Paleozoic Stratigraphy in the Northwest Coastal Area of Prince of Wales Island, Southeastern Alaska

GEOLOGICAL SURVEY BULLETIN 1284

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By G. DONALD EBERLEIN *and* MICHAEL CHURKIN, JR.

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PALEOZOIC STRATIGRAPHY IN THE NORTHWEST COASTAL AREA OF PRINCE OF WALES ISLAND, SOUTHEASTERN ALASKA

By G. Donald Eberlein and Michael Churkin, Jr.

ABSTRACT

Paleozoic rocks that represent every system from Ordovician to Pennsylvanian are well exposed along the northwest coastal area of Prince of Wales Island and on the adjacent islands to the west from the north end of Tlevak Strait to Sea Otter Sound and El Capitan Passage. These marine sedimentary and volcanic rocks have an aggregate thickness of at least 35,000 feet, are richly fossiliferous, and are herein divided into ten newly named formations.

The Descon Formation is the most widely distributed and is considered to be at least 10,000 feet thick. It is informally subdivided into five lithologic units: (1) graywacke and banded mudstone, (2) conglomerate and sedimentary breccia, (3) black chert and siliceous shale, with minor lenses of limestone, (4) basaltic volcanic rocks, including pillow flows, flow breccia, volcanic conglomerate, and agglomerate, (5) quartzo-feldspathic arenite. Graptolites, collected mainly from the black chert and siliceous shale unit, suggest continuous deposition from Early Ordovician into Early Silurian time, with episodes of submarine volcanism in the late Early and late Middle Ordovician, and locally in the Early Silurian.

The Heceta Limestone, of Middle and Late Silurian age, rests conformably upon the Descon Formation and consists predominantly of massive thick-bedded fine-grained high-calcium limestone that contains a medial zone of locally thick lenses and pods of polymictic conglomerate, limestone breccia, sandstone, and argillaceous rocks. The thickest known section occurs on western Heceta Island, where a minimum thickness of 10,000 feet can be demonstrated; the formation thins rapidly southward on Prince of Wales Island and finally disappears, probably because of pre-Karheen erosion.

The Karheen Formation, in its type area, is about 6,000 feet thick, appears to rest conformably upon the Heceta Limestone, and consists mainly of greenish-gray and reddish-brown lithic wacke and graywacke with minor shale, siltstone, thin-bedded limestone, and conglomerate. The formation coarsens southward and westward into the San Fernando-Lulu-Noyes Islands area, where it rests unconformably upon rocks of the Descon Formation and is dominantly a polymictic pebble-to-cobble conglomerate. Fossil evidence indicates that the age of the Karheen Formation is Late Silurian and Early Devonian.

The St. Joseph Island Volcanics underlies all of St. Joseph Island and the northwestern tip of Noyes Island; and it is also present throughout the western Maurelle Islands, where it has been regionally metamorphosed to a greenschist

facies. This newly defined unit consists mainly of basaltic submarine flows, breccia, conglomerate, and well-bedded tuff. Included in the formation is a distinctive thinly bedded unit of alternating pale-green to pale-red and purple calcareous siltstone and shale approximately 600 feet thick. Since neither the upper nor lower contact is exposed, the total thickness and the relations to other formations are not known. However, between 7,500 and 10,000 feet of section is exposed at the type locality on St. Joseph Island. No fossils have been found in the St. Joseph Island Volcanics, but indirect evidence for a minimum age of 328±10 million years (Mississippian) is indicated by potassium-argon dating on biotite from a dike that cuts the formation of northwestern Noyes Island. This evidence, together with its lithologic similarity to parts of the Devonian Coronados Volcanics and the Port Refugio Formation, suggests that the St. Joseph Island Volcanics is pre-Mississippian and may be of Devonian age.

The Coronados Volcanics comprises a sequence of predominantly fragmental basaltic rocks with interlayered massive fossiliferous limestone. The formation is estimated to be about 500 feet thick and is exposed in a narrow belt of islands that extends southeastward from Port St. Nicholas to the head of Trocadero Bay. The lower contact is not exposed, but the upper part is interbedded with limestone that lithologically and faunally resembles the overlying Wadleigh Limestone. The Coronados Volcanics is considered to be of Middle Devonian age on the basis of fossils and probably is coeval with the lower part of the Wadleigh.

The Wadleigh Limestone is 1,000 feet or more thick and is exposed on islands that fringe the east sides of San Alberto and Bucareli Bays. It consists of medium- to dark-gray medium- to thick-bedded commonly fragmented-fossil limestone and breccia with interbedded argillaceous limestone and calcareous shale. The Wadleigh conformably overlies the Karheen Formation and, elsewhere, the Coronados Volcanics. Its age is considered to be Middle and Late Devonian.

The Port Refugio Formation, of Late Devonian age, is several thousand feet thick and is composed mainly of graywacke and conglomerate with numerous thin interbeds of siltstone and shale. Basaltic volcanic rocks, including pillow flows, locally from units several hundred feet thick. The base is not exposed, but geologic mapping suggests that the formation locally rests unconformably on, and may be in part a lateral equivalent of, the Wadleigh Limestone. The upper part of the Port Refugio Formation is overlain accordantly by thin-bedded dark-gray chert and limestone of the Mississippian Peratrovich Formation.

The Mississippian Peratrovich Formation is about 800 feet thick and consists of fragmented-fossil limestone and dolomite with variable amounts of interbedded dark-gray chert, especially in its lower part. Three members are recognized: (1) a chert member of Early Mississippian age, (2) a limestone and chert member of Early and Late Mississippian (Osage and Meramec) age, and (3) a limestone member, of Late Mississippian (Meramec and Chester) age. The Peratrovich Formation conformably overlies the Port Refugio Formation; elsewhere, its contact with the underlying Wadleigh Limestone is not exposed but appears to be accordant. The upper part of the Peratrovich is conformably overlain by the Klawak Formation and the Ladrones Limestone.

The Klawak Formation is generally well bedded and consists of calcareous siltstone and sandstone or silty and arenaceous limestone, with subordinate interbedded almost pure fragmented-fossil limestone and chert pebble conglomerate. The top is not exposed, but its basal beds conformably overlie the limestone member of the Peratrovich Formation. Fusulinids, associated with brachiopods and corals, indicate the Klawak Formation is of Early Pennsylvanian age. The formation is estimated to be 500–1,000 feet thick.

The name Ladrones Limestone is applied to a sequence of thick to indistinctly bedded medium-gray to olive-gray in part fragmented-fossil oolitic and pelletoid limestone that generally lacks chert and noticeable quantities of terrigenous detritus. The contact with the underlying Peratrovich Formation appears to be conformable and transitional; the top is not exposed, but field geologic mapping indicates a thickness of at least 1,000 feet. Preliminary study of its endothyroid Foraminifera and fusulinid, coral, and brachiopod faunas indicates the Ladrones Limestone ranges in age from Early to early Middle Pennsylvanian and is partly coeval with the Klawak Formation.

INTRODUCTION

Thick deposits of marine Paleozoic rocks have been known to be widely distributed in a broad northwest-trending geanticlinal belt that includes Prince of Wales Island and the islands to the west at least since A. H. Brooks' reconnaissance investigations of the Ketchikan mining district in 1901 (Brooks, 1902, p. 19–21). Subsequent field investigations, primarily by F. E. Wright and C. W. Wright in 1908, P. S. Smith in 1913–14, Theodore Chapin in 1915–17, and A. F. Buddington in 1921–25, supported mainly by the paleontological studies of Edwin Kirk, Rudolf Reudemann, and G. H. Girty, brought out the completeness of the Paleozoic sequence that led the present authors to the selection of the area indicated in figure 1 for detailed geologic mapping and biostratigraphic study. Geologic maps of the Craig B–4, C–4, C–5, and C–6 quadrangles and parts of D–4 and D–5 quadrangles (1:63,360) prepared by us demonstrate the propriety of and provide the necessary basis for establishing the stratigraphic names discussed in this report.

The proposed nomenclature includes ten newly named formations that collectively range in age from Early Ordovician to Middle Pennsylvanian. In ascending order, these are the Descon Formation (Ordovician and Silurian), Heceta Limestone (Silurian), Karheen Formation (Silurian and Devonian), Coronados Volcanics (Devonian), Wadleigh Limestone (Devonian), Port Refugio Formation (Devonian), Peratrovich (Mississippian) and Klawak (Pennsylvanian) Formations, and the Ladrones Limestone (Pennsylvanian). In addition, the name St. Joseph Island Volcanics is applied to a lithologically distinctive assemblage of probable Devonian volcanic rocks, the age and stratigraphic relationships of which are poorly known. The general distribution of these units is shown on the map (pl. 1), and a comparison with past usages is presented on plate 2.

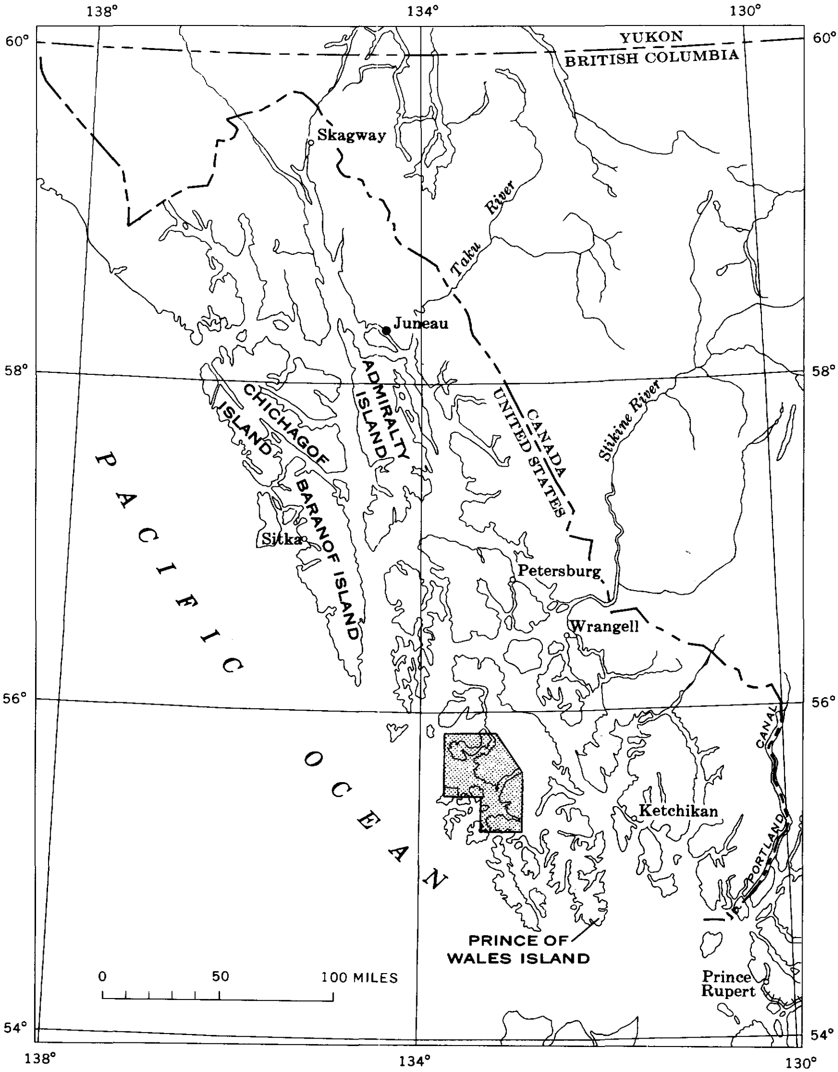

FIGURE 1.—Map of southeastern Alaska showing area of this report.

The purpose of this paper is to briefly describe the physical stratigraphy of the area; this will be the first part of a series of publications on the Paleozoic stratigraphy of all of southeastern Alaska. Detailed biostratigraphic studies closely tied to the geologic maps of the 15-minute quadrangles now being prepared for U.S. Geological Survey GQ map series hopefully will develop this area as a standard from which geologic mapping can be extended into surrounding areas of southeastern Alaska.

DESCON FORMATION

A thick sequence of coarse- and fine-grained marine rocks, predominantly graywacke-type with interbedded basaltic volcanics and minor limestone, comprises the oldest known rocks exposed in the northwest coastal area of Prince of Wales Island. This sequence is here named the Descon Formation for the typical exposures in the vicinity of triangulation station Descon, the type locality on southern Heceta Island, where many of the characteristic lithologies are exposed (loc. A, pl. 1). The general distribution of these rocks within the area presently under study is shown on plate 1, but they are known to extend much farther to the north and east on Kosciusko and Prince of Wales Island. Their extension to the south is incompletely known, but it is likely that their metamorphic equivalents have been included in the Wales Group of pre-Ordovician to Devonian age, as mapped by Buddington and Chapin (1929).

Geologic mapping in the area between Sea Otter Sound and Trocadero Bay has demonstrated the practicality of informally dividing the Descon Formation into five general lithofacies:

1. Graywacke and banded mudstone.
2. Conglomerate and sedimentary breccia.
3. Black chert and siliceous shale, with minor lenses of limestone.
4. Basaltic volcanic rocks, including pillow flows, flow breccia, volcanic conglomerate, and agglomerate.
5. Quartzo-feldspathic wacke.

These units are interbedded, and some of the clastic lithologies can be demonstrated to be distal or proximal equivalents of one another. Their designation as formal members may be called for eventually, but outcrop limitations have not yet made it possible to extend the units with sufficient confidence.

GRAYWACKE AND BANDED MUDSTONE

Graywacke and banded mudstone are the most widespread and quantitatively important lithologies of the Descon Formation. The graywacke is typically dark greenish gray, massive, medium to coarse grained, and compact. It is a poorly sized sandstone composed mainly of relatively fresh mineral and intraformational rock fragments set in a chloritic matrix. The matrix may constitute as much as 25 percent of the rock and has generally undergone some degree of mimetic recrystallization; as a result, there is a tendency for the rock to break through rather than around the grains. Diagenic analcime and laumontite (leonhardite), and a minor amount of carbonate also may

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occur in the matrix. Much of the graywacke is a volcanic sandstone with the texture of a microbreccia and is composed mainly of intraformational basaltic debris and subordinate chert and mudstone fragments. Although beds of graywacke up to 20 feet thick are common, they may range in thickness from a few inches to 150 feet or more. In many outcrops no bedding is apparent, but locally a crude stratification is manifest by interbeds and pebble strings of intraformational siltstone and banded mudstone. Graded bedding tends to be well developed in graywacke beds 2–24 inches thick, and in places even the coarser grained and thicker beds exhibit large-scale vertical grading. Cross-laminae, where developed, are confined within parallel-bedded sets that rarely exceed 3 inches in thickness.

The banded mudstone interbedded with the graywacke occurs as thin beds of olive-gray, grayish-black, and dusky-yellow siltstone and very fine- to medium-grained sandstone. Individual beds are seldom more than a few inches thick, and most are less than 1 inch thick. Color differences among the beds, due mainly to differences in grain size and composition, give the rock a banded appearance that locally becomes rhythmically alternating, reminiscent of seasonal varving. Contacts between adjacent beds are normally sharp and may show evidence of penecontemporaneous erosion. Cross-laminations, confined to single beds, are not uncommon, and many of the sets show excellent graded bedding. These rocks generally are indurated and lack fissility. Where fissility is developed, it commonly is related to a rather widely spaced fracture cleavage or is parallel to selected bedding planes. Excellent exposures of banded mudstone occur along the west shore of Warm Chuck Inlet and inland from triangulation station Descon on southern Heceta Island, on Anguilla and San Lorenzo Islands, along El Capitan Passage, on the northwest shore of Cap Island, and on the north end of Tuxekan Island.

CONGLOMERATE AND SEDIMENTARY BRECCIA

Conglomerate and sedimentary breccia, although quantitatively subordinate to graywacke, are just as widely distributed as the finer grained equivalents with which they are interbedded. Their composition is quite variable, ranging from wholly volcaniclastic material to polymictic varieties with megaclasts of varicolored chert, limestone, felsic volcanics, and granitic to gabbroic rock types. In most places however, plutonic rock fragments are not as numerous as in the younger conglomerates and breccias of the Heceta Limestone and Karheen Formation.

A common variety of conglomerate and breccia consists predominantly of porphyritic basaltic detritus that is rich in euhedral pyroxene crystals and that is petrologically identical to the flows in the Descon Formation. Subordinate amounts of mudstone, graywacke, and gray-green chert and rare limestone make up the remaining megaclasts. In most places 40 percent or less of indurated matrix is present, and the megaclasts tend to be in contact with one another. Sorting with respect to size is poor, and there tends to be a complete gradation from the coarsest to finest grained detritus, especially in oligomictic varieties. Locally, however, the largest fragments are completely separated by sand-size matrix. This texture is especially common in the basaltic sedimentary breccias.

Excellent examples of basaltic conglomerate and breccia may be seen on the west shore of Warm Chuck Inlet, 1.6 miles northeast of triangulation station Descon, where several beds up to 15 feet thick are interbedded with indurated banded mudstone and massive fine- to coarse-grained graywacke. The largest fragments have a maximum diameter of 3 feet and are composed of relatively unaltered porphyritic basalt containing phenocrysts of augite and plagioclase. Other examples occur in shoreline outcrops of the Harmony Islands and on the adjacent coast of Prince of Wales Island, where basaltic sedimentary breccias are interstratified with flows and agglomerate.

Polymictic conglomerate with abundant limestone detritus has been observed at only a few localities. One of the most accessible is on the southwest shore of Heceta Island approximately 2.7 miles northwest of Point Descon, where 15–20 feet of limestone-bearing conglomerate is interbedded with fine- to coarse-grained graywacke, quartzo-feldspathic sandstone, and black cherty shale and siltstone. Limestone cobbles make up more than half of the coarse-size fraction in the conglomerate and are set in a tuffaceous graywacke matrix. Cobbles of chert and porphyritic basalt also are present. On the west coast of Heceta Island from Dead Tree Point northward for a distance of 1¼ miles, limestone boulders and cobbles are associated with clastic sedimentary, plutonic, and basaltic volcanic rock detritus in beds of conglomerate and breccia.

