The matrix forms from 20 to 50 percent of the massive graywackes; figure 45b shows that this range is the same as that of the thin-bedded graywackes.

Plagioclase is the most common detrital mineral in either type of graywacke, and ranges from 0 (in one specimen) to 50 percent of the total rock with the average about 35 percent. The plagioclase grains are generally partially altered to sericite; calcite, chlorite, and epidote are also common but less abundant alteration products. The degree of alteration varies considerably even within a single thin section, and ranges from fresh, clear plagioclase grains having only a few small patches of sericite to grains completely sericitized. Most grains of plagioclase show complex polysnythetic twinning.

Universal stage measurements indicate that the composition of the detrital plagioclase grains fall into two groups: An_{43} to An_{53} and An_1 to An_8. Both groups are polysynthetically twinned, and cannot always be distinguished from one another by their appearance. However, all determinations falling in the range An_1 to An_8 were from cloudy, sericitized grains, whereas the grains having compositions in the range An_{43} to An_{53} range from clear to cloudy and sericitized. In most thin sections all

plagioclase grains examined belong to one group or the other, but in a few sections both groups were represented.

In addition to detrital plagioclase, authigenic albite occurs as small crystals in the matrix, as rims on calcic plagioclase grains, and in veins. In these occurrences, the albite is water-clear and rarely twinned. In veins the albite is commonly associated with quartz, calcite, and in a few thin sections with analcime.

Quartz is a minor constituent among the detrital grains forming less than 8.0 percent of the grains. Its proportion of the clastic grains increases in the siltstones and argillites, but since the amount of matrix also increases in these rocks, it is doubtful whether there is a real increase in the amount of quartz.

Quartz also commonly occurs as microgranular aggregates in the matrix and in quartz veins.

Analcime occurs in a few thin sections as veins and small aggregates scattered in the matrix. It occurs as euhedral inclusions in quartz, and also as euhedral drusy linings of cavities the central part of which has been filled by anhedral quartz.

Calcite or limestone clasts are rare in the graywackes of type 1, but in the massive graywackes, type 2, they may form as much as 45 percent of the total rock. The grains are commonly rounded and have rather indistinct margins, and irregular outlines; they are generally larger than the average grain size of the rock in which they occur, as large as 5 mm in diameter in some samples. The grains themselves are coarse aggregates of murky, slightly twinned calcite commonly showing vague fossil structures. In one locality a lenticular bed within a thick massive graywacke was composed entirely of slightly rounded calcite cleavage rhombs averaging 0.4 mm in length embedded in a sparce matrix of finely crystalline, murky calcite.

Secondary calcite occurs in isolated patches and as veins in the matrix of both types of graywacke, but it is abundant only in the massive graywackes of type 2, where it may form as much as 25 percent of the total rock. In almost every occurrence calcite appears to replace the other rock constituents in contact with it.

Chlorite is an important constituent of the matrix, and also of many of the detrital rock fragments. Generally it occurs in the matrix as irregular aggregates of various sizes ranging from less than 0.005 mm to 0.5 mm in diameter; the larger aggregates probably represent detrital grains replaced by chlorite. The chlorite aggregates themselves are equigranular and composed either of nonpleochroic or of slightly pleochroic pale yellowish-green chlorite having a first order gray birefringence. In only one section was the chlorite intensely pleochroic, X = green to Z = yellow green.

Detrital rock fragments, other than limestone are of three general types: 1) volcanic rocks; 2) argillite, and 3) chert. The volcanic fragments consist of plagioclase microlites in a chloritic groundmass. The plagioclase in these volcanic rocks appears to have the same composition as the individual plagioclase clasts, but determinations were difficult to make and in general unreliable. Argillite fragments, which also include sparse, fine-grained graywacke, consist generally of a cloudy, dark-brown, chloritic and sericitic matrix which also contains a variable amount of microgranular quartz. Plagioclase clasts are scattered through the matrix. Chert fragments range from microgranular quartz aggregates to mixtures of chlorite and microgranular quartz, and appear to grade into argillite. The separation of chert from argillite in order to prepare the diagram in figure 45a was difficult and arbitrary. However, since chert forms, at most, less than 5 percent of the grains, it has small effect on the total composition and classification.

Altered volcanic rocks.--Altered volcanic flows and breccias are a minor rock type in the Cannery formation, but locally in the area east of Snug Cove at Gambier Bay, they form units as much as several hundred feet thick. These rocks are medium gray to greenish gray in color, fine-grained or aphanitic, and contain scattered calcite amygdales 1.0 to 5.0 mm in diameter. Slightly sheared pillow structure is common; the pillows average about one foot in longest dimension. In one locality, the same rock type resembles a sheared breccia and contains a few scattered boulders of dark-gray, finely crystalline limestone 1.0 to 3.0 feet in diameter.

Most thin sections examined display pilotaxitic textures consisting of altered plagioclase laths averaging 0.09 mm in length in a groundmass of chlorite, calcite, pyrite, and limonite. The plagioclase laths are altered to sericite and calcite. One section contained about 10 percent colorless clinopyroxene in subhedral crystals averaging 0.1 mm in diameter scattered throughout the rock. Quartz, albite, and sphene are abundant in the groundmass of a few sections.

Two thin sections, one from the area south of Snug Cove, and the other from a creek west of Gambier Bay, contain 40 percent slightly granulated colorless clinopyroxene crystals about 0.5 mm in diameter ($2V_z$ = 50°-55°), 50 percent antigorite serpentine, and 10 percent interstitial secondary quartz and albite. This rock is olive gray and massive in outcrop, and usually breaks with a lustrous, serpentinuous surface. The high percentage of pyroxene suggests an altered ultramafic igneous rock such as a pyroxenite or peridotite. Although much less deformed and containing serpentine instead of chlorite, tremolite, and epidote, this rock resembles the pyroxene-bearing phyllonites of the Gambier Bay formation. Perhaps both rocks represent the same series of ultramafic intrusions, those in the Gambier Bay formation (p.134) being subjected to greater deformation and

metamorphism because of deeper burial.

Pybus dolomite

Dolomite.--The amount of limestone included in the Pybus dolomite is unknown. Every specimen collected upon being treated by cupric nitrate ($Cu(NO_3)_2$) solution (Rodgers, 1940, p. 788-798) was stained blue only on veinlets and cavity fillings, indicating that the bulk of the rock is dolomite. All specimens stained have the brownish hues and sugary texture characteristic of the carbonate rocks of this formation. Therefore, it is concluded that, if limestone is present, it is present in minor amounts.

The dolomite consists of a subhedral mosaic of dolomite crystals showing a tendency to form imperfect rhombs averaging about 0.2 mm in length (fig. 46). The crystals are cloudy because of the inclusion of very fine brown dust--probably iron-rich. Pores ranging from 0.1 mm to 0.9 mm in diameter are scattered through the dolomite mosaic; these are commonly represented by fillings of clear calcite, and, in places, by quartz. Partially filled pores having drusy linings of calcite occur less commonly. The pores typically contain a thin opaque film between the filling mineral and the walls.

In general, the dolomite is equigranular, but patches of coarser and finer crystals occur which have the vague form of fossil structures. Detrital grains of rounded quartz, chert, and argillite are minor constituents of a few thin sections.

Chert.--The chert occurs as both beds or lenses, and as scattered fragments. In both it has two aspects which can be seen within a single lens or fragment: 1) a porous, rough-weathering mass consisting of silicified fossils (largely brachiopod, bryozoan, and crinoid debris) (fig. 6a, b); 2) solid, smooth-weathering masses (fig. 5b). Type 1 grades into type 2 by the filling of the pore spaces between the fossils with chert (fig. 5a).

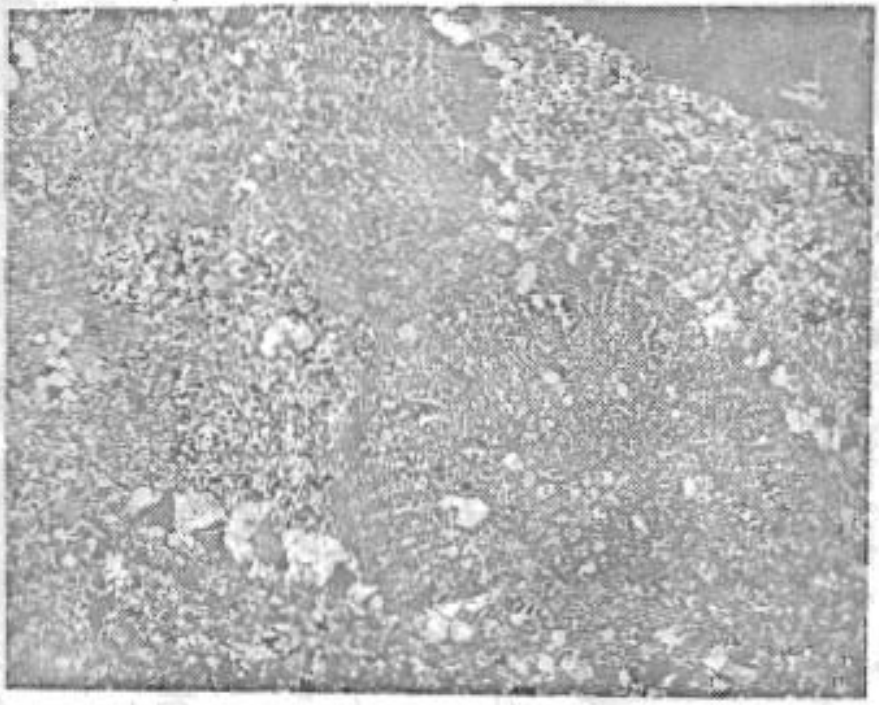


Figure 46.--Photomicrograph of fossil preserved as spherulitic chalcedony in granular dolomite showing imperfect rhombic crystal outlines (crossed nicols, 20 X).

The chert lenses are commonly broken, but the fragments as a rule have not moved far. Dolomite has invaded the fractures and spaces between the fragments (fig. 47).

