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THE GEOLOGY OF THE SAN JUAN ISLANDS

by

ROY DAVIDSON McLELLAN

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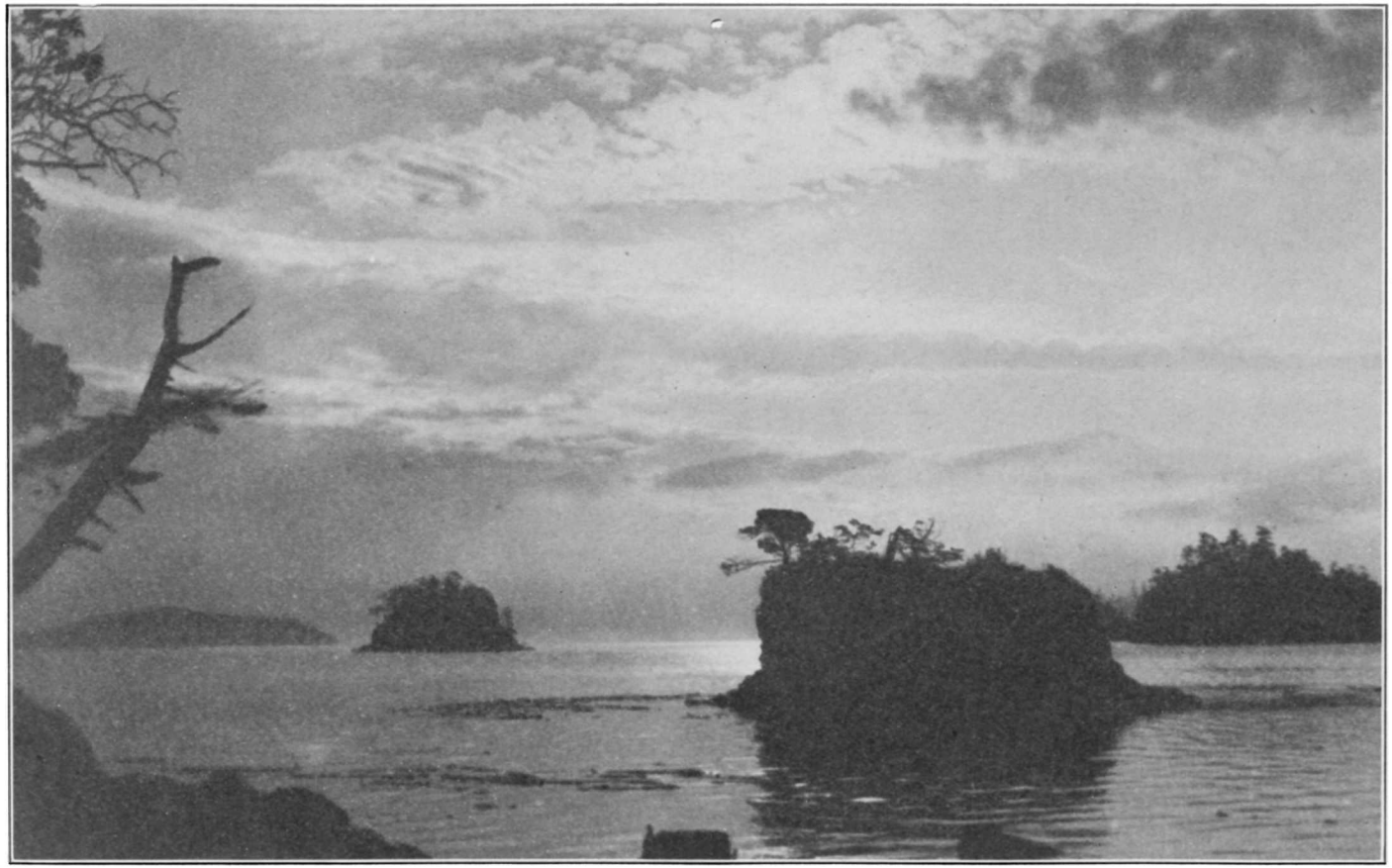

PLATE I
The Cone Islands.

Photograph by A. O. McCormick.

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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THE GEOLOGY OF THE SAN JUAN ISLANDS

THE GEOLOGY OF THE SAN JUAN ISLANDS

INTRODUCTION

LOCATION AND AREA OF THE REGION

In a restricted sense the San Juan Islands consist only of the area included within San Juan County, Washington. To the eastward occur islands belonging to Skagit and Whatcom Counties, and these are commonly regarded as a part of the San Juan Island group. The area considered in this report includes the American islands located within Washington Sound. The center of the map-area can be located by the point of intersection of the 123rd meridian of west longitude with the north latitude line of 48° 30′.

The San Juan Islands are bounded on the west by the waters of Haro Strait and Boundary Pass which serve as the International boundary line. Still farther westward lies Vancouver Island and the smaller Canadian islands which fringe its eastern margin.

The San Juan Islands were first surveyed and divided into townships in 1874 and 1875. During the years 1888 to 1897 the islands were accurately surveyed by the United States Coast and Geodetic Survey. The results of this survey are shown in reduced scale in the United States Coast and Geodetic Survey chart No. 6380. Corrections as well as new data have been added to this chart from year to year and its accuracy has been thereby increased and kept up to date.

The region included in this report embraces an area of land and water 33 miles long and 27 miles wide, or an approximate surface of 890 square miles. The waters of the map-area are dotted with islands, some large and mountainous while others are small and covered by water at high tide. A careful count of all the isolated land areas exposed at lower low tide, revealed no less than 786 islands and reefs within the map-area, 743 of which occur in San Juan County. At high tide the number of island masses is only 457, with 428 within San Juan County. These are grouped into approximately 175 islands and reefs of sufficient importance to warrant individual names.

A list showing in detail the areas of the islands of the San Juan group is found on page 178.

The total amount of land included in the map-area is 206 square miles. It includes 175 square miles or all of the land area of San Juan County, together with about 10 square miles belonging to Whatcom County and 21 square miles belonging to Skagit County. Although Samish Island has an area of 931 acres, but 234 acres are included in the map-area.

FIELD WORK AND ACKNOWLEDGMENTS

During the summer of 1922 the writer spent two months in the field doing reconnaissance work and making a systematic collection of rock samples and fossils. The following winter was occupied in preparing and examining thin sections of the samples.

During the summer of 1923 he spent four months in the field examining the formations in more detail and making more extensive collections of fossils, several new localities having been discovered. Late in the autumn of that year the writer made a brief examination of the formations on Vancouver Island from Nanaimo to Victoria. Several short trips to the San Juan Islands were made during the following winter to re-examine certain areas in more detail.

The entire area was again covered during the summer of 1924 when three months were spent in the field. Additional collections of rocks and fossils were made and certain areas were further studied. Short trips to the San Juan Islands were made during the following winter, and also during the spring and summer of 1925, in order to study again certain problems in the structural geology of the region.

The writer wishes to thank the members of the Puget Sound Biological Station for the many courtesies extended to him.

For helpful suggestions in connection with the igneous geology of the region, he wishes to express his indebtedness to Professor George E. Goodspeed, Jr. He wishes to acknowledge the assistance received from the late Professor Edwin J. Saunders on problems dealing with the glacial geology of the map area. For helpful suggestions regarding the correlation and nomenclature of certain sedimentary rock formations, he wishes to express his indebtedness to Dr. Charles E. Weaver and Professor M. A. Hanna.

For helpful suggestions in the compilation of this report, especial thanks are due to Dr. Charles Schuchert of Yale University, and to Dr. T. W. Stanton of the United States National Museum. The writer wishes to express his appreciation of the many helpful suggestions received from Dean Henry Landes, under whose direction the work was carried out.

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OUTLINE OF THE GEOGRAPHY AND THE GEOLOGY

The San Juan Islands consist of an archipelago situated in that body of water known as Washington Sound, which separates southern Vancouver Island from the mainland to the east. The islands represent the highest points of a submerged mountain range that connects Vancouver Island with the mainland, and forms the southern boundary of the Gulf of Georgia.

The complex systems of channels and harbors composing Puget Sound and

Washington Sound are supplied with ocean water by the Strait of Juan de Fuca. The major portion of the enormous volume of water that flows in and out of the Gulf of Georgia at every tide is derived from the southward, and therefore it must pass through the channels surrounding the San Juan Islands. Very heavy tide-rips are consequently produced in many of the channels.

For the most part the individual islands are rugged and mountainous. The map-area includes 15 mountain peaks with elevations exceeding 1000 feet, and these are typically located near the shore-lines and rise precipitously from the water's edge. Where sufficient soil permits, the more elevated portions of the islands are heavily wooded, especially on their northern slopes.

The islands usually present irregular shore-lines deeply indented by narrow fjord-like harbors. The intervening channels, which are commonly narrow and U-shaped due to glacial erosion, often attain depths of 600 feet, and occasionally exceed 1000 feet in depth.

The San Juan Islands range in size from that of Orcas Island with approximately 57 square miles, to that of the smallest reefs which are scarcely awash at low tide. The majority of the islands have an area of less than one-quarter of an acre.

The nucleus of the San Juan Island group is formed by Orcas, San Juan, and Lopez islands. These large islands are bounded on the west by Haro Strait and Boundary Pass, which contain the smaller islands belonging to the Stuart Island and Waldron Island groups. On the south the whole San Juan Island group is bounded by the open waters of Washington Sound and the Strait of Juan de Fuca. The nucleus of the San Juan Island group is separated from the mainland to the east by the waters of Rosario Strait, which contain Cypress, Guemes, Lummi, Sinclair, and other lesser islands and reefs. The San Juan Island group is bounded on the north by the Gulf of Georgia, which contains the small islands, Patos, Sucia, Matia, Barnes, and Clark, together with several smaller islands and reefs that fringe the northern shores of Orcas Island.

A large number of islands and reefs occur in the channels separating Orcas, San Juan, and Lopez islands. The largest of these, Shaw Island, has an area of nearly 5000 acres.

San Juan Island is separated from Lopez, Shaw, and Orcas islands, by the waters of San Juan Channel. The narrows occurring at the southern entrance of San Juan Channel were originally given the name of Little Belt Passage. This name has fallen into disuse and it is now known as Cattle Point Narrows.

A narrow channel trending east and west, separates Shaw and Orcas islands. This is called Harney Channel. Shaw Island is separated from Lopez Island by Upright Channel which trends northeasterly and blends with Harney Channel. Still farther eastward these combined channels merge into Lopez Sound and East Sound at their common meeting point.

Orcas Island is nearly cut into two islands by the narrow fjord-like harbor known as East Sound, which opens towards the south and merges with

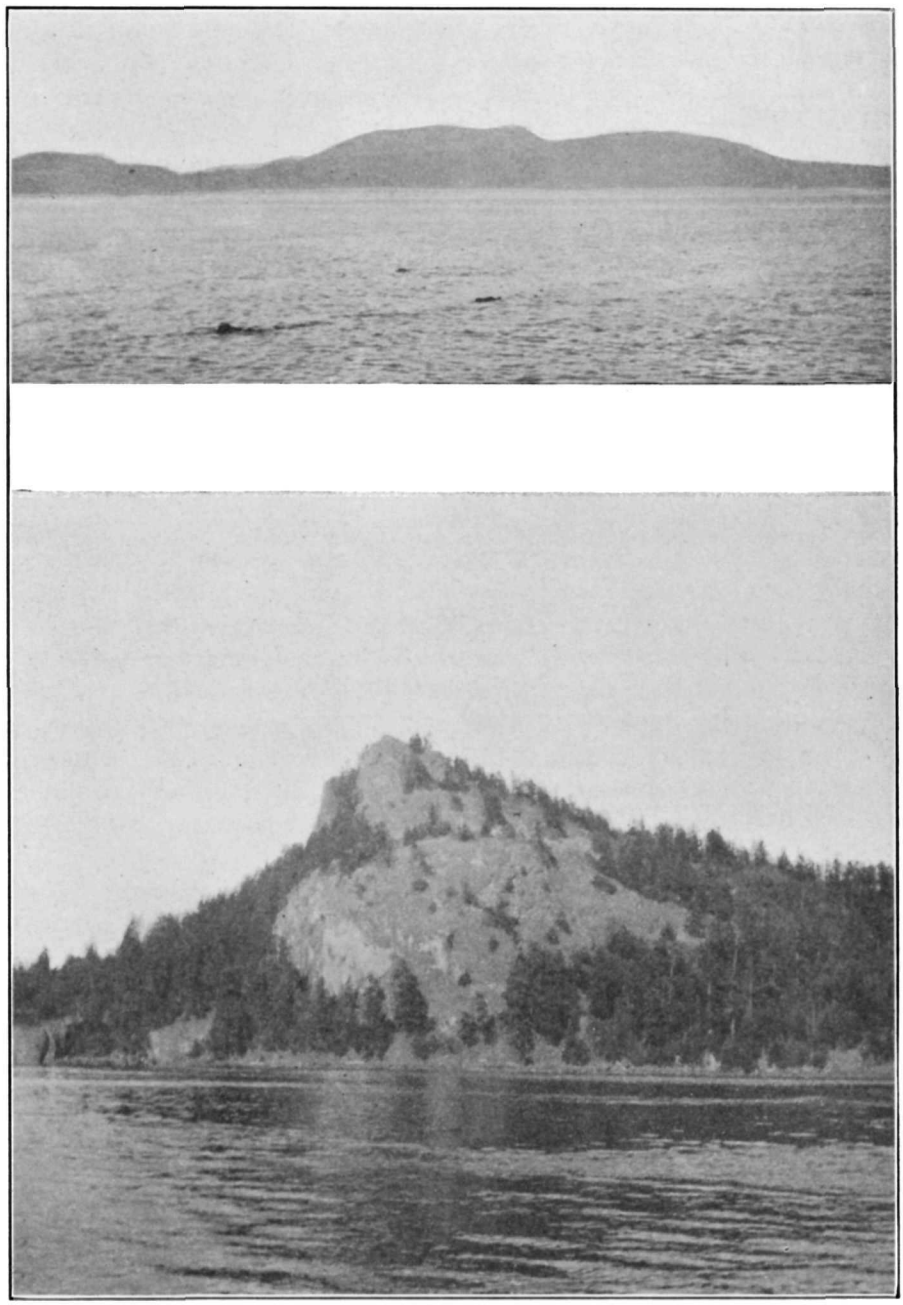


PLATE II

Above: The eastern lobe of Orcas Island as seen from Cypress Island. At the extreme left is Mount Entrance, in the center is Mount Constitution, and to the right is Mount Pickett. *Below*: Eagle Cliff, Cypress Island.

Lopez Sound, a somewhat similar depression with a general north-south trend that penetrates the northern margin of the Lopez Island landmass. The land occurring on the east side of Lopez Sound has been penetrated by several narrow channels connecting directly with Rosario Strait, and consequently the eastern shore of Lopez Sound is formed by Lopez Island only near the southern end, while farther north its place is taken by Decatur, Blakeley, and Obstruction Islands.

The San Juan Islands are composed chiefly of Paleozoic and Mesozoic sedimentary rocks, the former having been intruded and metamorphosed by igneous rocks of Mesozoic age. The Paleozoic strata, which include the bulk of the sedimentary rocks of the region, have been folded into a broad syncline that plunges towards the eastward or southeastward at a moderate angle. The structure of these rocks has been greatly complicated by later folding and faulting.

In the eastern part of the map-area, large irregular masses of peridotite have been intruded into the Paleozoic sedimentary rocks. The Paleozoic sedimentary strata in all parts of the map-area, have been almost everywhere intruded by a series of dikes and sills of basic igneous rocks that apparently served as feeders to flow rocks that have since been removed by erosion.

Some parts of the map-area have suffered further from the intrusion of a series of igneous off-shoots derived from the late Jurassic batholith that is now exposed along the shore of Vancouver Island to the west of the San Juan Island map-area. The intrusion of these off-shoots into the strata that were already shattered by folding and previous intrusions of igneous materials, took the form of an injection breccia. This injection breccia was composed of igneous rocks, both acid and basic, and these now occur intermingled with the older igneous materials, and occasionally remnants of the sedimentary host rocks are to be seen.

The islands forming the northern and northwestern margins of the map-area are composed of closely folded though unmetamorphosed sedimentary rocks of late Mesozoic and early Tertiary age. Within the map-area these sedimentary rocks have not been intruded by any igneous materials.

The islands have been completely overridden by glaciers and even the top of Mount Constitution is deeply striated and polished by glacial action. Considerable areas on many of the islands are covered with glacial drift and several excellent examples of recessional moraines occur within the map-area.

The latest geological movement appears to have been a general uplift, and excellent examples of recently upraised wave-cut benches are to be seen in many places at elevations of about 20 feet or higher.

During the winter season the great storm waves that otherwise would be very effective agents of erosion, are broken up by the interference of the tide-rips, and it is only at slack tide (particularly near the time of high tide, when the tide-rips are not active) that the storm waves are free from such interference. (See Plate IX). As a result, a remarkably well developed wave-cut bench near high tide-level is encountered on all exposed shores throughout the region.

TOPOGRAPHY

RELIEF

The San Juan Islands owe their origin to the partial submergence of a mountain range that crosses Washington Sound in a northwesterly direction. The higher points of the range constitute the islands and reefs, while the valleys and ravines form the channels and harbors. Due to the fact that many of the latter have been greatly modified by glacial erosion, they may be considered as fjord-like in character.

The surface of the region is marked by its abrupt changes in elevation. The maximum point above sea-level is found on Mount Constitution with an altitude of 2409 feet. The deepest sounding recorded in the map-area occurs in Haro Strait near Stuart Island, with a depth of 1356 feet below sea-level. The San Juan Island region therefore presents an extreme relief of 3765 feet.

ISLANDS

ORCAS ISLAND

Orcas Island, the largest island of the archipelago, has an area of 56.92 square miles. In general its shape is that of a trapezoid whose northwest and southeast sides are nearly parallel and trend about N 45° E. The northeast shore-line, which follows the strike of the rock formations, is quite free from harbors or other irregularities. It trends N 60° W. The south side, which trends approximately east and west, differs from the other three sides in the fact that its shore-line is extremely irregular, being penetrated by three long narrow harbors or sounds.

Orcas Island is cut into two almost equal parts by a narrow and deep depression averaging nearly a mile in width, which trends about N 30° W. Excepting for a distance of one and one-fourth miles at its northern end, this valley is filled with sea-water known as East Sound. The depth of water throughout the submerged eight miles of its course is quite constant and it averages around 90 feet.

A considerable part of the land area at the northern end of East Sound is even now below sea-level, the sea being held back by wave-built sand bars. A submergence of 20 feet would cause Orcas Island to be divided into two islands of nearly equal size.

A second long narrow harbor known as West Sound penetrates the southern shore of the island about three and one-half miles west of East Sound. It is nearly a mile in width and its length is about four miles. At its northern end it is divided into two bays by an elevated spur of land sloping down from Ship Peak, a portion of the Turtleback Range. West Sound trends about parallel to East Sound. Its bed is shallow and rocky at its northern end, but its depth increases steadily and uniformly until, at the entrance, it is about 180 feet deep.

The peninsula to the west of West Sound is cut by a third and much smaller indentation known as Deer Harbor. It is about one and one-half miles long with its east shore trending parallel to West Sound, while the other side trends northeasterly and causes the harbor to have the shape of a blunt wedge that opens towards the southward. At its northern end, Deer Harbor, after narrowing down to a width of a few feet, opens out into a broad shallow lagoon. A small though deep bay occurs on the west shore of Deer Harbor, and a narrow valley, 50 to 100 yards wide, extends northwesterly from it and crosses to the west shore of Orcas Island.

Deer Harbor is shallow and sandy near its eastern margin. The deepest part of the harbor lies near the western shore and the depth increases rapidly to the south of Fisherman Island until, near the southwest entrance to the harbor, the depth is about 100 feet.

The narrow peninsula between West Sound and Deer Harbor is partly covered with glacial drift, but the old metamorphic rocks outcrop along nearly all parts of the shore-line at tide level. Elevations up to 200 feet may be found in this area.

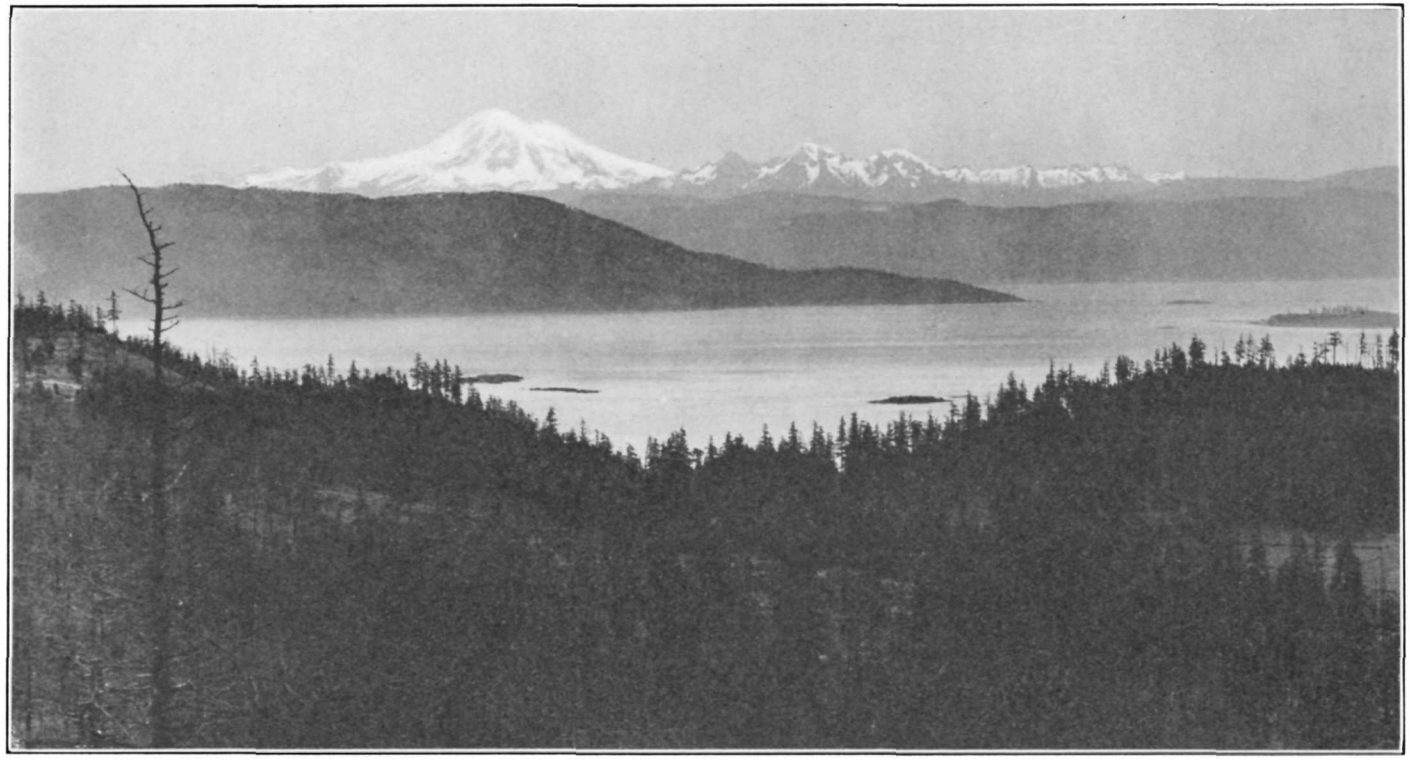
The elevation which forms the peninsula to the west of Deer Harbor continues northward as a subdued ridge with an average elevation of 300 feet, until it reaches the precipitous slopes of Orcas Knob. This region has been strongly glaciated but little or no mantle rock now covers the rounded hills. Here and there a poorly drained swamp or peat-bog may be found in the depressions carved out of the solid rock by the glaciers.

To the northward a dome-shaped hill known as Orcas Knob (the head of the "turtle") rises abruptly to an elevation of 1050 feet. It is separated from the Turtleback Range by the narrow divide which continues southward to form West Sound. The Turtleback Range extends northward from Haida Point on West Sound, and continues as far north as Kimple Beach, a distance of three and one-half miles. Turtleback Mountain, the summit of the range, is a broad, flat and heavily wooded upland with a maximum elevation of 1497 feet.

The Turtleback Range is quite steep on the east and north sides, but its southern slopes are somewhat more gentle. Its most southern prolongation, known as Ship Peak, has an elevation of 900 feet and it slopes down towards West Sound. The slopes of the Turtleback Range are either bare and rocky, or they contain only the thin layer of soil necessary to support the forests that grow upon them.

Near the northwest extremity of East Sound there is a small group of rocky hills known as the Double Hill Range, which trends in a northeasterly direction. Lookout Mountain, the highest point on the range, has an elevation of 680 feet.

The Double Hill Range is steep and precipitous on the southeast side but in every other direction its slopes are more gentle. To the northward a drift-covered ridge extends out from the base of the range and continues as far as



Photograph by J. A. McCormick.

PLATE III

Looking eastward from Mount Entrance. The Rosario Strait and the south end of Lummi Island in the middle background; Mount Baker and the Cascade Range in the distant background.

the north shore of the island. A long rocky and elevated ridge extends out from the northwest corner of Orcas Island to form Point Doughty. At a distance of about one and one-half miles to the southward another rocky point projects from the northwest side of the island to form Point Kimple.

The Double Hill Range is separated from the Turtleback Range by a valley that is almost a mile wide. To the westward this valley extends down towards Kimple Beach.

Extending southwestward from East Sound, near the base of Lookout Mountain, there is a broad valley of low elevation. This valley continues on to West Sound, being flanked on the west by the steep slopes of Turtleback Range. Its eastern margin is not so well defined but its average width is about a mile. To the southeast it is bounded by the group of hills that belong to or surround Mount Woolard Range.

The peninsula located between East Sound and West Sound is covered with a complicated group of hills and valleys. Some of these valleys were carved out by the glaciers, others follow the strike of the rock formations, while still others owe their existence to the presence of fracture or fault zones.

Near the west shore of East Sound, about a mile south of Lookout Mountain, there is a group of rocky hills with a maximum elevation of 400 feet.

The highest elevation in the southern part of the peninsula is found on Mount Woolard, which is 1180 feet in height. On its north and east sides, Mount Woolard is steep and precipitous, but it slopes more gently towards the southwest. To the northward there are several lesser ridges and dome-shaped hills, one of which has an elevation of 800 feet. A large limestone ledge is located on a long ridge situated about a mile north of Mount Woolard.

A valley extends along the southwest side of Mount Woolard and continues southward towards Grindstone Harbor. It is joined by another valley connecting with Orcas Bay. The region to the west of this valley is heavily wooded, excepting in the valleys that are under cultivation, and some of the hills have elevations up to 500 feet.

To the southeast of Mount Woolard there is another high rocky hill known as Diamond Hill, which has an elevation of 1020 feet. It is somewhat dome-shaped though its major axis trends in a northeasterly direction.

The depression between Mount Woolard and Diamond Hill is about half a mile wide, and its elevation at the middle of the divide is about 500 feet, though it slopes rapidly to the southward and continues on towards Grindstone Harbor. The valley contains a small lake, known as Killebrews Lake, which has an elevation of about 250 feet.

The eastern lobe of Orcas Island is more rugged than the western portion. Extending up from the lowland that lies to the north of East Sound, there is a rocky dome-shaped mountain known as Buck Mountain, which has an elevation of 1383 feet. To the southeastward it is connected with Mount Constitution Range by means of an elevated ridge, the elevation of which is only slightly lower than the top of Buck Mountain. A broad ravine extends

towards the southwest and separates Buck Mountain from the western part of Mount Constitution Range. A small lake, known as Buck Lake, is situated on the lowest point along the crest of the divide.

The Mount Constitution Range has the form of a truncated dome with a summit that is broad and relatively flat. Its slopes are usually quite steep and precipitous, but in places, particularly on the south side, its flanks grade off at a more gentle angle. The elevated upland at the top of Mount Constitution Range, which is more than a mile in diameter, has a gently undulating surface that is heavily wooded where sufficient mantle rock is present to support such vegetation. Several large bogs containing sphagnum moss are located in depressions carved out of the solid rock by glacial erosion. Mount Constitution, the summit of the range, is located at the extreme northeast margin of the elevated upland and its altitude is 2409 feet.

From an elevation of about 1400 feet a rocky spur extends southwestward from Mount Constitution Range and continues toward East Sound. Near the shore of East Sound it rises to a sharp peak known as Mount Rosario, which has an elevation of 860 feet. A portion of this rocky spur projects into East Sound and forms Cascade Bay.

Rising precipitously from the shores of East Sound and extending from the village of Rosario to the village of Olga, the sharp knife-like summit of Entrance Mountain reaches a maximum elevation of 1200 feet. The eastern slope is more gentle and, in general, it follows the dip-slope of the rock formations.

Situated in the depression between Entrance Mountain and Mount Constitution, and bounded on the northwest by Mount Rosario, is a large lake known as Cascade Lake which is three-quarters of a mile long and has an elevation of 350 feet.

A broad divide occurs on the east side of Mount Constitution Range and separates it from another upland region that for purposes of description will be here referred to as Mount Pickett Range. At its northern end, this depression contains Twin Lakes, which have an elevation of 1100 feet. Mountain Lake, the largest lake in the map-area, is situated to the south of Twin Lakes, at an elevation of 915 feet. It is more than a mile long and it trends in a general north and south direction. To the south of Mountain Lake the valley turns toward the southwest and joins another valley extending southeastward from Cascade Lake. The combined valleys continue southward towards the village of Olga, being flanked on the west by Mount Entrance and on the east by a mountain spur extending southwestward from Mount Pickett Range.

The highest point of land occurring to the east of Mount Constitution Range is here called Mount Pickett, in honor of Captain George Pickett of the United States Army, during the San Juan dispute. It has an elevation of 1890 feet, and with the exception of the higher peaks occurring on Mount

Constitution Range, it is the highest mountain in the map-area. For the most part, Mount Pickett and the whole Mount Pickett Range are heavily wooded.

A long ridge-shaped rocky spur extends out from the east side of Mount Pickett Range and continues as far as Point Lawrence. On the southeast side the range slopes quite abruptly down towards the valley to the north of Doe Bay. This valley, which is somewhat interrupted in places, extends from the double bay at the south side of Point Lawrence to the village of Olga. To the south of this valley the peninsula extending towards Obstruction Pass is covered with heavily glaciated and striated rocky hills that are drumlinoidal in shape and of low relief.

The north shore of Orcas Island, from Point Lawrence to Buck Mountain, follows the strike of the rock formations and is practically a straight unbroken line that trends about N 60° W. This shore-line is formed by the steep and rocky slopes of Mount Pickett, Mount Constitution, and Buck Mountain. One or more flat drift-covered benches may be found at elevations of 200 feet or higher, but otherwise this whole shore-line is steep and precipitous.

Owing to its rugged topography the arable land on Orcas Island is chiefly limited to the valleys and depressions that are covered with glacial drift.

INDIAN ISLAND

Indian Island, which has an area of 1.25 acres is situated near East Sound village. It is located on the west side of Arbutus Point in the little harbor known as Fishing Bay. The island is low and rocky but it contains sufficient soil to support a limited amount of vegetation. At low tide it is connected with Orcas Island by a broad sand bar.