BLACK CHERT AND SILICEOUS SHALE

An important, albeit comparatively minor, lithologic assemblage within the Descon Formation consists of thin-bedded black to dark-gray chert and siliceous siltstone with black shale partings (figs. 2, 3). The importance of this unit is that it occurs interbedded with all the other lithologic units and that its shaly interbeds have proved to be a good source of well-preserved graptolites excellent for dating and correlation. Individual chert beds range in thickness from a fraction of an

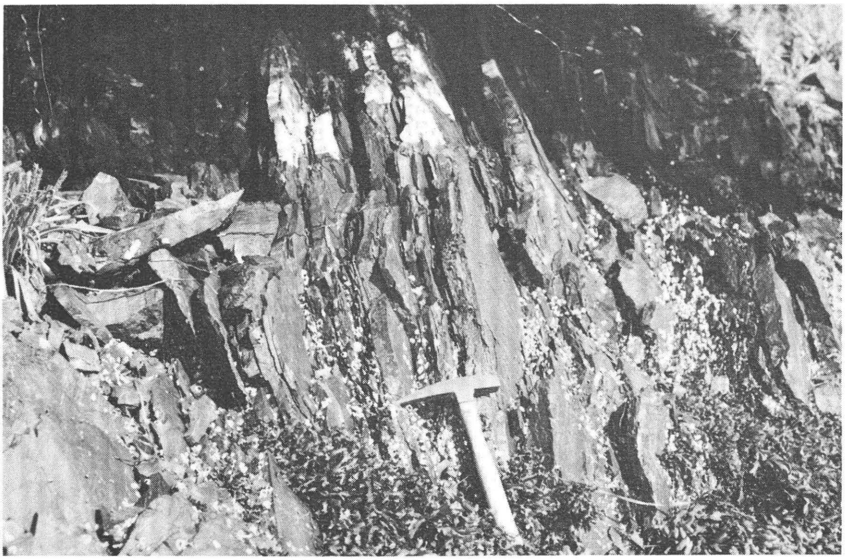

FIGURE 2.—Interbedded black chert and shale, Descon Formation. Shale contains graptolites of Middle Ordovician age. South entrance to Big Salt Lake, Prince of Wales Island.

inch to as much as 6 inches, but most are ½–1 inch thick. Locally present are lenses of laminated medium-dark-gray limestone up to 3 feet thick and beds of graywacke and chert arenite several inches thick.

Because graptolites are preserved in these fine-grained rocks, it is fortunate this facies has such a large areal, as well as stratigraphic, distribution. On the southwest shore of Heceta Island, good exposures occur in the vicinity of triangulation station Dog and south of Lost, 2.3 and 3.3 miles northwest of triangulation station Descon, respectively. Excellent exposures also occur on the islands at the north and south entrances to Big Salt Lake, where the chert and siliceous shale are interbedded with fragmental basaltic volcanics and graywacke. Other occurrences that have yielded useful graptolite collections are on the east shore of Steamboat Bay (Noyes Island), the northeast shore of Noyes Island, Esquibel Island, the west coast of Anguilla Island, and the Harmony Islands.

BASALTIC VOLCANIC ROCKS

Flows and associated fragmental volcanics (fig. 4), in the form of agglomerate and flow breccias, appear sporadically throughout the Descon Formation, and the ages determined from interbedded graptolitic shales imply that volcanism occurred repeatedly from different

FIGURE 3.—Siltstone and black siliceous shale interbedded with massive volcanic graywacke. Shale contains graptolites of Early Silurian age. Descon Formation. West shore, San Fernando Island.

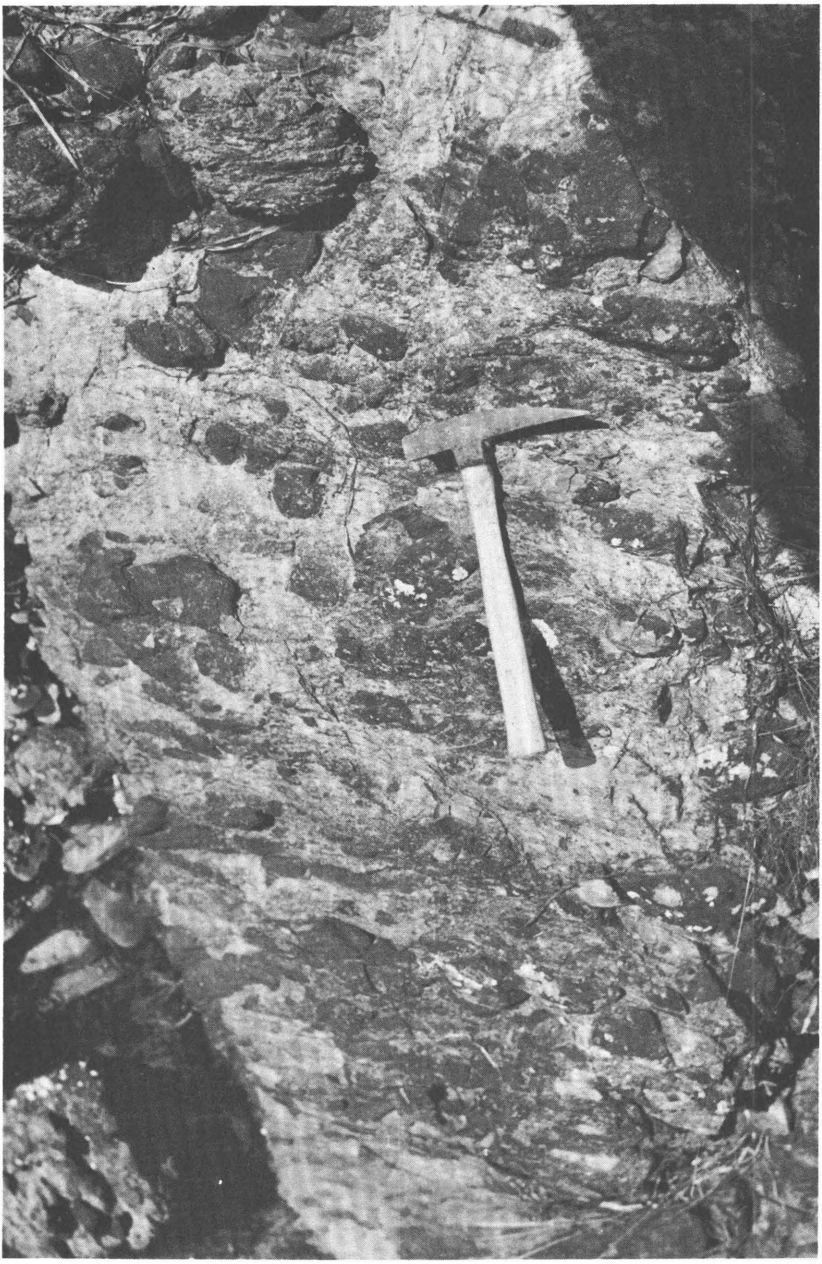

FIGURE 4.—Basaltic tuff-breccia in the Descon Formation. North entrance to Big Salt Lake, Prince of Wales Island.

centers during Early Ordovician through Early Silurian time. One of the thickest volcanic sections in the area mapped occurs on the southern part of El Capitan Island and on Knob Island, where at least 2,000 feet of pillow flows and associated pyroclastic rocks are believed to be present. Excellent pillow structures also are developed in the volcanics that crop out on the Harmony Islands (fig. 5) and adjacent shoreline of Prince of Wales Island, at the head of Salt Lake Bay, and on the Culebra Islands.

The lavas are predominantly medium-olive-gray porphyritic vesicular and amygdaloidal basalts. Stubby phenocrysts of diopsidic augite, locally up to 10 mm (millimeter) in diameter, are set in a groundmass of small granular augite, plagioclase microlites, and chloritic alteration products, probably derived in part from material that was originally glass. The plagioclase composition generally is in the range An_{35}–An_{48} (andesine), but may be as calcic as An_{60}. Unlike pyroxene, the plagioclase usually shows some degree of alteration to calcite, prehnite, and various zeolites. Olivine and (or) its alteration products are rare constituents of some of the flows. Thus these rocks have the petrographic characteristics of basalts except that the plagioclase normally is andesine rather than labradorite or bytownite. With a decrease in plagioclase and addition of analcite and olivine, they are transitional to limburgite. So far, true andesites have not been recognized, although their occurrence certainly is to be expected.

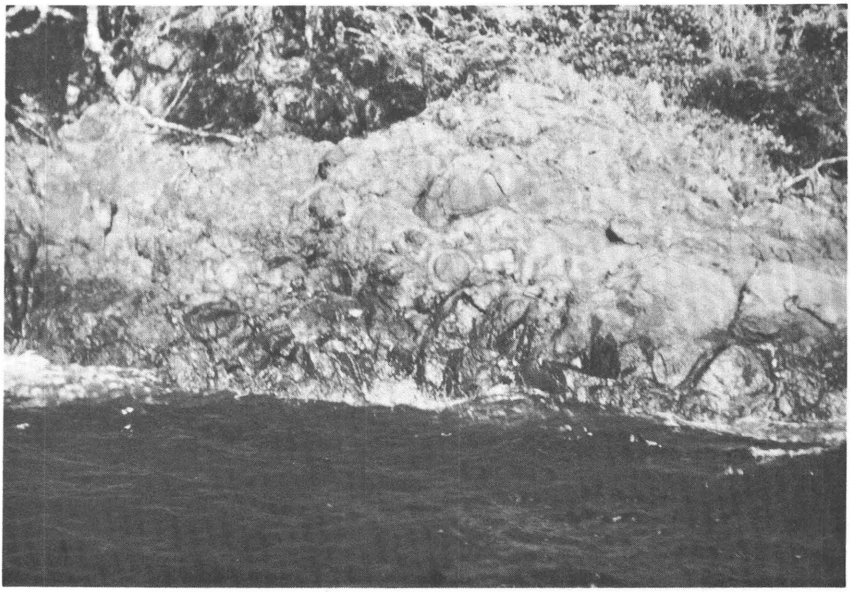

FIGURE 5.—Pillow basalt of the Descon Formation. Harmony Islands.

QUARTZO-FELDSPATHIC WACKE

Gritstone and medium- to fine-grained sandstone rich in feldspar and commonly containing 5–10 percent of detrital quartz occur interbedded with graywacke and banded mudstone on the west shore of Warm Chuck Inlet about 3.5 miles northeast of triangulation station Descon and on the northeast shore of Lulu Island about 2 miles southeast of Point Santa Gertrudis. Similar rocks are associated with basaltic volcanics and graywacke in a belt approximately half a mile wide extending southward and eastward across the entrance to Salt Lake Bay and onto Prince of Wales Island.

Typically, these rocks are poorly sized massive compact quartzo-feldspathic arenites. They tend to weather orange brown within the tidal zone. Fresh surfaces are medium gray to various shades of pistachio green, the green color being due mainly to the development of epidote in the matrix, which normally makes up about 25 percent of the rock. The thicknesses of individual beds range from several inches to 20 feet or more. The thicker beds sometimes exhibit a poorly developed parallel internal stratification and may show very crude grading. The principal constituents are angular grains of pale green and gray chert, broken crystals of twinned plagioclase, and broken, partly rounded euhedra of clear quartz. The quartz clasts are ubiquitous but rarely exceed 15 percent of the rock by volume. The quartz commonly has bipyramidal terminations and a suppressed prism zone, suggestive of the beta polymorph. Coarser grained facies of these rocks tend to be conglomeratic, with scattered angular megaclasts up to 6 inches in diameter of chert, quartzo-feldspathic arenite lithologically similar to the host rock, and mafic volcanic rock types. Some fragments are of rhyolitic composition and contain quartz phenocrysts of habit similar to quartz occurring as detrital grains. In addition to a partly reconstituted graywacke matrix, some calcite cement generally is present. As a result, the rock tends to be quite tough and breaks through, rather than around, the grains.

STRATIGRAPHIC RELATIONS AND AGE

Field mapping has not disclosed a complete section of the Descon Formation, but rapid facies changes and considerable variation in thickness of the principal lithologic units are evident. These factors, together with structural complications and the absence of an exposed base, make it impossible to give an accurate figure for the total thickness of the formation. One of the best and most continuous sections known occurs in the type area at and northwest of triangulation station Descon where a minimum thickness of about 8,700 feet of interbedded graywacke, banded mudstone, conglomerate, and quartzo-feldspathic arenite is believed to be present. Graptolite collections indicate the oldest beds in that section are of Middle Ordovician age; beds as old as Early Ordovician are known elsewhere in the area studied. It is therefore likely that the Descon Formation is at least 10,000 feet thick and may be considerably thicker.

The base of the Descon Formation is not exposed in the area studied, but beds as old as Early Ordovician have been recognized at several rather widely separated places. On the east shore of Steamboat Bay, Noyes Island (see loc. 65ACn1141, USGS M1031CO, pl. 1), black shale partings interbedded with thin-bedded dark-gray chert and chert arenite contain *Tetragraptus* cf. *T. serra*, *Cardiograptus*?, and *Didymograptus*?. This assemblage is indicative of a late Early Ordovician (Arenigian) age. On the west side of Anguilla Island (loc. 65AE65, USGS M1032CO, pl. 1) about the same Early Ordovician stratigraphic position is indicated by *Didymograptus protobifidus* Elles?, *Bryograptus sp.*, *Didymograptus* sp., and *Phyllograptus anna* Hall in gray siltstone interbedded with volcanic graywacke and basaltic sedimentary breccia.

The most widespread and richest graptolite faunas, however, are Middle Ordovician, equivalent to the lower Caradocian zones 9–10 of Elles and Wood (1901–18). Very large collections from this horizon, which is well developed in the Big Salt Lake area, commonly contain the following species:

Glossograptus spp.
Cryptograptus tricornis (Carruthers)
Dicellograptus sextans J. Hall
Climacograptus bicornis J. Hall
Didymograptus sp.
Glyptograptus teretiusculus (Hisinger)
Orthograptus calcaratus (Lapworth)
Retiograptus geinitzianus J. Hall

Other Middle Ordovician collections have been obtained from the west shore of Warm Chuck Inlet 0.5 mile south of triangulation station Silla, the Harmony Islands, the east side of Cruz Pass, and the north shore of Shinaku Inlet. In practically all these places, the fossils were collected from shaly partings in thin-bedded black to dark-gray-green chert and cherty siltstone that have minor laminated limestone.

A slightly higher horizon of early Late Ordovician age, about Caradocian zone 13 of Elles and Wood (1901–18), is indicated by collection 65ACn953 from the north tip of Anguilla Island, which contains *Orthograptus truncatus* (Lapworth), *Dicellograptus* sp., and *Leptograptus flaccidus* (J. Hall), in addition to certain of the more common Ordovician genera listed above. About the same horizon is

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represented by *Orthograptus truncatus* (Lapworth), *Lasiograptus* sp., and *Orthoretiolites?* from northeastern Noyes Island. The highest Ordovician horizon was found at locality 64ACn1562 on the south shore of Heceta Island near triangulation station Dog. Here *Climacograptus* cf. *hastatus* (T. S. Hall) and *Dicellograptus complanatus?* Lapworth, together with *Orthograptus truncatus* (Lapworth), suggest a Late Ordovician (Ashgillian) age about equivalent to zones 14–15 of Elles and Wood (1901–18).

Exceptionally abundant and well-preserved earliest Silurian graptolites were collected on the east shore of Esquibel Island (loc. 65ACn-1502), the west shore of San Fernando Island, the east coast of Noyes Island, and the east shore of Steamboat Bay (Noyes Island). Among the more common species in these collections are:

Akidograptus acuminatus (Nicholson)
Pseudoclimacograptus hughesi (Nicholson)
Climacograptus innotatus Nicholson
Glyptograptus tamariscus (Nicholson)
Orthograptus vesiculosus Nicholson
Dimorphograptus swanstoni (Lapworth)
Orthograptus insectiformis (Nicholson)
Monograptus acinaces Tornquist
    atavus Jones
    cyphus Lapworth
    gregarius Lapworth
Petalograptus spp.
Rastrites spp.

These species, the first discoveries of earliest Silurian graptolites in western North America, are being monographically described by Churkin and Carter in another paper (Churkin and Carter, 1969).

The youngest known beds of the Descon Formation are conformably overlain by the Heceta Limestone 3.6 miles northwest of Point Desconocida on southwestern Heceta Island and on the south end of Two Crack Island. At the former locality, approximately 1,500 feet stratigraphically beneath the contact (loc. 64ACn1561), thin-bedded siliceous siltstone with interbedded graywacke contains *Petalograptus* sp., *Rastrites* and several species of *Monograptus*, including *M. convolutus* (Hisinger) and *M.* cf. *argenteus* var. *cygneus* (Tornquist); such an assemblage suggests a middle or late Llandoverian (middle or late Early Silurian) age. At the south end of Two Crack Island, approximately 50 feet of deformed siltstone, shale, and silty limestone, with thin graywacke interbeds, occurs beneath the Heceta Limestone. The shales contain a graptolite assemblage that indicates a slightly younger Llandoverian age than those on southwestern Heceta Island.

At most places in the Heceta-Tuxekan Islands area, massive Descon conglomerate and graywacke are overlain conformably by the Heceta Limestone. South of the Harmony Islands, where the Heceta Limestone is missing, clastic rocks of the Karheen Formation rest unconformably upon the Descon Formation. No major discontinuities within the Descon have been recognized. In fact, the numerous graptolite collections suggest continuous deposition from Early Ordovician into Early Silurian time, with episodes of volcanism in the late Early and late Middle Ordovician, and locally in the Early Silurian.