The chert consists of small (averaging about 0.004 mm in diameter) masses of spherulitic quartz (chalcedony). Dolomite rhombs are scattered irregularly through the chert, and small patches of quartz occur in the surrounding dolomite in the vicinity of the chert-dolomite contact. Fossil structures are outlined by streaks and patches of coarser- or finer-grained quartz masses (fig. 46).

One thin section examined was divided into two approximately equal parts parallel to the bedding: in one part the fossils were well preserved as chert, and in the other they were only faintly preserved as dolomite. Fossils, therefore, occur throughout the rock, but their superior state of preservation and hardness as chert makes silicified fossils much more prominent. Probably the enclosing and replacing of fossils by chert prevented them from being dolomitized, and has led to their better preservation.

Ryd formation

Basal breccia.--Microscopically the chert and argillite fragments of the green and red chert breccia are identical to the chert and argillite of the Cannery formation described in a previous section (p. 148). The matrix consists most commonly of a cloudy mixture of microgranular quartz, plagioclase, sericite, calcite, or dolomite; silt-sized clasts of quartz and plagioclase are scattered through the matrix. Pyrite in small euhedra is a common minor constituent of these rocks. The yellowish brown-weathering matrix in the vicinity of Gain Island consists almost entirely of iron-rich dolomite, and the chert fragments there consist of a sutured mosaic of quartz containing abundant sericite inclusions.

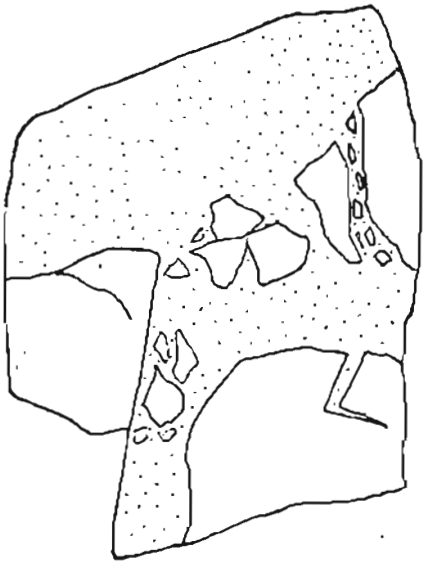


Figure 47.--Sketch of fractured chert (white) in dolomite (stippled).

Thin-bedded argillite member.--In thin section the three most common rock types--argillite, chert, and graywacke resemble one another in texture, and appear to differ only in the size and relative amounts of the same components. All have a matrix consisting of a cloudy mixture of microgranular quartz, new-formed plagioclase (albite), calcite, chlorite, sericite, and pyrite; also present is a fine, semiopaque dust which tends to form in tenuous layers delineating bedding surfaces. This dust is probably carbonaceous material, and is responsible for the prevailing dark color of the rocks. Scattered through the matrix are angular clasts of plagioclase, quartz, and more rounded clasts of calcite or limestone. The clasts are generally of coarse silt size except in the graywacke where the bottom layer of a graded bed (commonly one grain thick) may attain a grain size as much as 0.2 mm in diameter (fine sand).

In the calcareous rocks abundant calcite occurs in the matrix as murky patches which have corroded plagioclase grains in contact with them. An extreme type, a calcarenite, occurring sparsely in a few localities, consists of 40 percent clasts, 35 percent of which are rounded calcite grains showing faint fossil structures, in a matrix consisting of a fine aggregate of calcite crystals. The calcite clasts average about 0.2 mm in diameter, and are considerably larger than those in most graywacke.

In chert and siliceous argillites, microgranular quartz predominates over the other constituents. In the purer cherts, calcite, sericite, and chlorite are minor. One such chert, which is prominent near the top of the member, consists of a very fine grained, almost submicroscopic, mass of quartz through which are scattered flakes of sericite. Radiolarian tests, similar to those described above from the Hood Bay and Cannery formations, are scattered along the bedding surfaces of this rock. The tests are composed of spherulitic quartz, and have circular or elliptical outlines

averaging about 0.1 mm in diameter (fig. 48). The chert also contains very sparse, angular clasts of plagioclase and quartz ranging in diameter from 0.05 to 0.4 mm. The bedding planes in the chert are outlined by fine, dark-brown dust which tends to form very thin laminae. The light-colored rock layers between the dark laminae pinch and swell ranging in thickness from 0.5 to 2.0 mm.

Volcanic member.--In composition the volcanic rocks fall into two groups that cannot be distinguished in the field: 1) a predominant sodium-rich type in which all plagioclase appears to be albite; 2) a much less abundant potassium-rich type in which all the feldspar appears to be potassic.

The first type agrees with published descriptions of spilites (Turner and Verhoogen, 1960, p. 258-263; De Roever, 1942, p. 223-233); rocks of this type include both pillow and non-pillow structural types. Microscopically these rocks have an altered intergranular texture consisting of a cloudy, indistinct groundmass of albite, chlorite, epidote, calcite, and opaque minerals. The groundmass albite, which averages about 50 percent of the rock, occurs as an irregular, interconnecting mass containing abundant fine inclusions of chlorite, sericite, and calcite. Sparse, small, fresh, finely twinned albite laths, averaging about 0.18 mm in length, are also scattered throughout the groundmass. Chlorite, occurring as inclusions in albite, is the next most abundant constituent, and averages about 20 percent of the rock. In addition, the chlorite occurs throughout the groundmass as interstitial flakes, and also as larger aggregates whose forms suggest pyroxene and amphibole crystal outlines. Most of the chlorite is slightly pleochroic from Z = yellowish green to X and Y = pale green, and shows a low first order gray birefringence. However, the chlorite of one section displays more intense pleochroic colors from Z = bluish green to X and Y = green, and a first order yellow birefringence.

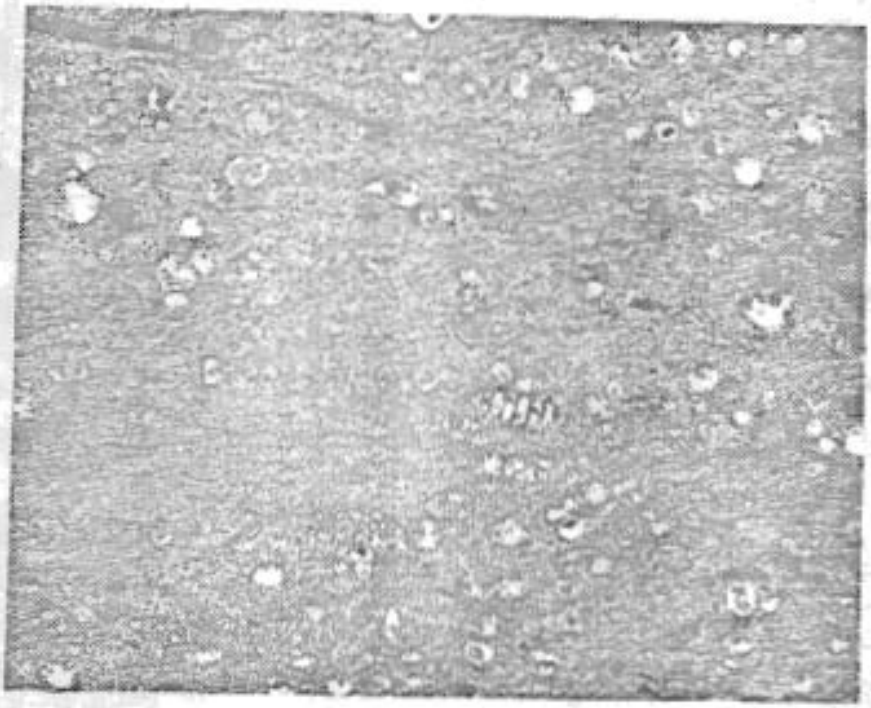


Figure 48.--Photomicrograph of Radiolarian chert, Ryd formation; Radiolarian tests, consisting of spherulitic quartz, in a matrix of argillaceous, microcrystalline quartz (plain light, 45 X).

In most specimens sparse plagioclase phenocrysts, averaging about 1.5 mm in length, are scattered throughout. The phenocrysts show polysynthetic twinning, and are strongly altered to chlorite, calcite, and sericite. Commonly only ragged remnants of the original phenocrysts remain; the alteration tends to be controlled by cleavage planes. Universal stage measurements of both small crystals of the groundmass and the phenocrysts indicate compositions in the range An_3 to An_7. The absence of potassic feldspar was indicated by sodium cobaltinitrite stain.

One massive flow contains nearly unaltered euhedral phenocrysts of hornblende and clinopyroxene averaging 3.0 mm in length set in a chloritic groundmass similar to that described above. The hornblende occurs in slightly ragged crystals which commonly show simple twinning; the pleochroism is as follows: X = pale yellow; Z = yellowish green; and Y = brownish green. Universal stage measurments indicate an angle $Z \wedge c$ of about 20°, and a 2V x of from 75° to 80°. The clinopyroxene is colorless and contains inclusions of epidote and chlorite around the margins; accurate measurements of optical properties could not be made.