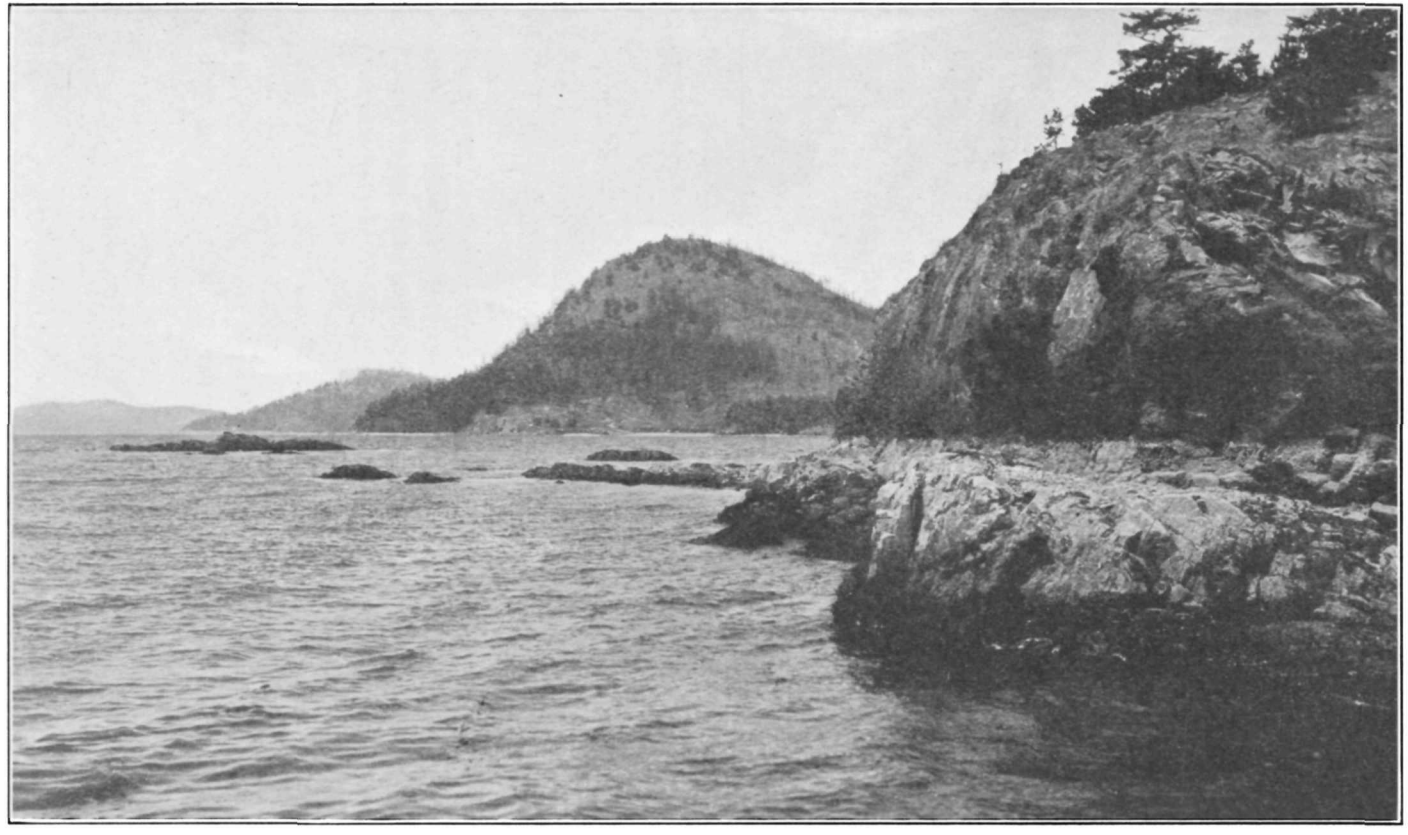
GIFFIN ROCKS

Giffin Rocks are located on the east side, and near the north end of East Sound. The rocks, which are two in number, are located near the shore of Orcas Island and occur as remnants of erosion. They extend but a few feet above high tide-level and their combined area is about equal to that of a city lot.

TWIN ROCKS

Twin Rocks are located on the west side of East Sound, directly opposite the village of Olga. They have a combined area of a little more than an acre and both have elevations of about 15 feet. They owe their presence to a spur of rock that projects out from the shore of Orcas Island, Twin Rocks being remnants of erosion. The inner rock is almost connected by a land bridge with Orcas Island at low tide.

Near the west shore of East Sound, about a mile north of Twin Rocks, there is small flat-topped island with an elevation of 25 feet. This un-named island is connected with Orcas Island at low tide.



Photograph by J. A. McCormick.

PLATE IV

Looking up the shore of East Sound from a point near the entrance to Obstruction Pass. Mount Entrance is located in the center, while still farther distant is Mount Rosario. Lookout Mountain appears in the distant background.

SHAG ROCK

Shag Rock is located at a distance of 275 yards from the south shore of Orcas Island, to the east of the entrance of Guthrie Bay. It is situated about 800 yards to the east of Foster Point. Shag Rock is only a few feet in diameter and it rises about two feet above high tide-level.

OAK ISLAND

Oak Island, which has an area of less than a quarter of an acre, is located in West Sound near its east entrance. This island is made up of two components both of which are nearly covered at high tide. At low tide they are connected with, and form a part of Orcas Island.

SHEEP ISLAND

Sheep Island is located in West Sound about a quarter of a mile south of the boat-landing at the village of West Sound. It has an elevation of about 20 feet, the top being flat and covered with several feet of glacial drift. This is surmounted by a dense growth of vegetation which includes a number of conifers. Sheep Island has an area of two acres.

HARBOR ROCK

Harbor Rock is a small rock or reef located in West Sound about half way between Haida Point and Indian Point. It is covered with water at half tide.

SKULL ISLAND

Skull Island is a rocky island located near the head of West Sound. It rises 25 feet above sea-level, and its rocky sides contain only a scanty amount of vegetation. Skull Island has an area of 2.7 acres.

In the vicinity of Skull Island there are several small un-named rocks and reefs, some of which are covered with water at high tide.

VICTIM ISLAND

Victim Island, which has an area of 3.0 acres, is located near the west shore of West Sound. It rises 45 feet above sea-level and its somewhat flattened surface is rocky though heavily wooded.

DOUBLE ISLAND

Double Island is located in West Sound about a quarter of a mile south of Victim Island. The two parts, which are separated by a channel about 10 feet wide, have a combined area of 25.94 acres. The larger or northern portion contains sufficient soil in places to permit cultivation. Its maximum elevation is about 85 feet. The southern portion has a maximum elevation of about 30 feet.

FISHERMAN ISLAND

Fisherman Island, which was formerly known as Fawn Island, is located near the west shore of Deer Harbor. It has an area of 2.75 acres and a maxi-

mum elevation of 40 feet. Its thinly drift-covered rocky sides are quite heavily wooded.

JONES ISLAND

Jones Island is located near the southwest corner of Orcas Island and separated from it by Spring Passage. It has an area of 200.18 acres and a maximum elevation of 140 feet. The shores of Jones Island are quite rugged but there are two large harbors, one entering from the north side and the other from the south. A considerable area in the south and south central part of the island is covered with a sufficient depth of soil to permit cultivation. Jones Island is now used as a fox farm.

FREEMAN ISLAND

Freeman Island is a small wooded island located near the northwest shore of Orcas Island, about half way between Point Doughty and Point Kimple. At high tide it has an area of less than half an acre, but at low tide the area is increased by the exposure of a broad flat rocky shelf that extends out from the south side of the island. Freeman Island has a maximum elevation of about 25 feet.

PARKER REEF

A broad flat submerged rocky shelf extends northward from the north shore of Orcas Island. At a distance of about a mile from the shore an elevation occurs on this platform and about five acres are exposed as a flat reef at extreme low tide. This reef which is known as Parker Reef, is located in a region frequented by very heavy tide-rips and during foggy weather it is a menace to navigation. Excepting for one small narrow ridge, Parker Reef is covered at high tide.

DOE ISLAND

Doe Island, which has an area of 6.43 acres, is located near the southeast shore of Orcas Island about three-quarters of a mile south of Doe Bay post office. Doe Island has a maximum elevation of about 30 feet. Although its rocky surface is only scantily covered with soil, the island is quite heavily wooded.

SAN JUAN ISLAND

San Juan Island is 14½ miles long and its maximum width is 6½ miles. It has an area of 55.39 square miles. The long dimension of the island trends in a northwesterly direction, and the southeast end projects out as a long narrow arm which culminates at Cattle Point.

Excepting at the southeast portion of the island, the shores are usually elevated and rocky. The southwest shore-line is broken by only one large bay, known as False Bay, and even here the shore-line is but slightly indented at low tide. False Bay is about a mile long and three-quarters of a mile wide, and it is so shallow that the greater part of the harbor is bare at low tide. At the

entrance of False Bay the margins are rocky, but elsewhere they are composed of glacial drift with a low relief. The mud in the bottom of False Bay was derived from glacial clays that occur in the San Juan Valley.

The west side of San Juan Island is cut by four large harbors or bays. From north to south these are Roche Harbor, Westcott Bay, Garrison Bay, and Mitchell Bay.

Roche Harbor has a length and width of about half a mile. It is quite shallow excepting at the north central part where a channel 20 feet deep at low tide extends to the wharf at Roche Harbor post office. At the entrance of the harbor the water is about 24 feet deep at low tide.

About one and a half miles south of Roche Harbor a very narrow steep-walled passage leads into Westcott Bay which trends northeasterly. It has a length of one and three-quarter miles and an average width of three-quarters of a mile. Westcott Bay is very shallow and the greater part of it is filled with a dense growth of eel-grass. The water is about 20 feet deep in the narrow passage at the entrance to Westcott Bay, but the average depth of water in the bay is much less.

Garrison Bay extends southeasterly from the south shore of Westcott Bay. It is irregular in shape and in general it is less than six feet deep at low tide. Garrison Bay has a length of about a mile, its southeastern extremity being extended as a narrow arm that nearly connects with Mitchell Bay. The remains of an old fort, which was built and occupied by the British during the time of the San Juan dispute, is located on the north shore of Garrison Bay.

Mitchell Bay has a length of about a mile. It trends in a general east and west direction, but it sends a narrow arm northward towards a similar narrow shallow arm extending down from Garrison Bay. The greater part of Mitchell Bay is less than six feet deep at low tide.

The northeast shore of San Juan Island is indented by Rocky Bay, whose straight shore-lines make an angle of about 90 degrees with each other. At the innermost part of the bay a small harbor trending northwesterly follows the direction of a fault zone that crosses the island at this point. The innermost portion of Rocky Bay is shallow, but farther out its depth is greater than 100 feet, excepting in the immediate vicinity of O'Neal Island.

The northeast shore-line of San Juan Island is also indented by Friday Harbor which is roughly rectangular in shape. Friday Harbor has an average width of one and one-half miles and a length of more than a mile. It opens towards the northeast. Brown Island, with an area of about 60 acres, is located in the center of the harbor. Between Brown Island and the harbor shore-line the water is rarely more than 60 feet deep at low tide, though a narrow passage exists at the southeast end of Brown Island that is about 130 feet deep. Near the entrance of Friday Harbor the water is more than 300 feet deep. Friday Harbor apparently owes its origin to the presence of two or more intersecting fault or fracture zones occurring in the underlying rock formations.

Griffin Bay, the largest bay occurring on San Juan Island, is located on the

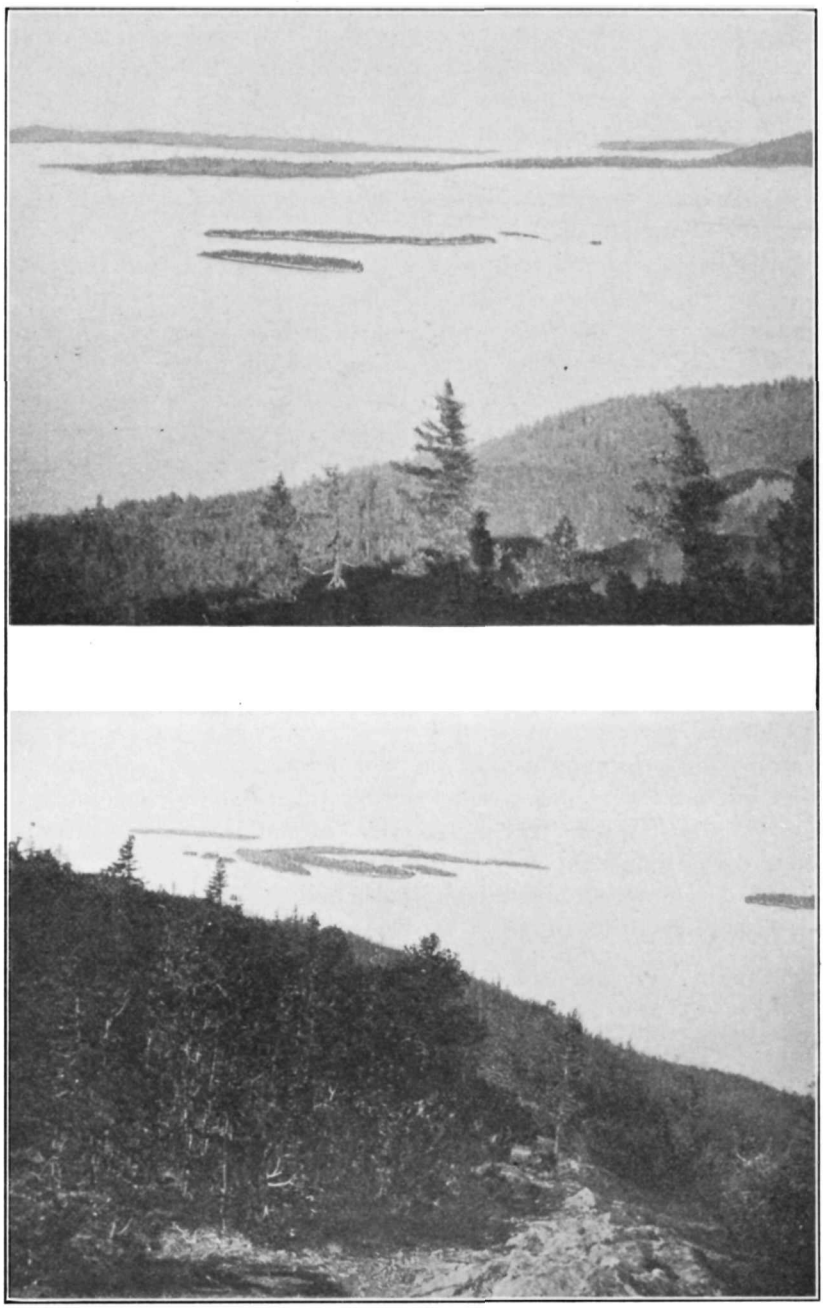


PLATE V

Above: Looking northeastward from Mount Constitution. Barnes and Clark Islands in the center, Lummi Island in the background. *Below*: Looking northwestward from Mount Constitution. The Sucia Islands, Patos Islands, and a portion of the Matia Islands in the background.

east side of the island between Cattle Point and Pear Point. It is somewhat rectangular in shape with a width of nearly four miles and a length of approximately two miles. The water near the shore is shallow in some places while in others the deep water extends close to the shore-line. Within half a mile from the shore there are numerous small scattered reefs and rocks, many of which do not rise high enough to be uncovered at low tide. Beyond a distance of half a mile from the shore the water increases rapidly in depth and reaches a maximum near the center of the bay with a depth of about 275 feet.

Near the middle of the southwest side of San Juan Island the shores are formed by the rugged slopes of Mount Dallas Range. Mount Dallas, the highest point on the range, has an elevation of 1036 feet, being the highest mountain on San Juan Island. The soil covering on the slopes of Mount Dallas Range is very scanty and it is only on the most favored portions, particularly on the northern slopes, that conifers have been able to gain a foothold. Mount Dallas Range trends about N 55° W, or approximately parallel to the southwest shore-line of San Juan Island.

About two and one-half miles to the southeast of the summit of Mount Dallas there is another more or less ridge-shaped mountain known as Little Mountain. Its maximum elevation is 475 feet and it is separated from Mount Dallas Range by a broad flat drift-covered valley.

To the northeast of Little Mountain and Mount Dallas Range there is a large drift-covered valley of low elevation. This is known as San Juan Valley and it is famous because of its fertility.

At a distance of approximately one and one-half miles to the north of the summit of Mount Dallas, there is an abrupt ridge-shaped elevation known as Mount Grant which is 680 feet in altitude. Mount Grant is scantily covered with soil and conifers occur only in scattered patches.

Between Mount Grant and Mount Dallas Range there is a low divide which contains Trout Lake, the source of the water supply for the village of Friday Harbor. Trout Lake has a length of about 600 yards and an elevation of about 200 feet.

About half a mile to the northwest of Mount Grant there is a small ridge-shaped peak with an elevation of 700 feet. The axis of the ridge trends a few degrees west of north. The northern slopes of this ridge are abrupt, and they extend downward towards a deep valley. The other sides slope abruptly towards a flat rocky upland that connects Mount Grant with an un-named peak 610 feet high, located one and one-half miles to the westward, near the shore of Andrews Bay.

Beginning at a point about a mile north of Mount Grant, San Juan Range crosses the center of the island in a northeasterly direction. A low divide which separates it from Mount Grant, connects with San Juan Valley to the southeast, while to the northwest it opens out into the broad lowland extending from Andrews Bay to Mitchell Bay.

The western extremity of San Juan Range ends in a steep escarpment

which starts at an elevation of about 100 feet and rises precipitously to an elevation of 640 feet. The northeast end of the San Juan Range slopes off more gradually and grades into the combination of low rolling wooded hills and irregular drift-covered valleys seen in the vicinity of Sportsmans Lake. The northern slopes of San Juan Range are considerably steeper than the southern ones, the latter being approximately the dip-slope of the underlying rock formations. The highest point on the range, Mount San Juan, has an elevation of 860 feet.

The lowland to the west of San Juan Range is largely drift-covered with only an occasional rocky outcrop. The peninsula to the south of Mitchell Bay has elevations up to 240 feet. It is largely drift-covered but the old metamorphic rocks are well exposed along the precipitous shore-lines.

The peninsula situated between Mitchell Bay and Garrison Bay is largely covered with glacial drift. Here the bed rock is exposed only at a few isolated points along the shore. Elevations up to 100 feet occur in the central part of the peninsula.

To the east of Garrison Bay and sloping down towards its shores, a dome-shaped elevation known as Mount Young rises to an altitude of 680 feet. Its wooded flanks extend toward the northwest as far as the shores of Westcott Bay.

A broad heavily-wooded upland extends southeastward from Mount Young towards San Juan Range and it embraces practically all of the region to the eastward from Rocky Bay to Sportsmans Lake. This upland is covered with low rolling wooded hills and irregular drift-covered valleys which are often swampy. Elevations up to 520 feet occur in the western part of the area, while the eastern part is lower and varies between 300 and 400 feet in elevation. A considerable portion of the upland area is covered with boulder debris which includes many large erratics.

A low drift-covered valley extends northwestward from Rocky Bay towards Roche Harbor, following in the path of a probable fault or fracture zone. To the north of this valley the region is low and rolling with a thin covering of glacial drift. Here and there a rocky ridge projects upward through the mantle materials. The hill to the south of Limestone Point, with an elevation of 260 feet, is the highest point in that region.

The peninsula situated between Mosquito Pass and Roche Harbor on the one side, and Westcott Bay on the other, is cut by a longitudinal valley trending northeasterly. To the northwestward this valley extends towards the wooded and rocky region near Bazalgette Point. The valley extends towards the southwest for a distance of three-quarters of a mile, as a low drift-covered arm that ends in the rocky elevation at White Point. The ridge between Roche Harbor and Westcott Bay, which is at the same time the eastern flank of the longitudinal valley, has elevations up to 200 feet.

Davidson Head, the most northern point on San Juan Island, is a rocky wooded peninsula with an area of 48 acres. It is connected with the mainland

by means of a narrow sand spit. Davidson Head is elongated in an east and west direction which is parallel to the strike of the rock formations.

Extending along the northeast shore of San Juan Island to the north of Sportsmans Lake, there is a range of hills with a maximum elevation of 520 feet. Farther to the southeast there is another hill with an elevation of 380 feet, which is separated from the others by the depression that contains the stream issuing from Sportsmans Lake. These hills are all heavily wooded on their northern slopes, while the southern slopes are either bare or covered by a few scattered conifers.

The lack of conifers on the southern slopes is noticeable on all of the islands where the soil is shallow or sandy. This phenomenon has been ascribed partly to the relative conservation of moisture on the northern or shady side, and partly to the fact that the most prevalent wind storms come from the southward and uproot the vegetation on the southern slopes, especially when the soil is sandy.

In the vicinity of Point Caution there is a rocky wooded elevation which is here called Biological Hill. It has an altitude of 440 feet. The slopes of Biological Hill are gentle in all directions, but in places the nearby shores are somewhat precipitous. The covering of soil is very scanty and the conifers occur in scattered patches on those areas which were especially favored with soil. The grounds of the Puget Sound Biological Station are located on the eastern slopes of Biological Hill, near the shore of Friday Harbor.

A broad drift-covered valley extends northwesterly from Friday Harbor, following the direction of a probable fault or fracture zone which loses itself in the irregular topography to the northwest of Sportsmans Lake.

A portion of this valley turns southwestward from Sportsman's Lake and extends along the east side of San Juan Range. It finally opens out towards San Juan Valley.

Sportsmans Lake and another much smaller lake, known as Egg Lake, are located in a low swampy valley surrounded by irregular rocky hills. These lakes have an elevation of approximately 160 feet.

Beginning near the village of Friday Harbor, a series of rocky ridges extend northwestward towards San Juan Range. This chain of elevated ridges separates San Juan Valley from the smaller valley to the northward. The highest of these ridges has an elevation of 440 feet.

Near the outskirts of the village of Friday Harbor a rocky and wooded elevation known as King Mountain rises to an altitude of 280 feet. A low ridge trends southward from King Mountain and with more or less modification it extends as far as the southern shore of the island near Eagle Point. Between False Bay and Griffin Bay this ridge widens out into a series of partly wooded hills with a maximum elevation of 320 feet.

The low gently undulating drift-covered area to the west of this ridge is known as San Juan Valley. This valley occupies a large area in the south central part of the island and it sends a number of small off-shoot valleys in among

the adjoining hills. The drainage slopes of San Juan Valley converge towards False Bay.

The peninsula situated between Friday Harbor and Griffin Bay is composed of low rocky hills and narrow drift-covered valleys. An elevation, known as Pork Hill, is located near the center of the peninsula and its altitude is 200 feet.

The isthmus between Friday Harbor and North Bay has the form of an elevated ridge known as Bald Hill, with an altitude of 321 feet. Bald Hill is composed entirely of glacial materials and a gravel quarry is located on its northern side near the shore of Friday Harbor.

The region between Eagle Point and Cattle Point is deeply covered with glacial drift. Near Cattle Point a sandy hill rises to an elevation of 292 feet. It is wooded on the northern side but quite devoid of conifers on its southern slopes. The old metamorphic rocks outcrop along the shore at Cattle Point and on the small peninsula to the northward.

While the shore-line is usually bounded by elevated rocky hills, the typical topography of the central part of San Juan Island, with its numerous drift-covered valleys and depressions, has furnished this island with an abundance of fertile land.

BROWN ISLAND

Brown Island, which has an area of 59.7 acres, is situated in the center of Friday Harbor. The island is rocky and its long dimension trends in a northwesterly direction. A drift-filled depression crosses the center of the island, while the two ends are rocky and more elevated. The highest point on the island is located near the northwest end and it has an elevation of 80 feet. The shores at this end of Brown Island are somewhat precipitous. The southern end of the island is lower but it contains elevations up to 60 feet. All parts of Brown Island are heavily wooded.

TURN ISLAND

Turn Island is located near the shore of San Juan Island, about one and one-half miles to the east of Brown Island. Turn Island has an area of 35.15 acres and a maximum elevation of 100 feet. The island is rocky excepting at the southwestern extremity, where the shore-line is fringed with glacial drift. The steepest slopes are found on the east side of the island but precipitous shore-lines are also found at other places. Two rocky knobs are connected with the southwest corner of the island by narrow drift-covered arms, one of the arms being covered with water at high tide. Conifers occur on all parts of Turn Island.

TURN ROCK

Turn Rock is situated about 350 yards to the northeast of Turn Island. It is a flat bench of rock that is covered with water at half tide. A lighthouse or beacon light is located on Turn Rock.

To the south of Turn Island the shore of San Juan Island is fringed with several groups of rocks and reefs. Across the narrow channel to the south of Turn Island, two rocky knobs that are joined together by a narrow arm of glacial materials and alluvium, are connected with San Juan Island by a sand spit and hook that is covered with water at half tide.

LITTLE ISLAND

Little Island is a small rocky knob situated near the village of Argyle. It is no longer isolated for it is connected with San Juan Island by the long sand-spits that enclose the Argyle Lagoon.

Near the shore of San Juan Island, to the south of Bald Hill, a small isolated rock rises to an elevation of ten feet.

DINNER ISLAND

Dinner Island is situated at the entrance of North Bay. Although it has an area of 9.1 acres, it rises but a few feet above high tide-level and the south side grades off into a submerged bench or reef. The highest points of this bench are exposed as reefs at low tide.

Situated in North Bay about 500 yards to the west or slightly northwest of Dinner Island, there is a reef that is covered with water at high tide.

HALF TIDE REEF

Half Tide Reef is located in Griffin Bay to the southeast of Low Point. This reef is awash at high tide.

HOPE REEF

Hope Reef is situated a short distance to the southwest of Half Tide Reef. It as awash only at the lowest tides.

NORTH PACIFIC ROCK

North Pacific Rock is located about three-quarters of a mile to the south of Half Tide Reef. At the lowest tide it extends about three feet above the surface of the water.

KELP ROCK

Kelp Rock, formerly known as Harbor Rock, is located near the rocky shore of San Juan Island at the south side of Griffin Bay. It is situated near the north end of the rocky peninsula that occurs to the north of Cattle Point. Kelp Rock has an elevation of about eight feet.

ANDREWS ISLAND

Andrews Island, formerly known as Low Island, is situated in Andrews Bay on the west side of San Juan Island. It is a small rocky bench that rises five feet above high tide.

A large number of rocks and reefs occur near the southwest shore of San

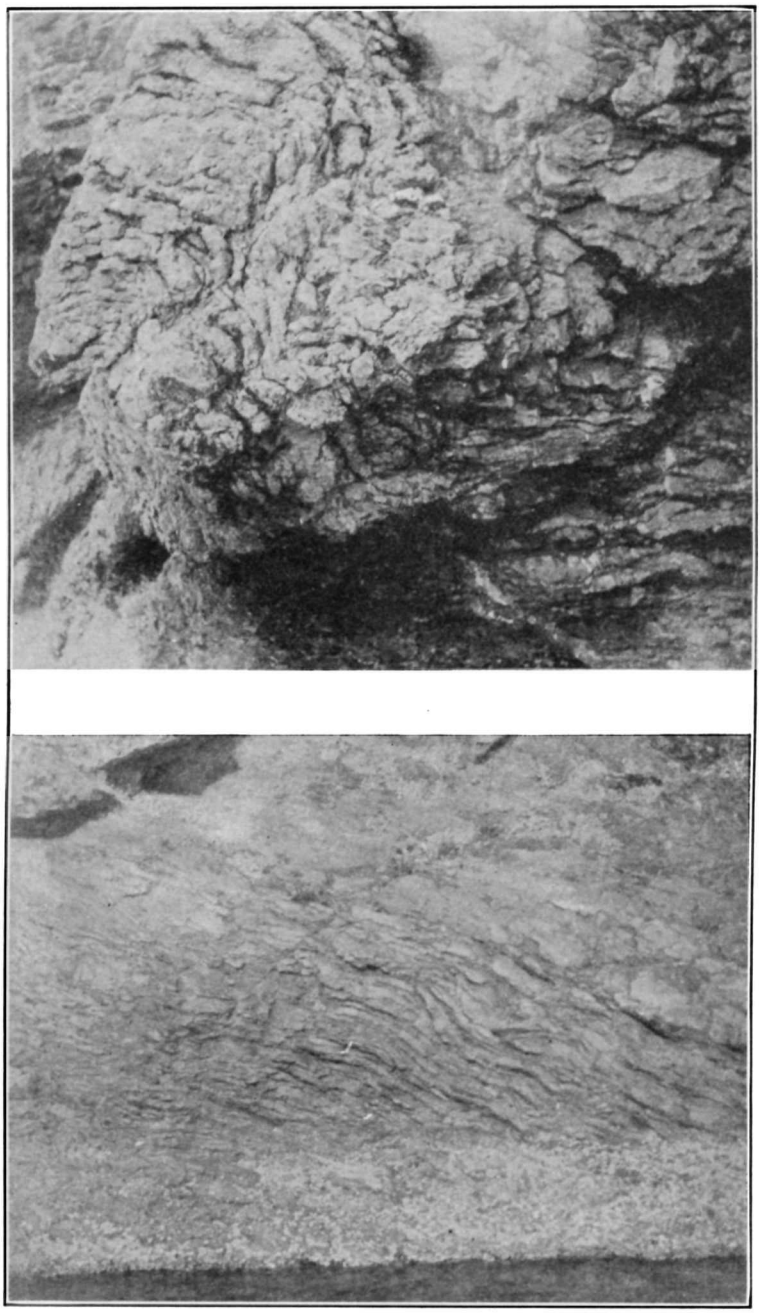


PLATE VI

Above: Contorted chert belonging to the Orcas group, Orcas Island. *Below*: Chert belonging to the Orcas group, Orcas Island.

Juan Island, being scattered over the region from Eagle Point to Mitchell Bay. With the exception of Andrews Island, these are all too small to warrant individual names.

Two small un-named rocks occur in Mitchell Bay, both of which project but a few feet above high tide-level.

GUSS ISLAND

Guss Island, with an area of 0.6 acres, is a rocky knob occurring in Garrison Bay. It has an elevation of about six feet, and at low tide it is connected with the mainland.

POLE ISLAND

Pole Island is situated in Mosquito Pass, which separates Henry Island from San Juan Island. Pole Island is located in the middle of the channel, a short distance south of Bazalgette Point. It is little more than a rock that rises eight feet above high tide-level.

HENRY ISLAND

Henry Island has an area of 1.59 square miles. It is located at the northwest end of San Juan Island, being separated from it by the narrow shallow waters of Mosquito Pass.

The island is composed of two curved parallel ridges trending about N 25° E, which are separated by a depression running parallel to the curved ridges. The convex sides of the curved ridges face towards the northwest. The outer or northwestern ridge is about three miles long and its average width is about 1000 yards. The other ridge is located about 500 yards to the southeastward. It is about one and one-half miles long with an average width of 500 yards. The southwestern extremities of the two ridges are located at points about opposite each other, but owing to the greater length of the outer ridge, it extends much farther northeastward than the other.

The longitudinal depression between the two ridges is filled with salt water excepting near the center of the shorter ridge, where a low sand bar connects the two ridges. Henry Island consequently has the general shape of the letter H.

The water entering the longitudinal depression from the south is known as Open Bay. It has a depth of approximately 500 feet at its entrance, but the depth decreases rapidly and the inner half of the bay is everywhere less than 30 feet deep. The deepest part of Open Bay is found near the western part of the entrance.