HECETA LIMESTONE

The new name Heceta Limestone is here applied to a sequence of predominantly massive and thick-bedded fine-grained high-calcium limestone that contains near the middle a zone of locally thick lenses and pods of polymictic conglomerate, limestone breccia, sandstone, and argillaceous rocks. The formation is named from exposures on Heceta Island, where it has been studied most thoroughly and is believed to be best exposed. The type locality is designated as the northeast side of Warm Chuck Inlet and includes the north shore of Heceta Island west of Camp Island. (See fig. 6 and loc. B, pl. 1.) The Heceta Limestone underlies most of the higher and well-drained terrane on Heceta and Tuxekan Islands and also crops out at numerous places along the

FIGURE 6.—Cuesta formed in massive Heceta Limestone. Here the Heceta is better bedded toward its contact with the underlying Descon Formation, which can be seen below the tree-covered area in the foreground. View northwestward toward Bald Mountain, southwestern Heceta Island.

adjacent shoreline of Prince of Wales Island. (See pl. 1.) To the north the unit forms most of the smaller islands in Sea Otter Sound and is known to underlie much of Kosciusko and the northern part of Prince of Wales Islands. Its distribution southward is apparently restricted to a narrow belt inland from the coast of Prince of Wales Island. However, carbonate rocks of similar age and lithology are known to reappear on north-central Dall Island about 35 miles south of the Craig-Klawak area.

LITHOLOGY AND THICKNESS

Fine-grained to sublithographic compact high-calcium limestone that characterizes the bulk of the formation ranges in color from light- to medium-dark-gray on freshly broken surfaces. Locally the rock is bluish gray to grayish black, and rarely it may be mottled pink, red, chocolate, green, yellow, and white. Weathered limestone along shorelines is usually buff-colored and within the tidal range tends to have a rough pockety surface. A whitish, almost powdery, surface coating of insoluble residues forms on inland exposures.

Much of the limestone is massive and occurs in beds a few tens to several hundreds of feet thick. Usually it is somewhat fractured, and the recementing of the fractures by calcite, or, rarely, by dolomite, gives the rock a brecciated appearance. Near the top of the formation, within the medial zone of interbedded clastic rocks and near its base, it tends to be more thinly bedded. Locally rather exotic limestone breccias are developed in the middle of the formation, as along the east shore of the north arm of Warm Chuck Inlet, in association with chert pebble and polymictic conglomerate, and near the base of the formation in excellent shoreline exposures on the east shore of the inlet, about 0.7 mile west of Chuck Creek. At the latter locale, the rock is fossil fragmental and locally contains abundant oolites and pisolites.

The clastic rocks that occur within the Heceta Limestone are predominantly pebble and cobble conglomerate, but sedimentary breccia, fine- to coarse-grained graywacke-type sandstone, siltstone, mudstone, and even shale may locally occur in significant amounts. In the Heceta-Tuxekan Islands area, these lithologies occur in discontinuous lenses and large podlike bodies of extremely variable thickness and lateral extent, mainly in a zone near the middle of the otherwise essentially pure carbonate formation. (See pl. 1.)

The conglomerates are typically polymictic, with a variety of plutonic, supracrustal volcanic, and sedimentary lithologies represented among the clasts. Locally, however, the clasts are almost entirely of a single rock type (oligomictic), as exemplified by beds of chert pebble or limestone pebble conglomerate (see fig. 7) and by beds of limestone breccia (see fig. 8) exposed along the east shore of the north arm of

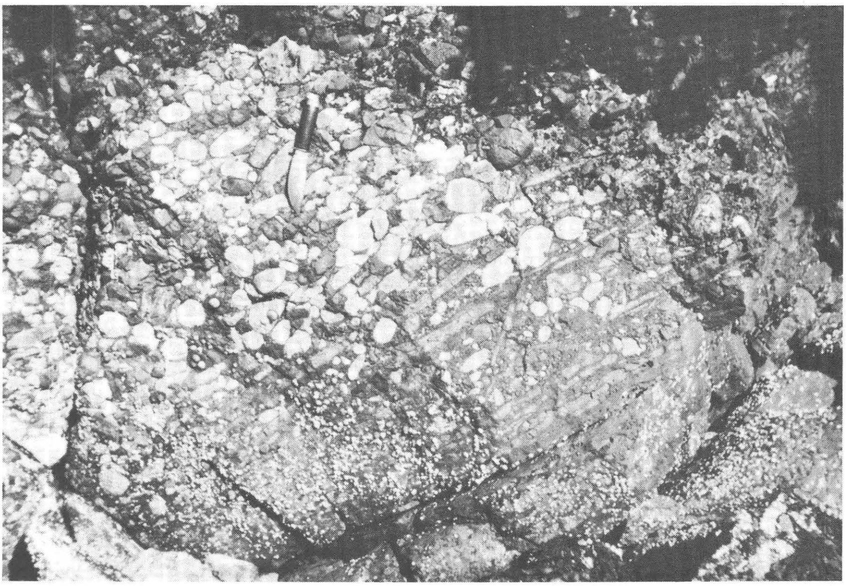

FIGURE 7.—Intraformational limestone conglomerate of the Heceta Limestone. East shore, Port Alice, northwestern Heceta Island.

FIGURE 8.—Intraformational limestone breccia of the Heceta Limestone. East shore Warm Chuck Inlet, Heceta Island.

Warm Chuck Inlet. Volcanic detritus, especially porphyritic andesite and gray-green and black chert, tends to predominate in the coarser size grades. Generally, however, the volcanic detritus differs from the basaltic material in the Descon Formation by having a much finer grained to aphanitic and in places silicified groundmass and by having scattered phenocrysts of plagioclase and amphibole, rather than numerous large, stubby clinopyroxene crystals. These differences suggest derivation from differing sources. Some limestone clasts are almost always present. Locally they compose more than half of the rock and occur as exotic blocks several feet in maximum dimension (fig. 9). Other lithologies commonly present are red and white chert, white vein quartz, siltstone, graywacke, banded mudstone, and equigranular calc-alkalic plutonic rock fragments of granitic to gabbroic composition. The matrix is typically graywacke and generally carbonate cemented.

The larger components, as well as the matrix, tend to be poorly sized and commonly are distributed in untouching relationship relative to neighboring clasts of comparable size. Imbricate structure has been observed, but only at a few places.

The thickness of the formation seems to vary strikingly over short lateral distances. The thickest known section is on western Heceta Island, where a minimum thickness of 10,000 feet can be demonstrated.

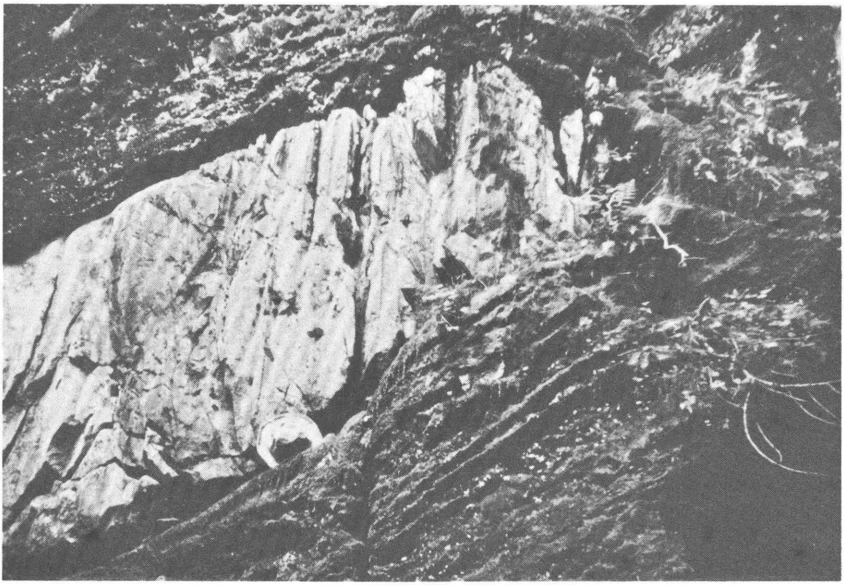

FIGURE 9.—Exotic block of Heceta Limestone, 15 feet long and 6 feet thick, in thin-bedded calcareous intraformational sandstone of the Heceta Limestone. Northwestern Tuxekan Island.

The top is not exposed. That section contains two sequences of clastic rocks aggregating about 1,600 feet in thickness. On the south flank of the Tuxekan syncline, approximately 8,500 feet of interbedded limestone, sandstone, polymictic conglomerate, and limestone breccia are exposed. This sequence appears to thin rapidly southward on Prince of Wales Island and finally disappears a few miles inland, probably because of pre-Karheen erosion.

STRATIGRAPHIC RELATIONS

Wherever the base of the Heceta Limestone has been observed without structural complications, it rests conformably upon graywacke, conglomerate, and siltstone of the Descon Formation. Such contact relations are exposed inland from the east headland of Warm Chuck Inlet, along the base of the ridge that constitutes the Bald Mountain cuesta of western Heceta Island, and along the northern shoreline of Tuxekan Island at the north end of El Capitan Passage.

Despite the generally conformable contact relations, however, there is evidence that limestone lithologically similar to that which overlies the Descon Formation was being deposited elsewhere prior to the time represented by the first appearance of the Heceta Limestone in the Heceta-Tuxekan Islands area. At Dead Tree Point, on the west coast of Heceta Island, poorly rounded cobbles of fossiliferous limestone and slabs of black siliceous pyritic siltstone occur in polymictic conglomerate that conformably underlies the Heceta. The limestone clasts appear to be lithologically identical to massive phases of the Heceta Limestone and, according to Buddington and Chapin (1929, p. 84), carry Silurian fossils. The siliceous siltstone clasts contain graptolites indicative of a Middle Ordovician to Early Silurian age. Similarly, an exotic conglomerate, composed predominantly of boulders and cobbles of porphyritic basalt with subordinate limestone debris, occurs stratigraphically below the Heceta Limestone on the south end of Keski Island, approximately 2 miles north of Cap Island just beyond the northern limit of the area shown on plate 1. Kirk (in Buddington and Chapin, 1929, p. 92–93) has identified *Schuchertella* and *Lichas* in the limestone cobbles and has considered them to be of Silurian age.

The presence of such limestone detritus indicates that carbonate sediments were deposited, lithified, and eroded during the early part of Silurian time prior to the main period of Heceta Limestone deposition in the Heceta-Tuxekan Islands area. The fossiliferous cobbles and slabs of siliceous siltstone also betray the existence of an unconformity, but not necessarily at the locales described above. The limestone cobbles may be lithogenetically correlative with the Heceta Limestone or belong to an older formation of Silurian age that as yet has not been recognized. If they have been derived from the Heceta, transgression of formation boundaries by time lines is clearly indicated.

In the Heceta-Tuxekan Islands area, the Heceta Limestone is conformably overlain in most places by the Karheen Formation—clastic rocks with red-bed affinities. Conformable contact relations are exposed on eastern Heceta Island, along the west shore of a bay approximately 1.5 miles north-northwest of Point Swift, where the upper 25 feet of the Heceta Limestone is well bedded, fossiliferous, sandy, and locally argillaceous. These beds pass upward into calcareous greenish-to reddish-brown shale and crossbedded sandstone through a transitional conglomeratic zone only a few feet thick that contains angular to subangular fragments of limestone up to 8 inches in diameter. Along the east shore of a cove about 1 mile south of Point Swift, massive locally thick-bedded, dark- to medium-gray, nodular fine-grained crystalline Heceta Limestone is conformably overlain by cross-laminated dark-gray Karheen sandstone with local pebble horizons. Where exposed along the north shore of Heceta Island eastward from Camp Island for a distance of 2¾ miles, a transitional contact zone between the two formations is measured in terms of tens of feet. There beds of limestone breccia are common, and the basal clastics of the Karheen tend to be unusually calcareous.

On the coast of Prince of Wales Island, along Tuxekan Passage, basal cross-laminated quartzose sandstone beds of the Karheen Formation rest conformably upon the upper part of the Heceta Limestone, which has changed facies southward into an interbedded sequence of massive to thin-bedded light- to dark-gray limestone and calcareous sandstone, shale, and mudstone. This sequence appears to thin drastically inland, giving way to rocks of Karheen lithology within 3 miles or so of the coast. Unfortunately, outcrop control is poor, owing to heavy vegetational cover, and it has not been possible to evaluate fully the effects of faulting, post-Heceta Formation erosion, or nondeposition.

AGE AND CORRELATION

The Heceta Limestone is richly fossiliferous. Corals and brachiopods tend to predominate, but stromatoporoids, gastropods, bryozoans, calcareous algae, and a few trilobites also occur. Unfortunately, most biostratigraphic conclusions based on early fossil collections suffer from a lack of physical stratigraphic control and from the fact that most of the species have not been described. Nevertheless, some tentative conclusions may be drawn from the older work and from preliminary results of a new paleontologic study now underway by C. W. Merriam and Michael Churkin, Jr.

Most of the collections that have been obtained from the lowest beds of the formation do not permit an age assignment more definitive than that they are indicative of a probable Silurian age. However, recent studies of conodonts recovered from limestone beds at the base of the Heceta Limestone on Cap Island suggest a latest Early Silurian age (A. T. Ovenshine and G. D. Webster, oral commun., 1968). A maximum age is established by several widely scattered graptolite collections obtained from the upper part of the underlying Descon Formation. Fragments of siliceous siltstone from polymictic conglomerate 200 feet stratigraphically below the massive Heceta Limestone at Dead Tree Point (pl. 1) contain *Glyptograptus* sp. The presence of this genus suggests the siltstone clasts were derived from rocks that could range in age from Middle Ordovician through Early Silurian. Buddington and Chapin (1929, p. 81–82) cited Ruedemann's identifications of *Monograptus*?, *Orthograptus* sp., and *Climacograptus* sp. from the same locality. About 3 miles to the southeast, as previously noted, several species of *Monograptus* occur approximately 1,500 feet stratigraphically below the base of the Heceta Limestone, and they indicate a late Early or Middle Silurian age (Churkin and Carter, 1969). Thus the basal beds of the Heceta Limestone are considered to be no older than middle Early Silurian.

Limestone beds that conformably overlie the uppermost of two clastic sequences within the Heceta Limestone on western Heceta Island contain the pelecypod *Pycinodesma* (Edwin Kirk, written commun., 1953), which has been referred to the Upper Silurian by Kirk (1927) but which also occurs in the Wadleigh Limestone associated with a fauna that is generally considered to be Devonian. On western Marble Island, about 3.2 miles north of White Cliff Island, the upper of two similar clastic sequences within the Heceta overlies limestone that contains conodonts suggestive of a Late Silurian but not younger than Middle Late Silurian age (A. T. Ovenshine and G. D. Webster, oral commun., 1968). The uppermost part of the Heceta Limestone contains several species of the brachiopods *Conchidium*, *Harpidium*, and *Brooksina*, solitary and colonial corals, and stromatoporoids, including *Amphipora*. At one locality on the north shore of Heceta Island, 0.8 mile southwest of the south tip of Camp Island (fossil loc. 61AE17, pl. 1), *Amphipora* occurs with the coral *Zelophyllum*, considered by many workers to be restricted to the Silurian. *Conchidium alaskense* Kirk and Amsden was found in nearby beds at the same stratigraphic position. Brachiopods from the Karheen Formation, at least 2,000 feet above the top of the Heceta Limestone (fossil loc. 47AR120, pl. 1), have been referred to the Upper Silurian by Kirk and Amsden (1952, USNM loc. 2689).

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On the basis of the biostratigraphic evidence presently available, the authors have tentatively correlated the base of the Heceta Limestone with the Early-Middle Silurian boundary, and that part below the medial zone of clastic rocks is considered to be of Middle Silurian age. That the age of the upper part of the formation is most likely Late Silurian (Ludlow) is confirmed by newly discovered monograptids with straight simple thecae. The faunal evidence thus favors assignment of a Middle and Late Silurian age to the Heceta Limestone.

KARHEEN FORMATION

The Karheen Formation consists mainly of a wide variety of predominantly fine- to coarse-grained clastic sedimentary rocks having red-bed affinities; limestone is subordinate. Rocks assignable to the Karheen were first described by Buddington and Chapin (1929, p. 88–90 and pl. 1), who mapped them as predominantly graywacke with locally interbedded red, green-gray, and gray sandstone, conglomerate, and shale. The new formation is named here from exposures along the southwest side of Karheen Passage and vicinity, designated the type locality (loc. C, pl. 1), where its base and most of its representative lithologies are known to be present.

LITHOLOGY, DISTRIBUTION, AND THICKNESS

In the type locality, and extending along the southeast shore of Tuxekan Passage opposite Tuxekan Island into Naukati Bay (pl. 1), the prevalent lithology is green-gray, gray, and reddish-brown lithic wacke and graywacke. Present in minor amounts are siltstone, red, red-brown, and green shale, thin-bedded sandy limestone, contorted platy limestone, pebble-to-cobble polymictic conglomerate, and even biostromal limestone and reef breccia.

Most of the sandstone is medium to fine grained and commonly has a carbonate cement. The sandstone may be quite massive, especially the graywacke, but most typically it is well bedded in sets a few inches to several feet thick. Graded bedding may be present in the finer grained facies but is not as common or well developed as in the banded mudstones of the Descon Formation. Cross-laminations, many of which are of the festoon type, are best developed in the coarser sandy facies. (See fig. 10.) Ripple marks, and locally mud cracks, have been observed in the red-brown fine-grained silty sandstones and shales.