Volcanic rocks of the potassium-rich second type are known only from one locality: the peninsula northwest of Good Island, where about 500 feet of pillow lava crop out in the hinge of a tightly folded anticline. Microscopically the potassium-rich rock is composed of sparse, subhedral, potassic feldspar phenocrysts in an altered pilotaxitic groundmass consisting of thin potassic feldspar laths and interstitial chlorite, calcite, and opaque minerals (fig. 49). The groundmass feldspar averages about 0.1 mm in length, and commonly displays simple twinning; the margins of the laths are indistinct and contain chlorite and calcite inclusions. Calcite also occurs as clear patches ranging from 0.04 mm to 5.0 mm in diameter, most of which probably represent amygdales. The opaque minerals are largely limonite,

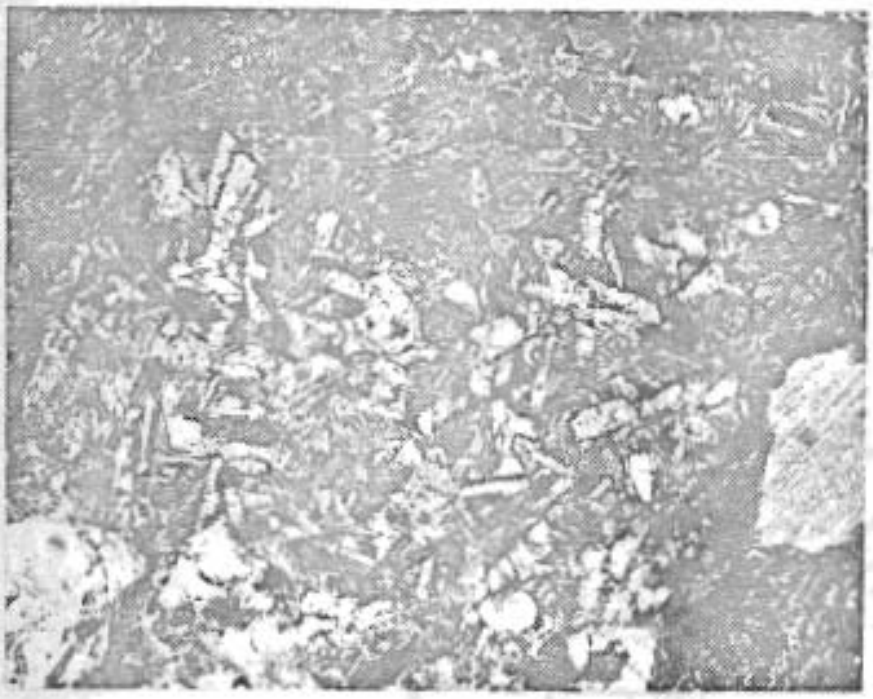


Figure 49.--Photomicrograph of poeneitic pillow lava, Hyd formation; cluster of simply twinned potassic feldspar phenocrysts in groundmass of potassic feldspar microlites, chlorite, calcite, and opaque minerals; patch of calcite at right margin is an amygdule (crossed nicols, 40 X).

and are especially abundant as fine dust in the larger chlorite patches whose outlines suggest pyroxene and amphibole crystal forms.

The potassic feldspar phenocrysts are subhedral with a tendency toward irregular, indistinct borders. Both untwinned or simply twinned types are present; in general, the birefringence is a first order gray, noticeably lower than that for plagioclase. The phenocrysts contain abundant chlorite inclusions, but appear to be unaltered in other respects. Sodium cobaltinitrite stain showed both phenocrysts and groundmass feldspar to be potassic. Universal stage measurements indicate that the feldspar is monoclinic with the optic plane perpendicular to (010); a few, rather poor measurements indicate that 2Vx is about 60°. The value of the optic axial angle, and the orientation of the optic plane places these feldspars in the orthoclase cryptoperthite series of Tuttle (1952, p. 557-558). Ragged feldspar crystals suggestive of altered remnants of original calcic plagioclase, such as present in the spilitic rocks, are lacking from the potassic rocks. In thelatter no textures were seen which might be interpreted as indicating replacement of an original feldspar by potassic feldspar.

A chemical analysis of the above rock showed it to contain 5.4 percent K_2O and 1.9 percent Na_2O in contrast to 0.75 percent K_2O and 4.93 percent Na_2O for the average spilite (Sundius, 1930, p. 9). De Roever (1942, p. 223-224) reported potassic equivalents of spilites, which he calls poenites after Brouwer (1940, p. 263), associated with spilites and keratophyres, from the Permian of Timor. Figure 50 shows a comparison of chemical analysis of a typical poenite, an average spilite, and the pillow lava. De Roever found all transitions between spilites and poenites, and suggested intermediate rock names such as spilitic poenite and poenitic spilite. Most of the poenites described by De Roever contain more than 8.0 percent K_2O, and hence the present rock might be called a spilitic poenite in his classification.

Figure 50.-- Chemical analyses of poeneite.

	1	2	3
SiO_2	44.6	52.05	51.22
Al_2O_3	17.1	18.35	13.66
Fe_2O_3	1.6	10.07	2.84
FeO	8.5	0.40	9.20
MnO	0.1	0.16	0.25
Mgo	5.1	0.91	4.55
CaO	4.5	1.96	6.89
Na_2O	1.9	1.39	4.93
K_2O	5.4	8.97	0.75
H_2O	5.3	2.88	1.88
TiO_2	1.8	2.24	3.32
P_2O_5	0.6	0.94	0.29
CO_2	3.2	none	0.94
Rest	-	0.11	-
	100.	100.43	100.72

1. Pillow lava, Gambier Bay, Admiralty Island, Alaska; rapid rock analysis by L. D. Elmore, H. Barlow, S. D. Botts, G. Chloe of U.S.G.S.

2. Poeneite, Noil Tobe, Timor (De Roever, 1942, p. 237-238).

3. Average spilite, average of 19 analyses (N. Sundius, 1930, p. 9).

Seymour Canal formation

Argillite and thin-bedded graywacke.--The fracture cleavage that is characteristic of the Seymour Canal formation throughout most of its area of outcrop (see section on Pybus structural province) is much more pronounced in the salt water shoreline exposures than in exposures away from shore. Probably wedging by the crystallization of salt in the cleavage fractures is necessary for them to appear as open fractures.

Microscopically the typical, noncalcareous argillite consists of an almost unresolvable brown matrix composed of chlorite, sericite, clay mineral, pyrite, and very fine semi-opaque dust, through which is scattered angular grains of plagioclase and quartz averaging less than 0.02 mm in diameter. The matrix commonly forms about 90 percent of the rock.

The concretions of the argillite are composed of dark-brown, fine-grained limestone that weathers a light yellowish gray, and shows faint bedding parallel to that of the argillite. Although the bedding in the argillite bows out slightly above and below the concretions, it seems to do so no more than would be expected from differential compaction of a soft matrix around a body that became gradually more competent than the matrix as compaction proceeded. The concretions average about 2.0 feet in length, and about 6 inches in thickness; a few occur as thin beds 2 or 3 inches in thickness, and range from 6.0 to 10 feet in length. Typically, as indicated by figure 13a, a sharp contact exists between the light-weathering concretion and the dark-colored argillite, however, commonly the argillite in the vicinity of the concretion has been penetrated by calcite to a thickness of one or two inches normal to the bedding and of one or two feet parallel to the bedding. This calcareous zone weathers to a rough, brown surface from which project angular remnants of noncalcareous argillite. Similar brown-weathering, calcareous patches and layers are

often seen without an obvious core of limestone; in some places these calcareous zones contain small limestone and fossil fragments.

The concretions, both as lenses and beds, may be true concretions in the sense used by Pettijohn (1957, p. 203) in which calcite has accumulated in the pore spaces of the rock around nuclei, such as calcareous fossil and other limestone fragments. The strong deformation to which the rocks of the Seymour Canal formation have been subjected probably account for the pull-apart and typical boudinage structures seen in concretions at some localities.

The exotic inclusions also found in the argillite consist of fragments of limestone of any shape, commonly angular, ranging from a few inches to a few feet in longest dimension, in which the bedding may have any orientation relative to that of the surrounding argillite (fig. 13b). Unlike the concretions, the exotic inclusions do not have diffuse, calcareous aureoles in the enclosing argillite. Furthermore, these inclusions strongly bend down the beds below without having sustained complementary deformation to themselves indicating that they were introduced as consolidated limestone fragments into soft mud.

The inclusion consists largely of a dark-gray or brown, fine-grained limestone which weathers light gray, and a less common type consists of medium-gray, fine-grained marble; both varieties are probably fragments of older rock. They commonly occur in argillite sections containing no calcareous beds of any type from which they might have been derived by submarine erosion and redeposition or by tectonic disruption; furthermore, the inclusions are commonly embedded in thinly bedded, fine-grained rocks characteristic of a quiet environment relatively distant from shore (Pettijohn, 1957, p. 293-294), and not in the chaotic, landslide deposits seen elsewhere in the formation. Rafting and dumping by some agent such as

icebergs, tree roots, or other floating objects seem to be the most logical origin.

The thin-bedded graywackes are medium to dark gray, highly indurated rocks that weather light gray in calcareous varieties and olive gray in chloritic varieties. The graywacke beds show little tendency to break or weather-out along bedding surfaces, and sole markings, such as flute casts, drag marks, and load casts, are generally seen only in section. In detail the graywacke beds grade upward from medium or fine sandstone at the base to coarse siltstone at the top. The lower contact with the argillite is commonly sharp and irregular, containing channels, depressions, and irregular upward-projections of the argillite; thin slabs of argillite are commonly scattered along the bottom layers of the graywacke bed (fig. 51). The upper contact is more indistinct; it commonly shows smooth, undulating ripple mark cross sections. A bed may simply grade upward from base to top in a single cycle, but thicker beds tend to be composed of several cycles of grading, commonly associated with sets of small-scale cross-bedding, superposed one upon the other. However, such beds ordinarily tend to become finer from base to top in spite of repeated cycles of grading and repeated sets of crossbedding (fig. 51). Convolute bedding (Kuenen, 1953, p. 1056; Crowell, 1955, p. 1364) is a less common feature than those described above (fig. 12b); the irregularly distorted laminae constituting convolute bedding occur generally in the finer parts of the beds. The distortion of the laminae may die out either upward or downward in both directions in the manner described by Webby (1959, p. 469).