To the north of the connecting sand bar the land is swampy for a distance of several hundred feet. The remainder of the depression is filled with shallow water entering from the northeast. This shallow body of water, which is little more than six feet deep at low tide, is known as Nelson Bay.

The inner ridge is rocky at each end, with elevations up to 100 feet at the southern end, and up to 60 feet at the northern end. The central part of this

ridge is low and covered with glacial drift. A large part of the higher portions of the ridge is thinly drift-covered.

The southern half of the western ridge is rocky with elevations up to 355 feet. At the extreme southern end of this ridge there is a hill 310 feet high, with precipitous sides that extend down into very deep water. This hill is known as Kelletts Bluff.

The shores along the west side of Henry Island are steep and precipitous. The southern half of this shore-line is rocky, while the northern part is chiefly sandy and less elevated. Henry Island is bounded on the west by the exceedingly deep waters of Haro Strait.

The central part of the western ridge slopes gently down towards the shores of Nelson Bay. This area is largely drift-covered. A rocky peninsula rising to an elevation of 60 feet extends eastwardly near the entrance of Nelson Bay. To the north of this peninsula the eastern shores are precipitous and elevations up to 200 feet may be found.

The northern end of the island is low and drift-covered with occasional rocky knobs outcropping at the shore-line. A large part of Henry Island is covered with conifers and other trees and shrubs.

BATTLESHIP ISLAND

Battleship Island, formerly known as Morse Island, is located near the north end of Henry Island. It has an area of 3.2 acres and a maximum elevation of 40 feet. A submerged reef or rock platform connects Battleship Island with Henry Island.

PEARL ISLAND

Pearl Island, which has an area of 38.6 acres, is located at the north side of Roche Harbor. This island is elongated in an east and west direction and it almost forms a connection between San Juan Island and Henry Island. Pearl Island is rocky at its eastern end with elevations up to 40 feet, but the western end is low and drift-covered with rocks outcropping near the water's edge. Pearl Island is heavily wooded.

POSEY ISLAND

Posey Island is a low flat rocky island with an area of approximately an acre. It is connected with the north side of Pearl Island by means of a sand spit that is covered at half tide.

BARREN ISLAND

Barren Island, so-called because it is practically devoid of vegetation, is located midway between Posey Island and Davidson Head. The island has an area of 1.37 acres and it rises to an elevation of 25 feet. Barren Island is more or less dome-shaped.

O'NEAL ISLAND

O'Neal Island is located in Rocky Bay near the northeast shore of San Juan Island. It has an area of 4.5 acres and its rocky shores are steep on all sides. The maximum elevation is about 40 feet. The vegetation growing on the flat top of O'Neal Island is chiefly confined to low shrubs and grasses.

Farther in towards the head of Rocky Bay there is a small reef that is bare at low tide.

LOPEZ ISLAND

Lopez Island has an area of 29.45 square miles. It is less mountainous than Orcas or San Juan Island, the surface being typically flat or gently undulating and covered with glacial drift. The southeast portion of Lopez Island is more rugged than the remainder, and the shore-line is broken by a complicated group of harbors.

At the north end of Lopez Island there are two elevated rocky masses that extend out from the shore as long parallel ridges trending north and south. These rocky masses are, in reality, islands that have been tied to the main part of Lopez Island by broad arms of glacial drift and alluvium.

The western mass, which is known as Upright Head, is about a mile long and 600 yards wide. The west side rises precipitously to an elevation of 260 feet, but the eastern slopes are more gentle and they approximate the dip-slopes of the rock formations. Upright Head is heavily wooded.

At a distance of approximately three-quarters of a mile to the eastward, there is another somewhat smaller ridge known as Humphreys Head. It is about three-quarters of a mile long and has an average width of 500 yards. As in the case of Upright Head, the western shore rises precipitously to an elevation of 260 feet, while the eastern slopes are more gentle.

Humphreys Head is separated from Upright Head by Shoal Bay, which is rectangular in shape. Midway between the two ridges there is a submerged ridge that trends parallel to the others.

To the west of Upright Head the shore is sandy, and vertical cliffs of glacial drift up to 60 feet in height extend along the shore of Upright Channel. Flat Point has been built out from the base of the cliff at the northwest corner of the island where two converging sand spits contain a small swampy lagoon between them.

To the south of Flat Point the sandy cliffs rise to an elevation of nearly 100 feet, but in the vicinity of Fisherman Bay the low drift-covered hills slope gently towards the water's edge.

Fisherman Bay is formed by a low and somewhat rocky island mass, the south end of which has been connected with Lopez Island by a long narrow sand bar. A narrow opening located near Lopez post office leads into the bay which is about one and one-half miles long. Fisherman Bay is essentially a lagoon and the water is more or less stagnant. It is 24 feet deep at a point just inside of the narrow inlet, but elsewhere it is quite shallow and contains an abundant growth of eel-grass.

To the south of Fisherman Bay the shores are again formed by sandy cliffs that in places rise almost vertically to an elevation exceeding 100 feet. Rock outcrops begin to appear at the southwest corner of the island along the shores of Cattle Point Narrows, about a mile north of Point Davis.

The eastern shore-line of Lopez Island is somewhat more broken than the western one. To the south of Humphreys Head a broad shallow bay known as Swifts Bay opens out towards the northeast. Along the east shore of the island south of Swifts Bay two long sand spits extend towards the eastward and converge to a sharp point. A shallow swampy lagoon occurs between these sand spits which are fused together near the eastern extremity. This double sand spit is known as Spencers Spit and it almost connects with Frost Island.

The shore-line for a distance of nearly four miles to the south of Spencers Spit is formed by sandy cliffs with an average height of about 50 feet. From Small Island to Hunter Bay the shore-line is rocky but usually it is not precipitous and the elevations depart but little from those of the sandy cliffs to the northward.

Lopez Sound, which bounds the eastern side of the island, is divided at its southern end into two shallow bays which trend southwesterly. These are called Hunter Bay and Mud Bay.

The eastern shores of Mud Bay and Southern Lopez Sound are formed by a rocky peninsula that extends northward as far as Lopez Pass. Near the northeast side of Mud Bay, this rocky peninsula, which is triangular in shape and almost a mile across, is connected with Lopez Island by a broad sand bar. On the east side of this sand bar, there is a wide shallow bay called Shoal Bight that opens to the eastward towards the waters of Rosario Strait. The shores of Shoal Bight are low and sandy.

The shore-line to the south of Cape St. Mary is rocky and irregular, being indented by Telegraph Bay and Watmough Bight. The latter opens towards the northeast and its northern shore is formed by the precipitous side of Mount Chadwick, which rises almost vertically from the water's edge to an elevation of 464 feet. The bottom of Watmough Bight is quite flat and the depth of water at low tide is about 12 feet.

From Watmough Head to Cape Colville the shores are either rocky and nearly vertical or they are formed by sandy cliffs with large erratic boulders along the beach. Watmough Head and Cape Colville form the southeast extremity of Lopez Island.

The shore-line from Cape Colville to Iceberg Point is rugged and irregular. From east to west this precipitous shore-line is broken successively by McArdle Bay, Hughes Bay, and Aleck Bay. The average depth of water in McArdle Bay and Hughes Bay is about 30 feet. Aleck Bay is somewhat larger and deeper, being more than half a mile long and averaging about 60 feet in depth. Aleck Bay trends northwesterly and approximately follows the strike of the rock formations.

From Iceberg Point the shore-line trends northeasterly for a distance

of two and one-fourth miles, being broken by the elevated rocky peninsula that extends out and separates Outer Bay from Mackaye Harbor.

Outer Bay contains a number of islands and submerged reefs that cause its depth to vary considerably. It is shallow and sandy at its head and the shore-line is low and sandy.

Mackaye Harbor is also shallow and sandy at its head and the depth gradually increases until, at the entrance, it is about 60 feet deep. At the southeast extremity of Mackaye Harbor the rocky peninsula is penetrated by Barlow Bay, which is shallow and sandy.

The northern shore of Mackaye Harbor is rocky and precipitous and it trends in an east and west direction. Near the boat-landing at Richardson there is a small bay known as Jones Bay that is nearly circular in shape.

Still farther westward there is another large bay, known as Davis Bay, which is about a mile wide. Near the southeast margin of Davis Bay an elevated rocky ridge ends abruptly at the water's edge and forms a steep cliff known as Nigger Head. (See Plate XIX A). Davis Bay is shallow and sandy near the shore and the depth increases gradually until at the entrance it is about 60 feet deep. The shores of Davis Bay are generally of moderate relief, but here and there elevated rocky knobs and ridges extend down to the water's edge. Point Davis is located at the west side of Davis Bay and forms the southwestern extremity of Lopez Island.

The surface of Lopez Island is relatively flat and free from abrupt changes in elevation. The rocky points that extend out from the north end of the island to form Upright Head and Humphreys Head, are in reality islands that are tied to Lopez Island by arms of glacial drift and alluvium. The low wooded peninsula on the west side of Fisherman Bay contains some exposures of the old metamorphic rocks. With these exceptions, the whole northern half of Lopez Island is covered with a deep mantle of glacial materials.

Near the northwest corner of the island in the vicinity of Flat Point, and again in the northeast corner near Spencers Spit, the drift-covered hills rise to elevations of 180 feet.

About a mile to the east of Lopez post office there is a small lake called Lopez Lake. It has an elevation of 91 feet, and a small stream issuing from it empties into Swifts Bay near Port Stanley.

To the southeast of Fishermans Bay a drift-covered ridge with elevations up to 280 feet, trends in a northeasterly direction. The southeastern slopes of this ridge are very gentle. In fact they lose but little of their elevation before they finally merge with the northwestern flanks of Lopez Range.

To the west and northwest of Hunter Bay, a roughly circular area, with a diameter of about two miles, is occupied by the wooded and rocky hills belonging to Lopez Range. Mount Lopez, the highest point on the range, has an elevation of 486 feet. The Lopez Range consists of rounded and glacially striated rocky hills in which the local depressions contain sufficient

mantle materials to support the forests growing upon it. Here and there the drift-filled depressions are large enough to permit a limited amount of cultivation.

The area to the west of Lopez Range is almost entirely covered with glacial drift and in most places the covering is very deep. Elevations up to 220 feet may be found in this region.

The old metamorphic rocks appear along the shore of Cattle Point Narrows and their outcrops extend northward from Point Davis for a distance of about a mile. Throughout this distance the tops of the hills are covered with glacial drift.

Rocky points project at several places on Davis Bay but farther inland they are covered with drift. From the east side of Davis Bay an elevated rocky ridge extends eastward, and, with one or two minor interruptions continues along the entire north shore of Mackaye Harbor. This ridge has elevations up to 200 feet and in places it is heavily wooded. To the south of Hunter Bay it merges with a dome-shaped hill that has an elevation of 340 feet.

To the north of this ridge, or series of ridges as the case may be, there is a broad lowland that extends from Davis Bay to Hunter Bay.

Between Mackaye Harbor and Mud Bay the land is low and flat with elevations usually below 50 feet. The peninsula between Mackaye Harbor and Outer Bay is rocky and precipitous with elevations up to 100 feet. A rocky ridge that forms the entrance to Barlow Bay, trends southeasterly and forms the north shore of Aleck Bay. To the north of this ridge another lowland extends from Hughes Bay to Mackaye Harbor. To the south of this ridge, which follows the strike of the rock formations, another lowland extends from Aleck Bay to Outer Bay. The group of ridges extending from the south side of Aleck Bay to Iceberg Point is crossed by a depression that merges with the broad lowland to the northward.

The ridge extending eastward from Iceberg Point has a maximum elevation of 220 feet and contains a remarkable display of glacial grooving and polishing. The glacial striations trend approximately at right angles to the strike of the upturned rock formations.

To the southeast of Mud Bay a wooded and rocky hill rises to an elevation of 240 feet. The surrounding area is largely drift-covered. Near Cape St. Mary there is a wooded and rocky hill, with an elevation of 200 feet which is separated from Mount Chadwick on the south by a drift-covered lowland that extends toward Telegraph Bay.

Mount Chadwick has an elevation of 464 feet. Its southeast side is a sheer precipice that reaches the water's edge at Watmough Bight. To the northwestward the slopes of Mount Chadwick are more gentle and are covered with a dense entanglement of vegetation.

A low narrow valley connects Watmough Bight with McArdle Bay. At the southeast side of McArdle Bay a dome-shaped hill rises abruptly to

an elevation of 260 feet. This hill is really a portion of the ridge extending westward from Cape Colville. The area in the vicinity of Watmough Head is relatively flat and in places it contains a scanty covering of glacial drift.

The peninsula to the northeast of Mud Bay contains two parallel rocky ridges that trend about N 55° E. Their maximum elevation, which occurs on the southeastern ridge, is 220 feet. The greater part of this peninsula is heavily wooded.

Lopez Island contains an abundance of land suitable for cultivation and water is readily obtained in most parts of the island.

FLOWER ISLAND

Flower Island, with an area of 4.6 acres, is located near the northeast corner of Lopez Island. It is rocky throughout and contains only a scanty amount of vegetation. Flower Island trends north and south and the northwest corner extends out as a low rocky shelf. The highest part of the island is located along the eastern margin with a maximum elevation of 74 feet. The eastern shore of Flower Island is practically a vertical cliff that resembles a fault-scarp.

Situated at a point about half a mile north of Flower Island there are two reefs. One of these is awash at high tide while the other is uncovered only at lower low tide.

FROST ISLAND

Frost Island has an area of 69.95 acres. Its maximum elevation is 220 feet, the highest and most precipitous side being located on the northwest part of the island. Frost Island is rocky and wooded throughout and it contains a very scanty amount of soil. The small irregular depressions in the rocky surface contain scarcely sufficient soil to support the conifers that grow on the island. Spencers Spit extends out from Lopez Island and almost connects with Frost Island at low tide.

SMALL ISLAND

Small Island is a low flat rocky island situated near the shore of Lopez Island to the northeast of Lopez Range. Its area is about that of a city lot.

CRAB ROCKS

Crab Rocks are situated near the extremity of the peninsula that separates Hunter Bay from Mud Bay. Their size is about that of a city lot.

FORTRESS ISLAND

Fortress Island (shown on the British chart as Crown Island) has an area of 3.21 acres. It is located in Lopez Sound about a half mile to the northeast of Crab Rocks. Fortress Island has precipitous slopes on all sides and is surrounded by deep water near its shores. The island is somewhat dome-shaped and rises to an elevation of about 100 feet. All parts of it are rocky and almost devoid of vegetation.

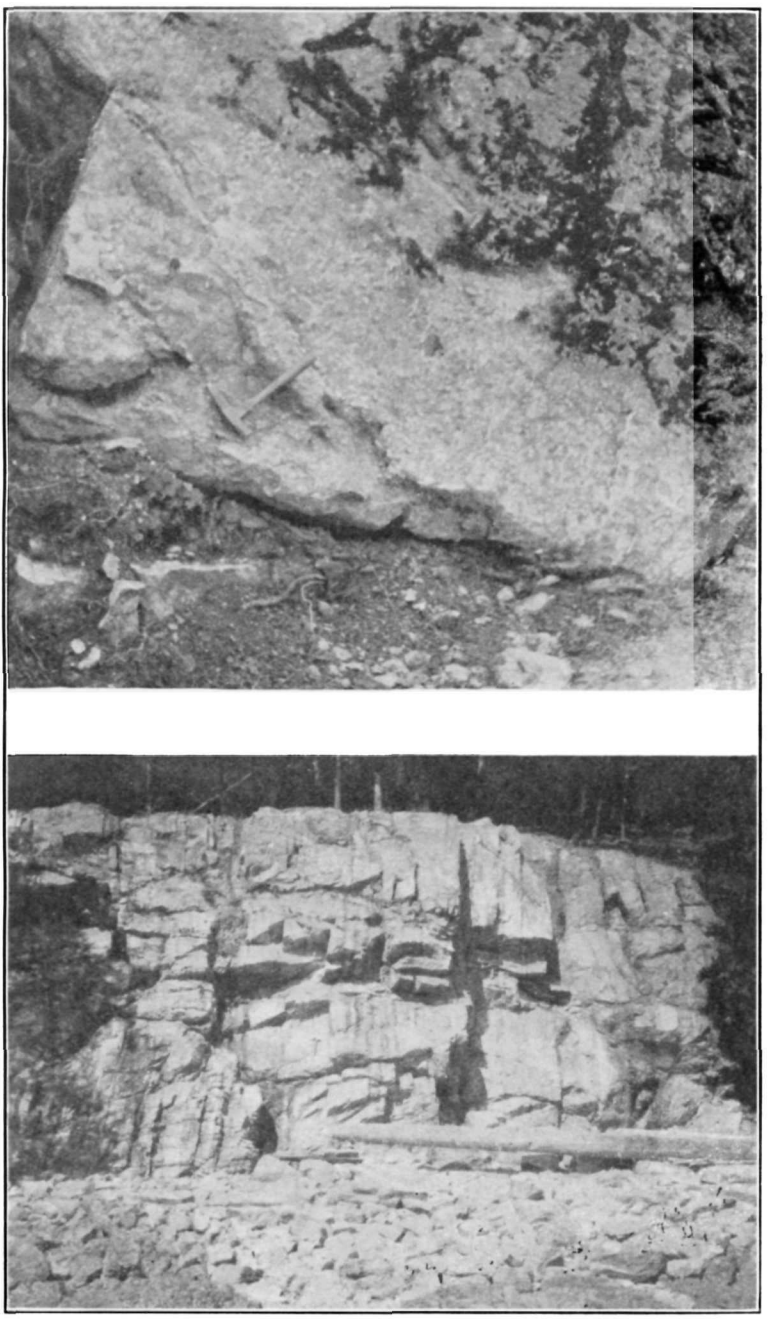


PLATE VII

Above: Devonian brachiopods in the Orcas Lime Quarry, Orcas Island. *Below*: Diallagite and hornblendite occurring as thin parallel stringers in the gabbro-diorite.

Situated about 300 yards to the northeast of Fortress Island there is a low rocky island with an area of about that of a city lot. About 600 yards to the southeast, and at the east side of Mud Bay near its entrance, there is a small reef that is exposed at low tide.

RAM ISLANDS

Ram Islands, which are three in number, are located near the west entrance to Lopez Pass. They are elongated in a northeasterly direction and all three of them are lined up as parts of the same ridge. The largest and most southwestern member of the group has a maximum elevation of 80 feet. A low reef extends eastward from the center of the southeast side of this island. Ram Islands have a combined area of 8.8 acres.

KELLETT LEDGE

Kellett Ledge is located about 700 yards to the northeast of Cape St. Mary. It is a reef that is uncovered only at the lowest tides.

BOULDER ISLAND

Boulder Island is located at the south entrance to Watmough Bight. It has an area of 6.9 acres and its maximum elevation is 79 feet. Boulder Island is almost circular in outline, although a narrow rocky point projects from the south side of the island. It is rocky throughout and contains only a scanty growth of vegetation.

DAVIDSON ROCK

Davidson Rock, which is covered with water at all times, is located about 600 yards to the east or slightly southeast of Colville Island.

COLVILLE ISLAND

Colville Island is located about half a mile south of the southeast corner of Lopez Island. It is elongated in an east and west direction, or parallel to the strike of the rock formations. Colville Island has an area of 11.48 acres and a maximum elevation of 40 feet. Like the small rocky island situated near its western end, it contains practically no soil, and it is used as a nesting-place by numerous gulls, cormorants and other sea-fowl.

CASTLE ISLAND

Castle Island is situated to the north of Colville Island and near the shore of Lopez Island. It has an area of 9.33 acres and a maximum elevation of 161 feet. It is roughly triangular in shape, with its north and southeast sides being almost vertical cliffs, while the west side, though less steeply inclined, can be climbed only with difficulty. There is practically no glacial drift or soil on this island and it is used as a nesting-place by many kinds of sea-fowl.

To the west of Castle Island there are two small rocky islands. The larger of these has an elevation of 45 feet, while the height of the smaller one is 35 feet.

ALECK ROCKS

Aleck Rocks include two groups of rocky islands and reefs situated at the south part of the entrance to Aleck Bay. They have a combined area of about 3.25 acres. The largest of these rocks occur in the northern group where two fairly large islets may be found. The larger or southeastern of these two islands is sometimes known as Fish-trap Island. It has an elevation of about 100 feet.

The southern group is composed of two small rocks, one of which has an elevation of 40 feet.

Near the head of Aleck Bay there are two small rocks, and at low tide four small reefs are exposed.

Between Aleck Bay and Iceberg Point there are a number of small rocky islands and reefs. The largest of these, which is situated in the small bay midway between Iceberg Point and Aleck Rocks, has an area of about two acres and is known as Barnacle Rock.

GEESE ISLETS

Geese Islets include a number of rocky islands and reefs situated near the southwest shore of Lopez Island. The majority of them are practically devoid of soil or vegetation, and any soil that might form would soon be blown away by the strong winds during the winter season.

Geese Islets include the following island masses,—Long Island, Charles Island, Goose Island, Iceberg Island, Hall Island, Buck Island, Secar Rock, Deadman Island, Richardson Rock, Mummy Rocks, Whale Rocks, and many smaller rocks and reefs.

LONG ISLAND

Long Island, the largest of the Geese group, has an area of 58.05 acres. It is elongated in a direction about N 70° W, or parallel to the strike of the rock formations. Its maximum elevation is 75 feet and the surface of the island is relatively flat.

Long Island is divided into two parts at high tide, but at low tide the parts are connected by a sand bar. On the south side of the island there are a number of small rocky islands that are connected with each other and with Long Island at low tide by means of a series of sand bars. Three small isolated islands are located near the southeast side of Long Island.

CHARLES ISLAND

Charles Island is located about 400 yards to the east or slightly northeast of Long Island. It has an area of 32.4 acres and a maximum elevation of about 75 feet. The shore lines of Charles Island usually have a nearly vertical slope with average elevations of about 30 feet. The height increases gradually from the shores to the center of the island, and in places, the surface is sparsely wooded. An uplifted arm of glacial drift and alluvium connects a small rocky island with the north side of Charles Island.

Two small rocks situated between Charles Island and Lopez Island rise 15 feet and 10 feet respectively, above high tide-level. Another small rock located 375 yards to the east of Charles Island rises to an elevation of 12 feet. This latter rock is known as Round Rock.

GOOSE ISLAND

Goose Island, which is located in Cattle Point Narrows, near the shore of San Juan Island, is the most western member of the Geese Islet group. It is more or less dome-shaped with a circular outline. Goose Island has an area of 4.25 acres and an elevation of approximately 50 feet. It is almost devoid of soil or vegetation.

ICEBERG ISLAND

Iceberg Island is located about 700 yards to the northeast of Iceberg Point, being the most eastern member of the Geese Islet group. It has an area of 3.5 acres and an elevation of about 50 feet. The shores of Iceberg Island are bare and rocky.

HALL ISLAND

Hall Island is located about 650 yards to the south of Charles Island. It has an area of 3.9 acres and rises 25 feet above high tide-level. A fracture zone crosses Hall Island in a northeasterly direction and differential erosion has caused the island to assume the shape of a dumbbell.

A small rock situated about 250 yards to the west of Hall Island rises a few feet above high tide.

DEADMAN ISLAND

Deadman Island is located in Cattle Point Narrows near the shore of Lopez Island. It is situated a short distance to the northwest of Point Davis. The island has an area of 3.5 acres and rises to an elevation of 50 feet. Deadman Island is elongated parallel to the strike of the rock formations, or about N 65° W. It is bare and rocky throughout, and the northeast side is low and flat.

RICHARDSON ROCK

Richardson Rock is located near the shore of Lopez Island, about 250 yards east of the boat-landing at Richardson post office. It has an area of 1.35 acres and its nearly vertical sides rise to an elevation of about 35 feet.

BUCK ISLAND

Buck Island is located in Davis Bay about 300 yards west of the promontory known as Nigger Head. It has an area of 1.25 acres and a maximum elevation of 35 feet. It is bare and rocky with steep or vertical shore lines.

A small rock situated about 100 yards to the north of Buck Island rises a few feet above high tide-level.

SECAR ROCK

Secar Rock, with an area of 0.6 acres, is located midway between Hall Island and Charles Island. It rises 15 feet above high tide.

MUMMY ROCKS

Mummy Rocks are located midway between Long Island and Point Davis on Lopez Island. They consist of two small rocks that rise about 25 feet above high tide.

To the northwest of Mummy Rocks, near Point Davis, there are a number of small rocks and reefs which are exposed at low tide.

WHALE ROCKS

Whale Rocks are located at the south entrance of Cattle Point Narrows, in a region that is swept by very strong tides. They are utterly devoid of either soil or vegetation and they have a combined area of about three-quarters of an acre.

SHARK REEF

Shark Reef is located near the west shore of Lopez Island, about 1½ miles north of Point Davis. It trends in a north and south direction, and is nearly covered with water at high tide.

DECATUR ISLAND

Decatur Island is situated on the east side of Lopez Sound. It is separated from Lopez Island to the south by the narrow waters of Lopez Pass. On the east it is bounded by the waters of Rosario Strait. It is separated from Blakeley Island to the north by the waters of Thatcher Pass.

Decatur Island has an area of 3.58 square miles. It is roughly triangular in shape, the north side being relatively straight while the other two sides converge into a long narrow arm that extends toward the south.

The northeast corner of Decatur Island projects toward the east, parallel to the strike of the rock formations, to form Fauntleroy Point. About a mile to the southward, along the east shore, a long elevated double sand spit extends out to connect with a dome-shaped rocky land mass 200 feet high. This dome-shaped rocky point is known as Decatur Head. The east side of the island from Fauntleroy Point southward is deeply covered with glacial drift. To the southwest of Decatur Head the cliffs of glacial drift rise to elevations of 180 feet. Farther southward the land slopes gently until it is only a few feet above high tide-level.

Along the west side of Decatur Island there is a dome-shaped rocky land mass that rises to an elevation of 160 feet. It is connected with the main portion of Decatur Island by a recently elevated double sand bar, and the lagoon which formerly existed between them has been filled with rocky debris. To the southeast the shore-line is formed by cliffs of glacial drift, with occasional outcrops of bed rock at the northern portion. Large glacial erratics together with many smaller boulders are scattered along this shore.

The northern and norwestern parts of Decatur Island are high and rocky. The maximum elevation on the island, which is located in the northwestern portion, is 540 feet. The northern part of the island is very heavily wooded.

A mountain spur extends southward towards the southwest shore of the island near Decatur post office. To the south of Decatur post office the elevations are low and the land is deeply covered with glacial drift. The curved shore-line to the south of Decatur post office is sometimes spoken of as the Macedonian Crescent.

The south end of Decatur Island is formed by an elevated and elongated rocky hill that rises to an altitude of 140 feet. To the westward at a distance of about 100 yards there is a dome-shaped hill with an elevation of 120 feet. This is connected with Decatur Island by means of a long sand bar which has been built above the level of high tide. Near the north side of this sand bar there is another and much smaller rocky island.

CENTER ISLAND

Center Island has an area of 178.25 acres. It is situated near the southwest side of Decatur Island, and a broad sandy submerged shelf extends from one island to the other at a depth of about 10 or 12 feet at low tide.

Center Island is roughly triangular in shape, with its north shore low and irregular. A large part of the southeast shore-line is formed by cliffs of glacial drift, but near the southern end the shores are rocky. The western shore is rocky and its relief is moderate. The elevations increase towards the center of the island where a maximum height of 200 feet is reached. Excepting for the central portions that are under cultivation, the island is covered with conifers and in many places these have scarcely enough soil to support their growth.

TRUMP ISLAND

Trump Island is located in Lopez Sound near the western shore of Decatur Island. It has an area of 29.4 acres, and its greatest elevation, which is located at its eastern margin, is 120 feet. The strike of the rock formations on Trump Island is approximately north and south, and the massive and elevated ridge occurring along the eastern margin was formed by the differential erosion of a resistant formation. The island is scantily wooded and the soil is very shallow. A small bank of glacial drift occurs at its southern extremity.

JAMES ISLAND

James Island is located on the east side of Decatur Island, near Decatur Head. It has the shape of a dumbbell with its longer axis in a north and south direction. James Island has an area of 113.65 acres.

The northern part of the island is dome-shaped with scarcely enough soil to support the conifers growing upon it. It rises to an elevation of 260 feet.

The southern portion of James Island is joined to the northern part by

a narrow arm of uplifted alluvial material that is densely overgrown with vegetation during the summer season. The southern portion of the island is cut into two almost equal parts by a low narrow valley trending in a northeasterly direction and parallel to a probable fracture zone. The highest elevation on James Island occurs on the eastern side of this valley, where a wooded dome-shaped hill rises to a height of 300 feet.

BELLE ROCK

Belle Rock is situated in Rosario Strait about one and one-fourth miles to the southeast of James Island. It is exposed only at low tide, but a tall cylindrical masonry structure has been erected upon it to support a beacon and a warning bell. It is a portion of a submerged reef that trends in a northeasterly direction.

BIRD ROCKS

Bird Rocks are situated in Rosario Strait about half a mile to the southwest of Belle Rock. The rocks are three in number and they are lined up in a northeast and southwest direction. They appear to be a part of the same submerged ridge or reef that forms Belle Rock.

Bird Rocks have a combined area of about 3.75 acres and the two most southern islands have elevations of about 40 feet. The northern island is much lower and it extends northward as a low reef.

Bird Rocks contain neither soil nor vegetation but they serve as the nesting-place for large numbers of sea-fowl. The waters surrounding Bird Rocks and Belle Rock are noted for their strong tide-rips and these small rocky islands are seldom visited.

BLAKELEY ISLAND

Blakeley Island is located on the east side of Lopez Sound. It is separated from Decatur Island on the south by the waters of Thatcher Pass. On the east it is bounded by the waters of Rosario Strait. It is separated from Obstruction Island on the north by the narrow waters of Peavine Pass.

Blakeley Island has an area of 6.93 square miles. With the exception of a fringe of glacial materials that occur as a bench about 90 feet high along the northwest side, and an occasional remnant of glacial material near the southern end of the island, the region is rocky and mountainous and the shore-lines are precipitous. Blakeley Dome, the highest elevation on the island, occurs near the northeast margin with an altitude of 1060 feet. Near the shore at the eastern extremity of the island a hill rises to an elevation of 780 feet. This hill is connected with Blakeley Dome by an elevated ridge that forms the shore-line in this vicinity.

The southern extremity of Blakeley Island is formed by a small hill that rises to an elevation of 260 feet. This hill is elongated in a northwest and southeast direction and its southern margin is flanked by a thick bench of glacial drift.

To the north of Thatcher Harbor there is a precipitous mountain known as Bald Bluff, which is elongated in a northeast and southwest direction. Bald Bluff rises to an elevation of 880 feet and its western sides are deeply striated and polished by glacial action. Along the north shore of Thatcher Harbor its sides are flanked by a thick bench of glacial drift.

Each of the dome-shaped mountain peaks that occur near the shores of Blakeley Island slope gradually towards the center of the island. In this central depression there are two large lakes. The northern or upper lake is known as Blakeley Lake, and its elevation is 374 feet. The lower one, which is known as Thatcher Lake, has an elevation of 188 feet and drains directly into Thatcher Harbor.

Blakeley Lake is separated from Thatcher Lake by a mountain spur that extends northeasterly from Bald Bluff, and the valley and meadow land that connects the two lakes is bent far to the eastward around this mountain spur.

From Thatcher Lake a broad valley extends southward towards the southeast shore line of the island.