Conglomerate is a comparatively rare constituent of the Karheen Formation in the Heceta-Tuxekan Islands area. Where present it generally is composed of polymictic pebbles to small cobbles that form lenses or thin beds in sandstone. Conglomerate, however, is the domi-

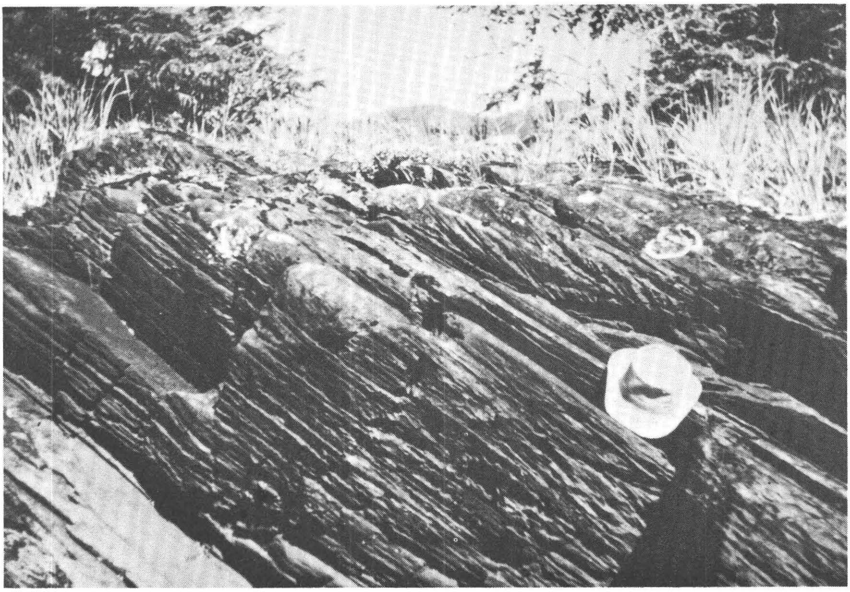

FIGURE 10.—Cross-laminated red-brown sandstone of the Karheen Formation. Northeastern Heceta Island on west shore of Karheen Passage.

nant lithology farther south on islands in the northern part of San Alberto Bay and San Christoval Channel, as well as on the north ends of San Fernando, Lulu, and Noyes Islands (pl. 1). Most of the conglomerate consists of pebbles, cobbles, and boulders of varied lithology that are generally well rounded but of low sphericity; the clasts are closely packed in a medium- to coarse-grained, generally calcareous greenish lithic wacke matrix. Many of the clasts have a red-brown ferruginous coating. Imbricate arrangement of flat pebbles (see fig. 11) and interbeds or lenses of friable carbonate-cemented crossbedded sandstone are common.

At many places porphyritic mafic volcanic rocks and gray-green to dark-gray chert are the most abundant lithologies represented by the larger clasts. Other lithologies present in subordinate to rare quantities are pale-greenish-weathering sandstone, graywacke, siliceous siltstone, red chert, quartzite, red-brown sandstone, white vein quartz, and limestone. Generally well rounded clasts of granitoid igneous rocks, ranging in composition from granite to gabbro, also are present, but they rarely, if ever, exceed 5 percent in pebble counts.

Karheen conglomerates differ from those in the Descon Formation in tending to be more mature and in generally having a carbonate-cemented in many places bright-greenish sandy matrix that is less reconstituted. As a result the rock tends to break around rather than

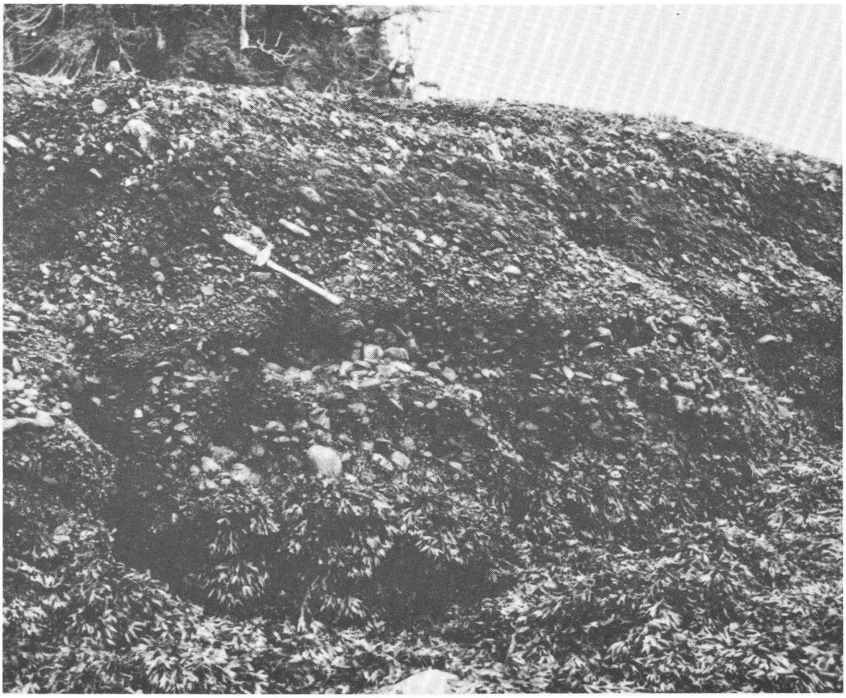

FIGURE 11.—Typical exposure of pebble and cobble polymictic conglomerate, Karheen Formation. Handle of hammer alined parallel to direction of imbrication. Larzatita Island, San Christoval Channel.

through the clasts, which consequently stand out in relief on weathered surfaces. Porphyritic basaltic detritus occurs in both formations, but the conglomerate and breccia (composed almost entirely of dark-green basalt with abundant large stubby phenocrysts of clinopyroxene and (or) plagioclase) that is so common in the Descon Formation is virtually absent from the Karheen. Red beds and festoon crossbedded sandstone are not characteristic of any pre-Karheen rocks, and the presence of abundant detrital K-feldspar and flakes of bronzy biotite has proved useful in distinguishing sandstones in the Karheen Formation from those that may superficially resemble them in the Descon. Conglomerate interbedded within the Heceta Limestone at places closely resembles the conglomerate in the Karheen, but the lack of association with bright-green and reddish-brown cross-laminated sandstone generally makes distinction between them possible. Red chert detritus tends to be a less characteristic constituent of the Karheen Formation.

Two rather distinctive limestone lithologies have been observed in the Karheen Formation. On eastern Heceta Island, at the head of the large bay north of Point Swift (pl. 1), thin-bedded laminated to platy limestone with local sandy and argillaceous partings overlies red and green siltstone a few hundred feet above the base of the formation. Limestone of similar lithology occurs along the northeast shore of San Christoval Channel at its narrowest point. The thickness of this unit is not known because the beds are almost everywhere highly contorted, probably owing in part to penecontemporaneous slumping. However, considerable variation in thickness is indicated because beds of platy limestone, apparently aggregating at least 2,000 feet on eastern Heceta Island, are missing from sections involving the same stratigraphic interval less than 2 miles to the west.

Thin-bedded medium-gray to medium-dark-gray limestone and calcareous pyritic siltstone locally occupy a stratigraphic position high in the Karheen Formation. At least two units of this lithology approximately 200 feet thick are exposed on the northeasternmost shoreline of Heceta Island. The lower of these is fossil locality USNM 2689, from which Kirk and Amsden (1952) described Upper Silurian brachiopods (loc. 47AR120, pl. 1).

A complete unfaulted section of the Karheen Formation in which the upper and lower contacts are exposed is unknown. The thickest sequence, apparently unfaulted, occurs on the easternmost end of Heceta Island, where beds aggregating about 6,000 feet are believed to be present. Because both the top and bottom are missing and some lithologies are not represented, this is considered to be a minimum, although probably locally thickened, section. On Prince of Wales Island, east of Tuxekan Passage, approximately 3,500 feet of Karheen beds is exposed in the central part of a large syncline—the Tuxekan syncline. A minimum of 3,500 feet of conglomerate and sandstone can be demonstrated on northern San Fernando Island. This thickness can be expanded to a total of at least 5,000 feet if the rocks exposed on the Cruz Islands have not been repeated by faulting along Cruz Pass.

STRATIGRAPHIC RELATIONS, AGE, AND CORRELATION

The evidence for a generally conformable contact between the Heceta Limestone and the Karheen Formation in the Heceta-Tuxekan Islands area has been reviewed under the discussion of the Heceta Limestone. In the center of the Tuxekan syncline on Prince of Wales Island east of Tuxekan Passage (pl. 1), grayish-brown to grayish-red medium- to fine-grained sandstone and shale of the Karheen Formation conformably underlie thinly bedded medium- to dark-gray Wadleigh Limestone. The actual contact is obscured by vegetation, but accordant bedding trends occur in the underlying and overlying beds within 100 feet of the contact. Here, the occurrence of the Middle Devonian coral genus *Grypophyllum* (C.W. Merriam, oral commun., 1962) in the Wadleigh establishes a minimum age for the Karheen Formation.

Kirk and Amsden (1952), (loc. 47AR120, USNM loc. 2689, pl. 1) have described Upper Silurian brachiopods from a sequence of limestone and calcareous siltstone believed to occur high within the Karheen Formation and well above the zone of crumpled platy limestone. These brachiopods, however, are only part of the fauna, which includes an abundance of corals and silicified tentaculitids. Preliminary examination of this fauna by Churkin suggests an Early Devonian age.

The coarsening of the Karheen Formation in a southward and southwestward direction is apparently not accompanied by a significant change in thickness. With the concomitant disappearance of the Heceta Limestone southward, however, the base of the Karheen marks a profound unconformity. Thus on the east shore of Steamboat Bay, Noyes Island, polymictic pebble conglomerate, chert wacke, and limestone of the Karheen Formation rest with angular discordance on Early Ordovician (Arenig) graptolitic shale and chert (loc. 65ACn 1141, USGS M1031CO, pl. 1), one of the oldest graptolitic horizons known in the Descon Formation. On the east shore of Noyes Island, similar Karheen beds are unconformably in contact with siltstone and sandstone of the Descon Formation that contain the graptolites *Orthograptus truncatus* (Lapworth), *Lasiograptus* sp., and *Orthoretiolites* ?, of early Late Ordovician (upper Caradocian) age. Approximately 1,400 feet above the base of the Karheen Formation in this area (loc. 65ACn1181, pl. 1), several species of *Monograptus*, including *M.* aff. *thomasi* Jaeger of Early Devonian age (H. Jaeger, written commun., 1969) occur in the same beds with dichotomously branching vascular plants resembling the *Baragwanathia* flora found in Australia (S. H. Mamay, written commun., 1967). A rich shelly fauna from calcareous siltstone below the graptolite- and plant-bearing shale includes the corals *Tryplasma* cf. *altaica* (Dybowski), *Thamnopora* sp., *Striatopora*, *Syringopora*, *Favosites*, spp., together with massive stromatoporoids and crinoids of Early Devonian age. An Early Devonian age is therefore indicated for the lower part of the Karheen Formation on Noyes Island. This significant association of graptolites, vascular plants, and corals is the subject of another paper by Churkin, Eberlein, Huber, and Mamay (1969).

At the south end of the Cruz Islands, polymictic pebble conglomerate of the Karheen Formation rests discordantly upon black very thin bedded cherty Descon siltstone with shaly partings and lenses of fine-grained dark-gray limestone. Angular fragments of the cherty siltstone occur in the basal Karheen beds as much as 1½ feet above the contact. Shaly partings in the siltstone contain *Climacograptus* (two or three species), *Dicellograptus* cf. *sextans* J. Hall, *Cryptograptus tricornis* (Carruthers), *Orthograptus calcaratus* (Lapworth), and *Climacograptus bicornis*? (J. Hall); this assemblage suggests an early Middle Ordovician age.

Thus the normally conformable contact relations at the base of the predominantly sandy Karheen Formation in the Heceta-Tuxekan Islands area give way southward and westward to a major unconformity, as evidenced by disappearance of the subjacent Heceta Limestone and a facies change of the Karheen into dominantly conglomeratic lithologies. The paleontologic evidence presently available for the Karheen Formation is believed to favor an age range from Late Silurian to Early Devonian. Apart from the fact that Lower Devonian rocks heretofore have not been recognized in southeastern Alaska, the Karheen has important paleotectonic implications that will be discussed in a separate paper.

ST. JOSEPH ISLAND VOLCANICS

The new name St. Joseph Island Volcanics is here applied to a thick sequence of flows and pyroclastics that exhibit a wide variety of textures and structures but are essentially all of basaltic composition. Interlayered with the volcanic rocks and included in the formation are subordinate amounts of fine-grained, largely argillaceous sedimentary rocks, some of which are calcareous and are interbedded with minor limestone. The formation is named for St. Joseph Island, the type area, where it is well exposed and most thoroughly studied (loc. F, pl. 1). The St. Joseph Island Volcanics is well exposed in headlands along the west shore of Noyes Island farther south, also. North of St. Joseph Island, regionally metamorphosed rocks of the St. Joseph Island Volcanics are exposed widely in a series of small islands that make up the western part of the Maurelle Islands.

LITHOLOGY AND THICKNESS

The St. Joseph Island Volcanics is composed mainly of dark-green massive basaltic submarine flows, breccia, conglomerate, and tuff that commonly shows good bedding.

Many of the flows are amygdaloidal and have well-developed pillow structures (fig. 12) which in places have been fragmented to various degrees and cemented by calcite to produce aquagene breccia and tuff. The pillows range in size from several inches to more than 5 feet in diameter. Locally the flows are scoriaceous. Calcite, chlorite, and more rarely chalcedony fill the vesicules in the flows. In addition, secondary limestone and quartz have been deposited in the spaces between pillows.

Typically the basalt contains augite and labradorite, which occur both as phenocrysts and as part of the groundmass. The normal groundmass texture is intersertal to intergranular, and not uncommonly the plagioclase microlites are well alined into flow structures. The presence of minor olivine is suggested by local patches of chrysotile that have the characteristic dipyramidal shape of olivine. Some degree of alteration is evident in almost all specimens examined. As a result of this alteration, original glass has been converted to chlorite and opaque oxide minerals; plagioclase has become saussuritized; and the original ferromagnesian minerals have been replaced by a mixture of chlorite and an unidentified carbonate mineral.

On the basis of two chemical analyses, basalts of the St. Joseph Island Volcanics seem to range between olivine tholeiite and tholeiite (saturated; hypersthene basalt) according to the classification of

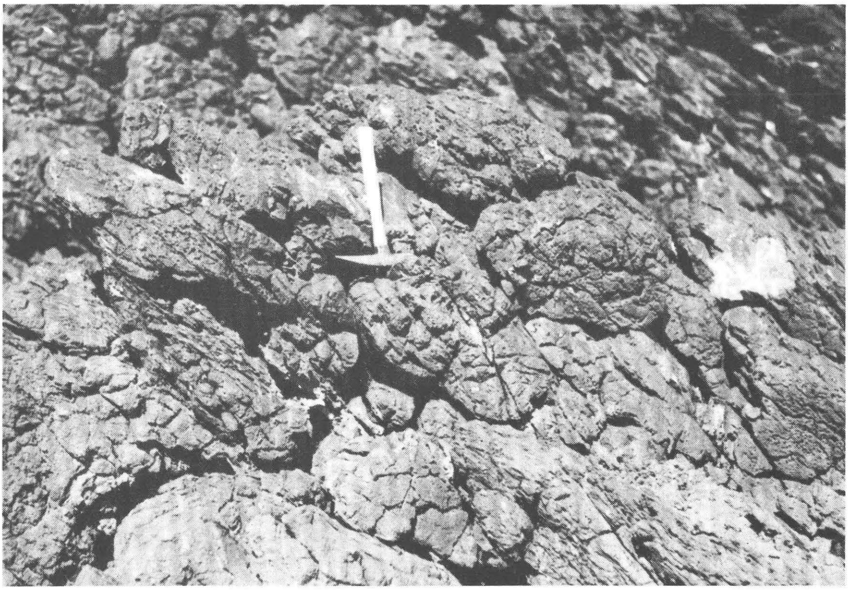

FIGURE 12.—Relict pillow structure in St. Joseph Island Volcanics. Note incipient schistosity that dips more steeply to the right in the photograph than crude flow-layering indicated by alinement of the pillows. Southern Wood Islands.

Yoder and Tilley (1962). However, the analyses show the basalts to be anomalously low in CaO and SiO_2 and high in MgO. Accordingly, they are richly hypersthene normative, but normative clinopyroxene is lacking. Modal hypersthene has not been identified in the St. Joseph Island Volcanics or in any of the other Paleozoic volcanics of this province. The analyses also show about 6 percent H_2O, and the disparity between the norm and the mode may therefore be due to the migration of constituents as a result of deuteric alteration attending eruption and final consolidation of the submarine flows.

Massive to well-bedded basaltic breccia, conglomerate, and lithic lapilli tuff of the same composition as the flows are quantitatively the most important fragmental rock types in the St. Joseph Island volcanic sequence. The coarsest grained representatives characteristically occur in beds and lenses 3–20 feet or more thick and consist of loosely packed angular to moderately rounded poorly sized clasts of variously textured basalt and minor limestone. These fragments, ranging up to as much as 12 inches in diameter, are set in a pebbly, sandy carbonate-cemented matrix. The ratio of clasts to matrix varies widely, the clasts constituting from 10 to 85 percent of the rock. Some of the more massive beds weather differentially as the amount of calcareous cement increases. This weathering accentuates the crude internal stratification (fig. 13). Well-bedded lithic lapilli tuff is interlayered with the flows

FIGURE 13.—Basaltic conglomerate in St. Joseph Island Volcanics. Bedding accentuated by differential weathering of carbonate-cemented tuffaceous matrix. Southern Wood Islands.

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and breccias or with argillaceous and calareous sedimentary rocks in the succession.