The typical thin-bedded graywacke consists largely of subrounded to angular grains of feldspar and volcanic and argillite rock fragments set in a murky brown chloritic or calcitic matrix. Minor grain types include biotite, quartz, chert, and limestone. The matrix ranges from 10 to 60

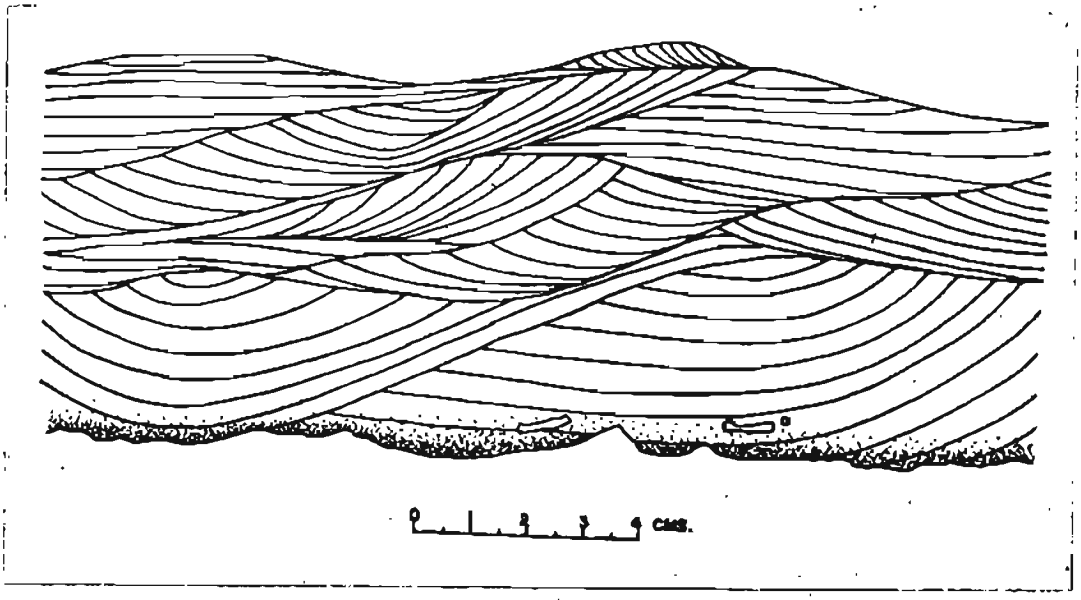


Figure 51.--Sketch of graywacke bed, Seymour Canal formation, showing small scale crossbedding; argillite above and below.

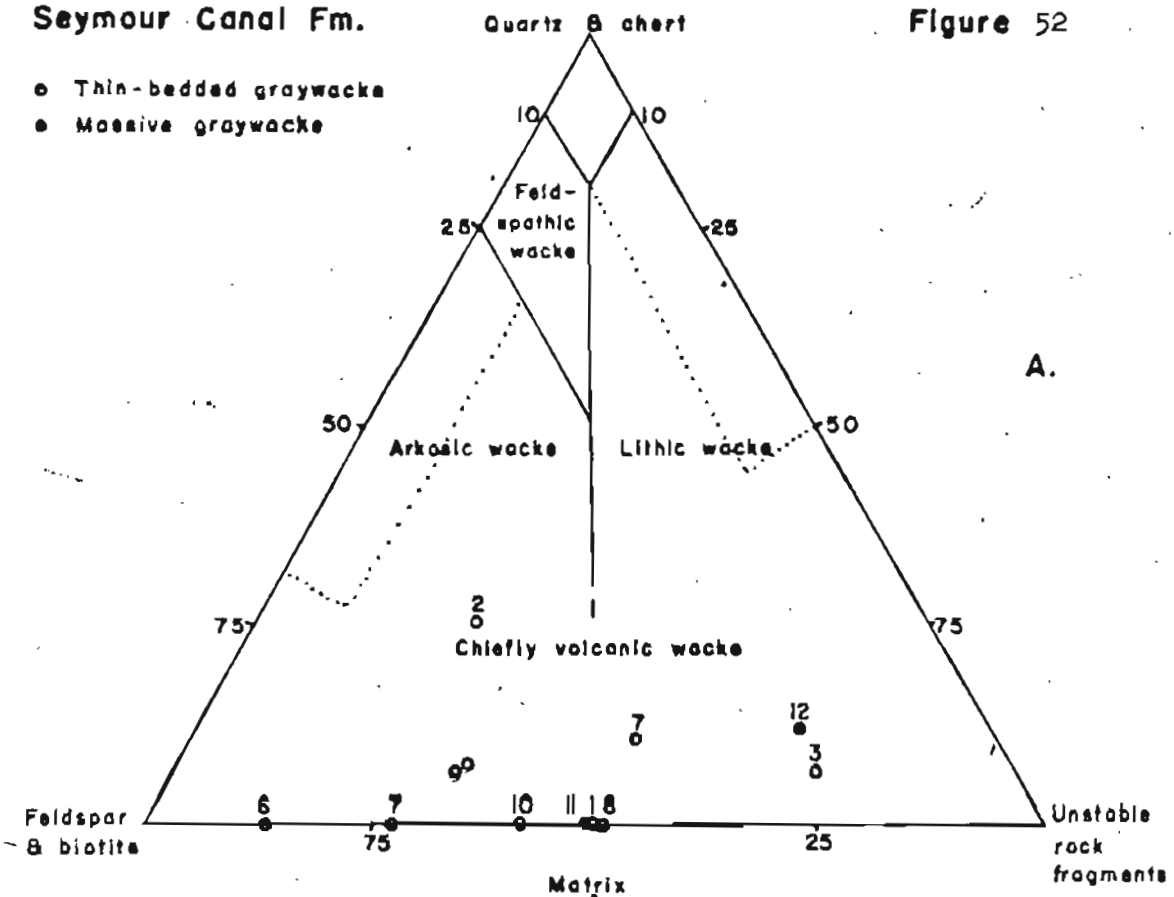
percent of the rock and averages about 35 percent (fig. 52b); these rocks, therefore, can be classified as graywackes under most recent classifications (Gilbert in Williams and others, 1954, p. 292-294; Pettijohn, 1957, p. 290-293).

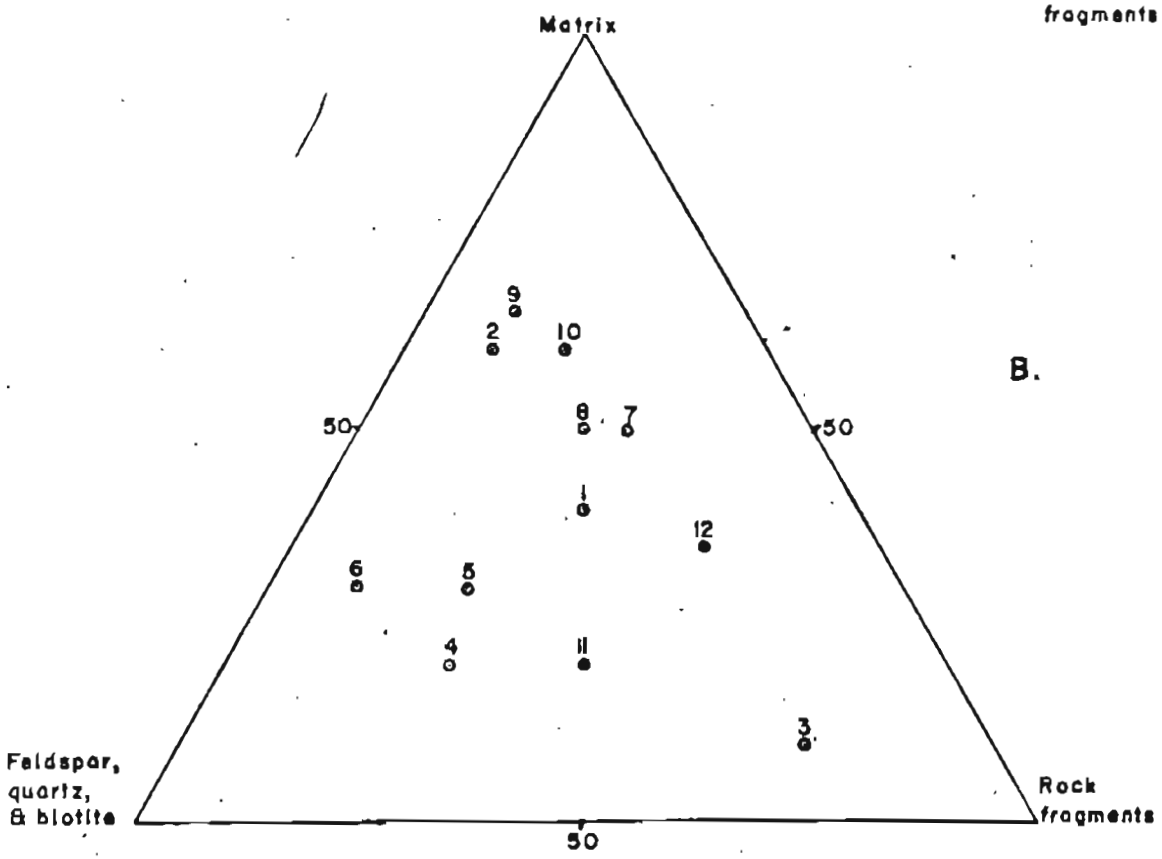
Figure 52a shows the relative amounts of the chief groups of grain types estimated in representative thin sections of thin-bedded graywackes (clear circles). The relatively unstable feldspar and rock fragment grains greatly predominate over the stable quartz and chert grains. The latter are commonly present in trace amounts only. The relative amounts of feldspars and rock fragments are about equal overall, but the finer grained rocks tend to contain a greater percentage of feldspar, and the coarser grained rocks tend to contain a greater percentage of rock fragments. The grains average about 0.2 mm in diameter and commonly grade from 0.5 mm to 0.02 mm in diameter from base to top of a one- or two-inch bed; the decrease in grain size upward is accompanied by an increase in the amount of matrix. For example, one specimen contained 60 percent matrix at the base of the bed and 95 percent near the top.