At the northern extremity of Blakeley Island, along Peavine Pass, a rocky island has been tied to the main island by means of double sand spits. (See Figure 10, page 141). A large lagoon still exists between these sand spits and it is connected with the sea at high tide. The rocky island or peninsula is elongated parallel to the shore of Peavine Pass, which is at the same time parallel to the strike of the underlying rock formations. All parts of Blakeley Island are heavily wooded.

WILLOW ISLAND

Willow Island is located near the southwest side of Blakeley Island and is composed of massive igneous rocks with scarcely any soil or vegetation. It has an area of 9.64 acres.

ARMITAGE ISLAND

Armitage Island, which has an area of 7.35 acres, is located near the southeast shore of Blakeley Island at the east entrance to Thatcher Pass. It has a maximum elevation of about 80 feet and its rocky sides slope down abruptly to the water's edge.

LAWSON ROCK

Lawson Rock is located at the east entrance of Thatcher Pass. It is exposed only at the lowest tides.

POINTER ROCK

Pointed Rock, a low flat-topped islet situated about 600 yards from the southeast shore of Blakeley Island, was formerly known as White Rock. It is about twice the size of a city lot and it rises 16 feet above high tide. Pointer Rock has a covering of glacial drift that is sufficiently deep to support the moderate growth of vegetation that occurs upon it.

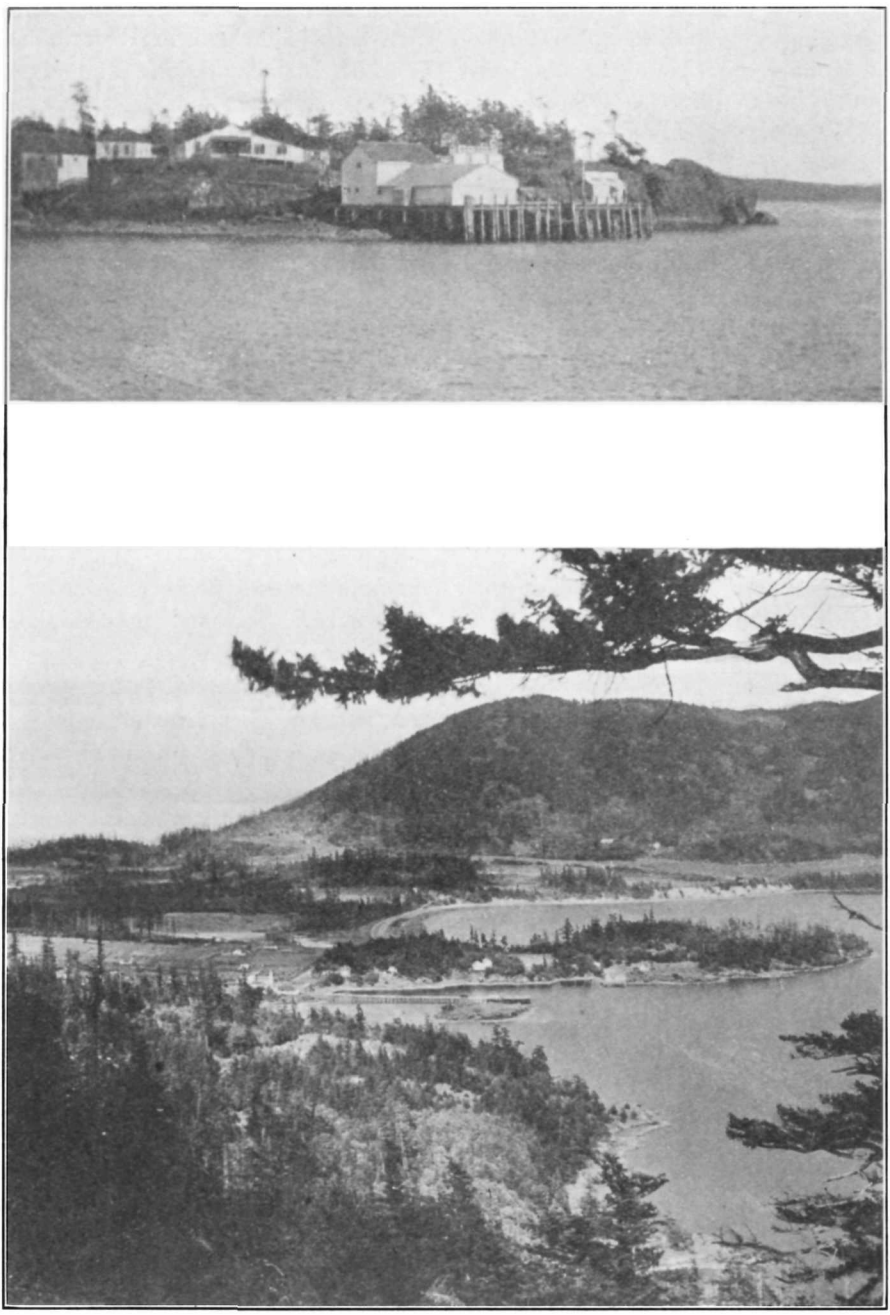


PLATE VIII

Above: Richardson, Lopez Island. *Below*: Looking eastward from Lookout Mountain; East Sound in the foreground, Buck Mountain in the background.

BLACK ROCK

A small rock rising 20 feet above high tide is located in Rosario Strait about a half mile from the southeast shore of Blakeley Island and about a mile to the northeast of Pointer Island. This landmass which is known as Black Rock, is composed of igneous materials.

SPINDLE ROCK

Spindle Rock is a small rocky mass that is located about 400 yards from the northeast shore of Blakeley Island near the east entrance to Peavine Pass. It rises about 20 feet above high tide.

Along the northeast shore of Blakeley Island, near Spindle Rock, there are two other small rocks that rise a few feet above high tide.

OBSTRUCTION ISLAND

Obstruction Island is separated from Blakeley Island on the south by the narrow waters of Peavine Pass. On the east it is bounded by the waters of Rosario Strait. It is separated from Orcas Island on the north by the narrow waters of Obstruction Pass. On the west it is bounded by the waters of East Sound and Lopez Sound at their common meeting point.

Obstruction Island has an area of 216.2 acres. It is triangular in shape with the north and west sides forming an approximate right angle. The other side trends about N 55° E. The island is relatively low and flat. Its maximum elevation is found in the west central portion where the altitude is 200 feet. A broad valley due to a fault or break in the rock formations crosses the southern part of the island.

A large part of Obstruction Island is covered with a thin mantle of glacial drift, and the island is heavily wooded. The shore lines are generally rocky.

SHAW ISLAND

Shaw Island is located in the center of the San Juan Island group. It is separated from San Juan Island on the southwest by San Juan Channel. On the southeast it is separated from Lopez Island by Upright Channel. It is separated from Orcas Island on the north by Harney Channel, while on the northwest it is separated from the Wasp group of islands by Wasp Passage.

Shaw Island has an area of 7.71 square miles. It is roughly triangular in shape and its shore lines are generally low and rocky, being cut by numerous harbors and bays.

The surface in the vicinity of Hankin Point, at the eastern extremity of the island, is elevated and rocky. Elevations up to 240 feet occur in this region.

The north shore of Shaw Island is penetrated by a large shallow bay known as Blind Bay. It is about a mile long and three-quarters of a mile wide. It is a part of a broad depression of glacial origin that crosses Shaw Island

in a north and south direction. At the south side of the island this broad valley is given its physiographic expression by the formation of the shallow bay known as Indian Cove.

To the west of Blind Bay the northern shore-line trends westerly without any important bays. Near the entrance of West Sound, an elevated rocky island is connected with Shaw Island by a long straight sand spit that is not covered at high tide. This island and sand spit together make up Broken Point.

Along Wasp Passage the shores are elevated and rocky. Near the western end of the island, a group of islands have been tied to Shaw Island by sand bars that have since been built up or elevated high above sea-level.

The southern shores of the island are broken by numerous irregular harbors and bays. A large rock mass projects out from the southwest side of Shaw Island in the form of a shoe, with Point George representing the toe. The upper side of the shoe is bounded by Parks Bay, which is nearly a mile long, while the heel and back part of the shoe are bounded by Hicks Bay. Another small bay forms the instep of the shoe. Parks Bay and Hicks Bay are connected by two narrow parallel valleys which follow fracture zones. These valleys also trend approximately parallel to the strike of the rock formations in this portion of the island.

To the west of Indian Cove there is a narrow shallow bay called Squaw Bay. It is about three-quarters of a mile long and is connected with both Parks Bay and Hicks Bay by low narrow valleys.

The greater part of the surface of Shaw Island is covered with rocky elevated knobs and intervening drift-covered valleys. It is probable that the latter generally follow fracture or fault zones. The irregularities in the shore-lines are caused largely by the drift-covered valleys which are at, or a little below, sea-level.

The most elevated knobs occur in the west central portion of the island where elevations up to 300 feet may be found. Deciduous trees predominate in the valleys, while conifers are abundant in the higher areas. Shaw Island is more heavily wooded than any of the other islands of the San Juan Island group.

CANOE ISLAND

Canoe Island is located in Upright Channel midway between Shaw Island and Flat Point on Lopez Island. It has an area of 49.58 acres and a maximum elevation of 60 feet. Although the island supports a moderately heavy growth of conifers, it contains but a scanty amount of soil and the rocks are exposed at all parts of the area. The rocky shores of Canoe Island are seldom too steep to climb.

BLIND ISLAND

Blind Island is located at the entrance to Blind Bay on Shaw Island. It has an area of 2.25 acres and its irregular rocky surface rises to a maximum elevation of 40 feet. It contains a very scanty amount of vegetation.

At a distance of 250 yards to the southeast of Blind Island there is a small reef that is awash at high tide. At about the same distance to the northwest of Blind Island there are a number of small reefs which are awash at low tide. Near the southwest shore of Blind Bay a small rock rises to an elevation of ten feet.

On the west side of the long sand spit that extends out towards Broken Point, a small rock island which is tied to the sand spit at low tide, rises to an elevation of 25 feet. Still farther westward along the shore of Shaw Island another rock mass is tied to the shore at half tide by means of a sand spit.

BELL ISLAND

Bell Island is located near the northeast extremity of Wasp Passage and midway between Orcas and Shaw islands. Though rocky it is moderately wooded and its maximum elevation is 40 feet. Bell Island has an area of 3.67 acres.

A small reef situated 250 yards to the east of Bell Island is uncovered at low tide.

CRANE ISLAND

Crane Island is located at the east side of the entrance to Deer Harbor and it is separated from Orcas Island by the waters of Pole Pass. Crane Island has an area of 221.66 acres, and with the exception of those portions which are under cultivation the whole island is wooded. In relief Crane Island is low and its surface is gently undulating and largely covered with glacial drift. The old metamorphic rocks outcrop along the shore near the water's edge. The maximum elevation on Crane Island, which occurs in the central or slightly southeastern portion, is 120 feet.

In Pole Pass near the shore of Crane Island a small rock rises a few feet above high tide. A reef that is covered at high tide is located near the eastern extremity of Crane Island. Several other reefs that are covered at high tide occur near the northeast shore of the island. Near the southwestern extremity of Crane Island a large mass of limestone and intrusive igneous material is tied to its shore by means of an uplifted arm of alluvial material.

Near the western extremity of Shaw Island and situated at a point about 500 yards to the east or slightly southeast of Cliff Island, there is a small rocky island of low relief.

TIFT ROCKS

Tift Rocks are located near the south shore of Shaw Island, at a point about a mile from its western extremity. Tift Rocks consist of five rock clusters, the highest points of which rise but a few feet above high tide. These rocks are practically devoid of soil or vegetation.

Near the north shore of Parks Bay, not far from its entrance, there is a small rock island that is connected with Shaw Island at half-tide. This rocky

mass rises to an elevation of 40 feet and a reef extends out from its west shore-line.

A low reef which is scarcely seen at low tide is located near the eastern shore of Hicks Bay.

WASP ISLANDS

Wasp Islands include a group of small rocky islands and reefs which are situated to the west of Shaw and Crane islands. Among them are McConnell Island, Reef Island, Cliff Island, Yellow Island, Coon Island, Knob Island, Low Island, and Cormorant Rock.

MCCONNELL ISLAND

McConnell Island, the largest of the Wasp Island group, has an area of 31.68 acres. The southern part of the island is rocky and elevated, its maximum height being 100 feet. The northern part is largely covered with glacial drift or alluvial materials, and at one time this area was under cultivation.

McConnell Island is remarkable for the number of sand spit-tied rock masses that occur in its northern part. Six rock masses are tied in this manner to McConnell Island, and the most western of these is isolated at high tide. The greater part of the island is wooded.

REEF ISLAND

Reef Island, the most northern member of the Wasp Island group, has an area of 17.25 acres. It is elongated in a north and south direction and shallow reefs fringe its western and southern borders. The shore-lines are low and rocky and the highest elevation, which occurs near the northern end, is about 40 feet. Reef Island is wooded throughout its entire area.

CLIFF ISLAND

Cliff Island is located near the western extremity of Shaw Island. It has an area of 15.61 acres and a maximum elevation of 60 feet. The island is divided into three almost equal parts by two transverse drift-covered valleys. Elsewhere the drift covering is quite thin and only sufficient to support the forest growing upon it.

Though composed largely of igneous rocks, Cliff Island is elongated parallel to the strike of the sedimentary beds, which include a fairly large limestone ledge that at one time was quarried for lime rock.

YELLOW ISLAND

Yellow Island, so-called because of its arid nature and the typical color of its vegetation, is located 350 yards to the southwest of McConnell Island. It has an area of 10.27 acres, is thinly covered with glacial materials, and its low rolling hills reach a maximum elevation of 40 feet. Rocky masses of land are tied to the north end, and also to the south end of Yellow Island, by means of sand spits. A species of prickly cactus occurs in abundance on Yellow Island.

COON ISLAND

Coon Island, with an area of 2.7 acres, is located about 100 yards to the east of McConnell Island. It rises to an elevation of about 25 feet and is wooded throughout.

KNOB ISLAND

Knob Island is situated near the west side of Cliff Island, and separated from it by a deep channel. It has an area of 0.8 acres and rises to an elevation of 20 feet. A series of rocks and reefs extend to the southwest of Knob Island.

LOW ISLAND

As its name implies, Low Island rises but a few feet above high tide. Its surface is flat and rocky and its area amounts to about three-quarters of an acre. Low Island is situated at a point about one-third of a mile to the south of McConnell Island. Prickly cactus occurs on this island.

CORMORANT ROCK

Cormorant Rock, formerly known as Bird Rock, is located midway between Crane Island and McConnell Island. It is awash at high tide, but at other times it is generally covered with cormorants.

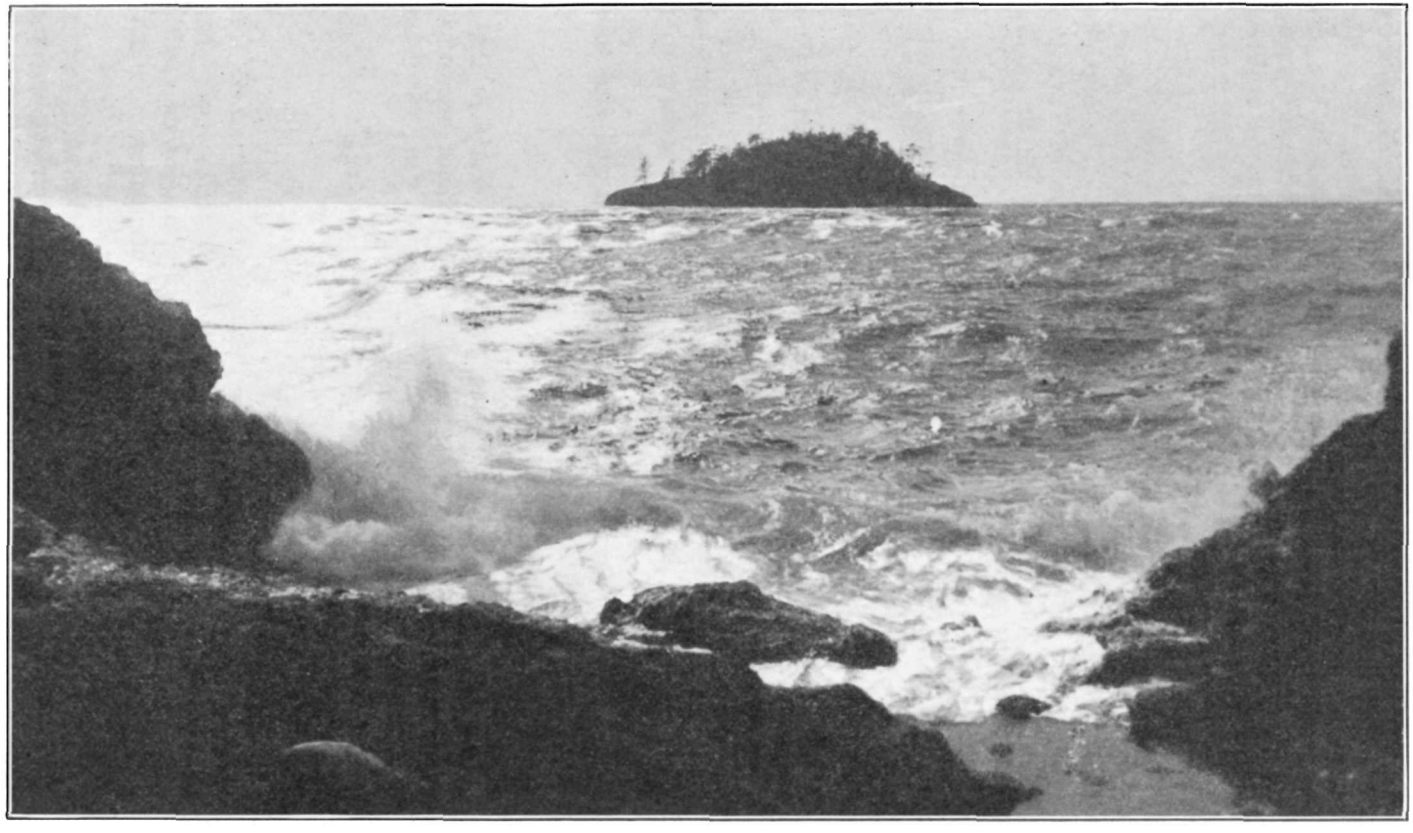
STUART ISLAND

Stuart Island is the most western of the San Juan Island group, being located in Haro Strait to the northwest of San Juan Island. It has an area of 2.79 square miles.

Due to the fact that Stuart Island is composed of closely folded sedimentary rocks which have suffered from differential erosion, the shore-line is exceedingly irregular. In certain cases the softer formations have been eroded to such an extent that they are now covered with water, and long narrow bays with parallel sides result. Were it not for the presence of two large harbors, Stuart Island would be roughly elliptical in shape with its major axis trending about N 65° W.

A long narrow embankment known as Reid Harbor enters the island near its southeast extremity. With an average width of 500 yards and an average depth of 25 feet at low tide, it trends in a northwesterly direction for a distance of nearly 2 miles. Reid Harbor is located on the axis of an elongated centroclinal fold in the underlying rock formations. To the northwest of Reid Harbor the same erosional and structural valley extends as far as the western shore-line of the island, being flanked on each side by an elevated and consequently more resistant rock formation. On the south side of the valley this resistant formation rises in the form of an elongated dome called Tiptop Mountain, which is 640 feet high. On the north side of the valley these same resistant strata again appear, and they serve as the narrow arm which separates Reid Harbor from Prevost Harbor.

To the north of this central resistant rock ridge there is another softer



Photograph by A. O. McCormick.

PLATE IX

A storm on the Rosario Strait, showing how the large storm-waves are broken up and their eroding power largely destroyed by the tide-rips at half tide.

formation which is represented by a valley of low relief. Still farther northward the same resistant strata appear for the third time, and they form the elevated northern margins of Stuart and Satellite islands. Along the northern side of Stuart Island this resistant formation is broken through in two places about a mile apart, and the water entering the valley to the southward connects the one inlet with the other and forms the large harbor known as Prevost Harbor. The elevated landmass occurring in, and surrounded by the waters of Prevost Harbor, is called Satellite Island.

The central elevated ridge has a maximum elevation of 420 feet, while the northern ridge attains an altitude of 500 feet. The shore-lines along the north and west sides of Stuart Island are steep and rugged. The precipitous rocky point at the northwest extremity of Stuart Island is called Turn Point, and here a lighthouse is located. The nearby waters of Haro Strait are characterized by strong tide-rips.

The northeast extremity of Stuart Island is formed by a rocky area that is connected with the remainder of the island by an uplifted arm of alluvial materials. Stuart Island is only moderately wooded.

SATELLITE ISLAND

Satellite Island is located in Prevost Harbor, on the north side of Stuart Island. It is very irregular in outline due to the differential erosion along two fracture or fault lines that cross the island. Satellite Island has an area of 106.15 acres and its maximum elevation, which occurs near the northern side, is 140 feet. It contains only a moderate growth of conifers because of the lack of soil.

Several reefs occur in Prevost Harbor to the southeast and also to the southwest of Satellite Island.

GOSSIP ISLANDS

Two small rock islands, called the Gossip Islands, are located at the entrance of Reid Harbor on Stuart Island. They have a combined area of 1.75 acres and rise but a few feet above sea-level. The larger of these two islands is sometimes known as George Island.

Several reefs occur near the shore of Stuart Island to the east of Gossip Islands.

JOHNS ISLAND

Johns Island, with an area of 214.55 acres, is located to the east of Stuart Island and separated from it by the narrow waters of Johns Pass. Johns Island is elongated parallel to the strike of the rock formations or about N. 60° W. It is about one and one-half miles long and its maximum width is 650 yards.

The northern side of Johns Island is elevated and rocky with steep and rugged shore-lines. It is penetrated by two small harbors that cut across the elevated resistant formation. The south side of the island is largely drift-covered with an occasional rock outcrop near the water's edge. A portion of

the southern shore-line is formed by an elevated wave-built sand bar and a swampy area occurs behind it.

The glacial drift occurring along the southern shore has been deposited on the glacially truncated and polished surfaces of the underlying rock formations.

Johns Island is heavily wooded in some parts, while in others the vegetation is very scanty.

A small reef occurs about 175 yards from the south shore opposite the central part of Johns Island.

RIPPLE ISLAND

Ripple Island, with an area of 3.25 acres, is located near the east end of Johns Island and separated from it by a narrow shallow channel. Ripple Island is low and flat and surrounded by reefs. Its maximum elevation is about 20 feet. Some portions of the surface of Ripple Island are covered with glacial drift and alluvium and a dense growth of shrubs and grasses occurs on these areas.

SHAG REEF

Shag Reef is located midway between Ripple Island and Cactus Islands. It is a flat reef and the highest points rise about a foot above high tide. Shag Reef trends in a northwesterly direction and it is divided into two parts by a deep depression that crosses the central portion of the reef.

GULL REEF

Gull Reef is located about 1000 yards to the west of Shag Reef. It rises about two feet above high tide. Between Gull Reef and Cactus Islands there is another small reef that is awash at half-tide.

CACTUS ISLANDS

Cactus Islands are located about midway between Ripple Island on the north and Spieden Island on the south, being separated from the latter by New Channel.

The western or smaller island has an area of 8.7 acres and its flat surface has a maximum elevation of about 40 feet.

The eastern island has an area of 22.7 acres and its maximum elevation is 60 feet. The south sides of both Cactus Islands trend about N 65° W, or parallel to the strike of the rock formations. The shore-lines are steep, being quite straight and smooth when running parallel to the strike of the rock formations, and jagged when crossing the strata.

Near the southeast end of the larger Cactus island there are two small rocky islands that are connected with it by a submerged reef. A reef occurs along the south shore of the same island.

Cactus Islands are both wooded but the soil covering is scarce.

SPIEDEN ISLAND

Spieden Island is situated about a mile from the north shore of San Juan Island, being separated from it by the deep waters of Spieden Channel. It has an area of 480.45 acres.

Spieden Island is nearly three miles long and its maximum width is only 875 yards. It trends about N 70° W, or roughly parallel to the strike of the rock formations. Near the central part of the island the elevation reaches a maximum of 410 feet. The east end of Spieden Island is less elevated than the western portion. The eastern extremity is formed by a dome-shaped hill rising 80 feet above sea-level, known as Green Point. To the west of the dome-shaped hill a broad lowland crosses the island at an elevation of about 25 feet. Still farther westward the land rises to a maximum elevation of 410 feet.

Beginning to the west of the lowland, a drift-covered shelf extends along the north side of Spieden Island for a distance of one and one-half miles. This shelf has an average elevation of about 40 feet at the water's edge, and rises at a gentle angle. At a distance of about 250 yards from the shore, near the central part of the shelf, and at a shorter distance when measured from a point to the east or west of the center, the elevations increase abruptly towards the top of the ridge. The north side of this elevated ridge, though somewhat precipitous, is heavily wooded, while the southern slopes are almost devoid of trees.

The western part of the north side of Spieden Island is bounded by sheer cliffs that rise to a height of 260 feet. The western extremity of the island is known as Spieden Bluff.

Spieden Island is surrounded on all sides by deep water near the shore, and it has the distinction of being the only large island of the San Juan Island group that does not possess a harbor.

SENTINEL ISLAND

Sentinel Island, with an area of 14.65 acres and a maximum elevation of 120 feet, is located near the south shore of Spieden Island. The island is somewhat dome-shaped although its south side is straight and trends in the direction of the strike of the rock formations. Sentinel Island has a moderately heavy growth of conifers though the soil covering is generally thin.

SENTINEL ROCK

At a distance of 350 yards to the west of Sentinel Island a small bare rock, known as Sentinel Rock, attains an elevation of five feet. A deeply submerged reef connects it with Sentinel Island.

CENTER REEF

In Spieden Channel, about 600 yards to the southwest of Sentinel Rock, there is a reef that is bare at low tide, known as Center Reef.

About a mile to the west of Sentinel Rock there is a submerged reef known as Danger Shoal.

FLATTOP ISLAND

Flattop Island is located about a mile to the northeast of Green Point on Spieden Island. It has an area of 49.3 acres.

Flattop Island is rounded or slightly elliptical in shape. Its northwest side is steep and precipitous and it rises to an elevation of 130 feet. The whole surface of the island slopes toward the southeast at an angle of approximately 25 degrees, or following the dip-slope of the rock formations. With this fact in mind the name of the island can scarcely be considered as appropriate.

The surface of Flattop Island is uniformly though scantily covered with conifers. The steep rocky northwest side of the island is used as a nesting place by numerous sea-fowl.

Reefs extend out from the northeast and also from the southwest ends of the island.

GULL ROCK

Gull Rock, with an area of 1.3 acres and an elevation of 30 feet, is located 500 yards to the northwest of Flattop Island. Gull Rock is almost divided into two parts by the differential erosion along a stratum of soft materials that is bounded on each side by hard layers of conglomerate. Numerous sea-gulls use Gull Rock as their nesting-place.

WHITE ROCKS

White Rocks have a combined area of 1.45 acres. They are located about one and three-fourths miles to the north of Flattop Island, and a like distance to the southwest of Point Disney on Waldron Island. The maximum elevation on White Rocks is 35 feet.

At low tide White Rocks are surrounded by reefs but at high tide there are but two rocks that extend above the surface of the water. Of these rocks the one located to the southeast is the larger, and it is used as the nesting-place of many kinds of sea-fowl.

Danger Rock is located to the southeast of White Rocks, and since it lies in the direction of the strike of the rock formations on the latter, it is probably formed from a part of the same resistant rock stratum.

WALDRON ISLAND

Waldron Island has an area of 4.59 square miles. It is located about one and one-half miles from the northwest shore of Orcas Island and separated from it by the deep waters of President Channel.

The southeast portion of Waldron Island is elevated and rocky, but elsewhere the island is deeply covered with glacial drift and elevations above 100 feet are rare.

The highest portion of the island is roughly elliptical in shape, with its longer axis trending about N 45° E. Although this area is surrounded on all sides by steep slopes, the structure of the under-lying rock formations is

just the reverse of the topography since this is at the same time the location of an elongated centroclinal fold. The maximum elevation of this region is 580 feet.

The southwest end of the elevated region projects out into the water about a mile beyond the adjoining shores to form Point Disney. The cliffs on the northwest side of Point Disney rise vertically from the water's edge to a height of nearly 500 feet.

The elevated portion of Waldron Island is covered with a moderately abundant growth of oak trees and conifers which have favored the soil derived from the weathering of certain shaly sandstones. As a consequence the trees now occur in curved rows which follow the outcrops of these rock formations.

A small double rock-bound bay occurs on the east side of Waldron Island near the northern extremity of the elevated area, known as Mail Bay.

To the north of the rock point which forms the northern margin of Mail Bay the region is low and covered with glacial drift. Near Point Hammond at the northeast corner of the island, the stratified cliffs of glacial materials rise to an elevation of 100 feet, while the bed rock outcrops near the water's edge. Several rock points outcrop along the north shore of the island beneath the cliffs of glacial materials. One of these rock points extends out from the northwest corner of the island to form Fishery Point.

The central part of the west side of Waldron Island projects to the westward as a long narrow point of glacial drift and alluvial materials which have a low relief. This long point is called Sandy Point. Between Sandy Point and Point Disney there is a broad embayment known as Cowlitz Bay. Waldron post office and boat-landing are located on the shore of this bay.

Near the southeast side of Cowlitz Bay there is a reef, known as Mouatt Reef, which rises about three feet above low tide.