The sedimentary rocks in the St. Joseph Island Volcanics are best exposed along the southeastern shoreline of St. Joseph Island and along the north side of Roller Bay in the northwestern part of Noyes Island. The dominant lithologies are siltstone and mudstone that have variable amounts of calcareous cement. The rocks, because they are very thinly bedded, have a distinctively banded appearance. Some coarser grained interbeds of feldspathic and (or) volcanic graywacke with generally well-developed graded bedding are also present. A distinctive unit of siltstone and shale, very thinly interbedded with more-calcareous layers and lenses, is exposed along the east coast of St. Joseph Island and locally along the north shore of Roller Bay. These thinly alternating lithologic units vary in color from pale green to pale red and purple and have a striking appearance on weathered surfaces (fig. 14). In places these rocks are highly contorted, perhaps owing in part to penecontemporaneous slumping. About 600 feet of these alternating reddish and greenish rocks is exposed nearly continuously on St. Joseph Island.

In the western part of the Maurelle Islands, the St. Joseph Island Volcanics has been subjected to low-grade dynamothermal metamorphism (greenschist facies). Locally the rocks have a pervasive schistosity and all but the major elements of their original texture and

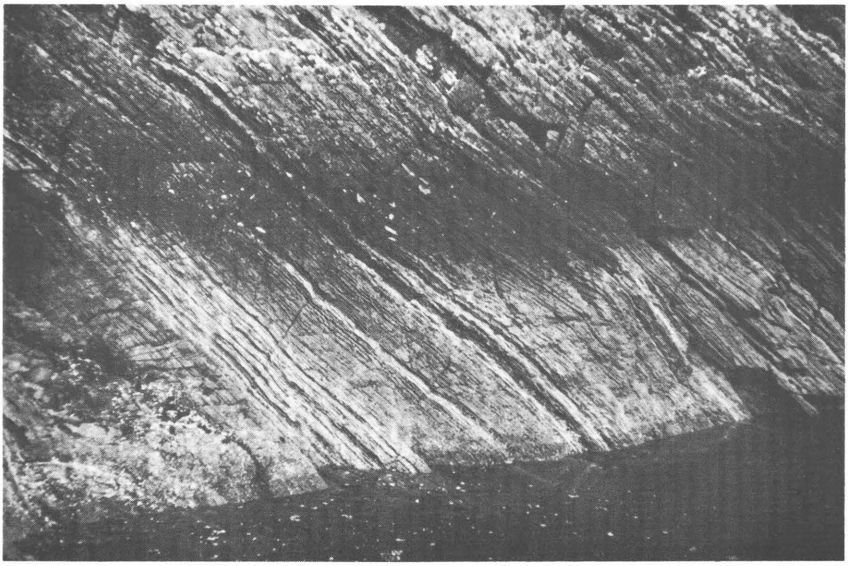

FIGURE 14.—Thin-bedded pale-green and red calcareous siltstone, shale, and limestone unit within St. Joseph Island Volcanics. East shore, St. Joseph Island.

structure are destroyed. The predominant northwestern-trending schistosity is roughly parallel to the strike of bedding and flow layering, but generally dips more steeply northward. At some places, such as the southwest end of the Wood Islands, the metamorphism has resulted in stretching and elongation of clasts to produce a well-developed lineation that plunges southeastward at moderate angles (fig. 15).

The total thickness of the St. Joseph Island Volcanics is unknown because neither the top nor the bottom of the formation is exposed in the area. On St. Joseph Island, the section consistently dips northwestward, except for the less competent thin-bedded sedimentary rocks that are internally contorted. Judging from this, somewhere between 7,500 and 10,000 feet of the formation is exposed across its type area. Apparently the St. Joseph Island Volcanics along the west side of Noyes Island and at the east end of the Maurelle Islands is separated from the Descon Formation by high-angle faults as suggested by intense shearing and by sharp reversals in strike and dip across the contact.

AGE AND CORRELATION

No fossils have been found in the St. Joseph Island Volcanics or in its interbedded sedimentary rocks. Judging by lithic similarity to other formations in the area, the St. Joseph Island Volcanics most closely resemble certain of the formations relatively richer in volcanic rock; namely, the Coronados Volcanics of Devonian age, the Port Refugio Formation also of Devonian age, and, less closely, the Descon Formation of Ordovician and Silurian age. The St. Joseph Island Volcanics differs mainly from the Coronados Volcanics in lacking massive interbeds of fossil-fragmental limestone. It differs from the Port Refugio Formation by containing far fewer sedimentary rocks, especially graywacke and polymictic conglomerate, and from the Descon Formation by again having mainly volcanic rather than sedimentary rocks. Furthermore, the sedimentary rocks of the Descon Formation are far less calcareous.

Although the age of the St. Joseph Island Volcanics is uncertain, indirect evidence for a minimum age has been obtained by radiometrically dating a lamprophyre dike that cuts the formation on the northwest coast of Noyes Island. Biotite from the dike gives a 328 ± 10 m.y. potassium-argon date (Joan Engels, written commun., 1968). This date indicates a minimum age of Mississippian for emplacement of the dike; therefore, the St. Joseph Island Volcanics is probably of pre-Mississippian age. The similarity of some aspects of the St. Joseph Island Volcanics to parts of the Coronados Volcanics

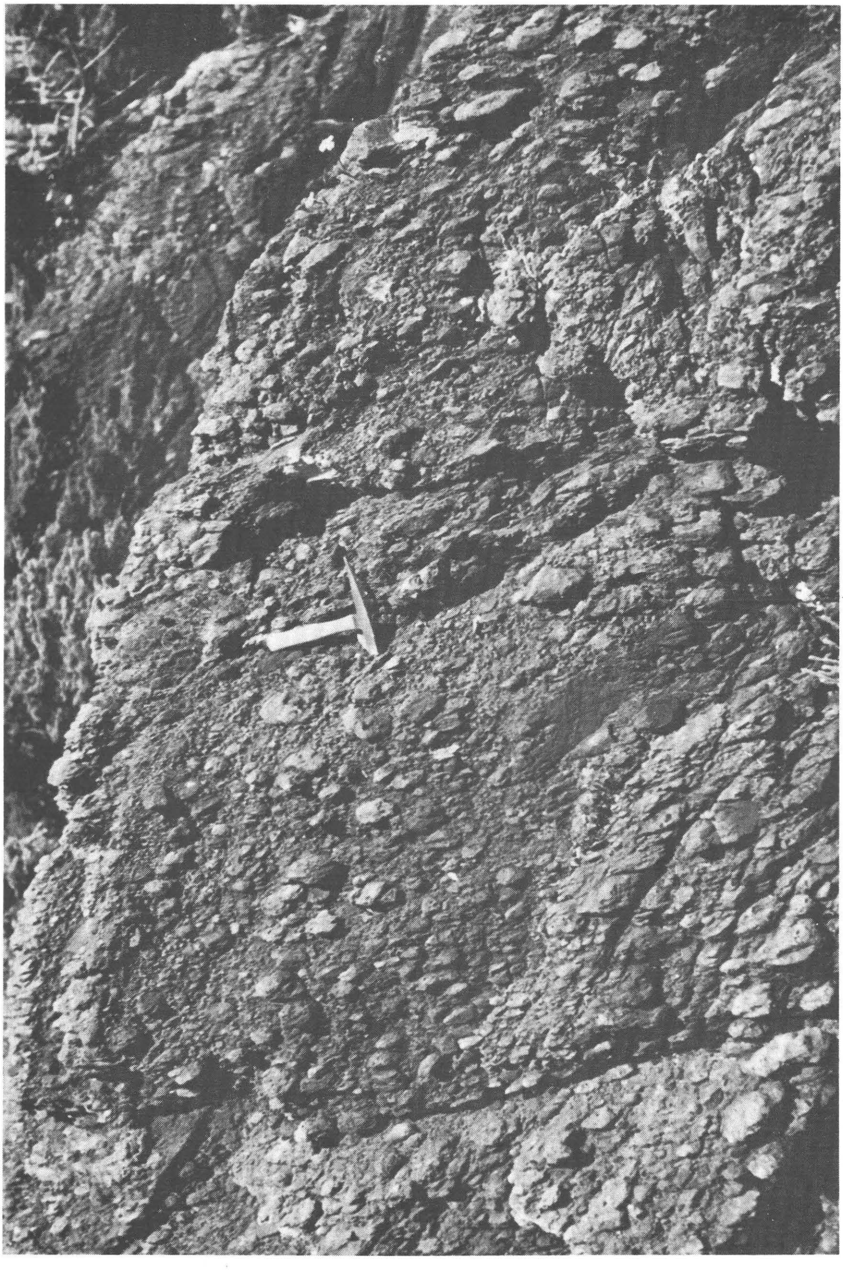

FIGURE 15.—Stretched clasts in metamorphosed (greenschist facies) volcanic breccia of the St. Joseph Island Volcanics, South end Woods Islands.

and the Port Refugio Formation suggests that the formation may be of Devonian age, as provisionally estimated by Buddington and Chapin (1929). Thus the unit is assigned a Devonian (?) age.

CORONADOS VOLCANICS

The Coronados Volcanics is largely composed of fragmental basaltic volcanic rocks interlayered with massive fossiliferous limestone. The type locality of this newly named formation is in the eastern part of the Coronados Islands at the entrance to Port St. Nicholas on the west coast of Prince of Wales Island (loc. E, pl. 1). In addition to its type locality, the formation was mapped in a narrow discontinuous belt that includes Rancheria and Canas Islands and extends southeastward to the head of Trocadero Bay.

LITHOLOGY, STRATIGRAPHIC RELATIONS, AND THICKNESS

The Coronados Volcanics is characterized by dark-greenish-gray pillow basalts that show various stages of fragmentation and cementation by calcite. Massive nearly pure limestone composed mainly of shelly fossils is intimately interbedded with the volcanic rocks. The fragmental basaltic rocks range from coarse pillow breccias (fig. 16) and agglomerates through fine-grained breccias to fine-grained lithic lapilli tuffs (fig. 17). Some of the fine-grained breccias and tuffs are essentially fragmented pillow lavas, as evidenced by several beds about 50 feet thick that show a progressive gradation within each bed from pillow breccia at the base to fine-grained tuff with scattered larger fragments of basalt near the top. These beds are essentially graded sets that have most of the stages of pillow fragmentation and carbonate cementation of typical aquagene breccias and tuffs (Carlisle, 1963). Many of the pillows and pillow fragments have abundant vesicules filled with calcite and chlorite.

Pillow lavas interstratified with aquagene tuffs and breccias are especially well developed on the islands at the head of Trocadero Bay. These volcanic rocks south of the type area probably belong to the Coronados Volcanics, although they lack interbedded limestone rich in fossils. The pillow structures here vary from 1 to 5 feet in diameter. The largest vesicules (1–2 mm in diameter) are filled mainly by calcite and chlorite and are considerably larger than those in the Descon pillow lavas. Petrographically the Coronados basalts tend to be porphyritic and amygdaloidal. Phenocrysts of augite, saussuritized plagioclase, and, rarely, green hornblende occur in a groundmass that for the most part appears to have been intersertal or intergranular.

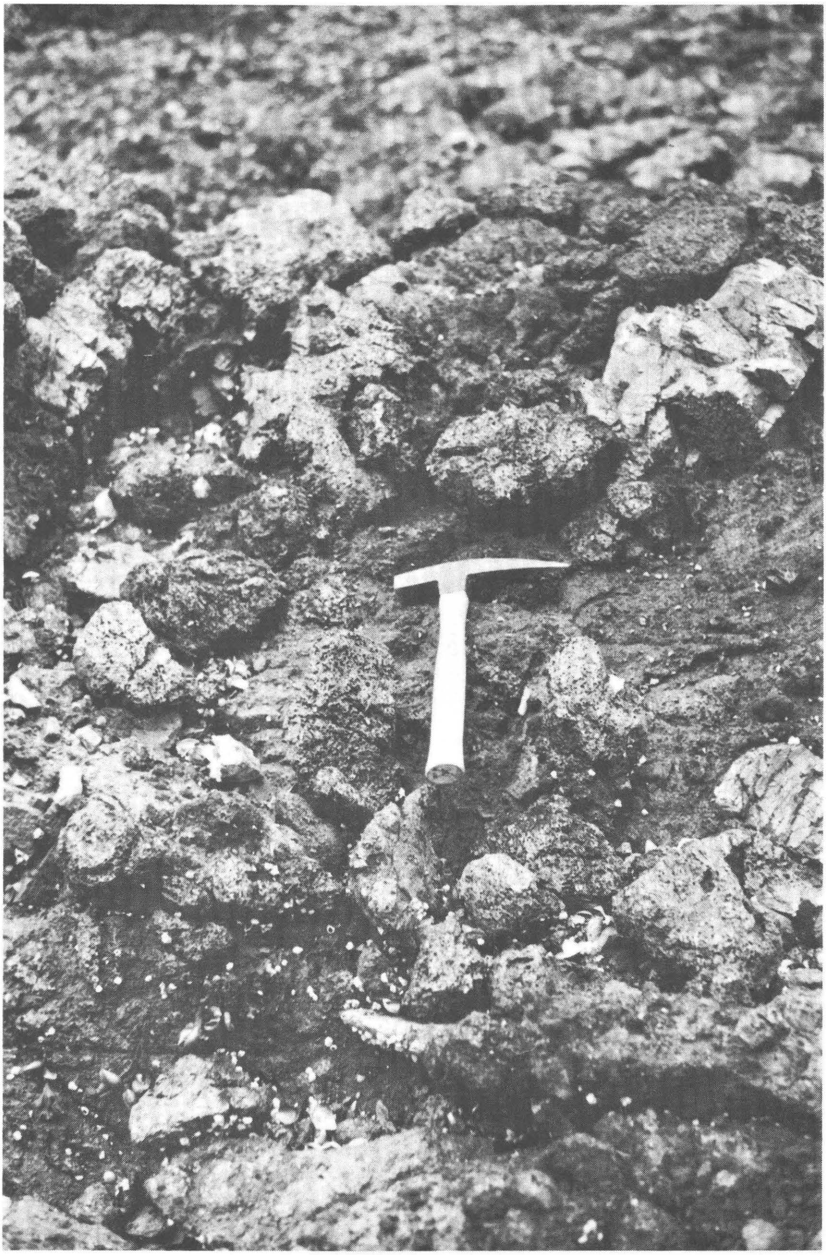

FIGURE 16.—Fragments of vesicular basalt in broken pillow breccia, Coronados Volcanics. Coronados Islands.

FIGURE 17.—Water-laid calcareous lapilli tuff, Coronados Volcanics. Canoe Point at entrance to Trocadero Bay, Prince of Wales Island.

However, any glass that originally may have been present has been transformed into a mixture of chlorite and abundant opaque oxide minerals. Where incomplete alteration of plagioclase has permitted its optical determination of composition, the plagioclase is labradorite that has a composition close to andesine. A few of the thin sections examined contain scattered aggregates of chlorite and a carbonate mineral. Many such aggregates have outlines which suggest the rare presence of former olivine phenocrysts.

Associated limestone has gradational contacts with the fragmental volcanic rocks with which they are interbedded. Many of the limestones are tuffaceous and have abundant isolated volcanic rock fragments. Furthermore, the associated fragmental volcanic rocks correspondingly contain fossiliferous limestone clasts. Locally the predominantly limestone sequence contains zones of friable siltstone, fine-grained salt-and-pepper calcareous sandstone, and subordinate black-chert pebble conglomerate in beds 6–8 inches thick. The thicker limestone beds are mainly medium-light-gray, nearly pure, massive limestone that is composed almost entirely of abraded fossil fragments. The fossils include mainly tabulate corals, both massive coral heads reaching 6 inches in diameter (*Favosites*, *Heliolites*) and branching fingerlike (thamnoporoid and *Alveolites*) corals, together with very abundant colonies of massive stromatoporoids. Less common are solitary horn corals, gastropods, and crinoid columnals up to three-eighths inch in diameter. Some beds contain abundant atrypoid brachiopods preserved in a fine-grained limestone matrix.

The lower contact of the Coronados Volcanics is unknown, but the upper part is interlayered with Wadleigh-type limestone, suggesting that the Coronados Volcanics is a lateral equivalent of the nonvolcanic Wadleigh Limestone a short distance farther north. Because of its discontinuous exposure, the thickness of the Coronados Volcanics is difficult to estimate, but must be on the order of 500 feet.

AGE

The fact that the upper part of the Coronados Volcanics is interlayered with limestone essentially identical lithically and faunally to that of the overlying Wadleigh Limestone implies that the Coronados is time-equivalent with the lower part of the Wadleigh Limestone. A preliminary study of the Coronados corals suggests that the formation is of Middle Devonian age. Other formations in that area that have similar volcanic rocks, especially aquagene tuffs and breccias, are the St. Joseph Island Volcanics and, to a lesser degree, parts of the Port Refugio Formation.

WADLEIGH LIMESTONE

The Wadleigh Limestone is a relatively pure fossil-fragmental limestone. The formation is mainly distributed in a series of islands along the east sides of San Alberto and Bucareli Bays where it forms, running from north to south, most of Wadleigh Island, the Alberto Islands, Clam Island, Fish Egg Island, small islands in Port Bagial, most of the Coronados Islands and Culebrina Island. Smaller areas of Wadleigh Limestone occur along the northeast end of Peratrovich Island, on the west shore of Klawak Lake, and at Fern Point on the east side of San Fernando Island. Farther north, Wadleigh Limestone is found in the Nossuk Bay-Tonowek Narrows area and on Ham and several other small islands in Karheen Passage. It also apparently underlies several hills along the axis of the Tuxekan syncline.

The type locality of the Wadleigh Limestone is on the southern end of Wadleigh Island (loc. D, pl. 1). The best exposures of the limestone extend from just north of the Alberto Islands around the south end of Wadleigh Island and then north along the southeast shore to triangulation station Upat. Because the limestone is here repeated several times in open folds, a type section is not designated, although the relative position of numerous fossil horizons is approximately known. The north end of Wadleigh Island may be less complicated structurally, but the poorer exposures and long strike shorelines make this a less satisfactory area to study the formation.