Plagioclase is abundant and forms most of the feldspar grains, whereas potassic feldspar is rare in most specimens, attaining a maximum of 10 percent of the grains in one specimen. The plagioclase occurs as slightly or moderately sericitized grains showing polysynthetic twinning and, in a few thin sections, faint zoning; universal stage measurements indicate compositions in the range An_{12} to An_{48}, most being in the range An_{42-45}. The potassic feldspar occurs as highly sericitized, untwinned grains, and was determined with the aid of sodium cobaltinitrite stain. The volcanic rock fragments, which are the most abundant of the unstable rock fragments, commonly show a trachytic or pilotaxitic texture consisting of partly sericitized plagioclase microlites averaging about 0.01 mm in length set

Seymour Canal Fm.

Figure 52





in a chloritic groundmass; sparse plagioclase phenocrysts are seen in a few grains. The argillite fragments consist of a cloudy, very fine grained, largely unresolvable, chloritic matrix through which are scattered silt-sized, angular grains of plagioclase and quartz.

Biotite is a ubiquitous minor constituent generally forming less than 5 percent of the rock. Its characteristic pleochroism is: Z and Y = reddish brown, and X = pale yellowish orange; commonly the flakes are partially altered to chlorite, and are distorted between more competent grains.

The matrix of the graywacke is a murky brownish mixture of chlorite, calcite, pyrite, epidote, limonite, and much nonbirefringent cloudy material; leucoxene and sericite are common in a few specimens. The chief variation in composition among the typical graywacke is in the relative proportion of chlorite and calcite. All gradations exist between graywackes in which calcite forms nearly 100 percent of the matrix to those in which chlorite is predominant and calcite occurs only in trace amounts. The matrix in all specimens has corroded and replaced themargins of the grains. This replacement of grains is especially pronounced in rocks having a calcareous matrix; in these calcite has strongly replaced the grains, especially the plagioclase grains, commonly leaving only isolated, ragged remnants of larger grains in patches of calcite. This process greatly reduces the size and total volume of clastic grains in calcareous graywackes.

Prehnite is the dominant mineral of the matrix in two of the specimens examined in which it forms about 50 percent of the rock. In these the matrix consists of a mosaic of anhedral prehnite crystals, ranging from 0.3 to 0.5 mm in diameter, which poikiloblastically encloses the clastic grains andminor patches of chlorite, calcite, and epidote. The prehnite has almost completely replaced the plagioclase clasts (An_{31}) (fig. 53), and to a lesser degree the other clasts (volcanic and argillite fragments). The

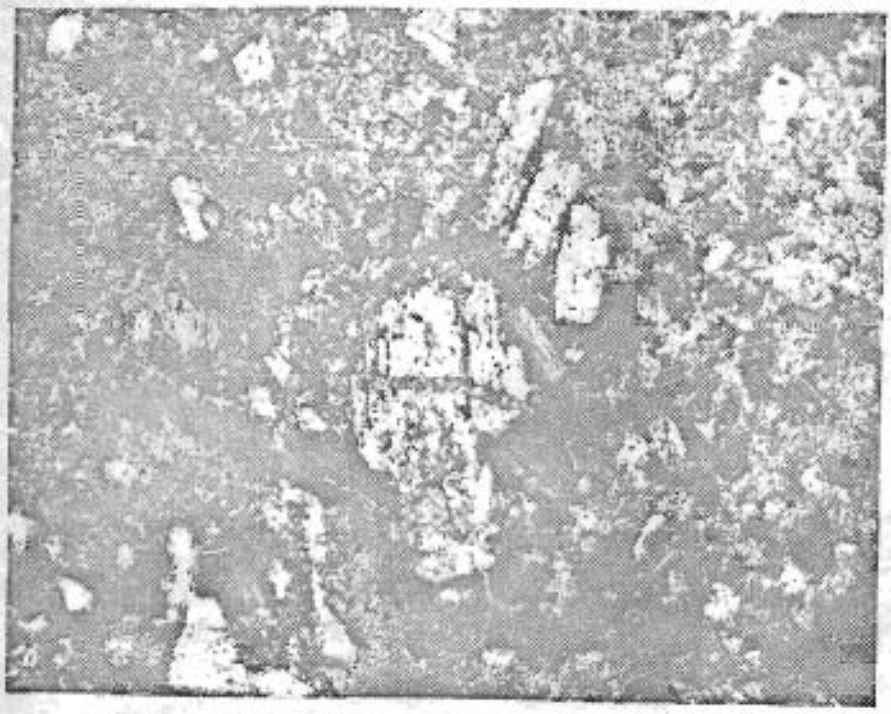


Figure 53.--Photomicrograph of graywacke, Seymour Canal formation in which a granular mosaic of prehnite (stippled gray) has partially replaced matrix and plagioclase grains (crossed nicols, 71 X).

prehnite is nearly colorless or very pale green, and has a maximum birefringence of second order blue.

Conglomerate and massive graywacke.--The amount of matrix in the conglomerate is variable, and ranges from less than 10 percent (fig. 15a) to more than 90 percent (fig. 15b). The most common matrix is a brownish-gray, medium- to coarse-grained graywacke identical in lithology to the massive graywacke. By a decrease in pebbles, conglomerates containing this matrix commonly grade into massive graywacke. A less abundant but widespread matrix consists of dark gray argillaceous graywacke or sandy argillite, which grades into massive argillite by a decrease in pebbles and sand (fig. 15b).

Massive graywacke and the similar matrix of the conglomerate closely resemble the thin-bedded graywackes in composition of matrix and in grain constituents (see black dots in fig. 52a, b). In general, the massive graywackes tend to contain a greater percentage of rock fragments than do the thin-bedded varieties. Remarks given above concerning variations in composition and petrographic details of the matrix of the thin-bedded graywacke are also appropriate for the massive graywacke.

The less abundant, dark gray, argillaceous matrix consists largely of clastic grains of plagioclase and volcanic and argillite rock fragments set in a chloritic matrix. The matrix consists of a murky brown, almost unresolvable misture of chlorite, calcite, semiopaque dust, and in places fine crystals of clinozoisite. The proportion of chlorite and calcite varies from one specimen to another but in general chlorite predominates and the matrix is at most only slightly calcareous. The argillaceous matrix grades from medium dark gray graywacke containing 60 percent sand grains to dark gray argillite containing 20 percent or less sand and coarse silt grains.

The fragments composing the conglomerates exclusive of the matrix consist largely of subrounded to rounded pebbles and cobbles of rock fragments. Boulders as much as 3 feet in diameter are scattered through the cobble conglomerate. These larger clasts are not seen in the pebble conglomerates. Two pebble counts made at two widely separated localities illustrate the common types of clasts:

	North end Long Island (150 pebbles) Percent	South end Gambier Island (150 pebbles) Percent
Limestone, fine-grained, dark-brown	9	11
Graywacke, medium- to fine-grained, dark-gray	21	11
Slate, dark-gray, noncalcareous	4	7
Argillite, dark-brown, calcareous	10	5
Chert, black	3	3
Chert, light-gray or brown	8	9
Volcanic rock, porphyritic (feldspar), grayish-green	2	19
Volcanic rock, porphyritic (feldspar), dark-gray	3	5
Felsite, quartz phenocrysts, light-gray	16	8
Granodiorite	12	4
Diorite, fine crystalline	10	12
Diorite, mafic phenocrysts	2	4
Quartz, white	--	2

Brothers volcanics

The typical flow rock contains phenocrysts of sericitized plagioclase (30 percent), pyroxene (15 percent), and hornblende (trace) set in a very fine grained, pilotaxitic groundmass composed of plagioclase microlites, chlorite, calcite, and opaque minerals. Plagioclase phenocrysts range in length from 0.2 to 1.0 mm and commonly show polysynthetic twinning and normal zoning. Seritization of the plagioclase prevents accurate determination of composition, but compositions from An_{25} to An_{48} are indicated. Clinopyroxene phenocrysts are euhedral, colorless, and show rare simple twinning; the angle $Z \wedge c$ lies in the range 39° to 45°, and $2Vz$ in the range 50° to 54°. Hornblende is generally euhedral and often shows simple twinning; its pleochroism is from Z and Y = greenish brown to X = pale yellowish brown. Both pyroxene and hornblende commonly have rims of chlorite and opaque grains.

The plagioclase microlites are indistinct needles less than 0.02 mm in length whose composition could not be determined. Chlorite occurs largely as interstitial aggregates; it shows a pleochroism from X and Y = green to Z = pale yellowish green and an anomalous bluish gray birefringence. Calcite occurs as patches scattered throughout the specimens examined; some of the patches represent amygdales. Fine opaquedust is disseminated throughout the groundmass and consists in part of pyrite. Pyrite also occurs as larger euhedral crystals as much as 0.2 mm in length.

Unnamed conglomerate and sandstone

Conglomerate.--The conglomerate consists of rounded clasts of various colors embedded in medium to light gray, coarse-grained, lithic sandstone matrix. The amount of matrix ranges from less than 10 to 40 percent of the

rock, and the average is near the lower end of the range. The sandstone of the matrix resembles closely the sandstone of the lenses but lacks the current structures of the latter. The conglomerate is commonly massive, but in places crude bedding is indicated by layers of clasts of contrasting size; individual units or beds range in thickness from a few feet to tens of feet (fig. 31a).

The clasts range from pebbles 0.25 inch in diameter to boulders 5.0 feet in longest dimension, and the average lies in the small cobble range (2.5 to 5.0 inches in diameter). As mentioned above, the uppermost few feet of the formation consists almost entirely of clasts of volcanic rocks similar in type to those of the overlying Admiralty Island volcanics (fig. 31b). These types decrease downward with a corresponding increase in types characteristic of the unit as a whole. Below the top few feet volcanic rock fragments are rare, but where locally abundant they are composed of rock types unlike those of the Admiralty Island volcanics. Characteristic clast constituents are illustrated by the following pebble count taken near the base of the formation (200 pebbles counted):

	Percent
Diorite (plagioclase phenocrysts)	9
granite	27
gneiss	9
quartz, white milky	5
quartzite	7
chert, black	6
argillite, dark gray	18
graywacke	6
greenschist	3
gabbro	5
sandstone, pale red	1
felsite, light gray (quartz phenocrysts)	1
tuff, green	3

The porphyritic diorite clasts appear to be identical to the diorite cropping out in the northwest part of the Pybus-Gambier Bay area (see p. 69),

and indicate that this plutonic body was undergoing erosion prior to or contemporaneous with the deposition of the conglomerate. The abundant argillite clasts could have been derived from any of the several pre-Tertiary formations previously described. The conglomerate of the Seymour Canal formation may have been a source of coarse detritus within the local area.