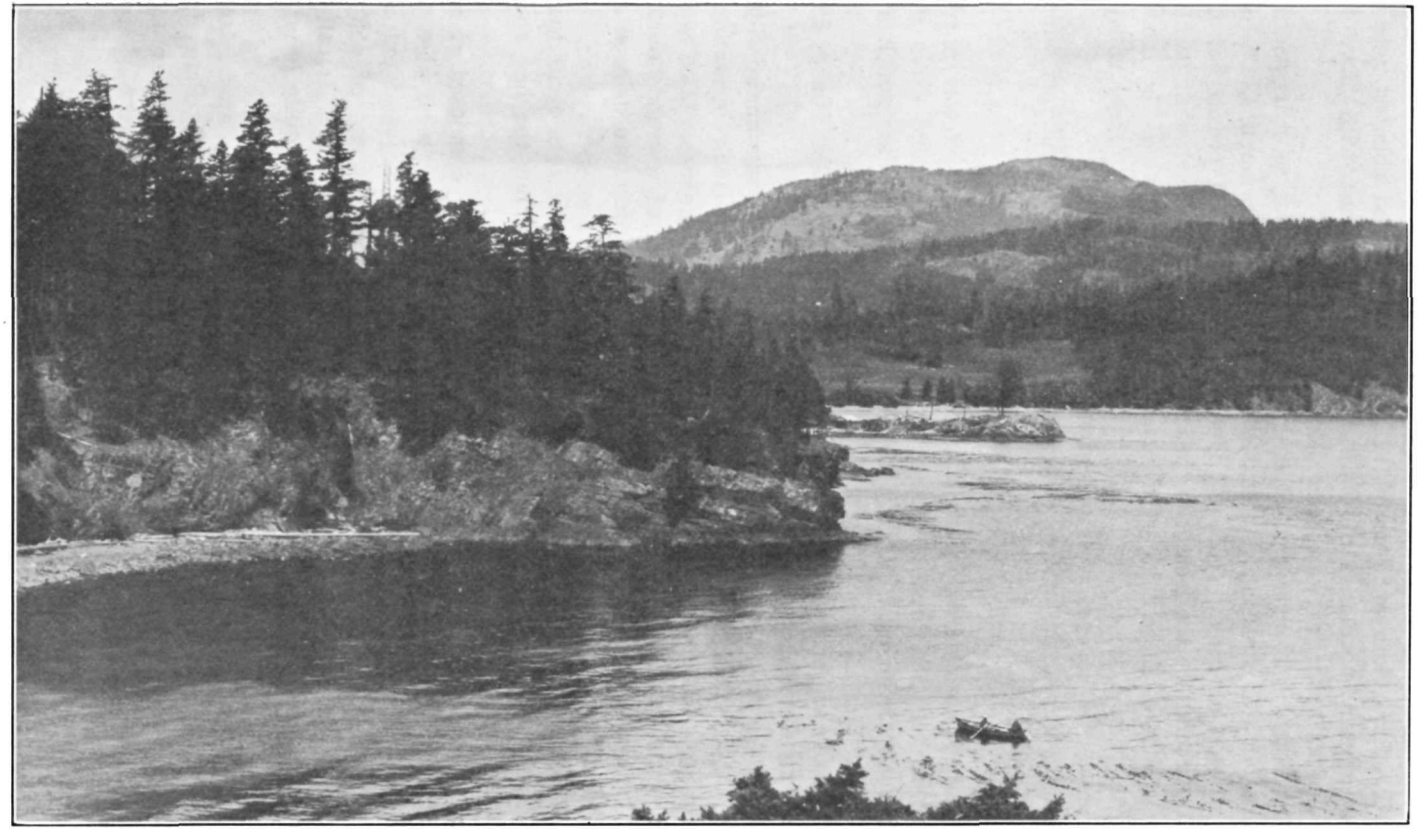
BARE ISLAND

Bare Island is located about three-quarters of a mile to the north of Waldron Island. It rises 40 feet above sea-level and has an area of 0.7 acres. The east and west sides of Bare Island are penetrated by narrow bays with parallell sides, formed by the differential erosion of nearly vertical shale strata.

Bare Island is practically void of vegetation. It is used as the nesting-place for many kinds of sea-fowl, including the puffin or sea-parrot which burrows into the bank of glacial drift or into the less resistant shale strata.

A flat rocky shelf extends southward from Bare Island and on it there is an elevated rock mass which occurs as a remnant of wave erosion.

At a distance of 450 yards to the west of Bare Island there is a reef which is covered at half-tide.



Photograph by J. A. McCormick.

PLATE X

Looking northward from Obstruction Island; Mount Constitution in the background.

SKIPJACK ISLAND

Skipjack Island, with an area of 19.28 acres, is located about a mile to the west or slightly northwest of Bare Island. In contrast with Bare Island it is wooded and rises to an elevation of 120 feet.

Skipjack Island is elongated in an east and west direction, with its parallel sides trending in the direction of the strike of the rock formations, the dip of which is steep or nearly vertical. Due to the differential erosion of the shale strata, the ends of the island are penetrated by narrow bays with parallel sides. The widths of these bays are determined by the thickness of the eroded strata. For the same reason the island is crossed by two longitudinal valleys, and these are partly covered with glacial drift.

About 200 yards to the east of Skipjack Island there is a small reef which is awash at high tide.

PATOS ISLANDS

Patos Islands are located in the Gulf of Georgia at the extreme northwest corner of the San Juan Island group. They are separated from the Canadian islands to the west by the deep waters of Boundary Pass which are conspicuous for their strong tide-rips.

Patos Islands are composed of Patos Island and Little Patos Island, and these have a combined area of 244.5 acres.

Patos Island is about one and one-half miles long and its maximum width is 550 yards. It is elongated parallel to the strike of the rock formations, and is curved so that its convex side points towards the south. The west end of the island trends northwesterly, while the east end of it trends northeasterly. The strike of the rock formations follows the curvature as well as the elongated direction of Patos Island.

The southern shore-line is rocky and elevations up to 60 feet occur near this side. The north side is low and largely drift-covered but the bed rock outcrops along the shore near sea-level.

At the east end of Patos Island there are three long points, composed of resistant material, that extend out far beyond the intervening spaces due to differential erosion. Since these long narrow parallel points of land extend out from the end of the island like the toes on the foot, this end of Patos Island is called Toe Point. The western extremity of Patos Island is called Alden Point, and a lighthouse is located upon it. Patos Island is quite heavily wooded.

Little Patos Island is located near the southwest shore of Patos Island and separated from it by the narrow waters of Active Cove. Little Patos Island is heavily wooded. The whole island is formed from the western extension of the resistant strata which follow along the southern shore of Patos Island. The maximum elevation on Little Patos Island is about 50 feet.

SUCIA ISLANDS

Sucia Islands are located in the Gulf of Georgia about three miles to the north of Orcas Island. They have a combined area of 749.0 acres.

Sucia Islands owe their origin to the differential erosion of stratified rocks which have been folded into the form of a trough or syncline that is inclined towards the eastward. During the lapse of time since the folding of these rocks, the region has been reduced by erosion to an approximate level, and due to the inclined trough-like structure of the rocks, the outcrop of each stratum has the general form of a horseshoe. By the processes of erosion, the shale strata have been eroded somewhat deeper than the more resistant sandstone and conglomerate layers which stand out to form parallel horseshoe-shaped ridges. In some cases the softer formations composing Sucia Islands are represented by drift-covered valleys, while in others they are covered by sea water to form long narrow bays or channels.

The Sucia Island group includes the following islands: Sucia Island, Little Sucia Island, Herndon Island, South Finger Islands, North Finger Island, Ewing Island, Clements Reef, and a number of other small rocks and reefs.

Sucia Island, which forms the nucleus of the Sucia Island group, is composed of portions of five parallel horseshoe-shaped strata, two of which are soft while the remaining three are relatively resistant. With the exception of the south side, the island is composed of two parallel resistant strata with an intervening softer stratum.

Near the western extremity of the island, the outer ridge of resistant material is broken through so that the water enters a portion of the shallow valley representing the softer stratum. The bay so formed is called Shallow Bay. The central portion of the horseshoe is occupied by the shallow waters of Echo Bay.

The north arm of Sucia Island is bounded by steep cliffs that slope abruptly down into deep water. This elevated region is known as Lawson Bluff and rises to a maximum height of 160 feet. The outer ridge belonging to the north arm of Sucia Island is crossed by a narrow channel which separates Ewing Island from Sucia Island. In this region the inner ridge is represented by a series of small rock islands, while the intervening softer stratum is covered with marine water.

The inner member of the south arm of Sucia Island extends out towards the east without any break in the ridge. The extremity of this ridge is called Johnson Point. The valley to the southward is largely filled with sea water, and the next ridge to the southward is broken through in two places. The intervening portion of this ridge forms Herndon Island. To the south of this ridge the water enters from the eastward along an erosional valley to form Fossil Bay. The head of Fossil Bay is separated from Fox Cove, another bay entering the island from the westward, by a narrow neck of land.

The rock formations on the south side of Fossil Bay are richly fossiliferous. These rock formations extend westward to form Little Sucia Island.

The surface of Sucia Island, and particularly that of the drift-covered

valleys, is covered with a dense growth of vegetation. Sucia Island is used as a fox farm.

Little Sucia Island is located near the southwest side of Sucia Island, being an extension of the fossiliferous strata which form the southern margin of Sucia Island. The shores of Little Sucia Island, as well as the exposed shores of the other islands of the group, are fringed by flat rocky shelves which have been formed by wave action at high tide. The island is crossed by a depression which is filled with glacial drift and alluvial material.

About a mile to the west of Little Sucia Island there is a submerged reef called West Bank. It forms a part of a submerged horseshoe-shaped ridge which occurs about two miles to the west of Sucia Island.

Herndon Island is a small knob-shaped island which is located at the north side of Fossil Bay.

South Finger Islands are located in Echo Bay near the south arm of Sucia Island, being separated from it by a narrow channel with a minimum depth of about 17 feet at low tide. South Finger Islands both represent parts of the same ridge or rock stratum and they are moderately wooded.

North Finger Island is situated about 325 yards to the north of South Finger Islands and it trends parallel with them. The intervening channel has a minimum depth of 72 feet at low tide.

Ewing Island is situated at the eastern extremity of the northern arm of Sucia Island and separated from it by a narrow shallow passage. Like the other large islands of the group, it is wooded and its long dimension follows the direction of the strike of the rock formations.

Near the north shore of Echo Bay, to the south of Ewing Island and the north arm of Sucia Island, there are a number of knob-shaped islands and reefs called the Cluster Islands, some of which are covered at high tide. The most western member of the Cluster Islands is known as Wiggins Reef. The most eastern member is called Stony Reef.

Clements Reef includes three small elongated reefs which are located to the north of Ewing Island. They are elongated in a direction about N 40° W. These reefs are either covered or awash at high tide.

MATIA ISLANDS

Matia Islands are located in the Gulf of Georgia about one and one-half miles east of Sucia Islands. They have a combined area of 170.11 acres, being composed of Matia Island, Puffin Island, and several small rocky islands and reefs.

Matia Island, the chief member of the group, is composed of three elevated parallel ridges and their narrow intervening drift-covered valleys. These ridges are composed of resistant sandstone and conglomerate formations, while the valleys represent the intervening shales and less resistant strata. At all parts of the island the ridges trend about N 68° W.

Matia Island has a length of one mile and a maximum width of 625 yards. At the ends of the island the less resistant formations are represented

by long narrow bays, while the ridges on each side of them extend out to form rocky islands and reefs. The greatest elevation occurs on the central ridge at the center of the island, with an altitude of 160 feet. Matia Island is quite heavily wooded, especially along the drift-covered valleys. The island is used as a fox farm.

A series of reefs extend along the north shore of Matia Island. At the northwest corned of the island there are two small islands, the larger of which is wooded.

Puffin Island is located 350 yards to the east of Matia Island. It rises to an elevation of about 60 feet and its grass-covered slopes are used as a nesting-place by many kinds of sea-fowl. The slopes of Puffin Island are precipitous, excepting on the east. A rocky shelf extends along the north side of the island, while to the eastward there are three small reefs which are covered at half tide.

BARNES ISLAND

Barnes Island is located about one and three-fourths miles from the northeast shore of Orcas Island, opposite Mount Pickett. It has a length of 1000 yards and a maximum width of 280 yards, with an area of 36.1 acres. It is elongated parallel to the strike of the rock formations. The surface of Barnes Island is wooded and quite flat and contains a thin covering of glacial drift in many places. The maximum elevation on Barnes Island is about 40 feet.

CLARK ISLAND

Clark Island, with an area of 55.05 acres, is located about 625 yards to the east of Barnes Island. It is about a mile long and its maximum width is about 300 yards. The northern part of the island trends in the direction of the strike of the rock formations, but the southern portion is formed largely of glacial drift that connects with another rocky ridge at the southeastern extremity of the island. Clark Island has a maximum elevation of about 50 feet and its flat drift-covered surface is heavily wooded.

THE SISTERS

Three small rocky islands situated to the south and southeast of Clark Island make up the group known as the Sisters. These have a combined area of 8.27 acres. The largest and most northern of the Sister islands has a single conifer tree growing upon it and it is sometimes known as Lone Tree Island. The other two islands are devoid of trees and one of them is completely free from vegetation. The two northern members of the group are low and partly covered with a thin layer of glacial drift. Lone Tree Island rises to an elevation of 20 feet while the other is only 15 feet high. The third or most southern of the Sister group is bare and rocky and rises abruptly from the water's edge to an elevation of 42 feet.

PEAPOD ROCKS

Peapod Rocks are located in Rosario Strait about a mile from the southeast shore of Orcas Island. They have a combined area of 6.9 acres.

North Peapod Rock is much the largest of the group, having an area of 5.5 acres. Its surface is quite flat and it has an elevation of 28 feet.

South Peapod Rock is situated about a mile to the southwest of North Peapod Rock. It rises about 25 feet above sea-level. Between the two rocks there is a chain of reefs which are largely covered with water at high tide. Peapod Rocks are not wooded.

LUMMI ISLAND

Lummi Island is located at the northern extremity of Rosario Strait where it merges with the Gulf of Georgia. It has an area of 8.2 square miles. The island is nine miles long and its maximum width is nearly two miles. It trends in a northwest and southeast direction and it is separated from the mainland and Portage Island to the east by the narrow waters of Hale Passage.

The northern half of Lummi Island is relatively low and flat. With the exception of a few rock hills near the northern extremity of the island, the whole northern half of Lummi Island is covered with glacial drift and its elevations are below 200 feet. The northern extremity of Lummi Island, which is called Point Migley, is rocky but its elevation is moderate. Along the west shore of the island, about two miles south of Point Migley, a low sandy point extends out to the westward to form Village Point. The village of Carlyle is located on this point. On the opposite side of the island a low sandy point, called Lummi Point, extends out to the eastward.

The region to the northeast of Village Point is covered with ridge-shaped rocky hills, the highest of which is located to the west of Lummi Point and rises to an elevation of 340 feet.

The topography of the southern half of Lummi Island is strikingly different from that of the northern portion. The southern half of Lummi Island is high and rocky and its greatest elevation, which is known as Lummi Peak, rises precipitously to an altitude of 1740 feet.

The whole southern part of the island is formed by a ridge which trends parallel to the strike of the rock formations. The southwest side is bounded by sheer cliffs and their talus slopes, while the northeastern side slopes away more gently and in general follows the dip-slope of the rock formations.

The talus slopes on the southwest side of Lummi Peak extend from the water's edge to a height of 1000 feet to form the "Devils Rock Slide." Several fatal accidents have occured to those who attempted to climb these talus slopes.

The southern end of Lummi Island extends out into a thin though elevated tapering point called Carter Point.

A small bay, known as Inati Bay, enters the east side of the island about opposite Lummi Peak. About half a mile to the southward there is another small open bay called Reil Harbor.

The abrupt change in the topography of the two halves of Lummi Island is probably due to a fault or break in the rock formations. Where it is not under cultivation, the northern half of the island is heavily wooded, particularly with deciduous trees. The southern half contains but little soil and the vegetation is largely limited to the soil-covered depressions in the rocks.

The delta of Lummi River, a distributary of the Nooksack River, is gradually encroaching on the north end of Lummi Island, and already a submerged sandy ridge extends from Lummi Island to the mainland.

LUMMI ROCKS

Lummi Rocks are located near the southwest side of the elevated portion of Lummi Island. They have a combined area of approximately three acres and rise about 25 feet above high tide-level.

VITI ROCKS

Viti Rocks are composed of two small rocky islands having a combined area of 2.75 acres. The northern and larger island rises to an elevation of about 35 feet. It contains a thick growth of small shrubs and grass but there are no conifers growing upon it. The southern island is a bare rocky reef which rises only a few feet above the water at high tide.

ELIZA ISLAND

Eliza Island is named in honor of Lieutenant Francisco Eliza, the Spanish explorer who discovered the San Juan Islands in the year 1791. It is located about three-quarters of a mile to the east of Carter Point on Lummi Island. Eliza Island has an area of 170.0 acres.

The main body of the island is composed of glacial drift which rises to an elevation of 40 feet. It is elongated in a direction about N 15° W, and connects with a high rocky knob at the southern extremity of the island. The latter has an elevation of 60 feet. A pair of long sand bars extends out from the center of the west side of Eliza Island to connect with a small rock knob nearly half a mile away. Between these sand bars the land is swampy and a small lagoon still exists. Eliza Island is heavily wooded.

ELIZA ROCK

Eliza Rock, with an area of about 0.4 acres, is located near the south end of Eliza Island, and rises to an elevation of about 6 feet.

PORTAGE ISLAND

Portage Island is located to the east of Lummi Island and separated from it by the waters of Hale Passage. It has an area of 923.25 acres and rises to a maximum elevation of 200 feet. At low tide its northwestern extremity is connected with the mainland by a long sand spit. The northeast corner of Portage Island is also extended to the northward as a long irregularly curved sandy hook. The east and southeast sides of the island are bounded by the waters of Bellingham Bay.

Portage Island is composed entirely of glacial drift, and its surface, which is heavily covered with deciduous trees, is for the most part flat or gently undulating. The southern shores of the island are bounded by elevated cliffs of glacial materials and the blunt rounded off southern margin is known as Point Frances.

VENDOVI ISLAND

Vendovi Island is located one and three-fourths miles to the south of Lummi Island. It has an area of 218.98 acres and its rugged sides rise to an elevation of 330 feet. Vendovi Island is elliptical in shape with the major axis trending in a northwest and southeast direction. There is a small harbor near the northwest corner of the island. Due to the scarcity of soil, Vendovi Island is only moderately wooded and it is used as a fox farm.

SINCLAIR ISLAND

Sinclair Island is located about a mile to the northeast of Cypress Island, at the north end of Bellingham Channel which separates Cypress and Guemes islands. Sinclair Island has an area of 1.65 square miles. It is heavily wooded with deciduous trees and is sometimes known as Cottonwood Island.

Excepting for its southern margin, Sinclair Island is covered with glacial drift and its relief is low. Along the southern margin there are a number of rock hills and the highest of these, which is located near the southeast extremity of the island, has an elevation of 180 feet.

About half a mile from the northwest shore of Sinclair Island there is a submerged reef known as Boulder Reef.

CYPRESS ISLAND

Cypress Island, with an area of 8.59 square miles, is located in Rosario Strait to the East of Blakeley Island. It is separated from Guemes Island on the east by Bellingham Channel.

In many respects the topography of Cypress Island is a duplicate of that occurring on Blakeley Island. Near the north end of Cypress Island a hill rises precipitously to an elevation of 720 feet. This is called Eagle Cliff. A narrow lowland crosses the island immediately south of Eagle Cliff, while still farther southward there are three dome-shaped hills. The most western of these, which has an elevation of 600 feet, merges with the elevated region to the southward. It is separated from the next dome-shaped hill to the eastward by a low swampy valley that connects with the depression crossing the island to the south of Eagle Cliff. The most eastern of the three domes is surrounded by water on all sides except its northwest corner. This dome-shaped hill forms the northeast side of Eagle Harbor.

The central part of the east side of Cypress Island projects towards the eastward. At the eastern extremity a small rocky elongated knob is connected with the island by a sand bar.

The southeast corner of Cypress Island is formed by a symmetrical dome-

PLATE XI
Aucella crassicollis Keyserling from the Spieden formation.

shaped hill which rises to an elevation of 600 feet. For purposes of description this hill is here called Olivine Hill because it is composed largely of a fresh vitreous variety of dunite, a rock composed almost entirely of the mineral olivine.

The southern margin of Cypress Island is fringed by glacial drift which forms elevated cliffs along the shore-line westward from Olivine Hill. Between Olivine Hill and the elevated central portion of the island, the sea water enters from the northeastward to form Secret Harbor. The north side of Olivine Hill is bounded by a broad open bay, called Deep Water Bay, of which Secret Harbor is a part.

The southern shore-line of Cypress Island is strewn with large glacially transported boulders, and the cliffs of glacial material rise to an elevation of 100 feet. These cliffs of glacial materials also extend along the west side of the island.

The southwest corner of Cypress Island is called Reef Point. About two miles north of Reef Point, along the west side of the island, a broad open bay called Strawberry Bay penetrates the marginal shelf of glacial materials. About two miles north of Strawberry Bay a low sandy point called Tide Point, extends out to the westward and marks the northern limit of the fringing shelf of glacial materials. To the south of Tide Point the shore is strewn with large glacial erratics.

The central portion of Cypress Island is elevated and rocky. It is composed of a group of rock domes which merge into each other. The highest of these, known as Cypress Dome, is located about a mile to the east of Tide Point and has an elevation of 1530 feet. Three small lakes occur in a depression on the east side of Cypress Dome, near the summit. The largest of these is known as Cypress Lake. To the southeast of Cypress Lake is a swampy region which cccupies the head of a canyon that slopes down towards Strawberry Bay. To the south of this elevated swampy region there is another large dome which rises to an altitude of 1480 feet. There is a small lake on the east side of the summit of this dome.

Excepting on the areas which are deeply covered with glacial drift, the surface of Cypress Island, though wooded, is quite free from underbrush. The elevated fringing bench of glacial materials is very heavily wooded.

TOWHEAD ISLAND

Towhead Island, with an area of 2.15 acres, is located about a quarter of a mile from the north end of Cypress Island. It has an elevation of about 50 feet and it is bounded by steep rocky cliffs. The surface of the island is quite flat and is covered with conifers.

About a quarter of a mile to the northwest of Towhead Island there is a submerged reef known as Cypress Reef. Three-quarters of a mile to the northwest of Cypress Reef is another submerged reef known as Buckeye Shoal.

STRAWBERRY ISLAND

Strawberry Island is located near the west shore of Cypress Island, at the entrance of Strawberry Bay. It is elongated in a north and south direction or parallel to the strike of the rock formations. It has an area of 10.5 acres and rises to an elevation of about 80 feet. It is scantily wooded.

CONE ISLANDS

The Cone Island group includes five small rock islands which are located near the northeast side of Cypress Island, in the vicinity of Eagle Harbor. They have a combined area of 6.5 acres and the largest or most eastern member of the group has an elevation of about 60 feet. The most western member of the group is little more than a small thin jagged rock which rises about eight feet above tide. Because the side of this island is perforated by a small hole, it is commonly known as Buttonhole Island. The larger members of the Cone Island group are wooded.

GUEMES ISLAND

Guemes Island is separated from Cypress Island on the west by the waters of Bellingham Channel. On the other sides it is bounded by the waters of Guemes Channel, which separate it from Fidalgo Island on the south, and from the mainland on the east.

Guemes Island has an area of 7.96 square miles. The island is roughly triangular in shape and its sides are not broken by any large bays or harbors. With the exception of a few elongated dome-shaped rock hills occurring near the southeast end, the island is entirely covered with stratified glacial drift. This material forms high cliffs along all of the shores excepting a portion of the southern margin near the village of Guemes which is low and flat. The maximum elevation occurring in the drift-covered portion of Guemes Island is 140 feet.

The rounded point which forms the southwest corner of the island is known as Yellow Bluff. The northern extremity of Guemes Island is called Clark Point.

Near the southeast corner of the island there are seven rocky hills, the highest of which has an elevation of 560 feet. A small protected harbor, known as Boat Harbor, occurs to the east of this hill.

All parts of Guemes Island that are not under cultivation are heavily wooded, both with conifers and with deciduous trees.

JACK ISLAND

Jack Island, with an area of 20 acres, is located about a mile from the northeast shore of Guemes Island. It is elliptical in shape, but the major axis of the ellipse does not follow the strike of the rock formations. Though Jack Island is moderately wooded, it contains a very scanty amount of soil. The maximum elevation is about 40 feet.

SAMISH ISLAND

Samish Island is located at the margin of the Samish delta and is connected with it at low tide. Samish Island has an area of 1.46 square miles. It is elongated in an east and west direction, and with the exception of two rock points near the western extremity, it is composed of glacial drift. Near the southern margin of the island the cliffs of glacial drift rise to an elevation of 120 feet.

At the western extremity of Samish Island the bed rock outcrops to form William Point. On the south side of William Point a low sand bar extends far to the southward. Samish Island is connected by a bridge with the mainland to the east. The surface of the island is quite heavily wooded in places where it is not under cultivation.

HUCKLEBERRY ISLAND

Huckleberry Island is situated in Guemes Channel near the entrance to Padilla Bay. It is located near the southeast corner of Guemes Island. It is elliptical in shape, with the major axis trending in a northwest and southeast direction. Huckleberry Island has an area of 11.74 acres and a maximum elevation of about 80 feet. A flat sandy beach extends out from the southwest side of the island, for at that portion the rocky sides are flanked by banks of glacial drift. Huckleberry Island is moderately wooded.

SADDLEBAG ISLAND

Saddlebag Island is situated at the entrance of Padilla Bay, about half a mile to the east of Huckleberry Island. It has an area of 20.6 acres and a maximum elevation of about 80 feet. Saddlebag Island is crossed by a lowland which trends north and south, and as a consequence, embayments enter the island from both the north and south sides. These are separated by an elevated sand bar. Saddlebag Island is moderately wooded.

DOT ISLAND

A small round wooded island near the southeast corner of Saddlebag Island is called Dot Island. It has an area of 2.5 acres and a maximum elevation of about 50 feet.

HAT ISLAND

Hat Island is located at the entrance to Padilla Bay, about half a mile to the southeast of Dot Island. It has an area of 91.85 acres and its maximum elevation is 300 feet. Hat Island is elliptical in outline and somewhat dome-shaped. It is rocky and moderately wooded at all parts of the island.

BURROWS ISLAND

Burrows Island, with an area of 473.7 acres, is situated in Rosario Strait, a short distance south of Fidalgo Head. Its rocky sides rise steeply from the water's edge to a maximum elevation of 690 feet. Burrows Island is scantily wooded.

YOUNG ISLAND

Young Island is located near the southeast shore of Burrows Island. It has an area of 6.76 acres and is elongated in a northeast and southwest direction. Its maximum elevation is about 80 feet and its surface is scantily wooded.

ALLAN ISLAND

Allan Island is located about 700 yards to the south of Burrows Island. It has an area of 287.55 acres and a maximum elevation of 260 feet. Its shore-lines are rocky and irregular, being cut by many small harbors. In places the surface has a thin covering of glacial drift and in such localities it is heavily wooded.

The south shore of Allan Island is fringed by a broad rock shelf which is partly uncovered at low tide. A submerged reef, located about 600 yards to the southwest of Allan Island, is known as Dennis Shoal.

WILLIAMSON ROCKS

Williamson Rocks, with a combined area of 1.2 acres, are located about 1000 yards to the south of Allan Island. They are bare and rocky and the largest of the group of five rocks has an elevation of 22 feet.

CHANNELS

HARO STRAIT

Haro Strait is located on the west side of the San Juan Island group and forms the International boundary line in this region. It has a minimum width of about six miles and the bed of its channel, which is located near the eastern margin, has an average depth of about 900 feet. The deepest point on the map-area occurs in Haro Strait less than a mile to the north of Turn Point, on Stuart Island, where there is a depth of 1356 feet. Due to the great width and depth of Haro Strait, and also to its proximity to the Strait of Juan de Fuca, it supplies the bulk of the water that flows in and out of the Gulf of Georgia at every tide.

To the north of Stuart Island Haro Strait merges with a number of smaller channels which separate the various Canadian and American islands. Here the channel bends sharply to the eastward and its northern limit, or the point where it merges with Boundary Pass, is located near the entrance to Plumper Sound.

BOUNDARY PASS

Boundary Pass is located between Patos Islands on the east and the Canadian island, Saturna, on the west. To the northward and eastward it merges with the waters of the Gulf of Georgia, while to the southward it merges with Haro Strait. Its channel has an average depth of 600 feet, and the deepest point, which is located to the northwest of Alden Point on Patos Island, is 960 feet deep.

PRESIDENT CHANNEL

President Channel is located between Waldron Island and Orcas Island. To the northward it merges with the waters of the Gulf of Georgia, while to the southward it is continuous with San Juan Channel and with the various off-shoot channels from Haro Strait. The bed of the channel has an average depth of 600 feet and its width is about two miles.

SPRING PASSAGE

Spring Passage separates Jones Island from Orcas Island. It is about half a mile wide and the average depth of its channel is about 80 feet.

NEW CHANNEL

New Channel is located between Spieden Island and Cactus Islands. It is about one-third of a mile wide and the depth of its bed varies between 100 and 300 feet. It forms one of the connections between San Juan Channel and Haro Strait.

SPIEDEN CHANNEL

Spieden Channel is located between Spieden Island and the north end of San Juan Island. It is about a mile wide at its eastern or narrow end, and the average depth of its bed is about 350 feet, though in places it is more than 500 feet deep. Spieden Channel forms one of the connections between Haro Strait and San Juan Channel.

SAN JUAN CHANNEL

San Juan Channel separates San Juan Island from Lopez, Shaw, and Orcas islands. At its southern extremity it is known as Cattle Point Narrows. In the vicinity of Turn Island it bends abruptly to the northwestward and it finally merges with Haro Strait and President Channel. Its width and depth vary greatly. At Cattle Point Narrows it is less than a mile wide, while in other places it is more than two miles wide. The average depth is about 350 feet, but near its northern end it is more than 600 feet deep.

UPRIGHT CHANNEL

Upright Channel branches off to the northeastward from San Jaun Channel and separates Lopez Island from Shaw Island. It has an average width of about a mile and the average depth of its bed is about 150 feet. To the northeastward it merges with Harney Channel.

HARNEY CHANNEL

Harney Channel separates Shaw Island from Orcas Island. At its western extremity it branches off to form Pole Pass and Wasp Passage. To the eastward it merges with Upright Channel and their combined channels finally merge with East Sound and Lopez Sound. Harney Channel has an average width of about half a mile, and the depth of its bed varies between 80 feet and 190 feet.

OBSTRUCTION PASS

Obstruction Pass is located between Orcas Island and Obstruction Island. Its average width is about 500 yards and the minimum depth of its bed is about 40 feet.

PEAVINE PASS

Peavine Pass is located between Obstruction Island and Blakeley Island. Its minimum width is about 250 yards and the minimum depth of its bed is about 35 feet at low tide.

THATCHER PASS

Thatcher Pass separates Blakeley Island from Decatur Island. It has a minimum width of about half a mile and the average depth of its bed is about 180 feet. It connects Lopez Sound with Rosario Strait.

LOPEZ PASS

Lopez Pass separates the south end of Decatur Island from the eastern arm of Lopez Island. It has a minimum width of 350 yards, and the minimum depth of its bed is about 80 feet.

ROSARIO STRAIT

Rosario Strait is located on the east side of Orcas, Blakeley, Decatur, and Lopez islands, and separates them from Fidalgo Island and the mainland to the eastward. Between Lopez and Fidalgo islands Rosario Strait is about five and one-half miles wide and the average depth of its channel is about 240 feet. Between Decatur and Fidalgo islands it is only four and one-half miles wide, but farther to the northward it widens out to surround Cypress, Guemes, Sinclair, and Lummi islands. The smaller channels separating these islands are known by their separate names but they are really a part of Rosario Strait.

Due to the presence of the large islands, the broad expanse of water that forms the southern end of Rosario Strait breaks up into Guemes Channel, Bellingham Channel, and Rosario Strait proper. These channels again unite near the south end of Lummi Island, only to be once more divided into Rosario Strait and Hale Passage, and these merge with the waters of the Gulf of Georgia to the northward. At its northern end the bed of Rosario Strait has an average depth of 240 feet.

BELLINGHAM CHANNEL

Bellingham Channel is that portion of Rosario Strait which separates Cypress Island from Guemes Island. It has an average width of about one and one-half miles, and the average depth of its bed is about 240 feet.

GUEMES CHANNEL

Guemes Channel is that portion of Rosario Strait which separates Guemes Island from Fidalgo Island and from the mainland to the east. The depth of its bed varies between 40 and 270 feet. Near the entrance to Padilla Bay,

Guemes Channel turns abruptly towards the north and finally merges with the waters at the north end of Bellingham Channel. To the northeast it merges with the waters of Samish Bay.

HALE PASSAGE

Hale Passage is that portion of Rosario Strait which separates Lummi Island from Portage Island and from the mainland to the east. In places its bed is only 12 feet deep at low tide, due to the encroachment of delta materials from the adjoining streams. To the southeastward it merges with the waters of Bellingham Bay.