LITHOLOGY AND THICKNESS

The Wadleigh Limestone is mainly a medium- to dark-gray thick- to medium-bedded massive commonly fetid fragmented-fossil limestone. Argillaceous limestone and calcareous shale are in many places cyclically repeated with pure limestone and are especially well developed in the upper parts of the Wadleigh at the south end of Wadleigh Island (fig. 18) and in the Nossuk Bay area (fig. 19). The Wadleigh is composed of varying proportions of fragmented shelly fossils cemented by fine-grained dark (medium-dark-gray to nearly black) small-crinoid-columnal-rich limestone that is frequently very rich in the spaghetti-shaped stromatoporoid *Amphipora*. Anthraxolite-bearing limestone breccia, associated with local patch reefs, occurs on several of the islets at the north and south entrances of Karheen Passage. Excellent examples of reef breccia are exposed at Fern Point on the east coast of San Fernando Island (fig. 20).

Corals and stromatoporoids are by far the most abundant fossils but rarely brachiopods, gastropods, and ostracodes, and to a smaller extent other fossils make up substantial quantities of the coarse fossil

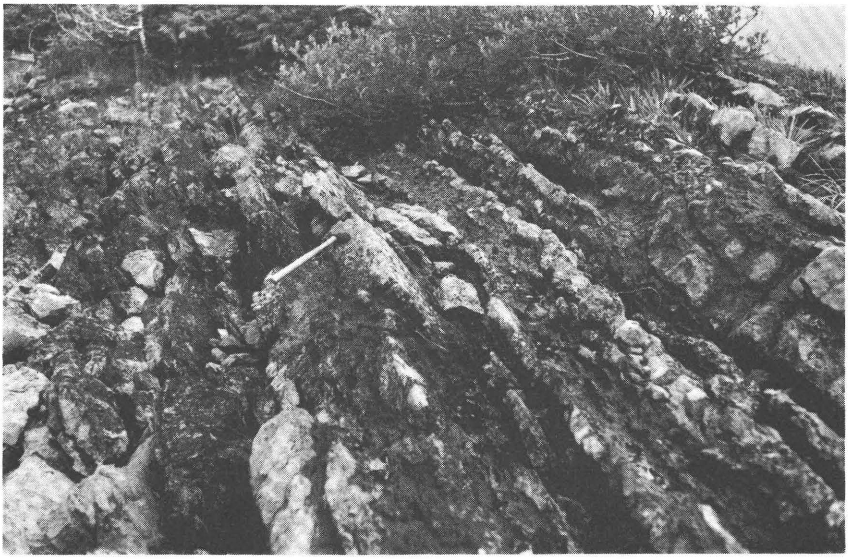

FIGURE 18.—Interbedded argillaceous (dark) and fragmented-fossil Wadleigh Limestone. South tip of Wadleigh Island.

detritus in the limestone. The most common fossils that have been identified from the Wadleigh in the field are:

- Corals:
  - Tabulate corals: *Favosites*, both hemispherical and branching forms, alveolitids, syringoporids and heliolitids.
  - Solitary septate corals: many genera.
  - Cerioid septate corals: many genera.
- Brachiopods: *Atrypa reticularis*, *Spinatrypa* sp.
- Pelecypods: *Pycinodesma* sp.

In most beds the fossils are somewhat fragmented or abraded but in some places the more massive colonial corals and stromatoporoids encrust fragments of other fossils and appear to be in growth position or nearly so (fig. 21).

Black chert is a very rare constituent of the Wadleigh Limestone. Several 5- to 10-foot-thick units of thin-bedded black chert are present in the Wadleigh Limestone on the southwestern tip of the westernmost and largest island of the Alberto Islands. Chert also occurs as nodules and as a replacement of fossils. Other very rare lithologies are sandstone, siltstone, and shale, which are found only on the west and east coasts of the largest island in the Coronados group and in the Nossuk Bay–Tonowek Narrows area, where they total only a few feet thick.

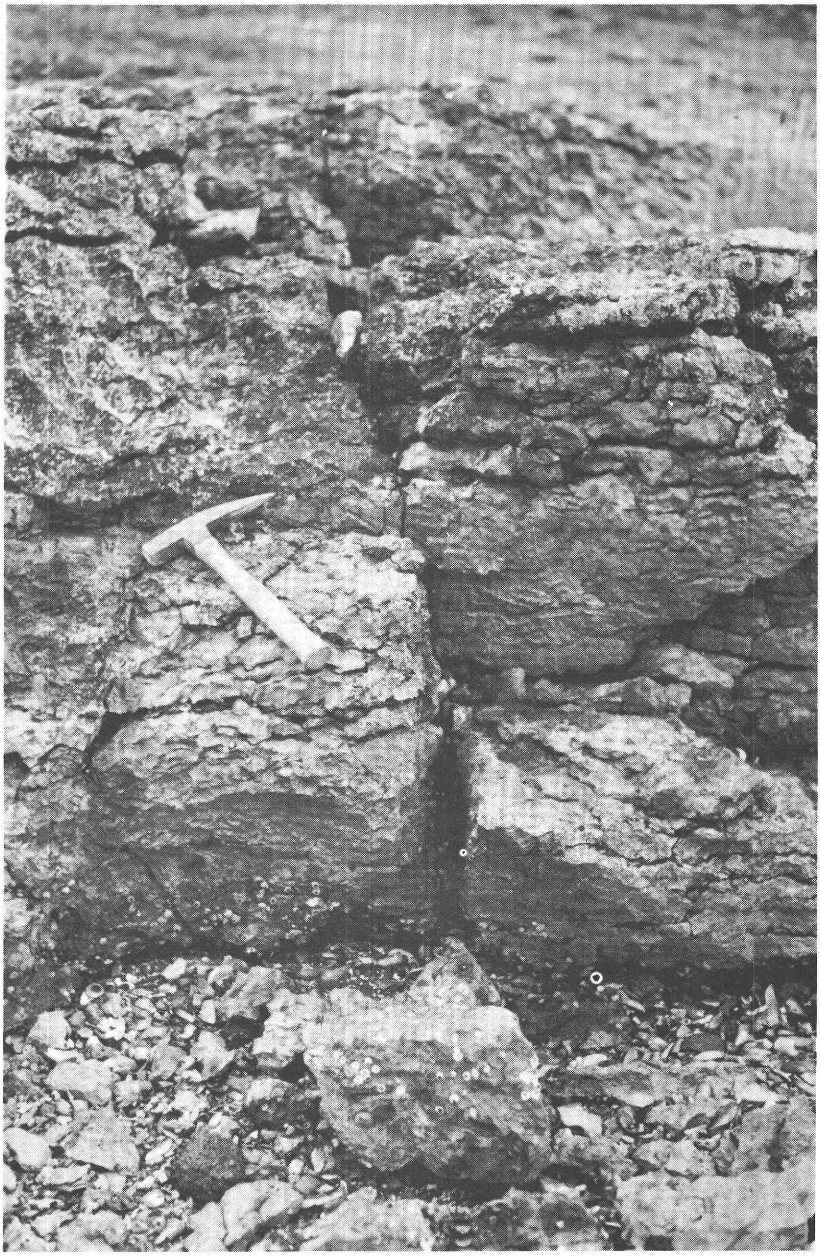

FIGURE 19.—Thin-bedded limestone, with argillaceous partings, that probably constitutes an off-reef facies of Wadleigh Limestone. Nossuk Bay, Prince of Wales Island.

FIGURE 20.—Reef breccia facies of Wadleigh Limestone. Fern Point, San Fernando Island.

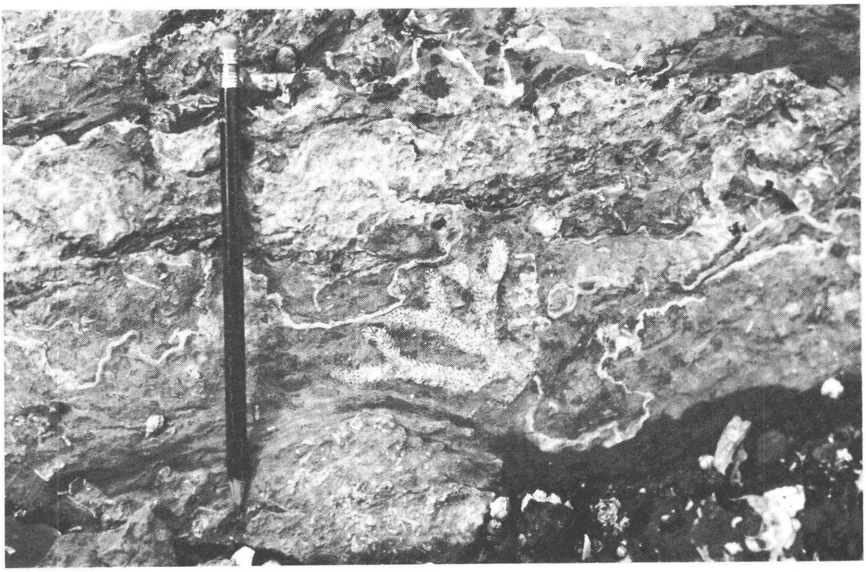

FIGURE 21.—Branching favositid corals in growth position, argillaceous Wadleigh Limestone. South tip of Wadleigh Island.

The thickness of the Wadleigh Limestone can be only roughly estimated because of the complicated structure in the area. On Wadleigh Island, the only place where its contacts are approximately known, the thickness of the Wadleigh, taking into account several folds that repeat various horizons within the formation, seems to be about 1,000 feet but could be as much as 2,000 feet.

STRATIGRAPHIC RELATIONS

The lower and upper contacts of the Wadleigh Limestone are nearly everywhere covered. At the northern end of the string of islets that continue to trend with Wadleigh Island, its lower contact with the underlying Karheen Formation is covered by a few tens of feet of water but seems accordant. In an overturned syncline on a small islet a few hundred yards to the southeast, *Amphipora*-bearing Wadleigh Limestone is interbedded with beds of reddish chert pebble conglomerate similar to the Karheen, thus suggesting a gradational contact of the Wadleigh Limestone with the underlying Karheen Formation.

Farther north, in the Nossuk Bay–Tonowek Narrows area, the top of the Karheen is polymictic boulder conglomerate interbedded with calcareous lithic wacke. The conglomerate has intercalated beds of massive light-gray aphanitic limestone containing seams and lacy partings of greenish-gray shale, and the basal 40–60 feet of Wadleigh Limestone here is very similar to the limestone in the uppermost 5–20 feet of the Karheen; thus the relationship suggested is a conformable, intercalated contact. In places the massive aphanitic limestone forming the basal member of the Wadleigh has domed laminar structures of probable algal origin.

AGE AND CORRELATION

Devonian fossils have long been known from rocks that are now assigned to the Wadleigh Limestone (Buddington and Chapin, 1929, p. 101, locs. 15ACh278, 15ACh280; p. 105, USNM colln. 1841 (field No. 2038), USNM colln. 2030 (field No. 2012), USNM colln. 2031 (field No. 2013), USNM colln. 2057 (field No. 2014), USNM colln. 2132 (field No. 2017)). These faunas were identified by Edwin Kirk as Middle Devonian.

Large fossil collections, especially corals, were systematically made throughout the Wadleigh. Preliminary identifications of the more common corals by Churkin in consultation with C. W. Merriam and Soviet coral specialists, mainly E. Z. Bulvanker, I. I. Chudinova, K. A. Ermakova, A. G. Kravtsov, and N. Ya. Spasskiy (oral commun., 1967) indicate the following coral genera are present:

Acanthophyllum
Alveolites
Arcophyllum
Australophyllum
Bethanyphyllum (?)
Chlamydophyllum
Coenites
Favosites
Heliolites
Heliophyllum
Loyolophyllum
Macgeea
Neostringophyllum
Parastriatopora
Phillipsastrea
Stringophyllum
Syringopora
Tabulophyllum
Thamnophyllum
Thamnopora
Tryplasma
Xystriphyllum

The known ranges of these corals, many of which are cosmopolitan, suggest that the Wadleigh includes Middle and Upper Devonian and possibly Lower Devonian. Until a full study of its faunas is completed, the Wadleigh is tentatively considered Middle and Upper Devonian.

PORT REFUGIO FORMATION

The Port Refugio Formation is here named for an interbedded sequence of graywacke, conglomerate, siltstone, shale, and very minor limestone. The sequence is rich in volcanic rock detritus and has numerous interbeds of pillow basalt and fragmental volcanic rocks. The type locality of the new formation is at Port Refugio on the northeast side of Suemez Island and includes the west shore of Ulloa Channel from Port Refugio to Adrian Cove (loc. G, pl. 1). Outside its type area the formation underlies the large peninsula on Prince of Wales Island bounded by Trocadero Bay, Bucareli Bay, Ulloa Channel, Tlevak Strait, and Soda Bay; rims San Juan Bautista Island; forms Meares Island and smaller islets in the Tlevak Strait area; and underlies the north tip of Dall Island.

LITHOLOGY AND THICKNESS

Although the Port Refugio Formation includes a wide range of lithologies, it is mainly a sequence of graywacke and conglomerate with abundant thin interbeds of siltstone and shale. Except for minor differences discussed below, the Port Refugio most closely resembles the considerably older Descon Formation.

The graywacke in the Port Refugio Formation is generally a dark-greenish-gray, thick-bedded, and massive poorly sorted sandstone. Most of the sand grains of the graywacke are plagioclase feldspar, pyroxene, siliceous argillaceous rock fragments, and chert. Commonly, pebbles and granules of basaltic lava and cherty sedimentary rocks occur isolated in finer grained graywacke or form conglomeratic beds at the base of graded beds.

Many of the graywackes are largely reworked basaltic lavas that contain euhedral crystals of plagioclase and pyroxene that resemble the phenocrysts in the basaltic flows of the formation. The graywackes range from feldspathic to volcanic graywacke, depending upon the proportion of feldspar, pyroxene, and fine-grained volcanic rock detritus, and, where cherty sedimentary rock detritus becomes dominant, they pass into lithic graywacke.

The matrix of the graywacke is dark-green chloritic material with enough calcite to almost always effervesce when treated with dilute (10 percent) cold hydrochloric acid. This contrasts with the almost unreactive nature of equivalent lithologies in the Descon Formation. The difference in degree of induration between these formations is probably related to their content of carbonate cement so that the beds of the relatively poor-in-carbonate Descon seem to be slightly more indurated than the beds of the younger Port Refugio Formation.

Interbedded with the graywacke are siltstone and shale (fig. 22). These finer grained detrital rocks are thin bedded to laminated and have well-preserved graded bedding, rhythmic layering, microscour and fill structures, and convolute bedding. Most of these rocks are various shades of green, but many of the purer argillaceous layers are grayish black.

The Port Refugio Formation contains a number of massive conglomerate beds. These conglomerates are poorly to moderately well sorted and have clasts that range in size from pebbles through cobbles to boulders in a matrix that is mainly volcanic lithic graywacke. A large proportion, if not most, of the larger clasts in the conglomerates are composed of fine-grained feldspar and pyroxene phenocryst-bearing andesitic or basaltic rocks that often are amygdaloidal. Graywacke boulders are also abundant, and in the pebble sizes cherty sedimentary rocks are common. Granitic clasts, although locally common, seem to be subordinate. Locally, along Ulloa Channel and along the south shore of Ulloa Island, limestone boulders and lenses up to 20 feet long occur in these conglomerates. The limestone fragments are fine grained and nonfossiliferous.

Volcanic rocks interbedded with the detrital sedimentary rocks are present throughout the Port Refugio Formation and in some places constitute massive units several hundred feet thick. There are several types of volcanic rock, distinguished mainly by texture and structure rather than by major differences in the mineralogical composition of the lavas. Pillow basalt (fig. 23) and more rarely columnar-jointed basalt flows contrast with basaltic breccias and tuffs, their fragmental equivalents. In many places pillow basalt progressively grades into a broken pillow breccia and then into finer breccia and tuff in which original pillow structures are not readily recognizable. Where these pyroclastic rocks are associated with limestone, as in Port Refugio, on Shelikof Island, and locally along the east shore of Ulloa Channel, the volcanic rock fragments are cemented by calcite to produce aquagene tuff and breccia (fig. 24). The east side of Shelikof Island and the south shore of a smaller unnamed island 1 mile due west of Shelikof Island (fig. 25) have good exposures of aquagene tuff that forms the top of the Port Refugio Formation, where it is directly overlain by thin-bedded chert and limestone of the Peratrovich Formation. Here the aquagene tuff is a thin-bedded to laminated bluish-gray to dark-greenish-gray smoothly weathering rock composed mostly of lapilli-sized vesicular or amygdaloidal basalt fragments in a crystalline white calcite cement. Similar calcareous tuffs and breccias are associated with brachiopod-rich silty limestones and calcareous siltstone well within the Port Refugio Formation in its type area.