Sandstone.--A well-indurated, lithic, coarse-grained sandstone is the most abundant rock type in this category; it occurs both in beds and as matrix in the conglomerate. Two general varieties are recognized between which all gradations occur: 1) light yellowish gray sandstone containing an abundant calcareous matrix and sparse dark gray phyllite fragments; 2) medium dark gray sandstone containing a sparse micaceous matrix and abundant dark gray phyllite fragments. The phyllite fragments are lustrous slabs that lie subparallel to the bedding, and give the rocks in which they are abundant a slight bluish cast. The sandstone of the beds commonly contains scattered pebbles and cobbles, and, unlike that of the conglomerate matrix, often displays crossbedding in sets ranging in thickness from 0.5 to 2.0 feet (fig. 32b).

In a few places, light to medium gray, fissile siltstones and silty shales are intercalated with the sandstones. These rocks commonly show symmetrical ripple marks and small scale crossbedding (fig. 32a). Muscovite is an abundant detrital constituent and imparts a lustrous sheen to the bedding surfaces. In a few places, the silty shales contain layers of carbonized plant fragments and coaly material a few millimeters thick.

The calcareous sandstone consists of rounded to subangular grains of the following kinds embedded in a calcareous matrix: quartz (10-15 percent), quartzite (5-10 percent), partially sericitized, multiple-twinned plagioclase (10-20 percent), phyllite (10 percent), biotite (2-5 percent),

muscovite (1-5 percent), quartzofeldspathic aggregates (2-5 percent), graywacke (0-1 percent), and chert (trace). The calcareous matrix, which averages about 40 percent of the rock, consists of a cloudy mosaic of anhedral calcite crystals containing a few, frayed patches of fine detrital grains and authigenic sericite. These patches seem to be remnants of an original micaceous-detrital matrix similar to that of the micaceous sandstone (p.181), which has been almost completely replaced by calcite. The calcite has also partially replaced the larger detrital grains, resulting in a greater percentage of matrix in the calcareous sandstone than in the non-calcareous sandstone (average 10 percent); plagioclase grains have been the most strongly replaced.

The calcareous sandstones would ordinarily be classified as lithic arenites in Gilbert's classification (in Williams, and others, 1954, p. 297), because of the abundant rock fragments and the calcite cement or matrix. However, the evidence above suggests that the original matrix consisted of a micaceous, detrital mixture, and hence these rocks were probably originally lithic wackes.

The micaceous sandstones contain grain types similar to those of the calcareous types, but contain a much greater amount of phyllite (30 percent or more). The phyllite is fine-grained rock containing abundant sericite showing a strong preferred orientation parallel to a prominent foliation surface; microfolds in this foliation surface are common. The matrix, which averages about 10 percent of the rock, consists of a sericite and chlorite mixture containing a few calcite patches and scattered fine detritus. The grains are either in contact with one another or separated by a thin layer of micaceous matrix. Dark reddish brown biotite, partly altered to chlorite, occurs sparsely as thin flakes distorted between competent grains. These rocks are also lithic wackes, although some of them contain slightly less than the requisite 10 percent matrix.

Admiralty Island volcanics

Unaltered rocks.--Rocks grouped under this heading are either completely unaltered or are only slightly altered. They are composed largely of plagioclase, pyroxene, magnetite-ilmenite, and less commonly of glass. The most common texture consists of plagioclase and lesser amounts of clinopyroxene phenocrysts embedded in a trachytic or pilotaxitic groundmass composed of abundant plagioclase microlites, interstitial pyroxene, andmagnetite-ilmenite. Two of the 19 thin sections studied contained a hyalopilitic groundmass in which the interstices between the plagioclase microlites are occupied by dark brown, slightly devitrified glass. Intergranular and subophitic textures involving the above minerals (except glass) are not common, and occur chiefly in dike rocks.

The Chayes system of modal analysis is not satisfactory in fine-grained rocks such as the present volcanic rocks (Chayes, 1956, p. 95), however a few such analyses were made in order to check visual estimates. Modal analysis of a typical holocrystalline, unaltered rock gave the following mineral composition (by volume): plagioclase, 60 percent; pyroxene, 20 percent; magnetite-ilmenite, 5 percent, and unresolvable material, 15 percent. Similar analysis of an unaltered glassy rock gave the following mineral composition: plagioclase, 42 percent; pyroxene, 8.0 percent, and glass, 50 percent.

Plagioclase phenocrysts are distributed widely in the rocks studied, however their abundance varies greatly. The phenocrysts may be uniformly scattered through the rock, or may occur in clots which commonly consist of larger phenocrysts partially enclosing smaller ones. The phenocrysts occur in two size groups: 1) larger phenocrysts ranging from 1.0 to 4.0 mm in length; 2) smaller phenocrysts ranging from 0.25 to 0.75 mm in length. Both the larger and the smaller phenocrysts are generally fractured, rounded,

and corroded, but the smaller ones tend to be less rounded and less corroded. Both groups are complexly and polysynthetically twinned, a distinct, oscillatory zoning. Because of the oscillatory zoning, the phenocrysts do not maintain a constant sense of composition change from core to rim. The larger phenocrysts range in composition from An_{55} to An_{88} (universal stage), but most fall in the range An_{70} to An_{84}. The smaller phenocrysts appear to be more sodic in general, and the majority fall in the range An_{54} to An_{68} (universal stage).

The composition of the groundmass plagioclase could not be determined with accuracy because of their small size (average about 0.25 mm in length). Extinction angle determinations in addition to a few universal stage measurements indicate that the composition of the microlites lies in the range An_{56} to An_{66}.

Clinopyroxene phenocrysts, ranging in length from 0.3 to 1.0 mm are common, but are far less abundant than plagioclase phenocrysts. The pyroxene of the phenocrysts is generally colorless, subhedral, rounded and commonly shows simple twinning on (100); the phenocryst tend to form clots, and in some places penetrate plagioclase phenocrysts. A few universal stage measurements indicate that 2V z lies in the range 52° to 70°, and the angle $Z \wedge c$ lies in the range 44° to 55°.

The pyroxene of the groundmass occurs chiefly as equant grains generally smaller than the plagioclase microlites with which they are associated; in a few sections, however, the pyroxenes of the groundmass are relatively larger and tend to ophitically enclose the plagioclase. Both colorless and pleochroic types are common; in the latter, which may be titanaugite (Winchell, 1951, p. 417), the pleochroism is Z = violet and X = pale yellowish brown.

The chief opaque minerals are metallic gray in reflected light, and commonly show octahedral sections characteristic of magnetite and angular, skeletal forms common in ilmenite; both minerals are probably present. The

opaque minerals occur largely as finely disseminated grains in the groundmass, and less commonly as larger crystals comparable in size to pyroxene crystals.

Altered rocks.--The alteration of the rocks of the Admiralty Island volcanics resembles propylization as used by Wilshire (1957, p. 244-245). This author defines propylization as the process of alteration of calc-alkaline or calcic volcanic rocks, unattended by deformation, which produces in andesites some combination of the following secondary minerals: epidote, albite, chlorite, and calcite. The chief alteration products found in the rocks of the Admiralty Island volcanics are chlorite, calcite, sericite, and epidote; albite, magnetite-ilmenite, and quartz are less important alteration products.

The groundmass appears to be the most susceptible to alteration, and is commonly altered where the phenocrysts are only slightly altered. In the last stage of alteration both the phenocrysts and the groundmass are composed of the alteration products listed above.

Plagioclase is most commonly altered to sericite, epidote, and calcite (fig. 54); in a few places it is also partially replaced by irregular masses of clear albite. These minerals may be present in any combination in a given specimen. The alteration products occur commonly along the cleavage and other fractures in the incipient stages; the cores of the plagioclase crystals seem to be the first to be attacked. A common type of alteration is one in which partially sericitized plagioclase is partially replaced by a mosaic of epidote and a cloudy aggregate of calcite. In a few rocks the plagioclase is entirely altered to a fine aggregate of sericite and an irregular mass of clear albite.

Both phenocrystic and groundmass pyroxene crystals are commonly completely altered where plagioclase is only slightly altered. The chief

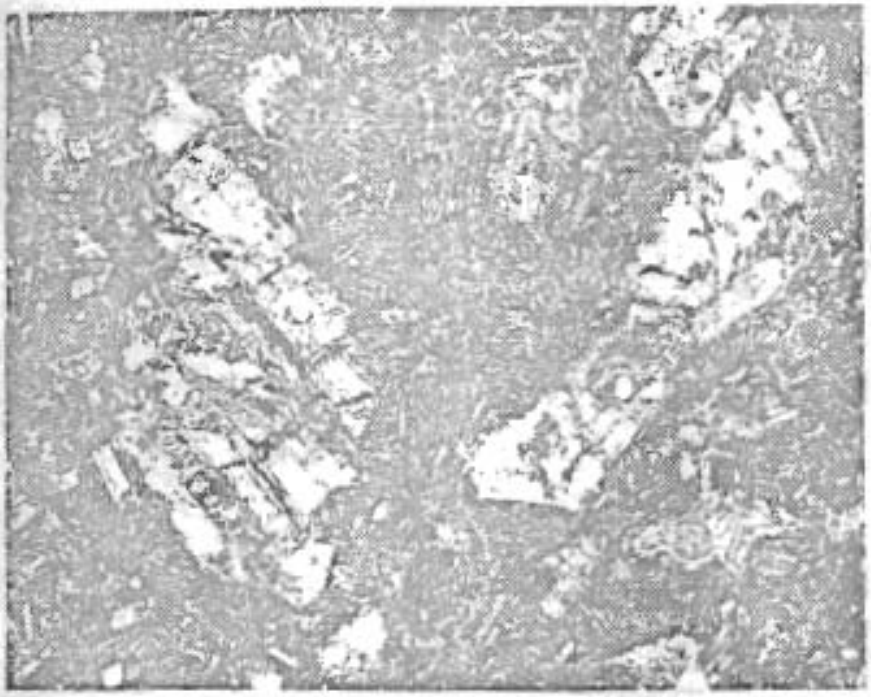


Figure 54.--Photomicrograph of partially altered andesitic flow, Admiralty Island volcanics, showing plagioclase phenocrysts (white) partially replaced by a fine-grained mixture (cloudy gray) composed chiefly of calcite and lesser amounts of sericite and chlorite; groundmass is composed largely of microlites of plagioclase, chlorite, calcite, and magnetite-ilmenite (crossed nicols, 40 X).

alteration products are chlorite, epidote, calcite, matnetite-ilmenite, and less commonly tremolite(?). The magnetite, in places is altered to limonite, occurs chiefly as small grains in chlorite, in and around the margins of altered pyroxene crystals. A colorless amphibole, possibly tremolite, occurs in one specimen as saw-toothed growths on the pyroxene crystals (see fig. 55).