Burrows Bay, Fidalgo Bay, Padilla Bay, Samish Bay, and Bellingham Bay occur along the shore of the mainland at the eastern margin of the waters of Rosario Strait.

It is worthy of note that the main channels leading through the San Juan islands have depths which greatly exceed those of the broad open waters to the north and to the south of the archipelago. It is probable that the scouring action of the powerful tidal currents is largely responsible for this condition.

DRAINAGE

The streams occurring on the various islands of the San Juan group are few in number and are all quite small. They usually follow courses that were determined by fault or fracture zones which have been subjected to glacial erosion and modification.

ISLANDS

ORCAS ISLAND

The large bogs occurring on Mount Constitution Range retain a large part of the rain falling on this area during the wet season. This water is delivered to the sea by streams radiating in every direction from the center of the Range. The bogs are so efficient in storing the rain water that many of the streams vary but little in size during the different seasons of the year.

Mountain Lake, with an elevation of 915 feet, derives a large part of its water from bogs which occur on Mount Constitution Range. An artificial dam at the south end of the lake has raised the water level to such an extent that many of the trees occurring near the original shores of the lake have been partly submerged.

Twin Lakes, with an elevation of 1100 feet, drain both to the northward directly into the sea, and also to the southward where a small stream issuing from them empties into Mountain Lake. A large stream issues from the south end of Mountain Lake. By means of a series of waterfalls and rapids its drops about 600 feet within a distance of one and one-half miles. It is joined by another stream issuing from Cascade Lake, and the combined streams empty into the waters of East Sound at the village of Olga. The natural courses of these streams have been considerably changed by water-flumes and other artificial means.

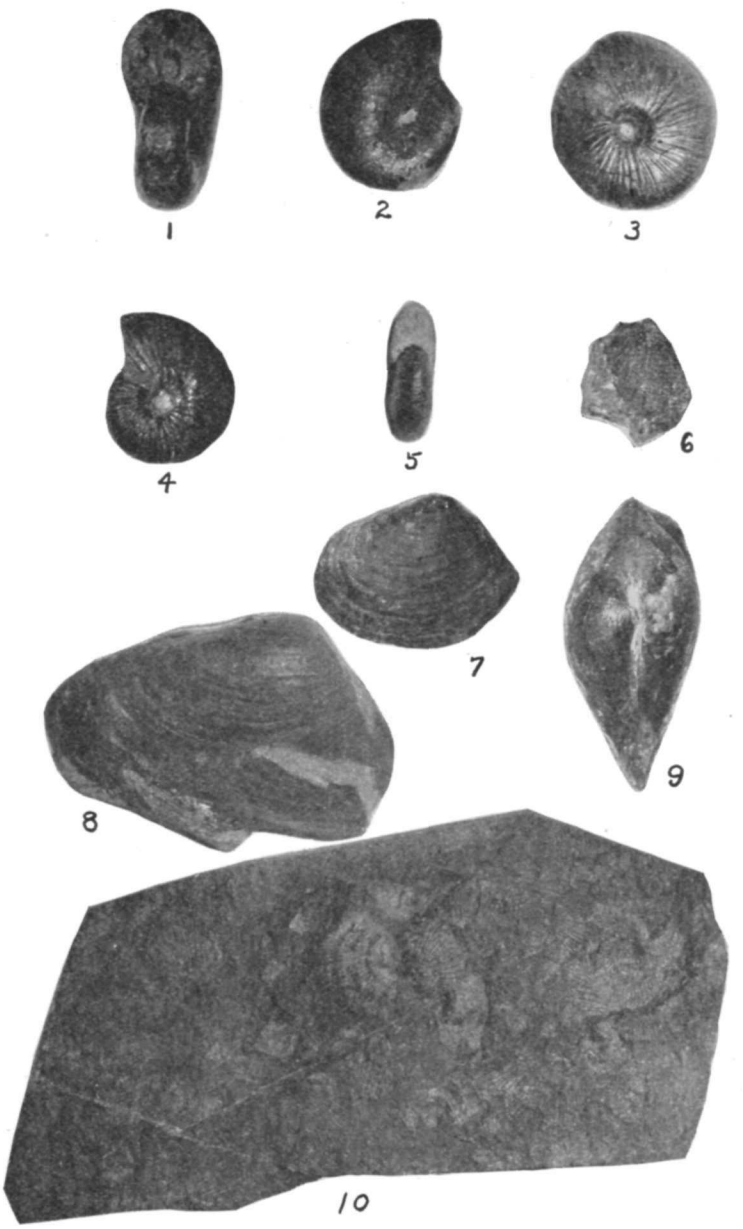


PLATE XII

Figs. 1 & 2. *Phylloceras spiedenensis* n.sp. Type specimen. Fig. 3. *Holcodiscus ??stantoni* n.sp. Paratype. Figs. 4 & 5. *Holcodiscus??stantoni* n.sp. Type specimens. Fig. 6. *Lima spiedenensis* n.sp. Type specimen. Fig. 7. *Pleuromya typa* n.sp. Type specimen. Figs. 8 & 9. *Pleuromya thor* n.sp. Type specimen. Fig. 10. *Halobia* sp. Halobia impressions in a carbonaceous shale from the Haro formation.

Cascade Lake, with an elevation of 350 feet, drains to the westward directly into Cascade Bay. This water is now used to furnish power for a large electric generating plant.

A small stream drains southward from the slopes of Mount Constitution Range and empties into Cascade Lake. Another small stream which issued from the western slopes of this range empties into East Sound near Giffin Park.

Small intermittent streams issue from Buck Lake and from Killebrews Lake. A small intermittent stream flows into the waters of West Sound at its northern extremity. About half a mile to the south of Point Doughty there is a small continuous stream which issues from water seepages along the slopes of the adjoining hill.

SAN JUAN ISLAND

There are no continuous streams on San Juan Island. During the wet season a small stream follows the bottom of the San Juan Valley and empties into False Bay.

Sportsmans Lake, the largest lake on the island, is drained by a small intermittent stream which flows eastward and empties into San Juan Channel. Egg Lake has no outlet though it is connected with Sportsmans Lake by a narrow swampy passage.

The village of Friday Harbor is supplied with water derived from Trout Lake nearly five miles away. Trout Lake has no outlet which reaches the sea.

A small intermittent stream enters the eastern corner of Westcott Bay. Another intermittent stream follows the valley to the southeast of Sportsmans Lake and empties into Friday Harbor.

LOPEZ ISLAND

Lopez Lake, with an elevation of 91 feet, is drained by a small stream which empties into Swifts Bay at the village of Port Stanley.

A small intermittent stream which flows southwesterly empties into the east side of Davis Bay, to the north of Nigger Head.

BLAKELEY ISLAND

A small stream issues from Blakeley Lake and flows southeasterly. Although it flows in the direction of Thatcher Lake it sinks into the ground before reaching that point. A large stream issues from Thatcher Lake and empties into Thatcher Harbor. This stream has a very steep gradient and the water is used to supply power for a saw-mill at Thatcher post office.

CYPRESS ISLAND

A small intermittent stream which originates in the swampy region to the south of Cypress Lake empties into Strawberry Bay.

CULTURE

The majority of the smaller islands are void of human habitation.

On Orcas Island, which is relatively rugged and mountainous, the villages are located in areas of low relief. Like all other villages occurring in the map-area, they are confined to the margins or shores of the islands and are usually located on good harbors or bays. The villages occurring on Orcas Island are East Sound, West Sound, Deer Harbor, Orcas, Dolphin, Rosario, Olga, and Doe Bay. The largest of these is East Sound and its population probably does not exceed 200 inhabitants. These villages are all connected by good dirt roads.

On San Juan Island there are three villages, Friday Harbor, Argyle, and Roche Harbor. In addition to being the county seat, Friday Harbor is the largest town in San Juan County, with a population of about 500 inhabitants. An important fish-canning and vegetable-canning industry is located on the adjoining waterfront. The Puget Sound Biological Station is located at the outskirts of Friday Harbor. The village of Argyle is located to the south of Friday Harbor and almost adjoins it.

Roche Harbor includes a little settlement which has grown up around the lime-quarrying and lime-burning industry. Two other lime quarries are now operating on San Juan Island. One of these is located on the shores of Mosquito Pass, while the other is located on the west side of Mount Dallas Range.

San Juan Island is crossed by a network of dirt roads which connect all parts of the island with Friday Harbor.

The boundary treaty of 1846 between the British and American governments stated that the International boundary should follow the channel between Vancouver Island and the mainland as far north at the 49th parallel of latitude. As a result of the ambiguity arising from this definition, the islands now included in San Juan County were claimed by both governments. The British contended that Rosario Strait was the channel referred to in the treaty, while the American government regarded the Haro Strait as the main waterway.

Owing to the fact that the region was very sparsely settled, the dispute did not come to a head until the year 1859. During that year war was narrowly averted by a compromise whereby each government was allowed to maintain troops and fortifications on San Juan Island pending the decision of an arbitrator.

From 1860 to 1872 the disputed territory was held jointly by the troops of the two governments. The Americans were stationed in the sandy region to the northwest of Cattle Point, while the British block-house and gun emplacements were located on the eastern shore of Garrison Bay about opposite Guss Island. The remains of both the British and American fortifications are still preserved on San Juan Island.

On October 21st, 1872, William I of Germany as arbitrator gave the disputed territory to the United States.

Lopez Island has four small villages which amount to little more than boat-landings. These are Richardson, Otis, Lopez, and Port Stanley. The island is crossed by several dirt roads which connect the villages with each other.

On Stuart Island there is a boat-landing and post office at Prevost, which is located on the northwest side of Prevost Harbor.

A boat-landing and post office is located on Decatur Island at the northern extremity of the so-called Macedonian Crescent. This is known as Decatur post office. A small settlement is located on the narrow peninsula at the southern end of the Macedonian Crescent.

A saw-mill and post office are located at Thatcher Harbor on Blakeley Island. This is known as Thatcher post office.

A boat-landing on the east side of Blind Bay on Shaw Island is the location of Shaw Island post office. A net-work of dirt roads connect with different parts of Shaw Island.

The small village and post office of Waldron is located on Cowlitz Bay at the southwest side of Waldron Island.

The village of Carlyle is located at Village Point on Lummi Island. It is the seat of an important fish-canning industry. The northern half of Lummi Island is a well settled farming district.

Urban post office is located on Sinclair Island. It is supported by the good farming land which occurs on the greater part of the island.

Boat-landings occur on both Strawberry Bay and Secret Harbor on Cypress Island, but owing to the rugged nature of the island it is very scantily populated.

The boat-landing and settlement of Guemes are situated near the southwest end of Guemes Island along the shore of Guemes Channel. Dirt roads connect the different parts of the island with this boat-landing.

Anacortes, with a population of 5300, is located on Fidalgo Island on the south shore of Guemes Channel. It is the seat of important lumbering and fish-canning industries.

CLIMATE AND VEGETATION

The San Juan Islands are located within a "dry belt." Along the west coast of Vancouver Island the annual rainfall is about 150 inches. On the east side of Vancouver Island in the vicinity of Victoria, however, the yearly rainfall is only 22 inches. At Friday Harbor the rainfall is about 25 inches, and farther eastward the amount increases until a maximum is reached on the western slopes of the Cascade Mountains. The annual rainfall occurring on Mount Constitution Range and on other mountain ranges of the region, is considerably greater than that on the areas of low relief. The rainfall on the San Juan Islands is largely confined to the winter months, though occasional rains do occur at all times of the year. During the winter months the region is swept by strong wind-storms which usually come from the southward.

The residents of the San Juan Islands enjoy remarkably beautiful sunsets,

due to the fact that the sun appears to set in the rainy district on the west side of Vancouver Island.

The vegetation on some of the islands is dense and varied while on others it is wholly lacking. Forests of conifers occur on many of the larger islands. The wood contains an unusually large amount of pitch, and while this condition injures its value for lumber, it greatly adds to its value as fuel.

The following is a list of the trees and shrubs occurring on the San Juan Islands,—

(Taken from an unpublished manuscript called the "Key-Trees and Shrubs of San Juan Islands," compiled by Miss Leona Sundquist of the University of Washington.)

Taxus brevifolia (Western Yew)
Juniperous scopularum (Rocky Mountain Juniper)
Thuja plicata (Giant Cedar)
Abies grandis (White Pine)
Picea sitchensis (Spruce)
Pseudotsuga taxifolia (Douglas Fir)
Tsuga heterophylla (Hemlock)
Pinus contorta (Twisted Cone Pine)
Pinus monticola (Western White Pine or Mountain Pine)
Fatsia horrida (Devil's Club)
Hedera helix (Ivy)
Oxycoccus oxycoccus (Cranberry)
Vaccinium parvifolium (Red Huckleberry)
Ledum greenlandicum (Laborador Tea)
Arbutus menziesii (Madrona)
Gaultheria shallon (Salal)
Kalmia polifolia (Swamp Laurel)
Pachistima myrsinites
Chimaphila umbellata
Berberis nervosa (Dull Oregon Grape)
Berberis aquifolium (Shining Oregon Grape)
Ulex europeus (Gorse)
Cytisus scoparius (Scotch Broom)
Corylus california (Hazel)
Betula occidentalis (Western Birch)
Alnus oregona (Red Alder)
Populus tremuloides (Aspen)
Populus trichocarpa (Cottonwood)
Salix lasiandra (Gland Willow)
Salix scouleriana (Scouler Willow)
Salix hookeriana (Hooker Willow)
Quercus garryana (White Oak)
Crataegus rivularis (Hawthorn)
Amelanchier florida (Service Berry)
Osmaronia cerasiformis (Indian Plum)
Prunus emarginata (Wild Cherry)
Holodiscus discolor (Ocean Spray)
Spiraea douglasii (Hardhack)
Rubus parviflorus (Thimbleberry)
Rubus ursinus (Trailing Blackberry)
Rubus laciniatus (Evergreen Blackberry)
Rubus spectabilis (Salmonberry)
Rubus leucodermis
Rosa gymnocarpa (Naked Rose)
Rosa nutkana (Nutka Rose)
Rosa pisocarpa (Bunched Rose)
Shepherdia canadensis (Soap Olallee)
Cornus nuttallii (Flowering Dogwood)
Cornus occidentalis (Western Dogwood)
Linnea borealis (Twin Flower)

Symphoricarpos racemosus (Snowberry)
Sambucus callicarpa (Red Elder)
Lonicera involucrata (Black Twin Berry)
Lonicera ciliosa (Orange Honey Suckle)
Lonicera hispidula (Pink Honey Suckle)
Ribes sanquineum (Red-flowered Currant)
Ribes divaricatum (Gooseberry)
Ribes lacustre (Swamp Gooseberry)
Acer macrophyllum (Large Leaved Maple)
Acer glabrum (Rocky Mountain Maple)
Acer circinatum (Vine Maple)
Philadelphus gordonianus (Syringa)
Fraxinus oregona (Oregon Ash)

On Cypress Island, and on other islands composed of the Fidalgo formation, it is noticeable that very little underbrush or surface vegetation exists. This condition is probably brought about by the oxidation of chromite to form chromic salts. (Dr. T. C. Frye, Professor of Botany at the University of Washington, called the author's attention to the fact that chromic salts are poisonous to plant life.)

In places where the rocks of the Fidalgo formation are covered with a few inches of glacial drift, the surface vegetation is usually dense.

Sphagnum moss-bogs occur on Mount Constitution Range at an elevation of about 2000 feet. They are also found at many other localities in the San Juan Island map-area.

Some of the small barren islands have a species of prickly cactus growing on them.

DESCRIPTIVE GEOLOGY

SEDIMENTARY ROCKS

GENERAL CHARACTER

The sedimentary rocks exposed on the San Juan Islands range from middle Paleozoic to Recent in age.

The Paleozoic rocks belong to one more or less conformable series, known as the San Juan series.[1]

The lower portions of the San Juan series are composed largely of cherty quartzite and argillite with scattered lens-shaped deposits of crystalline limestone. The upper portions of the series have a more varied lithology, but tuffaceous graywacke, argillite, schist, and conglomerate are the most abundant rock types. Almost all of the Paleozoic rocks are highly metamorphosed.

On Vancouver Island there is a series of rocks known as the Sicker series[2] which is apparently unfossiliferous. It is suspected by the writer that the Sicker series and the San Juan series are identical, even though the former has been provisionally correlated with the Jurassic.

The Mesozoic sedimentary rocks occurring on the San Juan Islands belong to the Triassic, lower Cretaceous, and upper Cretaceous systems. They are composed chiefly of conglomerate, arkosic sandstone, and shale. Mesozoic limestone beds are small and quite rare in this region. The Mesozoic rocks, particularly those belonging to the upper Cretaceous system, are only slightly metamorphosed. The Tertiary rocks are composed of unmetamorphosed arkosic sandstones and conglomerates of brackish or fresh water origin. The Tertiary and late Mesozoic rocks have apparently been subjected to the same period or periods of folding.

During the Pleistocene period the glaciers cut deeply into the older formations and, on retreating, left a thick mantle of glacial drift on many of the islands.

DEVONO-MISSISSIPPIAN SYSTEMS

Orcas Group

Principal Features. The Orcas group[3] is the oldest one exposed on the San Juan Islands, and the outcrops are all included within a belt 22 miles long and 10 miles wide. The underlying strata are covered by the waters of the sea. The Orcas group is overlain with approximate conformity by the tuffaceous graywackes of the Leech River group. The rocks of the Orcas group are complexly folded and contorted, while fracture zones and faults of unknown magnitude further complicate the structure. Up to the present time it has not been possible to distinguish the Devonian formations from those belonging to the Mississippian.

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[1] McLellan, R. D., The Devonian Orcas Groups of Washington: *Amer. Jour. Sci.*, 5 Ser., vol. 8, p. 217, 1924.

[2] Clapp, C. H., Southern Vancouver Island: *Geol. Survey Canada, Summary Report*, 1909. pp. 88-89, 1910.

[3] McLellan, R. D., The Devonian Orcas Group of Washington: *Amer. Jour Sci.*, 5 Ser., vol. 8, pp. 217-222, 1924.

Lithology and Structure. The Orcas group was laid down by normal processes of marine sedimentation in fairly deep water and at a considerable distance from the shore. Periodic conditions produced thin strata of fine-grained and perhaps semi-colloidal silica sands alternating with thin strata of mud. The sediments have been highly metamorphosed and contorted as a result of folding and igneous intrusions.

The outstanding lithological component of the Orcas group is a light bluish-gray chert. The chert is so badly fractured and the joint planes so intricately recemented by white quartz that it is impossible to obtain a thin section that will not show several quartz veinlets within its area. The veinlets are usually parallel for the bedding plane and in places they are so abundant that the rock passes into a cherty quartzite.

The chert strata range from half an inch to three inches in thickness with an average of slightly more than an inch. Each band of chert is separated from the next by layers of argillite. The thickness of the argillite bands is generally slightly less than that of the chert layers and they vary in color from light brownish-gray to dark brown. Near the uppermost part of the Orcas group the rhythmical alternation of thin strata of chert and argillite is somewhat broken. Occasional strata of argillite here reach a thickness of several feet, while above and below them the regular alternation of thin strata persists. By differential erosion, especially along the coast, the argillite layers have been largely removed, while the cherty layers stand out in relief and present a surface and structure resembling that of shredded wheat. The argillite has a tendency to pass into the chert, although in places it is highly schistose.

Thin sections of the chert show numerous small round "spots" filled with quartz, and these are occasionally present in the interbedded argillites. The size of the "spots" is approximately that of the radiolarians seen in the cherts of the Franciscan formation of California, and since radiolarian cherts have also been found in northern California[4] in formations of similar age and lithology, it is assumed that the quartz-filled "spots" were originally radiolarian tests which have since recrystallized. A recent examination of selected samples of the chert has revealed the fact that the "spots" are due to microorganisms which were probably radiolarians. These microorganisms occur in such a poor state of preservation that little can be specifically learned concerning them.

Numerous lens-shaped beds of limestone occur interbedded with the cherty quartzite. These are not confined to any one horizon, but occur scattered throughout the whole group. However a fairly persistent series of lenses occur at a horizon near the lowest part of the group exposed, and another one near the top of the group. The limestone is always recrystallized and recemented with calcite. In the vicinity of igneous dikes, the limestones are usually silicified and irregular masses of flint are found. Limestone beds oc-

[4] Diller, J. S., Mineral Resources of Southwestern Oregon: *U. S. Geol. Survey, Bull.* 546, pp. 15-16, 1914.

SYSTEM OR SERIES	FORMATION AND GROUP	SECTION	THICKNESS	CHARACTER OF ROCKS
Recent	*Colwood formation*		0'- 50'	Post Vashon alluvium.
Pleistocene	*Vashon formation*		0'- 50'	Glacial till and sediments.
	Puyallup formation		0'-150'	Interglacial sediments.
	Admiralty formation		0'- 50'	Glacial till and sediments.
Lower Eocene	*Chuckanut formation*		500'±	Cross-bedded arkosic sandstone and conglomerate, with coal.
Upper Cretaceous	Nanaimo series		5000'±	Arkosic sandstone, shale, conglomerate, and coal.
Lower Cretaceous	Spieden formation		2000'+	Conglomerate, sandstone, shale, and limestone.
Upper Triassic	Haro formation		1250'+	Conglomerate, sandstone, shale, and limestone.
Permian	Leech River group		15000'±	Tuffaceous graywacke, argillite, phyllite, schist, grit, breccia, conglomerate, limestone and coal.
Pennsylvanian				Chiefly fresh or brackish water deposits.
Mississippian	Orcas group		10000'±	Thin alternating beds of cherty quartzite and argillite. Occasional limestone lenses.
Devonian				

Figure 1. Table of Formations.

curring in the vicinity of aplite and pegmatite dikes are sometimes replaced by contact minerals such as tremolite and wollastonite. Still other limestones contain a considerable quantity of carbonaceous matter, and in such cases the limestone is black in color and the joint planes are often covered with glistening films of graphite. The limestones of the Orcas group contain remarkably low percentages of magnesium, and this fact is all the more remarkable when it is considered that they are frequently intruded by dikes of igneous materials containing high percentages of magnesium.

A series of cherty and tuffaceous graywackes having a thickness exceeding a hundred feet appear to occupy a definite horizon somewhat higher than the middle of the Orcas group. It is possible that this horizon marks the dividing-line between the Devonian and the Mississippian.

ORCAS ISLAND

It is possible that the conglomerate exposed along the shore near the foot of Orcas Knob represents the base of the Orcas group. The coarse greenish sandstone that forms its matrix greatly predominates over the enclosed boulders which consist chiefly of altered andesite, quartzite, and granite. Its thickness is at least 35 feet. The conglomerate is overlain by 25 to 50 feet of thin alternating beds of quartzite and argillite and these are followed by a fairly persistent limestone bed about 30 feet thick. This limestone bed contains Devonian fossils and the surrounding rocks are somewhat less metomorphosed than those occurring in other parts of the region.

The limestone is overlain by thin-bedded quartzite and agillite, the former being cherty only at intervals. Like the true cherts which occur farther up in the group, this material contains the quartz-filled "spots." It is noticeable that some of the chert strata of the Orcas group contain a much larger number of the quartz-filled "spots" than others. Some of the cherts are free or nearly free from the quartz-filled "spots."

The succeeding strata are so broken up by igneous intrusions of several ages, that scattered remnants of the chert are all that remain. These remnants usually retain the same general strike and dip as that of the unintruded portions, i. e., the strike is northeast and the dip southeast. On the western half of Orcas Island the igneous intrusions take the form of a wide belt or zone running parallel to the strike of the chert. To the southeast of this igneous belt, which is shown on the accompanying geological map as the Turtleback Complex, the cherts are again almost free from igneous intrusions. If a straight line be drawn northeastward from Reef Island to the village of West Sound and continued on towards East Sound, it would mark the southern or upper boundary of the igneous belt.

In the southern part of Orcas Island the major trend of the Orcas group is modified by the presence of several minor folds which trend north and south or slightly northwest and southeast. The southern part of East Sound follows a minor anticlinal fold, while the structure of the region to the south of Mount Woolard is complicated by faulting.

The cherty rocks of the Orcas group appear along the west and northwest sides of the Mount Constitution Range. Here they trend northeasterly and dip towards the southeast at a moderate angle. These rocks make up the upper part of the group on Orcas Island and they contain several large limestone lenses which appear to belong to the same horizon as those occurring to the north of Mount Woolard.

VICTIM ISLAND

The cherty rocks occurring on Victim Island trend about N 60° W and dip towards the southwest. The same attitude is assumed by the rocks along the shore of Orcas Island to the west of Victim Island. The cherts on this island are cut by several igneous dikes or sills which follow the general trend of the sedimentary rocks.

DOUBLE ISLAND

The Orcas cherts occurring on Double Island have the same general trend and dip as those on Victim Island. The peninsula between West Sound and Deer Harbor is located on the axis of a minor synclinal fold which plunges towards the southward. The cherty rocks occurring on Double Island and on Victim Island are a part of the eastern limb of this fold.

BELL ISLAND

Bell Island is located on the axis of the synclinal fold which embraces the peninsula to the northward. The cherty rocks are here so broken up that they are practically structureless.

CRANE ISLAND

The western limb of the synclinal fold mentioned above embraces the rocks of the Orcas group occurring on Crane Island. In general these rocks are badly broken and dislocated, but they commonly trend northeasterly and dip towards the southeast. Near the southwest corner of Crane Island there is a limestone lens which is apparently a continuation of the limestone ledges occurring on Cliff Island.

CLIFF ISLAND

The cherty rocks belonging to the Orcas group which occur on Cliff Island, trend northeasterly parallel to the long direction of the island. They dip steeply towards the southeast. A series of large limestone lenses occur along the northwest shore of the island. Intrusions of the Eagle Cliff porphyrite have destroyed a large part of the cherty rocks on Cliff Island.

SHAW ISLAND

On Shaw Island the rocks of the Orcas group are so badly dislocated and broken up that each isolated outcrop may show a structure which does not conform to that of its neighbors. In general the rocks occurring along the southwest shore trend northwesterly and dip towards the northeast at moderate

angles. Along the Wasp Passage the rocks trend northeasterly and dip towards the southeast. Rocks belonging to the Leech River group have been folded and faulted in with those of the Orcas group at many localities on Shaw Island. The rocks of the Orcas group occurring on Shaw Island contain a number of limestone lenses, but none of these are large.

JONES ISLAND

On Jones Island the rocks belonging to the Orcas group are confined to the remnants of chert and limestone which have not been destroyed by the igneous rocks which make up the greater part of the island.

A limestone stratum with a maximum thickness of about 20 feet, outcrops along the east shore of the island and trends northwesterly. At the head of the large harbor which penetrates the north end of Jones Island, this limestone stratum turns abruptly and continues in a westerly direction until it reaches the western shore of the island.

SAN JUAN ISLAND

San Juan Island is located on the axis of a large synclinal fold which embraces practically all of the Paleozoic rocks occurring in the map-area. The fold plunges towards the southeast and as a consequence the outcrops of the rocks belonging to the Orcas group on San Juan Island take the general shape of a horseshoe which forms the northern shores of the island.

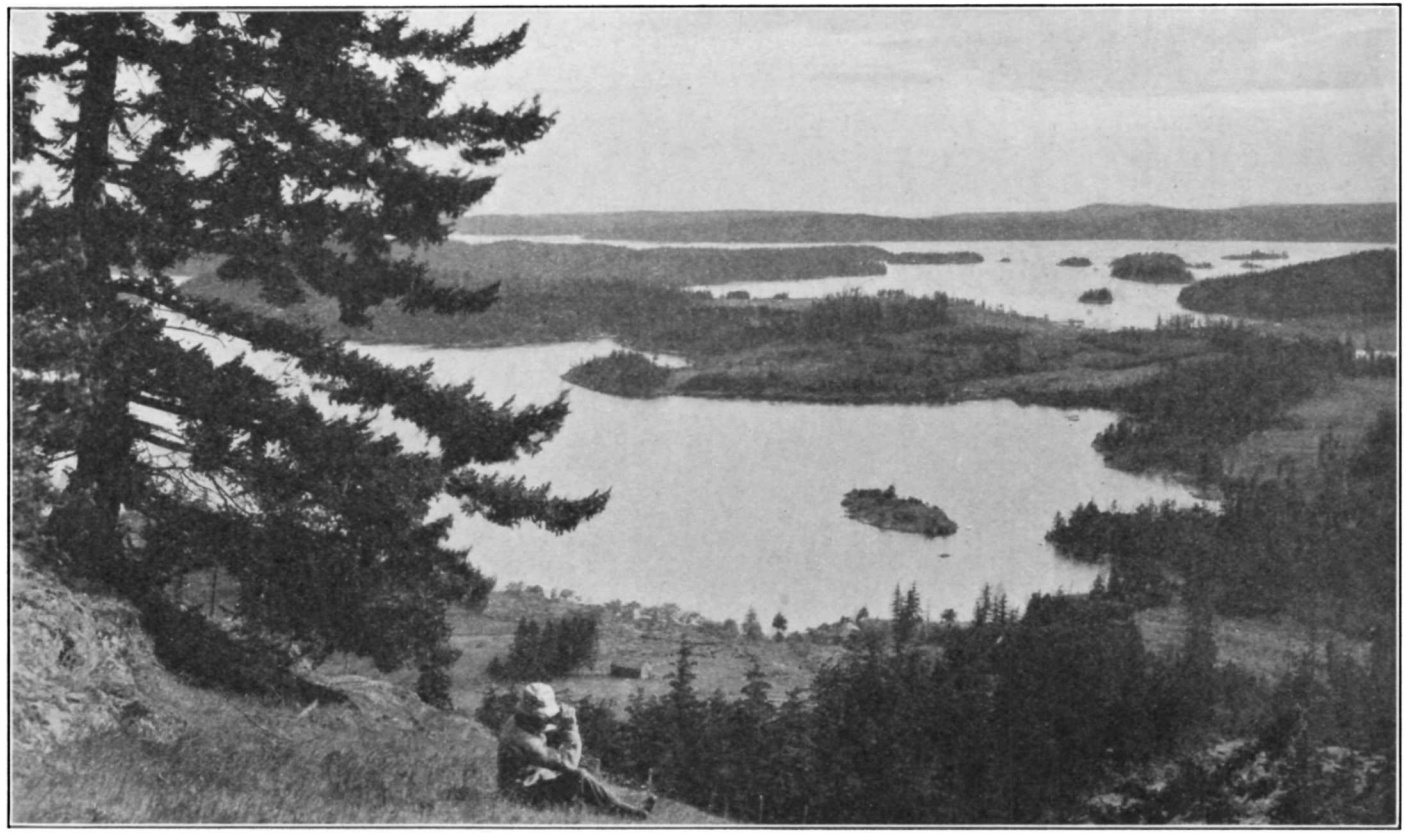
The contact between the cherts of the Orcas group and the overlying tuffaceous and somewhat cherty graywackes belonging to the Leech River group, may be seen along the northeast shore of San Juan Island, about a mile to the east of Sportsmans Lake. The rocks of the Orcas group occur at the northwest end of the island, to the northwest of San Juan Range. They also include Mount Dallas Range. The most southern outcrop of the Orcas cherts occurs at the southeast side of False Bay.

Along the southwest margin of San Juan Island the cherty rocks trend approximately parallel with the shore-line and dip towards the northeast. Along the northeast margin of the island the cherty rocks dip towards the southwest. The structure at the northwest end of the island has been complicated by minor folding and by faulting.