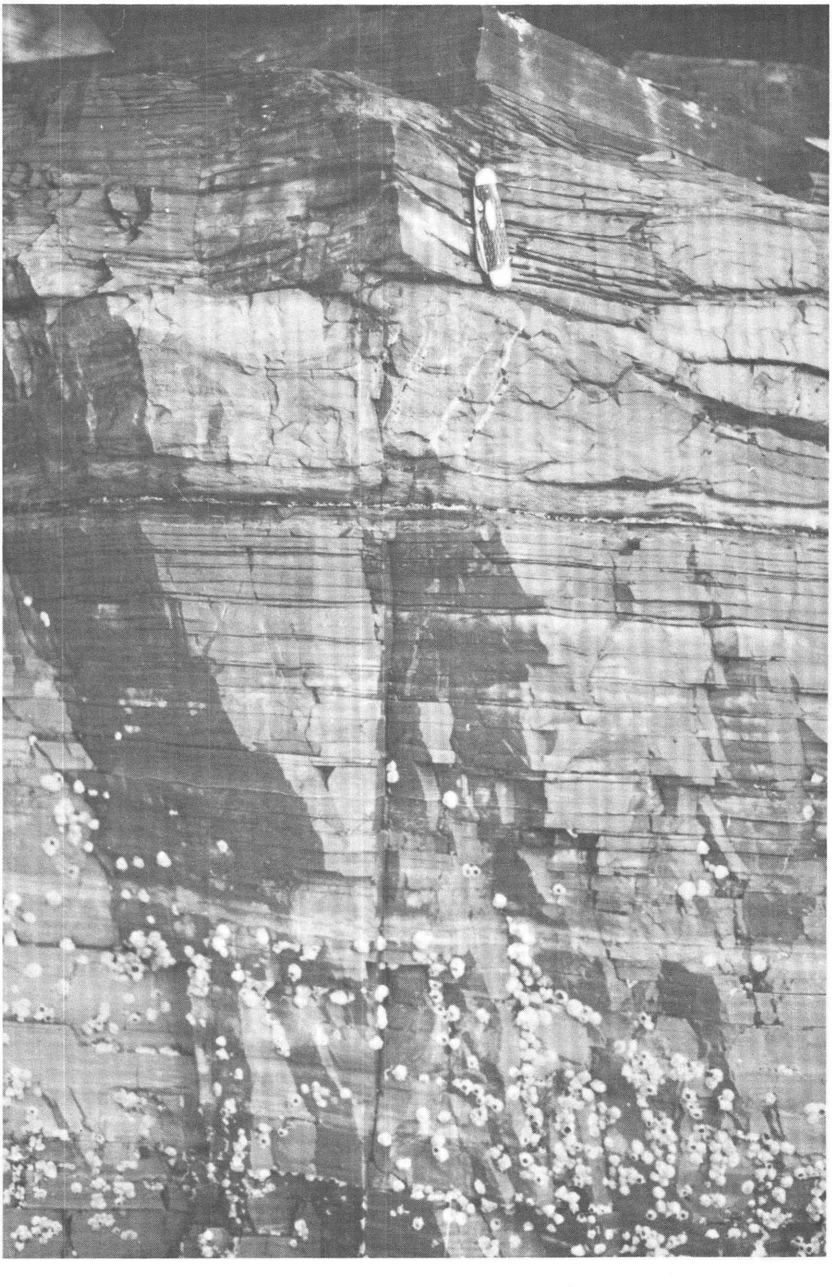

FIGURE 22.—Interbedded siltstone, graywacke, and shale of the Port Refugio Formation. East shore Ulloa Channel, 0.5 mile southeast of Waterfall cannery.

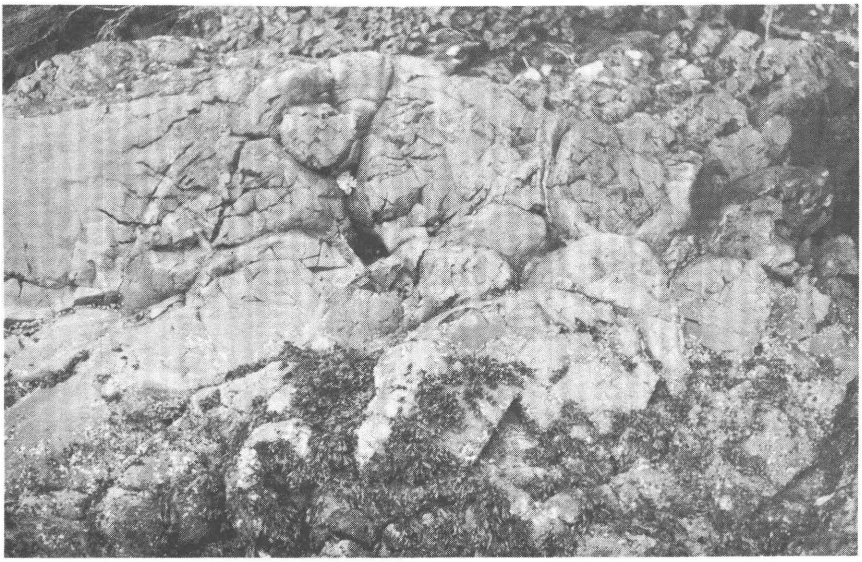

FIGURE 23.—Pillow structure in basaltic flow, Port Refugio Formation. East shore Ulloa Channel, 1.75 miles northwest of Waterfall cannery, Prince of Wales Island.

FIGURE 24.—Carbonate-cemented basaltic breccia, Port Refugio Formation. East shore Ulloa Channel, 1 mile southeast of Waterfall cannery, Prince of Wales Island.

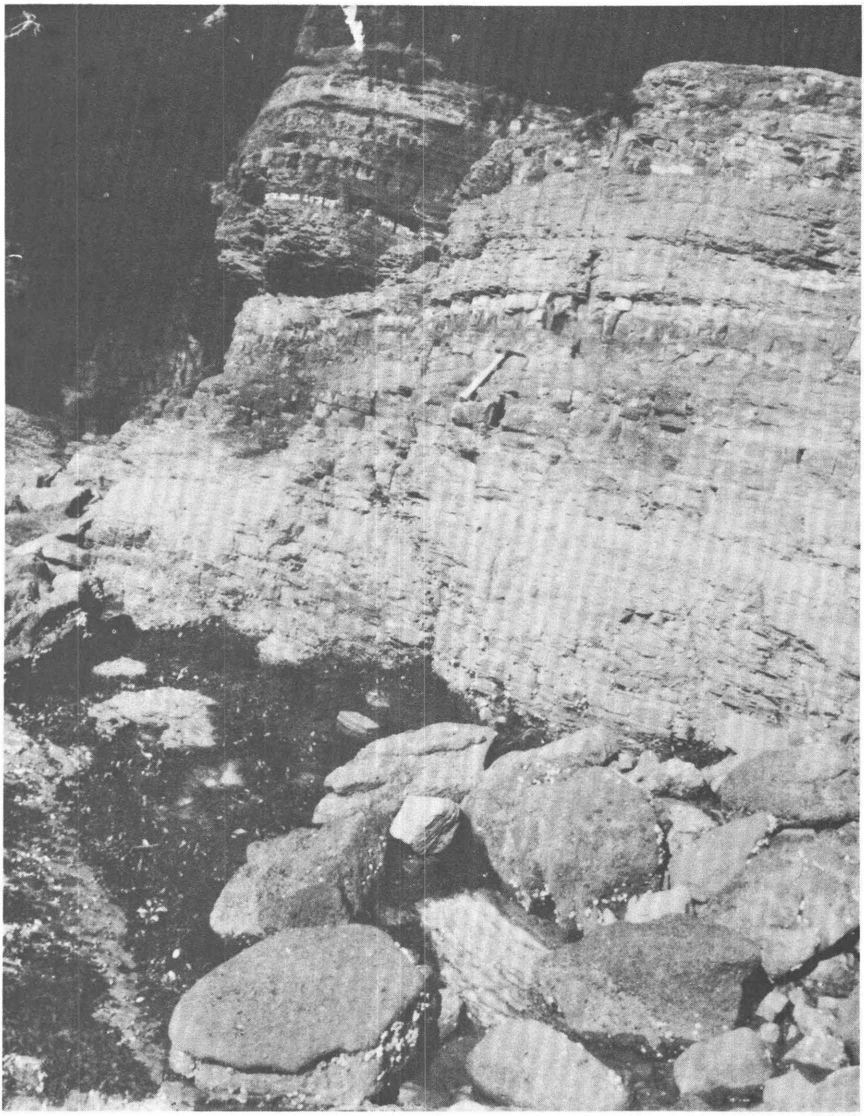

FIGURE 25.—Thin-bedded carbonate-cemented basaltic aquagene tuff interbedded with tuffaceous limestone. Uppermost part of Port Refugio Formation. Island 1 mile west of Shelikof Island, Tlevak Strait.

The Port Refugio Formation has only an occasional boulder of limestone in its conglomerates and a few tens of feet of limestone, much of which is silty and in places tuffaceous, interbedded in the otherwise detrital sedimentary and volcanic rock sequence. In Port Refugio this limestone is mostly medium bluish gray, silty, very thin bedded, and slabby and contains abundant brachiopods and fossil plants. A few feet of purer, more massive medium-dark-gray, in places pelletoidal, limestone is also associated with the silty limestone.

The thickness of the Port Refugio Formation is uncertain because the formation is tightly folded; but despite the presence of numerous folds, a thickness of several thousand feet is suggested by the lateral extent of the formation along Ulloa Channel.

STRATIGRAPHIC RELATIONS

The base of the Port Refugio Formation is not exposed. The only place where the Port Refugio may come in contact with older rocks is at the head of Trocadero Bay. Here the relations are uncertain because of extensive covered reaches of shoreline and the probability of large faults separating the Coronados Volcanics, and possibly the Descon Formation, from the Port Refugio Formation. It is likely that the Port Refugio Formation rests conformably on the Wadleigh Limestone and also that the Port Refugio is, in part, a lateral equivalent of the Wadleigh Limestone.

The Port Refugio Formation in the Shelikof Island area is overlain accordantly, and probably conformably, by thin-bedded dark-gray chert and limestone of the Peratrovich Formation. Here the upper part of the Port Refugio is aquagene tuff that has interbeds of tuffaceous limestone containing shelly fossils similar to those in the overlying Peratrovich Formation. Only a few tens of feet of cover obscure the contact itself. Near Point Bocas on the northeast edge of Suemez Island, the Port Refugio Formation is again overlain by the lower chert member of the Peratrovich Formation, but the contact here is covered and may be complicated by minor northwest-trending faults.

AGE AND CORRELATION

Stratigraphically the Port Refugio Formation is bracketed between the underlying, and possibly partly equivalent, Middle and Upper Devonian Wadleigh Limestone and the overlying Mississippian Peratrovich Formation. Very abundant and beautifully preserved brachiopods, mainly spiriferoids and rhynchonellids, were collected from silty limestone in Port Refugio (loc. 66ACn1662; head of the largest cove on northeast side of Port Refugio), and in a small cove (loc. 66ACn1672) facing Ulloa Channel some 2 miles north of Port Refugio. The brachiopods at loc. 66ACn1662 are associated with branching vascular plants. *Spirifer disjunctus*, along with several other diagnostic species, was first reported in Buddington and Chapin (1929, p. 108–109). A Late Devonian age was favored for the faunas in question.

The present writers, in the process of mapping, have greatly enlarged these old collections, and the current study of these fossils should enable a more precise dating and correlation of these rocks.

At Point Miliflores, the southeast tip of San Juan Bautista Island, wavecut benches expose massive thin-bedded argillaceous limestone that is very similar lithologically to the Wadleigh Limestone. The limestone also contains a fauna similar to the Wadleigh that is dominated by abundant horn corals, *Alveolites?* sp., *Syringopora* sp., branching *Favosites* sp., *Amphipora* sp., and atrypoid brachiopods. On the other hand, nearby San Juanito Island has well-bedded silty and sandy limestone with very abundant brachiopods resembling those in the typical Port Refugio Formation. The remainder of the shoreline of San Juan Bautista Island exposes graywacke, siltstone, and conglomerate resembling the typical Port Refugio Formation. The coralline limestone at Point Miliflores suggests that the Port Refugio Formation on San Juan Bautista Island may be in part a lateral equivalent of the Wadleigh Limestone.

On the basis of the paleontologic and stratigraphic information presently available, the Port Refugio Formation is assigned a Late Devonian age.

PERATROVICH FORMATION

The name Peratrovich Formation is here assigned to a sequence of fossiliferous limestone and dolomite, about 800 feet thick, containing nodules and beds of dark-gray chert, variable in amount but particularly abundant in its lower part. The type locality is on the southern end of Peratrovich Island about 1 mile north of the village of Klawock (loc. H, pl. 1). Southward the formation is exposed on Klawak Island, the east shore of Klawak Inlet, the island along the west side of Port Bagial, Toti Island, parts of Madre de Dios Island, the southern edge of the Ladrones Islands, and the long peninsula forming Point Bocas across from Waterfall cannery. Farther east the Peratrovich Formation forms Ridge Island, and most of several small islands just north of Ulloa Island. East of Tlevak Strait it underlies much of Shelikof Island and several smaller nearby islands.

In its type locality the Peratrovich Formation is exposed in a south-plunging syncline that is faulted on its east side. The Peratrovich here overlies the Devonian Wadleigh Limestone and underlies the Pennsylvanian Klawak Formation. The contacts seem to be accordant, although they are covered. Farther south, in the Soda Bay area, the base of the Peratrovich Formation overlies calcareous basaltic tuff at the top of the Port Refugio Formation with apparent conformity. In the Madre de Dios and Soda Bay areas, the upper limestone member of the

Peratrovich Formation is conformably overlain by the massive and dolomitic Ladrones Limestone of Pennsylvanian age.

Rocks herein assigned to the Peratrovich Formation have, earlier, yielded invertebrate faunas identified by Girty (in Buddington and Chapin, 1929, p. 110–112, 115–117) as Mississippian. He also recognized the fact that several of these early collections, especially those containing *Fusulina*, are "not without strong suggestions of Pennsylvanian time". These younger fusulinid-bearing beds are here included in the overlying Klawak Formation and Ladrones Limestone. Fusulinids are present, however, in the immediately underlying limestone member of the Peratrovich Formation; they are primitive *Millerella* sp. and are not detectable to the naked eye.

The Peratrovich Formation is predominantly a limestone composed of fossil fragments set in a limy mudstone matrix. The fossil fragments are mainly bryozoans and echinoderms; brachiopod, ostracod, and foraminiferal fragments also are present in some of the beds. The lower chert-rich parts of the Peratrovich have in places megafossils replaced by chert. The Peratrovich, on the basis of its general fauna and stratigraphic position, is definitely Carboniferous. Preliminary reports, made by Augustus K. Armstrong of the U.S. Geological Survey on detailed bed-by-bed fossil collections indicate that the Peratrovich Formation probably ranges from Early Mississippian (Kinderhookian or early Osagian) to Late Mississippian (Meramec and Chester) as indicated by the presence of *Millerella* sp. and *Bradyina sp.* (A. K. Armstrong, L. G. Henbest, and R. C. Douglass, oral commun., 1968).

The Peratrovich Formation has been separated into three map units—in ascending order; a chert member, a limestone and chert member, and a limestone member.

CHERT MEMBER

The chert member of the Peratrovich Formation forms the lower part of the formation wherever it has been recognized. The best exposures of the chert, where it seems to overlie the Wadleigh Limestone, are along the east shore of Klawak Inlet (fig. 26) and at Cape Suspiro. Here the chert member is a very thin bedded, grayish-black, nearly pure chert with some shaly partings and very rare lensoidal layers (¼–4 in. thick) of medium-dark-gray aphanitic limestone, dolomite, and crinoidal limestone. The chert and associated limestone are somewhat fetid. The only fossils present are articulate and inarticulate brachiopods and they are very rarely found. On Shelikof Island, where the chert member overlies aquagene tuff of the Port Refugio

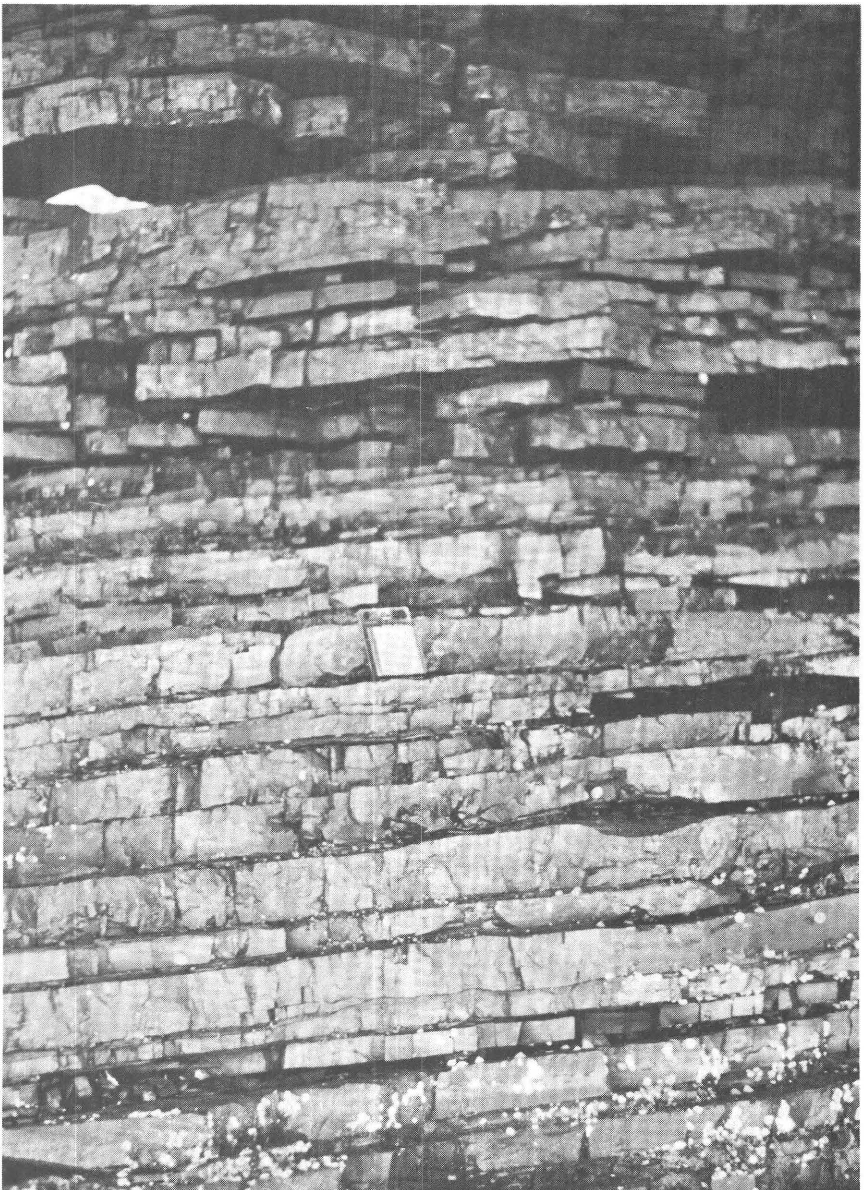

FIGURE 26.—Bedded chert with shale partings in the chert member of the Peratrovich Formation. West shore, Prince of Wales Island, 2.7 miles southwest of Klawock.