Chlorite most commonly shows a pleochroism from Z = pale yellowish green to X and Y = pale green, and an anomalous low order blue birefringence. The chlorite occurs ordinarily as a fine, flaky aggregate without a noticeable preferred orientation; in a few places it assumes a sperulitic habit.

Calcite occurs either as cloudy, fine aggregates, or as large, clear, crystals. Epidote occurs both as mosaics and as small, isolated, equant, subhedral crystals; its pleochroism is Z = greenish yellow and X = pale greenish yellow.

Quartz is a minor alteration product in a few rocks in which it occurs in small, irregular, individual crystals in and around plagioclase phenocrysts which have been almost completely altered to epidote, sericite, and calcite. In these rocks it is also present as very fine mosaics sparsely scattered through the groundmass.

Tuffs, breccias, and other minor rock types.--The minor pyroclastic rocks are generally of a lighter color than the flow rocks. The few examined are highly altered rocks composed of angular to subangular fragments of sericitized plagioclase and chloritic volcanic rock fragments, some of which contain abundant quartz mosaics, set in a matrix composed of a mass of shard-like forms now composed of microcrystalline quartz, clay minerals, and possible zeolites; small crystals of zircon and apatite are minor constituents. No glass was observed.

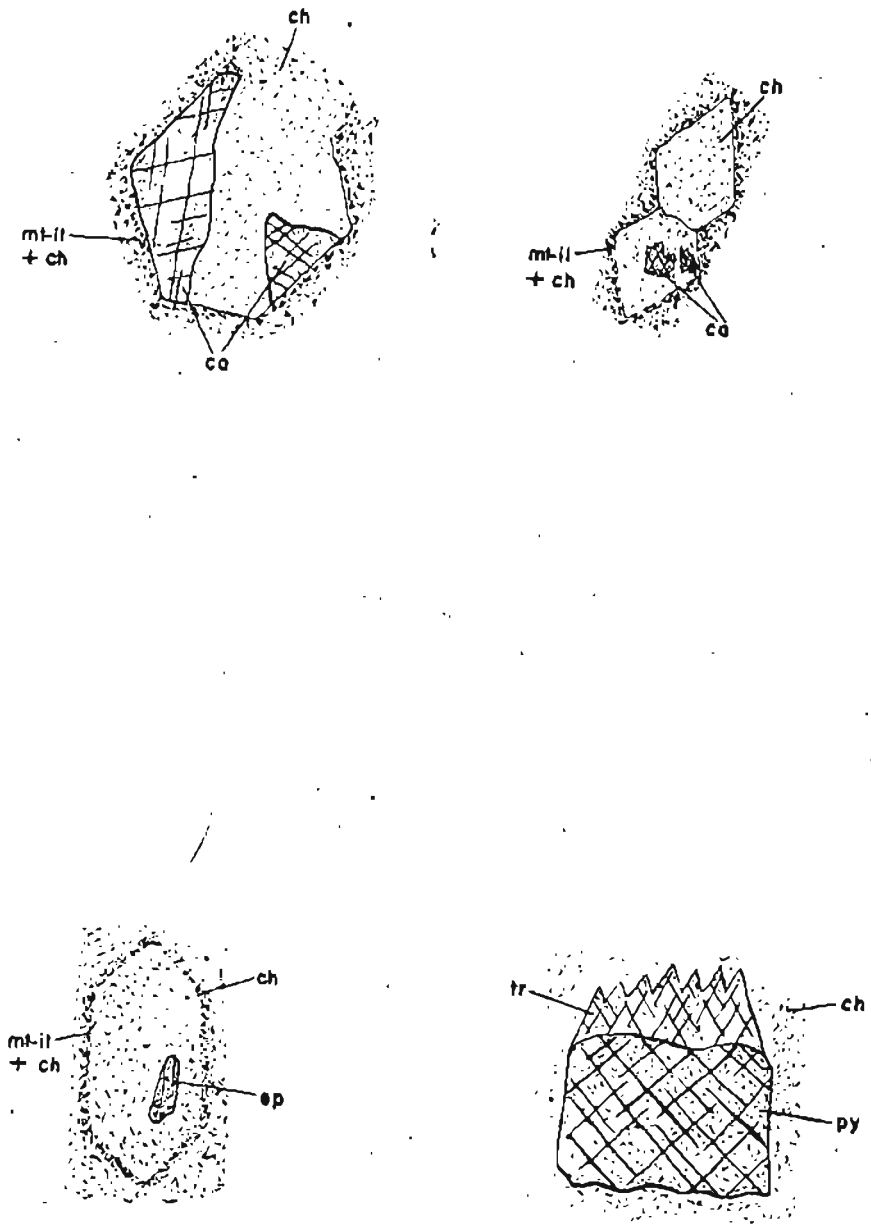


Figure 55.--Sketches from thin section of altered amphibole and pyroxene crystals; ch--chlorite, ep--epidote, py--pyroxene, mt-il and ch--magnetite-ilmenite and chlorite, ca--calcite, tr--tremolite.

A medium light gray, aphanitic flow occurring in one locality contains abundant pores or vesicles some of which are filled with epidote. The rock consists of scattered remnants of plagioclase phenocrysts averaging about 1.0 mm in length in a pilotaxitic groundmass composed largely of plagioclase microlites, equant epidote crystals, and interstitial chlorite. The plagioclase phenocryst are partially replaced by pale yellow epidote both as mosaics and as abundant fine inclusions; sericite is present in minor amounts. The plagioclase phenocrysts have a composition in the range An_{13} to An_{16}.

Fossil lists and localities

The following is a complete list of fossil collections made during the present investigation. The numbers before the description of each fossil locality are as follows: first number (in parentheses) refers to fossil locality shown in figure 56; second number is field station number, and third (in parentheses) is U. S. Geological Survey Museum locality number.

Gambier Bay formation

(1) 58ALy448; dark-gray marble on point of land 0.9 mile south-southwest of Gem Point on south shore of Snug Cove, Gambier Bay.

digonophylinid coral
Thamnopora? sp.
Amphipora? sp.

(2) 58ALy448a; same lithology as 448 on northwest side of same point of land.

unidentifiable colonial coral, hydrozoan, or bryozoan

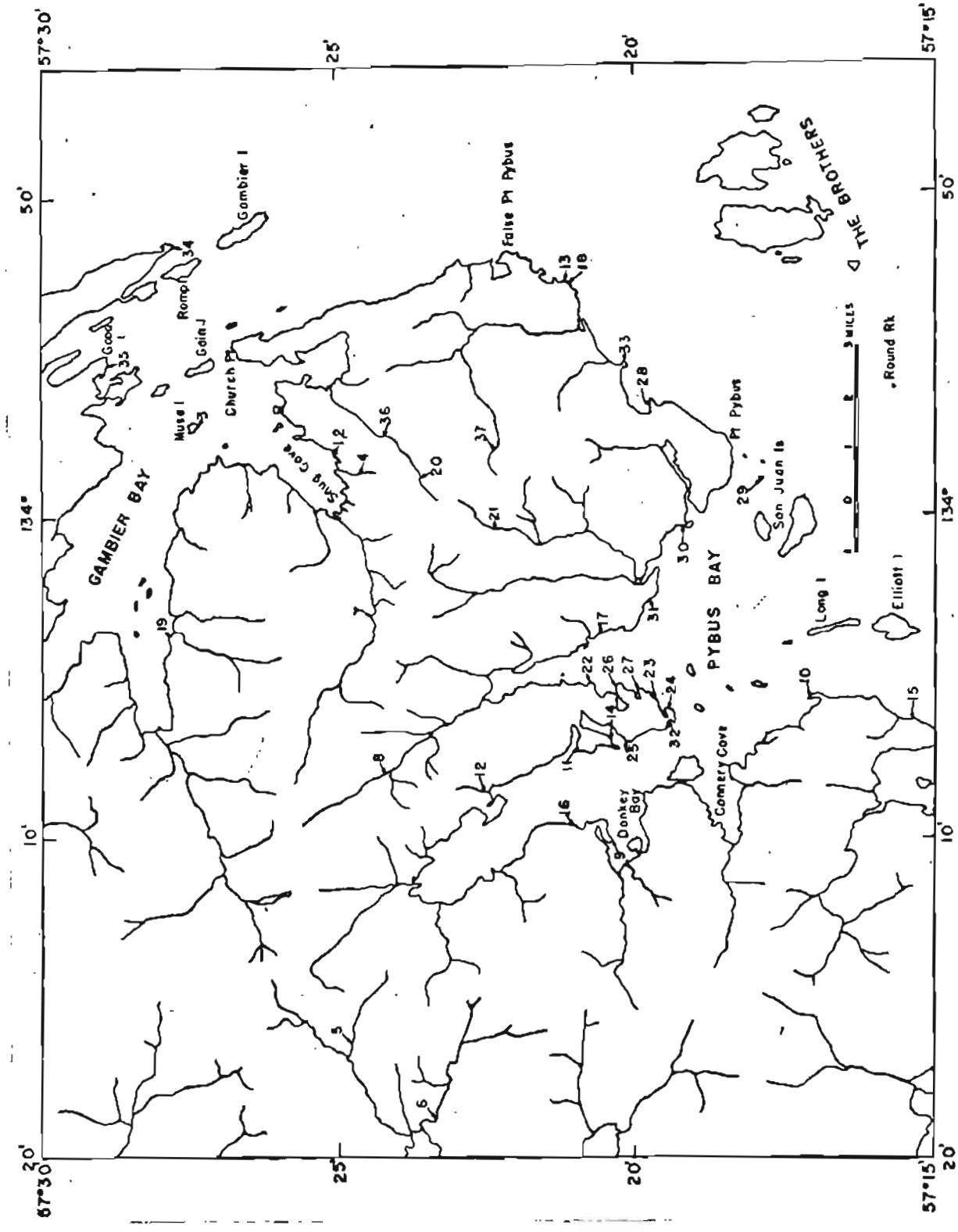


Figure 56.--Index map showing fossil localities (see text).