The cherty rocks belonging to the Orcas group on San Juan Island, contain numerous lenses of limestone. The largest of these is located at Roche Harbor. The cherty rocks have been intruded by scattered dikes and sills of igneous rocks which were not sufficiently abundant to destroy the structure of the cherts.

HENRY ISLAND

Henry Island is located on the axis of the plunging synclinal fold which embraces the Paleozoic rocks on San Juan Island. The two parallel elevated ridges which make up the island trend parallel with the strike of the Orcas cherts. In the vicinity of McCracken Point the cherts trend about N 75° W and



Photograph by J. A. McCormick.

PLATE XIII

The view across the islands as seen from the southwest slopes of the Turtleback Range.

dip steeply towards the southwest. The same trend and dip are seen on Battleship Island and on Pearl Island. Several limestone lenses, some of them quite large, are located on Henry Island.

O'NEAL ISLAND

O'Neal Island is composed largely of rocks belonging to the Orcas group. These rocks seem to have been dislocated from those occurring along the nearby shores of San Juan Island, for they trend about N 45° E and have a dip which is nearly vertical. A limestone stratum having a maximum thickness of about 20 feet crosses the southern part of the island.

Age and Correlation. In the Orcas Lime Quarry, near the foot of Orcas Knob, Sections 30 and 31, T 37 N, R 2 W, the writer discovered some fossil brachiopods on the weathered surface of the limestone ledge as it outcrops along the face of the cliff. These fossils occur to a depth of only one inch and beneath this the limestone is entirely recrystallized and shows no trace of fossil remains. Apparently this fossil-bearing ledge has been preserved in some unknown manner while the surrounding limestones have been completely recrystallized.

These brachiopods have been examined by Dr. Charles Schuchert, who determined them to be a variety of *Atrypa reticularis* Linneaus. He says in a letter to the writer;—

> "All of them are *Atrypa reticularis,* one of the commonest of all Paleozoic forms. This species ranges throughout the Silurian and Devonian, but your specimens look to me like the Euro-Asiatic variety seen in the late Middle and Upper Devonian throughout the west, from the Pacific to Iowa. The spirals show in a number of specimens, and these prove that their apexes turn to the center of the dorsal shells. Very few genera do this, so there is no doubt you have *Atrypa reticularis,* and, I think, a late Devonian form."

The Orcas group is to be correlated with the lower part of the Cache Creek series of British Columbia. The Cache Creek series was first described by Dawson[5] who found in it the Pennsylvanian fossil *Fusulina.* He also found fossils in the lower formations, however, which ranged back into the Devonian, and he remarks that "The lower portions of the Cache Creek formation may be older than the Carboniferous period."

In the Bridge River district, west of Lillooet, British Columbia, McCann[6, 6a] describes the Bridge River series, which he considers to be of Pennsylvanian-Permian age, but his description applies equally well to the rocks of the Orcas group.

The Orcas group may also be partly equivalent to the Hozomeen series[7] which occurs in the Skagit and Hozomeen ranges, near the forty-ninth parallel.

Deposits of chert, similar to that of the Orcas group, are known to occur

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[5] Dawson, G. M., Report on Area of the Kamloops Sheet, British Columbia: *Geol. Survey Canada, Ann. Rept.,* new ser. 7, pp. 39B-49B, 1896.

[6] McCann., W.S., Geology and Mineral Deposits of the Bridge River Map-Area, British Columbia.

[6a] *Ibid.,* Memoir 130, pp. 23-26, 1922.

[7] Smith, G. O., and Calkins, F. C., A Geological Reconaissance Across the Cascade Range near the Forty-nineth Parallel: *U. S. Geol. Survey, Bull.* 235, pp. 22-23, 1904.

in the Olympic Mountains of Washington, but as yet no detailed geological work has been done in this area.

The chert deposits in Northern California, described by Diller,[8] are similar in lithology, and in addition, they contain identical fossils. Radiolarian remains are still preserved in these cherts.

While the cherts of the Franciscan formation of California[9,10] are tentatively referred to the Triassic or Jurassic periods, their age is not definitely known, and it may prove that they too belong to the late Devonian and Mississippian periods.

The limestone ledges exposed on Orcas Island, to the south of Mount Woolard, in Sec. 2, T 36 N, R 2 W, are structurally near the top of the chert group. These limestones contain the Carboniferous coral *Lithostrotion.*

The argillites and graywackes of the Leech River group in this area contain fragments of the "spotted" chert, and also include *Fusulina*-bearing limestones, hence it is probable that the *Lithostrotion*-bearing limesstones are of Mississippian age.

The Orcas group, therefore, had its beginning in the Middle or Upper Devonian, and the deposition of its sediments continued on into the Lower Carboniferous.

PENNSYLVANIAN-PERMIAN SYSTEMS

Leech River Group

Principal Features. The Leech River group[11,12] is well represented in the rocks outcropping on the San Juan Island map-area. It forms the central part of the syncline on San Juan Island, and is well exposed on Lopez Island and other islands in the eastern portion of the map-area. It outcrops in many places on Orcas Island, and forms the south or mountainous half of Lummi Island. On the mainland to the east, the rocks belonging to the Leech River group outcrop at the south end of Chuckanut Drive, on the Pacific Highway.

The Leech River group is composed of a great variety of rock types. It contains graywacke, argillite, conglomerate and breccia, grit, schist, phyllite, slate, volcanic tuff, chert, limestone, and coal.

On the southern part of Vancouver Island, Clapp[13] distinguishes a group of metamorphosed "argillaceous and arenaceous sedimentary rocks," as the Leech River "formation.". Overlying the Leech River sediments and grading

[8] Diller, J. S., Mineral Resources of Southwestern Oregon: *U. S. Geol. Survey, Bull.* 546, pp. 15-16, 1914.

[9] Lawson, A. C., *U. S. Geol. Survey, Geol. Atlas, San Francisco folio* (no. 193), pp. 34-57, 1915.

[10] Davis, E. F., The Radiolarian Cherts of the Franciscan Group: *Univ. Calif. Publ. Bull. Dept. Geol.*, vol. 11, pp. 353-408, 1918.

[11] Dawson, G. M., Report on a Reconaissance of Leech River and Vicinity: *Geol. Survey Canada, Report of Progress, 1876-77,* pp. 95-102, 1878.

[12] Clapp, C. H., Southern Vancouver Island: *Geol. Survey Canada,* Mem. 13, p. 35, 1912.

[13] Clapp, C. H., Sooke and Duncan Map-Areas, Vancouver Island: *Geol. Survey Canada,* Mem. 96, pp. 66-93, 1917.

into them, he describes a group of tuffaceous rocks which are known as the Malahat volcanics.

On the San Juan Islands it is not possible to make such a sub-division, and on account of the wide range of rock types presented, it has been considered advisable to use the name, Leech River "group." Volcanic tuffs occur interbedded with the purely sedimentary strata at several horizons within the group. So far as lithology is concerned, the Malahat volcanics occurring on Southern Vancouver Island are identical with the tuffaceous graywackes which form the basal member of the Leech River group in the San Juan Island map-area.

Lithology and Structure. The dark colored slaty schists and argillites are perhaps the most abundant rock types occurring in the Leech River group. They range from quartz-mica schists and phyllites to normal slates and argillites. Quartz-biotite and quartz-sericite schists and phyllites are abundant in the eastern part of the map-area. These rocks usually contain considerable amounts of magnetite and graphite. When the percentage of carbonaceous matter is high the rocks are almost black in color when viewed from a distance.

The slates and argillites exhibit several stages of metamorphism and they are often somewhat schistose. They often alternate with massive beds of graywacke which is sometimes tuffaceous. The graywackes range from fine-grained rocks to coarse grits and are usually well cemented. They often contain rounded or nodular mudstone inclusions scattered irregularly through the coarser-grained deposits. Fragments of chert derived from the Orcas group form the most abundant constituent of the rocks of the Leech River group. Both orthoclase and plagioclase (about Ab 70 An30) are usually present in the sediments, but the percentage of quartz is below the typical amount for such rocks. Sericite, chlorite, epidote, serpentine, kaolinite, magnetite, and graphite occur in varying amounts. It is noticeable that the conglomerates are practically free from pebbles of granite, though fragments of granite porphyry and andesite are fairly common. In many localities the sediments of the Leech River group have been cut by dikes and stringers of white milky quartz.

SAN JUAN ISLAND

The lowest member of the Leech River group, as exposed on San Juan Island, is a tuffaceous and cherty graywacke. It overlies the Orcas cherts with approximate conformity. This graywacke is typically fine-grained and occurs in beds of varying thickness. In places it appears as thin beds which differ from each other only in the size of the fragments composing them. Occasionally the graywacke contains scattered layers of chert, and it is possible that the conditions which brought about the deposition of the Orcas cherts continued on, and additional sediments, including tuffaceous material, were added to them. The basal graywackes have a probable maximum thickness of several thousand feet. They have the general composition of a dacite, and their weathered surfaces are almost indistinguishable from that of a weathered andesite in the hand specimen.

The basal graywackes outcrop throughout the elevated region in the vicinity of Point Caution, and on account of their resistance to erosion, the outcrops form a series of elevated ridges. Since the rocks of both the Orcas and Leech River groups are embraced in the broad open synclinal fold which plunges towards the southeast, the individual rock formations outcrop in the form of a horseshoe. The elevated ridges representing the outcrops of the basal graywackes consequently have the shape of a horseshoe. They are seen on Biological Hill, the San Juan Range, Mount Grant, and on Little Mountain. The upper limit of the graywackes is marked by a well defined formation about 100 feet thick, composed of coarse breccia and conglomerate. This formation underlies a portion of the village of Friday Harbor and is encountered at several localities near the southwestern side of San Juan Island.

The breccia formation is followed by several hundred feet of carbonaceous argillite which has no banding or apparent structure of any kind. This is followed by a tremendous thickness of thin-bedded alternating light and dark layers of argillite which often grades into phyllite. Occasionally there are interbeds of graywacke, grit, or conglomerate.

The uppermost strata of the group are composed of thick conglomerate, grit, graywacke, and slate, and it is possible that these formations belong to the early Mesozoic systems. These upper formations occupy the core of the major plunging synclinal fold on Lopez Island and do not outcrop on San Juan Island.

In addition to the igneous intrustions which have almost everywhere penetrated the rocks of the Leech River group, these rocks are frequently cut by stringers and veins of white milky quartz.

BROWN ISLAND

Brown Island is composed of the basal graywackes of the Leech River group. These rocks have been intruded by dikes and sills of the Eagle Cliff porphyrite, and in places the sedimentary rocks have been overturned so that they dip towards the northward.

TURN ISLAND

The tuffaceous graywacke composing Turn Island has been largely destroyed by intrusions of the Eagle Cliff porphyrite. The igneous rocks now make up the greater part of the island.

DINNER ISLAND

Dinner Island is composed of thin-bedded graywacke which trends northwesterly and dips towards the southwest.

GOOSE ISLAND

Goose Island, and also the rocky peninsula to the north of Cattle Point on San Juan Island, are composed largely of graywacke which has been intruded by dikes and sills of the Eagle Cliff porphyrite. The rocks have an average

strike of about N 55° W, and they dip towards the northeast at angles varying from 35 to 65 degrees.

LOPEZ ISLAND

A great thickness of alternating beds of light and dark colored argillite occurs along the south margin of Lopez Island. The individual layers of argillite are from one to three inches thick. The dark layers contain notable quantities of graphite and this gives the rocks a dark sooty appearance. In places the argillites grade into mica schists and phyllites, and they sometimes contain interbeds of graywacke, grit, and conglomerate. These sedimentary rocks have been intruded by dikes and sills of the Eagle Cliff porphyrite and they are generally somewhat silicified near the contacts.

In the vicinity of Iceberg Point, the Leech River sediments trend about N 65° W and dip towards the northeast at angles varying between 40 and 70 degrees. Between Davis Bay and the boat-landing at Richardson, the rocks have an average strike of about N 55° W, and they dip towards the northeast at an angle of about 70 degrees.

The rocks occurring in the vicinity of Point Davis are composed of argillite, slate, graywacke, and conglomerate. At Point Davis they strike N 40° W and dip towards the northeast at an angle of 35 degrees. Along the shore of Cattle Point Narrows, about opposite Deadman Island, the rocks have a strike of N 35° W and a dip of 35 degrees towards the northeast. At the most northern of these outcrops, which occur along the shore about a mile to the north of Point Davis, the strike is N 10° E, and the dip is 35 degrees towards the southeast. Still farther northward on Shark Reef the rocks trend about north and south and dip towards the east at angles varying between 15 and 20 degrees. The bend in the strike of the rock formations to the north of Point Davis is quite evident when viewed from the westward.

The outcrops of graywacke and thin-bedded argillite occurring in the vicinity of Fishermans Bay have an average strike of about N 40° E and a dip of about 40 degrees towards the southeast.

The rocky peninsula which extends out from the north end of Lopez Island to form Upright Head is composed largely of conglomerate with minor amounts of graywacke. These rocks strike about N 20°-40° W and dip about 35° NE.

The rocks composing Humphreys Head consist of massive beds of graywacke and grit which contain scattered irregular nodules of black mudstone. These beds strike about N 10°-40° W and the average dip is about 45 degrees towards the northeast.

Near the southeast corner of Hunter Bay an outcrop of thin-bedded slate, argillite, and graywacke shows a strike of N 55° W and a dip of 60° N.E. At the southeast side of Mud Bay some thin-bedded graywackes show a strike of N 52° W and a dip of 42° NE.

In the vicinity of Watmough Bight the Leech River sediments have an average strike of N 55° E and a dip of about 70° NW. At Watmough Head

the strike is nearly east and west and the thin-bedded and somewhat schistose rocks dip steeply to the northward.

The rock outcrops occurring in the interior portions of Lopez Island are composed mainly of the Eagle Cliff porphyrites, and the scattered remnants of Leech River sediments are of little value in determining the structure.

DEADMAN ISLAND

The graywacke and grit which compose Deadman Island strike about N 65°-70° W and dip about 60° NE.

WHALE ROCKS

Whale Rocks are composed of fine-grained argillaceous graywacke which has a reddish color. These rocks have little or no banding but their general strike appears to be about N 40°-45° E and the dip is about 30° SE.

MUMMY ROCKS

Mummy Rocks are composed of graywacke and grit with occasional beds or pockets of argillite. In places the rocks are cut by quartz stringers. The beds strike N 60° W and dip 45° NE.

BUCK ISLAND

Buck Island is composed of graywacke which has been badly shattered by intrusions of Eagle Cliff porphyrites.

LONG ISLAND

Long Island is composed of conglomerate, grit, massive graywacke, thin-bedded argillaceous graywacke, and thin-bedded schistose argillites and slates. At the west end of the island the strike is N 40°-45° W and the dip is 35° NE. The central and eastern parts of the island have a strike of N 75° W and a dip of about 65° NE. The small islands to the south of the central part of Long Island, and tied to it by means of low sand bars, are composed chiefly of thin-bedded shaly argillites and graywackes.

CHARLES ISLAND

Charles Island is composed chiefly of thin-bedded alternating light and dark layers of somewhat schistose slates and argillites. The predominating dark color of these rocks is caused by their relatively high content of carbonaceous matter which gives them a dull sooty appearance when viewed from a distance. Interbeds of conglomerate, grit, and graywacke also occur on Charles Island. The strike of the beds varies from N 70° W to N 80° W, and the dip ranges from 60 to 75 degrees towards the northeast. The small rocky islands to the northeast of Charles Island are composed of carbonaceous slaty schists which have similar strikes and dips.

SECAR ROCK

The graywacke composing Secar Rock has been so greatly shattered by igneous intrusions that the structure is not in evidence.

HALL ISLAND

Hall Island is composed of thin-bedded graywacke and argillite which strike N 70° W and dip from 50° to 70° N.E.

ICEBERG ISLAND

The massive graywacke composing Iceberg Island has been intruded and shattered by Eagle Cliff porphyrites.

ALECK ROCKS

The thin-bedded carbonaceous slaty schists composing Aleck Rocks trend about N 75° W and dip steeply towards the northeast.

COLVILLE ISLAND

Colville Island is composed of thin-bedded carbonaceous slaty schists and graywackes with occasional beds of grit and conglomerate. The strata trend about east and west and the average dip is about 55 degrees towards the north.

BOULDER ISLAND

With the exception of a thin remnant of Leech River sediments extending out from its southern margin, Boulder Island is composed entirely of Eagle Cliff porphyrites. The Leech River sediments dip steeply towards the north.

CRAB ROCKS

The Leech River sediments composing Crab Rocks trend northeasterly and dip towards the southeast. At the end of the nearby peninsula on Lopez Island the strike is northwesterly and the rocks dip towards the northeast.

RAM ISLANDS

Although Ram Islands are composed largely of Eagle Cliff porphyrites, a sufficient amount of the host rocks have been left to show that the strike is parallel to the long direction of the islands, and the dip is about 20 degrees towards the southeast.

CENTER ISLAND

The thin-bedded carbonaceous slate, graywacke, and grit composing Center Island have a strike of about N 18° E and a dip of about 25° SE at the southern end of the island. At the northern part of the island the strike is about N 25°-30° W and the dip is about 30°-40° NE.

TRUMP ISLAND

Trump Island is composed chiefly of thin-bedded slate, argillite, and graywacke. In places these rocks weather to a bright red color. The elevated region along the east side of Trump Island is composed of massive graywacke. The rocks on Trump Island have a strike of about N 20° W and a dip of 45° NE.

DECATUR ISLAND

The massive graywacke, grit, and argillite which compose the elevated peninsula to the north of Trump Island strike about N 5° W and dip steeply towards the southwest.

The northern and elevated portion of Decatur Island is composed largely of massive and thin-bedded graywacke together with a considerable amount of conglomerate, grit, and argillite. In places these rocks have been shattered by igneous intrusions. The conglomerates at the northwest corner of the island strike about N 55° E and dip about 70° SE.

The thick and thin-bedded graywacke, grit, slate, and argillite occurring in the vicinity of Fauntleroy Point have a strike of about N 75° E and dip towards the northwest at an angle of 75 degrees.

The rounded and elevated dome which forms Decatur Head is composed of conglomerate with occasional interbeds of argillite, graywacke, and grit. The strike of these rocks is about N 80°-85° E, and the dip is about 45° NW.

An outcrop of carbonaceous thin-bedded argillite occurs on the west side of the elevated peninsula which forms the southern extremity of Decatur Island. The Leech River sediments occur as a narrow belt near the water's edge, while higher on the cliff and throughout the remainder of the peninsula the Leech River rocks have been practically destroyed by intrusions of Eagle Cliff porphyrite. The sediments occupy the crest of an anticlinal fold which plunges towards the east. At the northern end of these curved beds the strike is N 45° W and the dip is 40° N.E.

JAMES ISLAND

James Island is composed of conglomerate, shale, argillite, graywacke, and grit which have been intruded by one or two dikes of igneous material. The structure, as shown in the figure, is very complicated.

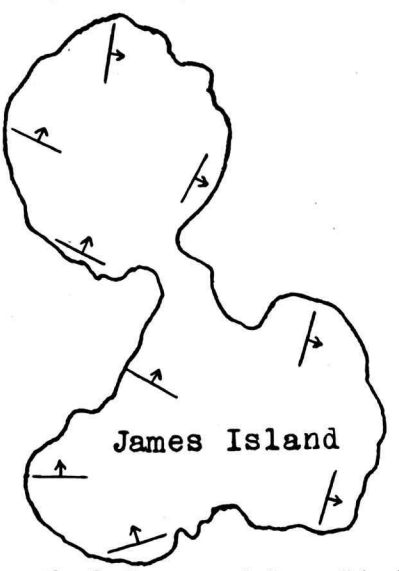

Figure 2. Outline map of James Island.

Some of the rocks occurring on James Island are much less metamorphosed than the usual Leech River sediments, and it is possible that they should be correlated with the Haro formation.

FLOWER ISLAND

Flower Island is composed of massive graywacke, grit, and conglomerate which have been considerably broken by folding. The strike and dip varies in different parts of the island, but in general the trend is about north and south and the dip averages around 60 degrees towards the west. The dip and strike at different parts of this island show a remarkable discordance with each other.

SHAW ISLAND

The Leech River sediments occurring on Shaw Island consist chiefly of the basal graywacke member. The rocks in this region are badly shattered and broken, and they contain in-folded and in-faulted fragments and blocks of the Orcas chert. Intrusions of igneous material serve to make the problems in structural geology still more complicated. The same type of conditions are encountered on Canoe Island.

ORCAS ISLAND

The Leech River sediments occurring on Orcas Island to the southeast of Mount Woolard are badly shattered by intense folding and faulting. They have been involved in the minor folding or crumpling which embraces the rocks along the southern side of Orcas Island. The Orcas cherts have been faulted in with the rocks belonging to the Leech River group. The basal graywacke forms the chief representative of the Leech River group in this region, but the overlying breccia and argillite are exposed in several places.

The Orcas cherts which outcrop along the west sides of Mount Entrance and Mount Constitution Range are overlain by the graywackes of the Leech River group. On Mount Constitution Range the graywackes trend about N 35°-45° E and dip towards the southeast at moderate angles. These rocks are largely confined to the basal graywacke member though occasionally the overlying argillites may be seen.

Along the northeast shore of Orcas Island, from Point Lawrence to the foot of Buck Mountain, the Leech River sediments trend about N 60° W and dip towards the southwest at an average angle of about 60 degrees. The strata are composed of thin-bedded graywacke, shale, argillite, slate, schist, grit, conglomerate, limestone, and coal. To the north of Mount Pickett these sediments are broken up by igneous intrusions, and sills of igneous material occur occasionally at all parts of the long straight shore-line.

A series of small lens-shaped deposits of limestone occur intermittently from Raccoon Point to Point Lawrence. These limestones contain a considerable amount of carbonaceous matter and their weathered surfaces are usually black in color. They contain micro-fossils of Carboniferous age. The in-er-

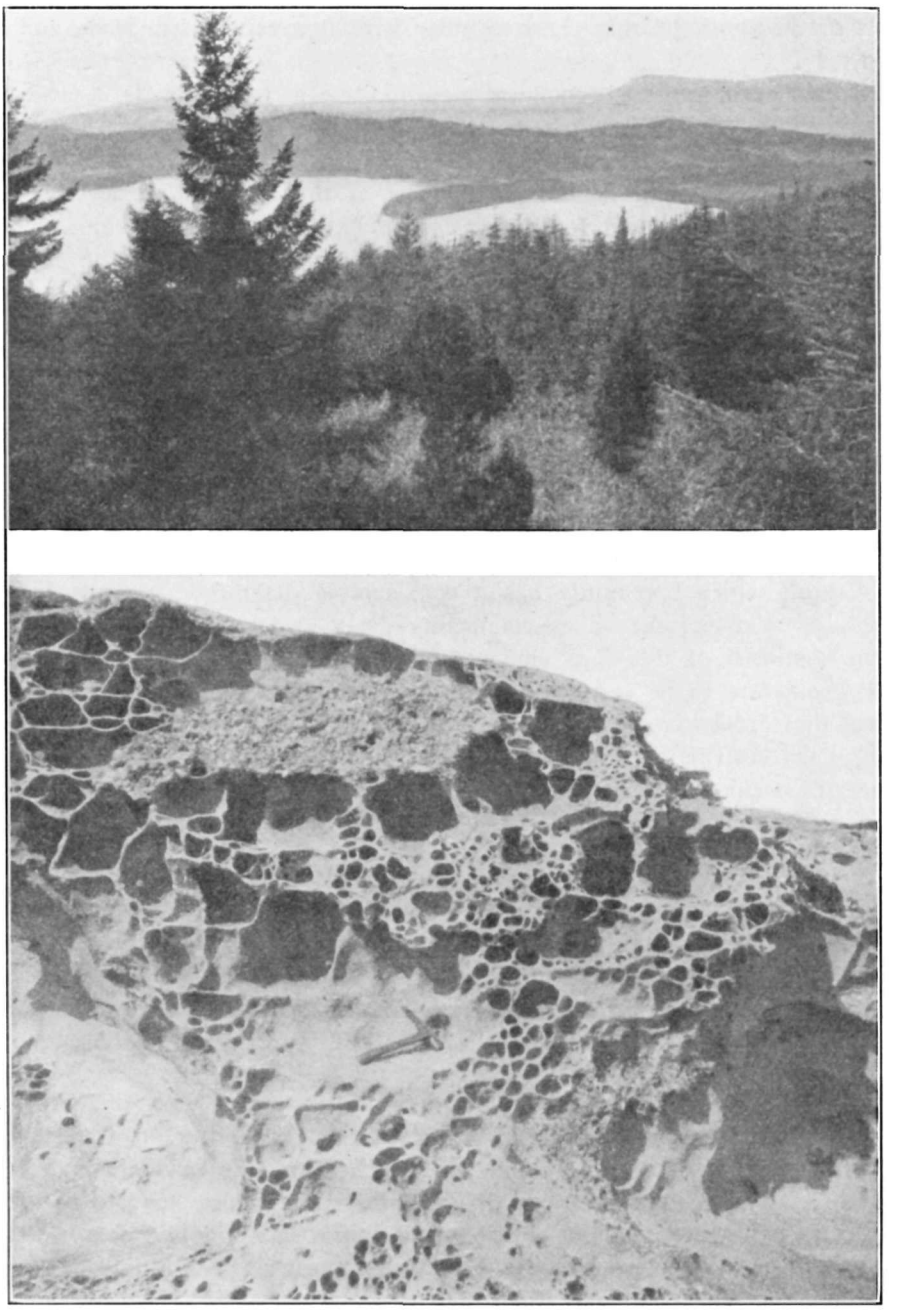

PLATE XIV

Above: Looking northwestward from the slopes of Mount Constitution. East Sound in the center; Canadian islands in the right background. *Below*: Honeycomb sandstone on the Sucia Islands.

bedded graywacke, grit, and conglomerate strata are composed largely of fragments of the spotted Orcas chert together with fragments of andesite and volcanic tuff.

On the accompanying geological map of the San Juan Islands, a large area in the vicinity of Mount Pickett Range is shown in the color denoting the Turtleback complex. It would have been just as logical to have shown this whole area in the color denoting the rocks of the Leech River group. The former color was adopted for two reasons: (1) The Leech River sediments are badly broken up by igneous intrusions of several kinds; (2) The structure of the rocks in this region would not be well indicated if the whole area were shown as one color. Apparently Mount Pickett Range is located on the axis of a synclinal fold. The southern limb of this fold is largely obliterated by igneous intrusions.

The rocks belonging to the Orcas and Leech River groups on Mount Constitution Range are clearly overthrust upon the Leech River sediments to the northward. The strike of the latter is nearly at right angles to that of the former, and the break or fault line between them is clearly evident. On the east side of the range the fault line is occupied by Mountain Lake.

A fault which apparently has a considerable magnitude extends through the island, following the valley connecting the villages of Olga and Doe Bay. To the southeast of this fault line only the uppermost members of the Leech River group are to be seen, and these are free from igneous intrusions. In general these rocks trend northeasterly and dip towards the southeast. In the vicinity of Obstruction Pass the Leech River graywackes, slates, and conglomerates occur in gently undulating folds. Near its southwest entrance Obstruction Pass occupies the axis of a synclinal fold, while farther eastward it follows the axis of an anticlinal fold.

OBSTRUCTION ISLAND

The graywacke, slate and grit found on Obstruction Island occur in gently undulating folds. At the eastern corner of the island an anticlinal fold plunges towards the eastward at a gentle angle. At the southwest corner of Obstruction Island the strike is about N 45°-50° E, and the dip is about 25° SE.

BLAKELEY ISLAND

The only outcrops of Leech River sediments occurring on Blakeley Island are located on the rocky peninsula which forms its northern extremity. This peninsula is composed largely of conglomerate which appears to be identical with that occurring at Upright Head on Lopez Island. The conglomerates and their interbedded graywackes and slates occurring on Blakeley Island strike about N 60° E and dip about 60° SE.

DOE ISLAND

The thick and thin-bedded argillite and graywacke occurring on Doe Island trend about N 70° E and dip towards the southeast at a gentle angle. These rocks are badly broken up by intrusions of the Eagle Cliff porphyrites.

PEAPOD ROCKS

Peapod Rocks are composed of graywacke, grit, conglomerate, and slate which trend northeasterly and dip towards the southeast. The rocks apparently belong to approximately the same horizons as those occurring in the vicinity of Obstruction Island.

STRAWBERRY ISLAND

The Leech River sediments which compose Strawberry Island, consist of thick-and thin-bedded carbonaceous argillite and graywacke. These rocks trend nearly north and south and the dips are almost vertical. The general dip is slightly towards the eastward.

CYPRESS ISLAND

Sedimentary rocks belonging to the Leech River group occur only at the northern extremity of Cypress Island. They consist chiefly of thin-bedded and dark-colored carbonaceous argillites, slates, and graywackes. Along the shore to the northwest of Eagle Cliff the rocks strike N 70° E and dip 30° SE. To the northeast of Eagle Cliff the Leech River sediments strike N 60°-75° W, and the dip varies from 25 to 55 degrees towards the southwest. The rocks have been considerably distorted by intrusions of the Eagle Cliff porphyrites. To the north of Eagle Harbor a remnant of the Leech River sediments shows a strike of N 60° E and a dip of 60° SE.

TOWHEAD ISLAND

Towhead Island is composed chiefly of dark-colored thin-bedded argillites and slates which strike N 70° E and dip 40° SE.

CONE ISLANDS

Cone Islands are composed of dark-colored thin-bedded schistose argillites and slates which have been intruded by Eagle Cliff porphyrites. One of the more northern islands of the Cone group shows a strike of N 70° E and a dip of 35° S.E. Another one of the islands shows a strike of N 55° E and a dip of 65° SE.

SINCLAIR ISLAND

The conglomerate, grit, graywacke, and slate occurring along the southern margin of Sinclair Island apparently being the same general horizons as those found in the vicinity of Obstruction Island. The rocks occurring on Sinclair Island have a persistent strike of N 70° E, and the dip varies between 35 and 60 degrees towards the southeast.

LUMMI ISLAND

The southeastern and elevated half of Lummi Island is composed of dark-colored and usually thin-bedded argillite, graywacke, slate, grit, and conglomerate belonging to the Leech River group. These rocks have an average strike of N 40° W and an average dip of 40° NE. At Carter Point the rocks

strike N 35° W and dip 40° NE. On Lummi Rocks and along the shore of Lummi Island to the eastward, the strike is N 40°-45° W and the dip is 35° NE. At the northern end of the elevated portion of Lummi Island the strike of the rock formations turns towards the westward. The most northern outcrop along the west side of the island has a strike of N 50°-65° W and a dip of 40°-50°NE.

Along the east or dip-slope side of Lummi Island the dips and strikes are not consistent. This is due to the fact that in places the slaty rocks have slipped down the dip-slopes. A few scattered dikes of the Eagle Cliff porphyrites may be seen in this region.

VITI ROCKS

The graywacke and grit composing Viti Rocks strike N 55° W and dip 55° SW. An apparent anticlinal fold occurs between Viti Rocks and the south end of Lummi Island.

ELIZA ISLAND

The dark-colored schistose slates and graywackes occurring at the western extremity of Eliza Island strike north and south and dip at an angle of about 50 degrees towards the east. The rocks occurring at the southern extremity of Eliza Island, and also on Eliza Rock, strike about N 10° E and dip about 10°-25° SE.