Formation, the chert has a higher proportion of interlayered fetid limestone and crystalline dolomite, is less evenly bedded, is nodular to irregular shaped (especially where it adjoins carbonate layers), and contains silicified crinoid columnals, brachiopods, and corals. The chert member seems to be most completely preserved in the Madre de Dios–Toti Islands area and on Shelikof Island, where it is about 200 feet thick.

The assigned age of the chert member, pending a more thorough study of its fossils, is Early Mississippian according to A. K. Armstrong (oral commun., 1968).

LIMESTONE AND CHERT MEMBER

The chert member at the base of the Peratrovich Formation grades up into the middle member of the formation, which is characterized by subequal amounts of limestone interlayered with black chert. Rocks of this unit are especially well exposed on Toti Island (fig. 27). The lower contact is arbitrarily set; sections in which limestone or dolomite form 25 percent or more of the total are assigned to the limestone and chert member, whereas those in which carbonate forms less than 25 percent are assigned to the underlying chert member.

The limestone of the middle member is a generally medium- to very thick bedded, massive, medium-gray to medium-dark-gray fragmented-fossil limestone. Most of the fossil fragments occur in a lime mudstone matrix and consist of bryozoans and echinoderms, with lesser amounts of spiriferoid and productoid brachiopods and both solitary and colonial corals. Rarely there are thin shaly interbeds, but most of the member, excluding the black chert layers and nodules, is relatively pure limestone. In a few places the limestone is dark gray, fetid, and thinly interbedded with irregular layers of black chert.

The thickness of this member seems to decrease southward from about 450 feet in the type area to about 300 feet on Shelikof Island.

Armstrong has found that the upper part of the underlying chert member and the lower 75 feet of the limestone and chert member contain a sparse foraminiferal fauna of *Septaglomospiranella* sp., *Septabrunsiina* sp., and *Endothyra* sp.; their presence indicates an Early Mississippian (Osage) age. The upper half of the limestone and chert member contains a coral fauna of which the following species are characteristic: *Lithostrotionella banffensis* (Warren), *L. pennsylvanica* (Shimer), *L.* (*Siphonodendron*) *multabile* (Kelly), *Thysanophyllum astraeiforme* (Warren), and new species of *Diphyphyllum*, *Sciophyllum*, *Ekvasophyllum*, and *Faberophyllum*. Also within this zone is a fauna of Foraminifera of which *Tournayella discoidea* Dain, *Septatournayella kennedyi* Skipp, Holcomb, and Gutschick, and a

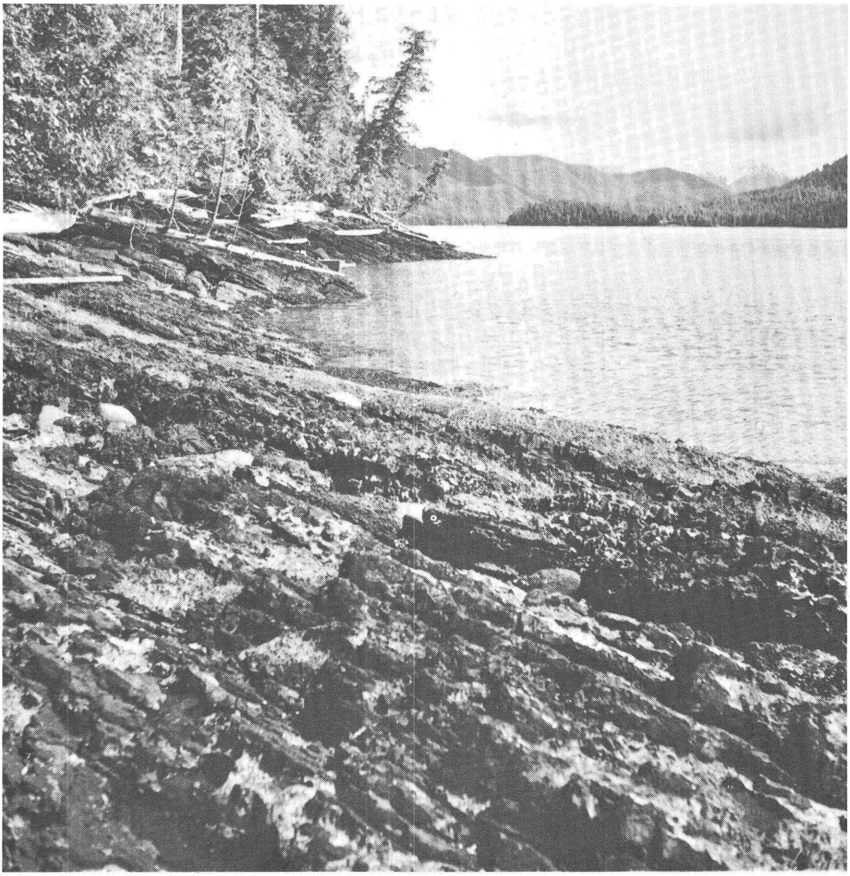

FIGURE 27.—Interbedded black chert and fragmented-fossil limestone of the basal part of the limestone and chert member, Peratrovich Formation. Southeast tip of Toti Island.

number of species of endothyrids are present in the member. For the upper half of this member, the corals and Foraminifera indicate a Late Mississippian (Meramec) age, according to Armstrong (1969).

LIMESTONE MEMBER

The limestone member is well exposed around the south tip of Peratrovich Island. The limestone member is also exposed in two salt chucks on Peratrovich Island, in the Madre de Dios Island group, and in the Shelikof Island area.

The limestone member of the Peratrovich Formation is a very thick to thick-bedded massive limestone, dolomitic limestone, and dolomite containing less than 25 percent, at most places less than 10 percent, of black chert nodules and lenses. The limestone is medium dark gray to medium gray, medium to fine grained, and is composed largely of echinoderm and bryozoan fragments, with varying amounts of limy mudstone matrix. The limestone texture in detail is predominantly clastic grains in contact with one another and cemented by subordinate aphanitic limestone.

On Peratrovich Island the upper contact of the limestone member of the Peratrovich Formation with the overlying Klawak Formation is concealed by a small covered interval at the outlet of the large salt chuck on Peratrovich Island. Here the uppermost part of the limestone member consists of pure, massive fragmented-fossil limestone that contains only a very few chert nodules. The basal part of the overlying Klawak Formation, on the other hand, is a very thinly interbedded and laminated sequence of chert, siliceous shale, and somewhat calcareous siltstone. The limestone member seems to be about 250–300 feet thick throughout the area.

Farther south in the Madre de Dios–Ladrones Islands group and in the Shelikof Island area, massive limestone at the top of the Peratrovich Formation is overlain by the Ladrones Limestone of somewhat similar lithology; however, the proportion of clastic grains in the Ladrones Limestone to aphanitic limestone cement is much lower than in the Peratrovich Formation. The grains generally are not in contact with one another and appear to be floating in a lime-mud matrix. The Ladrones is also characterized by much lighter gray, nearly white, patches of chert, minor dolomite, and dolomitic limestone and contains larger and morphologically more complex fusulinids.

Armstrong (1969) reported that the lower part of the limestone member contains a foraminiferal and *Lithostrotionella* sp. fauna of Meramec age, whereas the high beds of the member contain a microfauna of endothyrids and the primitive fusulinid *Millerella* sp. of Chester age. He therefore considers the limestone member to be Late Mississippian (Meramec and Chester) in age.

KLAWAK FORMATION

The Klawak Formation is exposed along the axis of a broad syncline that plunges southward from the northeast end of Peratrovich Island and includes widely separated exposures of the formation in the vicinity of Klawock and along the Klawak River. The best exposures of the Klawak, designated the type locality, are on small islands and along the shoreline of the fiord trending north from Klawock to near the south entrance of Big Salt Lake (loc. I, pl. 1).

LITHOLOGY, STRATIGRAPHIC RELATIONS, AND THICKNESS

Lithically and faunally the Klawak Formation is readily separable from all the other formations. The Klawak Formation is chiefly calcareous siltstone and sandstone or silty and arenaceous limestone (fig. 28) with occasional interbeds of nearly pure fragmented-fossil limestone (fig. 29). Well-rounded chert pebbles are scattered in some limestone beds, but they are more abundant in the uppermost exposed beds of the formation and there form beds of chert pebble conglomerate (fig. 30). Most of the siltstone and sandstone is a medium-gray to medium-dark-gray, distinctively orange-weathering thin-bedded slabby rock, with widely varying amounts of calcareous cement. The

FIGURE 28.—Well-bedded arenaceous limestone 30 feet stratigraphically below the highest exposed beds of the Klawak Formation. Small island 1.5 miles north-northeast of Klawock, west coast of Prince of Wales Island.

FIGURE 29.—Interbedded fragmented-fossil limestone and siltstone near the middle of the Klawak Formation. Small island 1.5 miles north-northeast of Klawock, west coast of Prince of Wales Island.

finer grained beds are generally laminated and in most places exhibit abundant trails, burrows, and other indications of the distinctive trace fossil *Spirophyton.* Graded bedding and crossbedding are readily apparent in many of the sandy and pebbly beds. A peculiar type of symmetrical convolute bedding is developed in the upper half of sandy limestone beds exposed in islets 1 mile northeast of Klawock (fig. 31).

Nearly pure limestone interbeds are rare and are only several, or at the most, a few tens of feet thick. These limestones are generally fine grained, thin to medium bedded, and medium dark gray to dark gray.

The lowest beds in the Klawak Formation are exposed at the entrance to the large salt chuck on Peratovich Island. There a black to light-

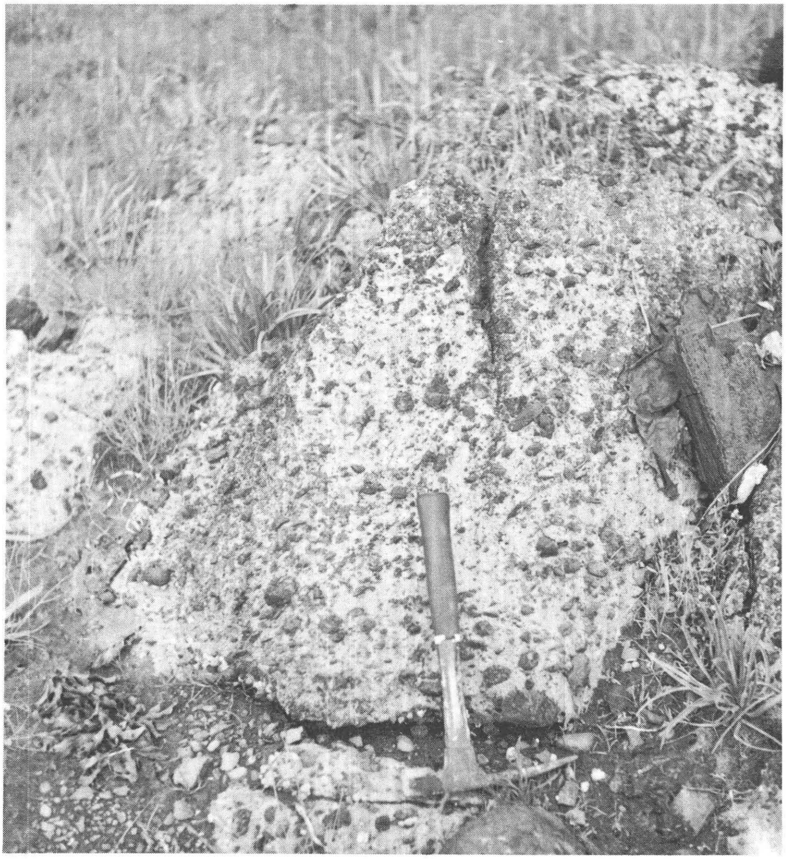

FIGURE 30.—Chert-pebble-rich, fusilinid-bearing fragmented-fossil limestone constituting the uppermost exposed beds of the Klawak Formation. Small island 1.5 miles north-northeast of Klawock, west coast of Prince of Wales Island.

gray sequence of about 100 feet of very thin bedded to laminated siliceous shale, chert, and calcareous siltstone overlies, with apparent conformity, the limestone member of the Peratrovich Formation. The upper contact of the Klawak, however, is unknown, because the syncline in which it forms the trough is faulted and obscured by large dioritic intrusions to the south and east, where younger beds could be expected. Thus the thickness of the Klawak Formation is uncertain especially since it is internally faulted and folded. Although the maximum continuous section exposed anywhere is less than 200 feet, the formation is probably about 500–1,000 feet thick.

FIGURE 31.—Convolute bedding developed in upper part of sandy limestone bed, Klawak Formation. 1 mile northeast of Klawock.

AGE AND CORRELATION

The Klawak Formation, especially its purer limestone beds, has abundant shelly fossils preserved in various stages of abrasion and fragmentation. Especially abundant are productoid brachiopods, solitary and colonial corals, fenestellid bryozoans, and crinoid fragments. Besides these fossils, which are also common in the underlying Peratrovich Formation, the Klawak Formation contains abundant fusulinids, especially in its sandy and pebbly limy beds. The only other unit in the area known to contain abundant fusulinids is the contemporaneous Ladrones Limestone farther south.

Earlier fossil collections made from rocks now included in the Klawak Formation were identified by Girty (in Buddington and Chapin, 1929, p. 113, 115–117), who recognized that *Fusulina* and other fossils had "strong suggestions of Pennsylvania age", but who grouped them into the Upper Mississippian together with all the Carboniferous fossil collections from rocks now mapped as the Peratrovich Formation. Girty recognized, however, that the Alaskan faunas differed widely from Mississippian faunas known then from the conterminous United States. He also noted the resemblance of some of the Alaskan species to those described from the Gschelian Stage of Russia.

The presence of fusulinids in the Klawak indicates that the formation is either Pennsylvanian or Permian. The small size and fairly simple structure of the fusulinids suggest they are Pennsylvanian rather than Permian. On the basis of a preliminary study of associated brachiopods and corals, A. K. Armstrong (oral commun., 1967) believes the Klawak is unquestionably of Early Pennsylvanian age. Furthermore, the presence of similar fusulinid species in the upper parts of the Klawak Formation and Ladrones Limestone suggests that these formations are of the same age. Thus, the Klawak Formation is assigned to an Early Pennsylvanian age.

LADRONES LIMESTONE

The name Ladrones Limestone is here applied to massive-bedded limestone exposed on the Ladrones Islands, designated the type locality, between Bucareli and Trocadero Bays (loc. J, pl. 1). Rocks assigned to the formation are also exposed in the Madre de Dios Island area, on several small islands at the north entrance to Tlevak Strait, and on the northwest shore of Shelikof Island.

LITHOLOGY, STRATIGRAPHIC RELATIONS, AND THICKNESS

The Ladrones Limestone is sublithographic, thick to indistinctly bedded, massive, and is medium gray to olive gray and weathers light gray. It is relatively pure and generally lacks chert and noticeable quantities of terrigenous detritus. The lower 300 feet is composed of aphanitic limestone with scattered fragments of bryozoans, echinoderms, and rare brachiopods. The upper 600 feet of the formation is similarly aphanitic, but the limestone contains interbeds of calcarenite composed of pellets, oolites, endothyroid foraminifera, fusulinids, and small fragments of shelly fossils. These sand-sized fossil fragments, pellets, and oolites are cemented together by aphanitic limestone with such a low ratio of grains to cement that many of the grains appear to be "floating" in the predominantly lime-mud matrix. The upper half of the formation also contains some thinner and more distinctly bedded limestone with well-preserved productoid brachiopods, corals, and calcareous algae.

The Ladrones Limestone on the northwest coast of Shelikof Island and on the nearby smaller islands farther west differs from that in the type area by containing conspicuous nodules and lenses of chert. Unlike the grayish-black chert of the Peratrovich Formation, the chert is generally light gray and contains relics of fusulinids and oolitic structures. Massive limestone possibly separates the Ladrones Limestone from the Peratrovich Formation in the Shelikof Island area.

This limestone is similar to that of the type Ladrones but contains subordinate amounts of interbedded fine-grained crystalline dolomite and dolomitic limestone and a fossil fauna characteristic of the Peratrovich Formation. More work is needed in the vicinity of Shelikof Island to determine the exact stratigraphic succession.

The contact between the Ladrones Limestone and the underlying Peratrovich Formation seems to be conformable and transitional. The top of the Ladrones is not exposed, but field geologic mapping indicates that the formation is at least 1,000 feet thick.

AGE AND CORRELATION

The age of the Ladrones Limestone—based on the presence of small Early Pennsylvania fusulinids in its type area (R. C. Douglass, oral commun., 1968) and a preliminary study by Augustus K. Armstrong of its endothyroid foraminifers, corals, and brachiopods—is considered to range from Early Pennsylvanian to early Middle Pennsylvanian. It thus seems to be at least in part coeval with the Klawak.

Exposures of fusulinid-bearing pelletoidal limestone on a group of small islands just north of Ulloa Island resemble the Peratrovich Formation by their dark-gray color and dark nodular chert. It is still uncertain to which formation these rocks should be assigned.

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