(3) 58ALy456; dark-gray marble on south point of Muse Island, Gambier Bay.

Thamnopora? sp.
Amphipora? sp.

(4) 59ALy54; dark-gray marble in creek bed 1.7 miles south-southwest of Gem Point, Snug Cove, Gambier Bay.

poorly preserved dendroid tabulates and other corals

Hood Bay formation

(5) 59ALy240; dark-gray clastic limestone 2.5 airline miles upstream from mouth of stream flowing southwest into North Arm of Hood Bay.

branching favositid coral
Stromatoporoids

(6) 59ALy276; dark-gray, calcareous argillite interbedded with grayish-black chert 0.5 mile upstream from mouth of stream flowing northwest into North Arm of Hood Bay.

Atrypa? sp.

Cannery formation

(7) 59ALy38 (USGS 18491-PC); massive, calcareous, coarse-grained graywacke in stream bed 2.0 airline miles from mouth of stream flowing east into the west end of Snug Cove, Gambier Bay.

?*Allotrophyllum*
bryozoan fragments
echinoderm debris

(8) 59ALy278; massive, calcareous, coarse-grained graywacke in thin-bedded chert and argillite section in bed of creek flowing southeast into head of north arm of Pybus Bay, 2½ miles from mouth.

bifoliate fistuliporoid bryozoan debris
ramose bryozoan debris
fenestrate bryozoan debris includes *Protoretepora* or *Synocladia*

(9) 58ALy128; massive, calcareous, coarse-grained graywacke in thin-bedded section of chert and argillite on tip of west-trending peninsula, north shore of Donkey Bay, Pybus Bay.

fistuliporoid, trepostomatous, stenoporoid, and fenestrate cryptomatous bryozoan debris
foraminiferal debris
algal debris
echinoderm debris

Pybus dolomite

(Fossils marked by asterisk are extremely abundant in that collection)

(10) 57ADu69 (USGS 18345-PC); light brownish gray, yellowish gray weathering sugary dolomite and bluish white chert nodules in beach outcrops on north end of peninsula on the southwest shore of Pybus Bay 1½.2 miles west of the north end of Long Island; exact stratigraphic position unknown, basal 25 feet of exposed section.

echinoderm debris, indet.
bryozoan fragments, indet.
Linoproductus? sp.
Wangenoconcha? sp.
**Stenocisma* cf. *S. plicata* (Kutorga)
Neospirifer sp.
Licharewia? sp.
Squamularia? sp.
**Spiriferella keilhavii* (von Buch)
Spiriferella sp.
"*Dielasma*" cf. "*D.*" *plica* (Kutorga)

(11) 58ALy195a; medium gray, reddish brown-weathering, clastic dolomite in beach outcrop on north shore of peninsula on northeast shore of main arm of Pybus Bay 1.9 miles N. 10° E. of triangulation station Hyd; probably near the top of the section.

echinoderm debris, indet.
bryozoan fragments, indet.
Terebyia sp.
*strophomenoid brachiopod, n. gen.
Chonetina? sp.
*Anidanthus aff. A. alatus Cooper
Waagenoconcha sp.
Spiriferella sp. (small)
Squamularia sp.
Crurithyris? sp.
Rhynchopora sp.
bellerophontid gastropod, indet.

Hyd formation

Limestone member:

(12) 58ALy290; in creek bed, altitude 90 feet, near northeast shore of main arm of Pybus Bay, 2.4 miles north of triangulation station Dro.

Montlivaltia?--or at least a scleractinian
solitary coral

(13) 58ALy330; small island close to shore 1.15 miles southwest of triangulation station Pybus near False Point Pybus; from yellowish brown weathering limestone (fig. 8b).

Tropites (Tropites) sp.
clionitid ammonites--two species
Cosmonautilus sp.
Pleuronautilus sp.
belemnoid
Gervilleia sp.
trigoniid pelecypod--"Myophoria" sp.

Thin-bedded argillite member:

(14) 58ALy204 (includes 57ADu74 and 75); northeast shore main arm of Pybus Bay 0.4 mile northeast of triangulation station Hyd.

Monotis subcircularis Gabb
Heterastridium sp.

(15) 58ALy36; west side of West Channel, Pybus Bay, 1.2 miles southwest of light on Grave Island.

Monotis subcircularis Gabb

(16) 57ADu77; southwest shore of main arm of Pybus Bay about 0.5 mile northwest of triangulation station Dro.

Halobia sp. *A*.

(17) 58ALy221 (includes 57ALy101); east shore north arm of Pybus Bay near line between sections 20 and 29, T. 52 S., R. 71 E.

Monotis subcircularis Gabb
Heterastridium sp.

(18) 58ALy328; shore 1.4 miles southwest of triangulation station Pybus near False Point Pybus.

Halobia? sp.
Atractites-like belemnoids
indeterminate crushed or fragmentary ammonoids

(19) 58ALy465; south shore of western Gambier Bay, 1.3 miles southwest of triangulation station Tie.

impression of a ribbed ammonite

(20) 58ALy494; in creek bed, altitude 300 feet, 2.3 miles south-southeast of Gem Point, Gambier Bay.

scleractinian solitary coral

(21) 58ALy494a; in creek bed, altitude 460 feet, 3.6 miles north of triangulation station Deer on north shore of Pybus Bay.

shell fragments with finely
spaced ribbing probably
Halobia

Seymour Canal formation

(22) 57ADu71 (Mes. loc. 27334); reefs near point of peninsula on western shore of the north arm of Pybus Bay 0.6 mile north of triangulation station Bob; in argillite.

Buchia rugosa (Fischer)

(23) 57ADu72 (Mes. loc. 27336); shore west of south of north arm of Pybus Bay 0.7 mile south-southwest of triangulation station Bob; in argillite.

Phylloceras sp.

(24) 57ADu73 (Mes. loc. 27335); reefs off tip of northeast-projecting peninsula near tip of major peninsula separating the armsof Pybus Bay 2,000 feet east of cabin; in argillite.

Buchia rugosa (Fischer)

(25) 58ALy87 (Mes. loc. 27066); on beach at entrance to narrow bay northeast shore main arm Pybus Bay 1,000 feet southeast of triangulation station Hyd; in argillite.

Buchia sp.
Spiticeras? sp.

(26) 58ALy230d (Mes. loc. 27067); on beach near mouth of north arm of Pybus Bay 500 feet north of triangulation station Bob; in argillite.

Camptonectes sp.

(27) 58ALy231a (Mes. loc. 27068); on beach at entrance to small bay west of the entrance to the north arm of Pybus Bay 2,000 feet south of triangulation station Bob; in argillite.

Buchia cf. *B. rugosa* (Fischer)

(28) 58ALy260 (Mes. loc. 27069; also 57AL114a, b, c, Mes. loc. 27332, 27333, 27334); on beach on south shore of bay 1.5 miles northeast of Point Pybus; in argillite.

Buchia cf. *B. volgensis* (Lahusen)
Spiticeres? sp.

(29) 58ALy266 (Mes. loc. 27070, 27071); on small island 1.0 mile southwest of Point Pybus; in argillite.

Buchia rugosa (Fischer)

(30) 58ALy270b (Mes. loc. 27072); on the north shore of Pybus Bay 1,000 feet north of triangulation station Deer; in argillite.

Buchia rugosa (Fischer)

(31) 58ALy275 (Mes. loc. 27073); on north shore of Pybus Bay 1.6 miles northwest of triangulation station Deer; in argillite.

Buchia rugosa (Fischer)

(32) 58ALy278 (Mes. loc. 27073); on beach east of mouth of the main arm of Pybus Bay 250 feet east of cabin; in argillite.

Pleuromya sp.
Lima sp.

(33) 58ALy324a (Mes. loc. 27075); low reef near shore 2.2 miles northeast of Point Pybus; in argillite.

Buchia sp.

(34) 58ALy338 (Mes.loc. 27076, 27077); south tip of peninsula in eastern Gambier Bay 3,400 feet northeast of triangulation station Romp; in argillite.

Buchia cf. *B. volgensis* (Lahusen)
Buchia sp.

(35) 58ALy409a (Mes. loc. 27078); south shore of peninsula in eastern Gambier Bay 0.8 mile northeast of triangulation station Nose; in argillite.

Buchia sp.

Quaternary deposits

(36) 58ALy512b; bluish gray, pebbly clay, in channel of stream flowing northeastward into southeastern Gambier Bay, altitude 150 feet.

pelecypods
Foraminifera

(37) 58ALy487; bluish gray, sandy clay; in channel of stream lying west of False Point Pybus, flowing east and south into Stephens Passage, altitude 475 feet.

Foraminifera

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