JACK ISLAND

Jack Island is composed of silvery-gray phyllite, schist, slate, graywacke, and grit. These rocks are cut by numerous veins and stringers of white quartz. At the northern end of the island the strike is N 65°W and the dip is 32° SW. At the southern extremity of Jack Island, the strike is N 75° W and the dip is 30° SW.

SAMISH ISLAND

The schistose slates and graywackes occurring near the western extremity of Samish Island are somewhat carbonaceous, though they possess a silver-gray lustre. The most northern of these outcrops has a strike of N 60°-85° E and a dip of 75°-80° SE. At William Point the strike is N 45° W and the dip is 35° SW. All of these rocks are cut by numerous stringers of quartz.

GUEMES ISLAND

Along the south shore of Guemes Island, near the southeast corner, the thin-bedded carbonaceous and somewhat schistose slates and graywackes strike about N 60° W to N 75° E, and dip towards the south at an angle of about 70 degrees. Immediately north of Boat Harbor the strike of the thin-bedded slaty rocks is N 45° W and the dip is about 80° NE.

The sedimentary rocks belonging to the Leech River group on Guemes Island are so greatly shattered and broken up by igneous intrusions of several periods that the structural features shown by the remnants are not very reliable.

FIDALGO ISLAND

The somewhat carbonaceous graywacke, grit, slate, conglomerate, and argillite occurring on Capsante Peninsula and underlying the City of Anacortes strike about N 20° W and dip about 70°-85° SW.

Age and Correlation. The Leech River group is for the most part of fresh or brackish water origin and virtually unfossiliferous. At intervals the marine waters came in for a sufficient length of time to deposit an occasional limestone bed. The weathered surfaces of these limestones are always covered with a layer of black carbonaceous matter apparently derived from the limestones themselves.

The limestones are usually recrystallized but along the shore of Orcas Island, to the north of Mount Constitution Range, some of them contain microfossils in abundance. Among these fossils the foraminifer, *Fusulina,* is perhaps the most abundant. Some of the beds are composed largely of small fragments of corals and other larger fossils, together with scattered specimens of *Fusulina.*

Fusulina reached its period of maximum development in the Pennsylvanian time. Since the deposition of the Orcas group of sediments continued on into the Mississippian, the sediments belonging to the Leech River group are probably to a large extent of Pennsylvanian age. The fossil-bearing limestones are probably located several thousand feet above the base of the Leech River group, with several distinct types of lithology intervening. It is probable that the lower members of the Leech River group are Mississippian in age, and that the uppermost members are of Permian and possibly Triassic age.

In the Skagit and Hozomeen ranges of Washington the upper part of the Hozomeen series[14] is to be correlated with the Leech River group. The Cache Creek series of central and northern British Columbia, which is apparently equivalent to the San Juan series, is argillaceous in its upper members and also contains *Fusulina*-bearing limestones scattered through it. At the International boundary between Washington and British Columbia a group of argillites and graywackes known as the Chilliwack series[15] seems to possess the same general characteristics as the rocks of the Leech River group.

The Leech River sediments occurring at the type locality on southern Vancouver Island are identical in lithology with those found in the San Juan Island map-area.

It is possible that some of the argillaceous rocks occurring in the central elevated portion of the Olympic Mountains are to be correlated with the rocks of the Leech River group.

[14] Smith, G. O., and Calkins, F. C., A Geological Reconnaissance Across the Cascade Range near the Forty-ninth Parallel: *U. S. Geol. Survey Bull.* 235, pp. 22-23, 1904.

[15] Daly, R. A., Geology of the North American Cordillera at the Forty-ninth Parallel: *Geol. Survey Canada,* Mem. 38, pp. 508-516, 1912.

TRIASSIC SYSTEM

Haro Formation

Principal Features. The peninsula known as Davidson Head, located at the northern extremity of San Juan Island, is composed of conglomerate, shale, slate, sandstone, graywacke, grit, and limestone of upper Triassic age. These rocks, which occupy an area of only 48 acres, make up what is here called the Haro formation. So far as it is definitely known, no other rock outcrops of this age occur in the San Juan Island region.

Lithology and Structure. The lowermost strata exposed on Davidson Head are made up chiefly of conglomerate with occasional thin interbeds of reddish-colored sandstone and shale. The sandstone layers pinch out along the strike and conglomerates take their place. The shales frequently show spheroidal weathering. The conglomerates generally have a coarse greenish-colored matrix, although in places the matrix is calcareous and stained with ferric oxide. In many cases the boulders of the conglomerate are not well sorted, for large subangular fragments occur along with smaller pebbles of various sizes. The boulders are composed of fragments of the Orcas chert and Leech River graywacke, granite, dacite porphyry with virtreous phenocrysts of sanidine up to half an inch in diameter, dark greenish altered andesite, and fine-grained bluish-gray limestone. The thickness of the conglomerate member as exposed on Davidson Head is 920 feet.

The conglomerates are overlain by thin-bedded carbonaceous shale, slate, graywacke, grit, and limestone. The layers of limestone are interbedded with carbonaceous shale and the individual strata do not exceed four feet in thickness. The uppermost strata of the Haro formation are largely concealed by glacial drift, but the location of the fault line between the rocks of the Haro formation and the Orcas cherts is evident from the surface features.

The rocks occurring on Davidson Head are somewhat shattered and dislocated so that the dip and strike vary considerably from place to place. However, the average strike is nearly east and west and the dip is moderately steep towards the south. The sediments belonging to the Haro formation have not been intruded by igneous rocks within the region in which these rocks are exposed. The total thickness of the Haro formation occurring in the vicinity of Davidson Head is 1250 feet. Aside from a moderate amount of induration these rocks have suffered from a relatively slight amount of metamorphism.

Age and Correlation. Nearly all of the strata which overlie the conglomerates are abundantly fossiliferous, but the fossils occur only as impressions. All of the fossils collected belong to the genus *Halobia,* which is restricted in its occurrence to the upper Triassic.

The limestones are metamorphosed to such a degree that only the distorted outlines of *Halobia* can be distinguished. The fossils are best preserved in the carbonaceous shales and slates which occur just below the limestones. In many cases the shells have been replaced by pyrite and marcasite.

The conglomerates occurring on Upright Head, Humphreys Head, north end of Blakeley Island, Decatur Island, James Island, southeast portion of Orcas Island, Obstruction Island, Peapod Rocks, and Sinclair Island, all of which being located in the upper part of the Leech River group, contain dacite porphyry and andesites along with fragments of chert and graywacke. On first examination the writer considered these rocks to be Jurassic or even of later age, because it was supposed that the andesites and dacite porphyry belonged to the Vancouver volcanics. The conglomerates of the Haro formation also contain similar andesites and dacite porphyry. Dikes of similar material actually cut the Orcas cherts on Turtleback Mountain Range, but their relationship to the other igneous intrusions could not be determined. Although the rocks at the above mentioned localities have been considered with the Leech River group, it is possible that they should be correlated with the Haro formation.

LOWER CRETACEOUS SYSTEM OR SERIES

Spieden Formation

Principal Features. Isolated outcrops of conglomerate, sandstone, and shale, called here the Spieden formation, occur in the northwest portion of the map-area. The outcrops of this formation are apparently confined to Spieden Island, Sentinel Island, and Sentinel Rock. The latter two islands are composed chiefly of conglomerate, while Spieden Island is also composed of conglomerate except along its northern margin. The rocks of the Spieden formation are evidently separated from those of the Nanaimo series to the northward by a normal fault trending in an east and west direction. Spieden Island is located on the upthrow side of this fault. Apparently there is another normal fault which follows the bed of the channel to the south of Spieden Island. In this case Spieden Island is located on the down-throw side of the fault.

Lithology and Structure. The Spieden formation is composed of conglomerate, breccia, sandstone, shale, and argillaceous limestone. Within the map-area the conglomerates make up about 85 per cent of the rocks. They contain fragments up to a foot in diameter although they are usually not larger than one inch. The fragments are composed of andesite, diorite, granodiorite porphyry, milky quartz, jasper, graywacke, chert, argillite, and limestone. Boulders of granodiorite occur very sparingly and these are generally fine-grained. A calcareous sandstone forms the matrix in most cases, although in some beds a ferruginous matrix prevails. The conglomerates on Sentinel Island are identical in lithology with those on Spieden Island.

SPIEDEN ISLAND

Along the northern margin of Spieden Island there is a group of thin-bedded and somewhat carbonaceous shales. These continue at least as far as low tide, but their thickness is unknown. Although they are soft and unmetamorphosed they have been badly contorted by folding. They grade up-

ward into sandy shales and sandstones, with an occasional bed of argillaceous limestone. These beds are usually olive-gray in color, and the individual strata average six inches in thickness. Throughout a thickness of about 35 feet these beds are richly fossiliferous.

The fossiliferous layers are overlain by fine-grained conglomerate and breccia. The arenaceous or calcareous matrix of the conglomerate greatly predominates over the boulders. Here and there, thin and well stratified sandstones occur throughout the conglomerate beds, but the sandstones pinch out along the strike and do not form definite horizons. The conglomerates have a thickness exceeding 2,000 feet.

The conglomerate beds of the Spieden formation have an average strike of N 70°-75° W, and they dip to the southward at angles of 45-60 degrees. Along the north shore, at the foot of Spieden Bluff, the fossiliferous shales and sandstones strike N 65° W, and dip 65° SW.

The conglomerates of the Spieden formation differ from those of the Nanaimo series, in the scarcity of boulders of granodiorite and other batholithic rocks. The late Jurassic batholiths apparently had not been deroofed in this region by upper Knoxville time.

SENTINEL ISLAND

Sentinel Island is composed of conglomerates identical in lithology with those occurring on Spieden Island. The alternating calcareous and ferruginous matrix of the conglomerates is peculiar to the Spieden formation. At the north edge of Sentinel Island the beds strike N 80° W and dip 45° SW. At the south edge of the island the beds strike N 82° W. and dip 55° S.W. The thickness of the strata outcropping on Sentinel Island is about 800 feet.

The outcrops occurring on Sentinel Rock are the equivalent of some of the strata on Sentinel Island.

Age and Correlation. Along the north shore of Spieden Island there is a belt of fossil-bearing sandstone and shale. The fauna was examined by Dr. T. W. Stanton, who determined its age to be lower Cretaceous and equivalent to the upper part of the Knoxville formation of California.

Aucella crassicollis Keyserling is by far the most abundant fossil and it makes up fully ninety-five per-cent of the fauna. The identical fossils are found on the Nooksak River, north of Mount Baker. One of these fossil beds is located in a road-cut about two miles east of the village of Glacier, in section 5, T 39 N, R 7 E.

The fossils collected on Spieden Island include the following;—

Aucella crassicollis Keyserling
Holcodiscus? stantoni n. sp.
Phylloceras spiedenensis n. sp.
Pleuromya thor n. sp.
Pleuromya typa n. sp.
Lima spiedenensis n. sp.
Pinna sp.
Inoceramus sp.
Gryphaea sp.
Belemnites sp.
Serpula sp.

The Spieden formation is to be correlated with the Pasayten formation which outcrops in the Hozomeen Range and other localities in north central Washington.[16]

[16] Smith, G. O., and Calkins, F. C., A Geological Reconnaissance Across the Cascade Range near the Forty-ninth Parallel: *U. S. Geol. Survey Bull.* 235, pp. 28-30, 1904.

DESCRIPTION OF NEW SPECIES

Order Ammonoidea

Family SILESITIDAE

GENUS HOLCODISCUS UHLIG

HOLCODISCUS?? STANTONI n. sp.

Plate XII. Figs. 3, 4, and 5.

Shell compressed, convex, and narrowly umbilicated; the umbilicus somewhat rounded with steep inner wall, occupying about one-fifth of the entire diameter; volutions closely involute, the inner ones being almost covered by those which succeed them; aperture higher than wide, sub-elliptical, but deeply emarginate by the encroachment of the preceding volution.

Surface marked with numerous slightly elevated, flexuous, transverse ribs, which are always somewhat narrower than the shallow concave spaces between them; the ribs are always bifurcate, and usually one or both branches are again divided so that near their summits they are generally trifurcate or tetrafurcate. There are approximately 25 major or parent ribs to each volution. The major ribs, though less strongly developed, continue to the inner wall of the umbilicus.

Sutural line not well seen, there being only two immature specimens collected that show a sutural line.

Dimensions.

	Diameter	Thickness	Diameter of Umbilicus
Type specimen	15.0 mm.	6.0 mm.	3.0 mm.
Paratype	20.5 mm.	7.5 mm.	3.75 mm.

The largest specimen known to the writer, and preserved only as a cast, measured about 125 mm. in diameter. The largest specimen actually collected has the dimensions: maximum diameter, 65 mm.; maximum thickness, 17 mm.; diameter of the umbilicus, 12 mm.

Locality. The type specimen was found on the north shore of Spieden Island at the foot of Spieden Bluff. The paratype was found at the same locality.

The same species is found in a road-cut along the south bank of the Nooksak River, about two miles east of the village of Glacier, in section 5, T 39 N, R 7 E.

Disposal of Type. University of Washington Paleontological Collection.

H. stantoni differs from *Holcodiscus cumshewaensis,* which species it most closely resembles, in the size of the umbilicus. *H. cumshewaensis,* in the type specimen at least, is much more loosely coiled than *H. stantoni.*

Named in honor of Dr. T. W. Stanton of the U. S. National Museum at Washington.

Family PHYLLOCERATIDAE

GENUS PHYLLOCERAS SUESS

PHYLLOCERAS SPIEDENENSIS n. sp.

Plate XII. Figs. 1 and 2.

Shell smooth and moderately inflated; the umbilical margin rounded and indistinctly defined; volutions increase rapidly in size, are closely convolute, the inner ones being completely covered by each succeeding volution; aperture higher than wide, nearly circular in the type specimen, but more elliptical in some of the other specimens collected; aperture, emarginate because of the encroachment of the preceding volutions, is somewhat pointed in the direction of the umbilicus, the specimen being very thin at this point.

Sutural line.

Dimensions.

	Diameter	Thickness
Type specimen	23.0 mm.	12.0 mm.

The thickness at the axis of the umbilicus approaches zero.

Locality. The type specimen was obtained on the north shore of Spieden Island at the foot of Spieden Bluff.

Disposal of Type. University of Washington Paleontological Collection.

P. spiedenensis, in the type specimen, is more inflated than is normal in the genus Phylloceras. In some of the specimens this is reduced more nearly to the normal inflation for the genus. The type specimen does not seem to be distorted, for several other specimens were collected possessing a similar shape.

PELECYPODA

Superfamily ANATINACEA Dall

GENUS PLEUROMYA AGASSIZ

PLEUROMYA THOR n. sp.

Plate XII. Figs. 8 and 9.

Shell compressed, being most convex near the anterior margin; valves closed in front but slightly open behind; anterior end short and sloping nearly

in a line from the beaks to the ventral margin; posterior end much longer, and somewhat pointed at its junction with the ventral margin; cardinal margin excavated and gently curved; umbones large, broad, and prominent; beaks small, anterior, and curved forward and downward; umbonal ridges nearly obsolete.

Surface marked by irregular, moderately fine concentric striations. Hinge teeth and muscular impressions unknown.

Dimensions.

	Length	Height	Thickness
Type specimen	51 mm.	32 mm.	21 mm.

Locality. The type specimen was collected on Spieden Island, at the foot of Spieden Bluff.

Disposal of Type. University of Washington Paleontological Collection.

P. thor is distinguished from the typical *Pleuromya subcompressus Meek,* by the fact that its beaks are less prominent, its surface markings finer and more irregular, and its posterior end is more pointed.

PLEUROMYA TYPA n. sp.

Plate XII. Fig. 7.

Shell moderately convex, rounded in outline, the height being but little less than the length; umbones broad and somewhat flattened; beaks small, elevated, slightly anterior, and curved forward and downward; valves closed in front, but apparently open behind; anterior end sloping rapidly to the ventral margin; posterior end rounded, though somewhat longer than the anterior end; anterior umbonal ridges well developed; posterior umbonal ridges obsolete; ventral margin convex and strongly curved.

Surface marked by deep, irregularly disposed, concentric striations. Hinge teeth and muscular impressions unknown.

Dimensions.

	Length	Height	Thickness
Type specimen	27 mm.	21 mm.	11 mm.
Paratype	40 mm.	36 mm.	24 mm.

Locality. Collected on Spieden Island at the foot of Spieden Bluff. Poorly preserved casts were seen at the Nooksak River locality, two miles east of the village of Glacier.

Disposal of Type. University of Washington Paleontological Collection.

The ventral margin of *P. typa* is much more strongly curved than that of any other Pleuromya known to the writer.

Superfamily PECTINACEA Reeve

GENUS LIMA BRUG

LIMA SPIEDENENSIS n. sp.

Plate XII. Fig. 6.

Shell small, moderately convex, obliquely subovate, posterior side produced below; beaks sharply incurved; ears small; surface markings consisting

of twelve narrow, radiating ribs; spaces between the ribs smooth and much wider than the ribs themselves; characters of the interiors of the valves unknown.

Dimensions. A single fragmental specimen has the following approximate dimensions,—length, 12+mm.; height, 15+mm.; thickness, 7 mm.

Locality. Collected on Spieden Island, at the foot of Spieden Bluff.

Disposal of Type. University of Washington Paleontological Collection.

L. spiedenensis differs from *Lima suciensis* in the fact that it contains no minor radiating ribs, and by the lack of concentric lines of growth.

UPPER CRETACEOUS SYSTEM OR SERIES

Nanaimo Series

Principal Features. The rocks of the Nanaimo series[17,18,19] outcrop on the small islands which fringe the northern margin of the San Juan Island group. The rocks are composed of unmetamorphosed conglomerates, grits, arkosic sandstones, and shales. They appear along the north shore of Orcas Island, the outcrops beginning at the base of Buck Mountain and extending westward around Point Doughty and continuing southward as far as Point Kimple. Rocks belonging to the Nanaimo series occur on Stuart Island, Satellite Island, Johns Island, Ripple Island, Cactus Islands, Flattop Island, Gull Rock, White Rocks, Waldron Island, Bare Island, Skipjack Island, Parker Reef, Patos Islands, Sucia Islands, Clements Reef, Matia Islands, and on the Barnes and Clark groups of islands.

The outcrops of the upper Cretaceous rocks are usually small and isolated and the geological record is fragmental. These rocks at one time covered the whole map-area with the possible exception of the extreme eastern or southeastern portion. The sediments belonging to the Nanaimo series in this region have not been intruded by any igneous rocks.

On the basis of determinations made on the fossil beds occurring on Sucia, Waldron, and Skipjack islands, as well as on Vancouver Island and vicinity, the rocks of the Nanaimo series have been placed in the upper Cretaceous and are essentially equivalent to the Chico Cretaceous of California.

Lithology and Structure. In the type locality the Nanaimo series has been divided into a number of formations mainly on the basis of their lithology.[20,21] The series is composed entirely of conglomerate, grit, arkosic sandstone, shale, and coal. Though some of the formations are fossiliferous they are noticeably lacking in true limestones.

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[17] Richardson, James, Report on the Coal Fields of Nanaimo, Comox, Cowichan, Burrard Inlet, and Sooke, British Columbia: *Geol. Survey Canada, Report of Progress, 1876-77,* pp. 160-192, 1878.

[18] Dawson, G. M., The Nanaimo Group: *Amer. Jour Sci.,* vol. 39, pp. 180-183, 1890.

[19] Clapp, C. H., Geology of the Nanaimo Map-Area: *Geol. Survey Canada,* Mem. 51, pp. 1-127, 1914.

[20] Clapp, C. H., Geology of the Nanaimo Map-Area: *Geol. Survey Canada,* Mem. 51, pp. 44-80, 1914.

[21] Clapp, C. H., Sooke and Duncan Map-Areas; Vancouver Island: *Geol. Survey Canada,* Mem. 96, pp. 224-227, 1917.

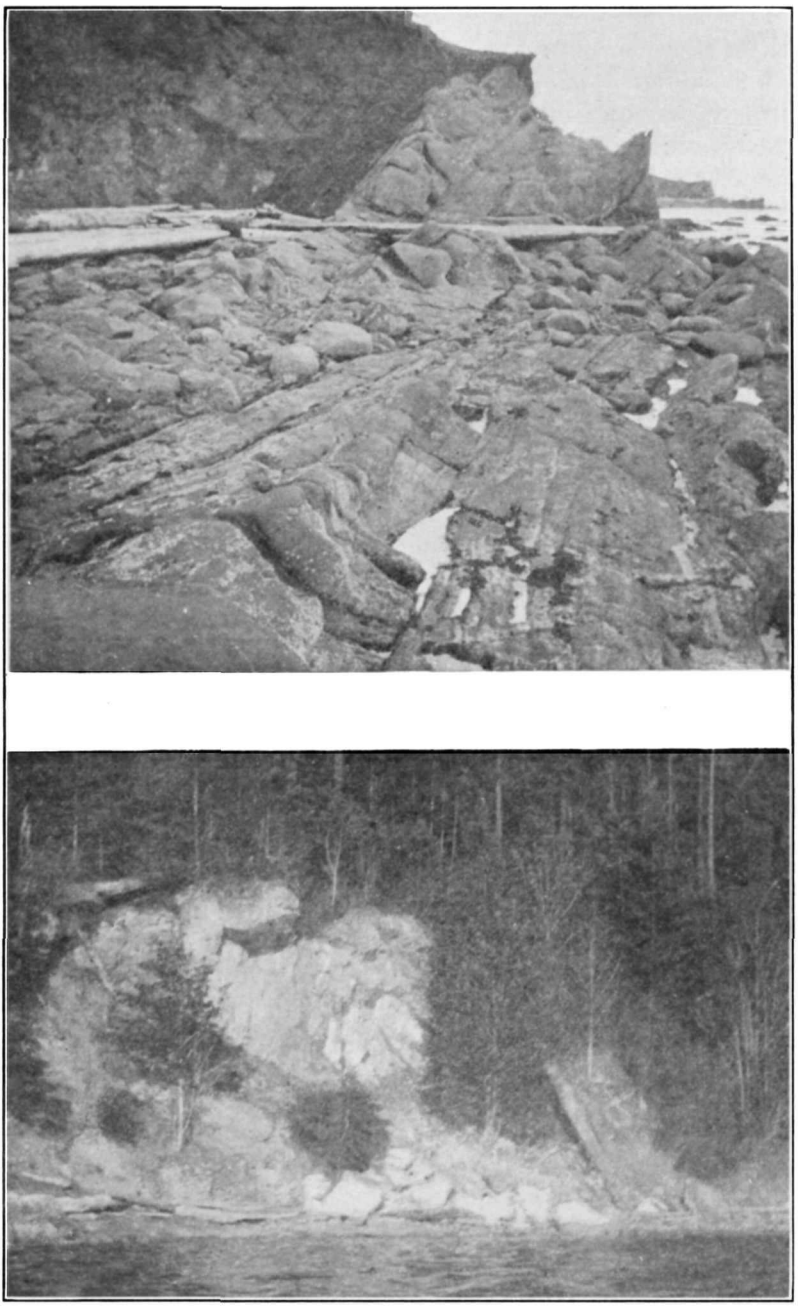


PLATE XV

Above: Upper Cretaceous rocks along the north shore of Orcas Island. *Below*: Limestone ledge on the shore of East Sound, at the foot of Mount Entrance.

BARNES AND CLARK ISLANDS

The rocks on the Barnes and Clark group are chiefly coarse conglomerates but they contain interbeds of sandstone and some shale. The pebbles of the conglomerate are composed of andesite, granodiorite, diorite, chert, argillite, graywacke, and specimens of all of the known older formations. The typical matrix is a grayish-brown arkosic sandstone.

The rocks on Barnes Island strike about N 12° E and dip 80° SE. On the north end of Clark Island the rocks strike N 8° W and dip 50° SW.

The southeast end of Clark Island shows a strike of N 30° E, and a dip of 30° SE. The islands and reefs making up the Sisters group, have a similar trend and dip.

Barnes and Clark Islands have been formed by the two limbs of the same syncline and evidently they belong to the same horizon. The north part of Clark Island also forms the limb of an anticline, with the south end and the Sisters group forming the other limb. These folds plunge to the southward at a moderate angle.

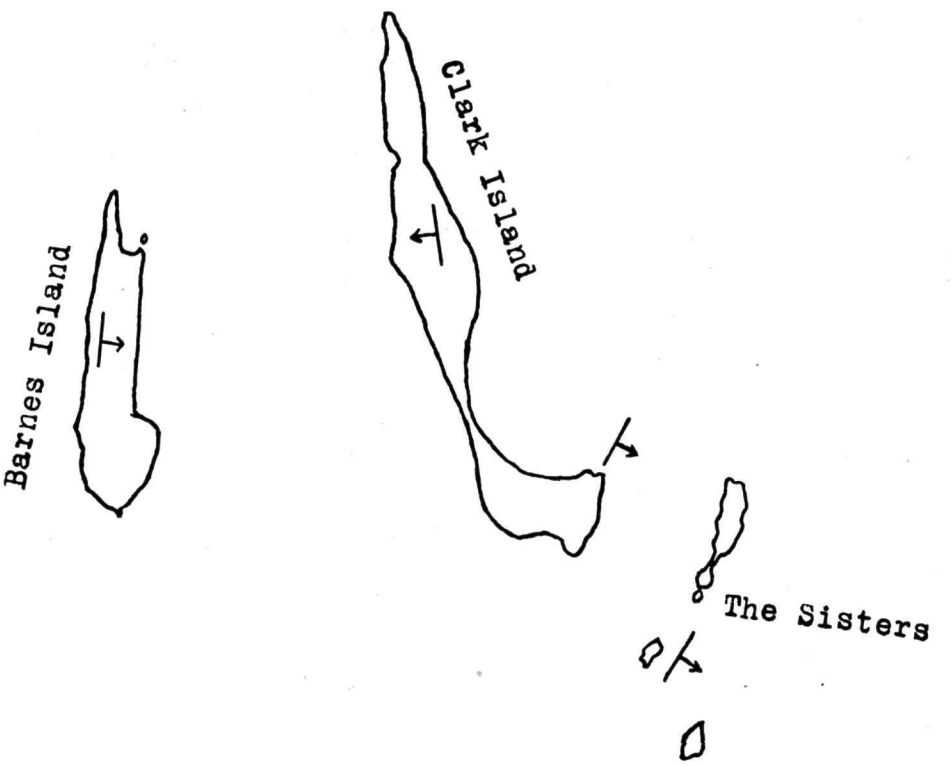


Figure 3. Outline map of the Barnes and Clark group of islands.

MATIA ISLANDS

Matia Islands are formed by a fragmental portion of a monoclinal fold which has a persistent strike of N 67° W, and a dip of 68° NE. The islands are composed of three parallel resistant formations separated by two less resistant ones. The latter are formed largely from shale and sandstone. The resistant formations are composed of medium-sized conglomerate and coarse buff-colored arkosic sandstone, with occasional scattered pebbles. In places there are irregular patches of coarse conglomerate. A generalized section across Matia Islands shows:

Medium to coarse buff sandstone	250+	feet
Conglomerate and sandstone	435	feet
Shale and sandstone	332	feet
Conglomerate and sandstone	375	feet
Shale and sandstone	180	feet
Sandstone with some conglomerate	450+	feet
	2022+	feet

The sandstones are usually crossbedded and are always arkosic. Occasionally there are fragments of Cretaceous trees which are now turned to coal or partly silicified. The sandstones and conglomerates are evidently delta deposits.

SUCIA ISLANDS

Sucia Islands are formed by the more resistant strata of a plunging syncline, the less resistant ones being covered by sea water. The syncline plunges to the eastward and the individual strata consequently outcrop in the form of a horseshoe, with the open side toward the east.

At the extreme southern edge of Sucia Islands there is a coarse conglomerate with fragments composed almost entirely of the Leech River schists, and fragments of the milky quartz veins that commonly cut these schists. The bluish-gray pulverized schists serve as the matrix of the conglomerate. The larger boulders are composed chiefly of white milky quartz and they stand out in strong contrast with the bluish-colored matrix. Because the conglomerate contains fairly large angular fragments of the fragile schist, and because it contains little besides the fragments of the Leech River schists, the source of the material must have been close at hand. In all probability the conglomerate is the basal member of the Nanaimo series at this locality.

The conglomerate grades upward into a bluish sandy shale composed of pulverized fragments of the schists. This in turn is overlain by light to dark-gray sandy shales. The shales are fossiliferous and they contain calcareous and concretionary beds of three inches or so in thickness, at intervals of about 15 feet. The shale appears to be identical with the Haslam formation on Vancouver Island.[22,23]

[22] Clapp, C. H., Geology of the Nanaimo Map-Area: *Geol. Survey Canada,* Mem. 51, pp. 53-56, 1914.

[23] Clapp, C. H., Sooke and Duncan Map-Areas, Vancouver Island: *Geol. Survey Canada,* Mem. 96, pp. 224-227, 1917.

The shale is overlain by a coarse to medium-grained buff-colored sandstone. The sandstone is even-grained and possesses a parting normal to the bedding-plane. For this reason it has been used for the manufacture of paving blocks.

Above the sandstone there is a less resistant formation, presumably a shale, which is entirely covered by soil or by tide-water.

The generalized section as exposed on Sucia Islands, is as follows:

Buff sandstone with some conglomerate	427+	feet
Concealed (probably shale)	470	feet
Buff sandstone with some conglomerate	300	feet
Concealed (probably shale)	250	feet
Conglomerate and cross-bedded sandstone	544	feet
Concealed (probably shale)	290	feet
Coarse to medium-grained standstone	655	feet
Fossiliferous olive-gray sandy shale	700	feet
Coarse conglomerate containing milky quartz boulders	100+	feet
	3736+	feet

By differential chemical action of the salt water on the sandstones of the Nanaimo series curious erosion surfaces have resulted. Sometimes hollow caverns have been produced, and more commonly the whole surface resembles a honeycomb. (See Plate XIV,B).

The northern limb of the synclinal fold on Sucia Island is also the southern limb of an anticline, with Clements Reef representing the northern dip.

PATOS ISLANDS

Patos Islands are composed entirely of cross-bedded sandstone and conglomerate. The individual strata pinch out rapidly along the strike and no division of the rocks into formations is possible. These cross-bedded sediments were laid down as delta deposits, and excellent examples of top-set, fore-set, and bottom-set beds are now exposed. From the nature of the sediments accurate measurements of the strike and dip are not possible. However, the strike follows parallel to the south shore-line, and the beds always dip to the northward at angles ranging from 45 to 65 degrees. The thickness of the rocks exposed on Patos Islands is about 1450 feet.

ORCAS ISLAND

The outcrops of the upper Cretaceous rocks occurring along the north and northwest shores of Orcas Island are composed chiefly of thin alternating beds of sandy shale and shaly sandstone. These beds change in lithology rapidly along the trike. The sandstones are generally well cemented, and like all of the rocks of the Nanaimo series in this map-area, they are always arkosic. They contain fragments of volcanic rocks, together with relatively undecomposed fragments of acid plutonic rocks. Quartz, in some instances, is only a subordinate constituent. Silica is the usual cementing material.

The massive conglomerate that forms Point Doughty, besides containing fragments of all of the older rocks exposed on the San Juan Islands, includes

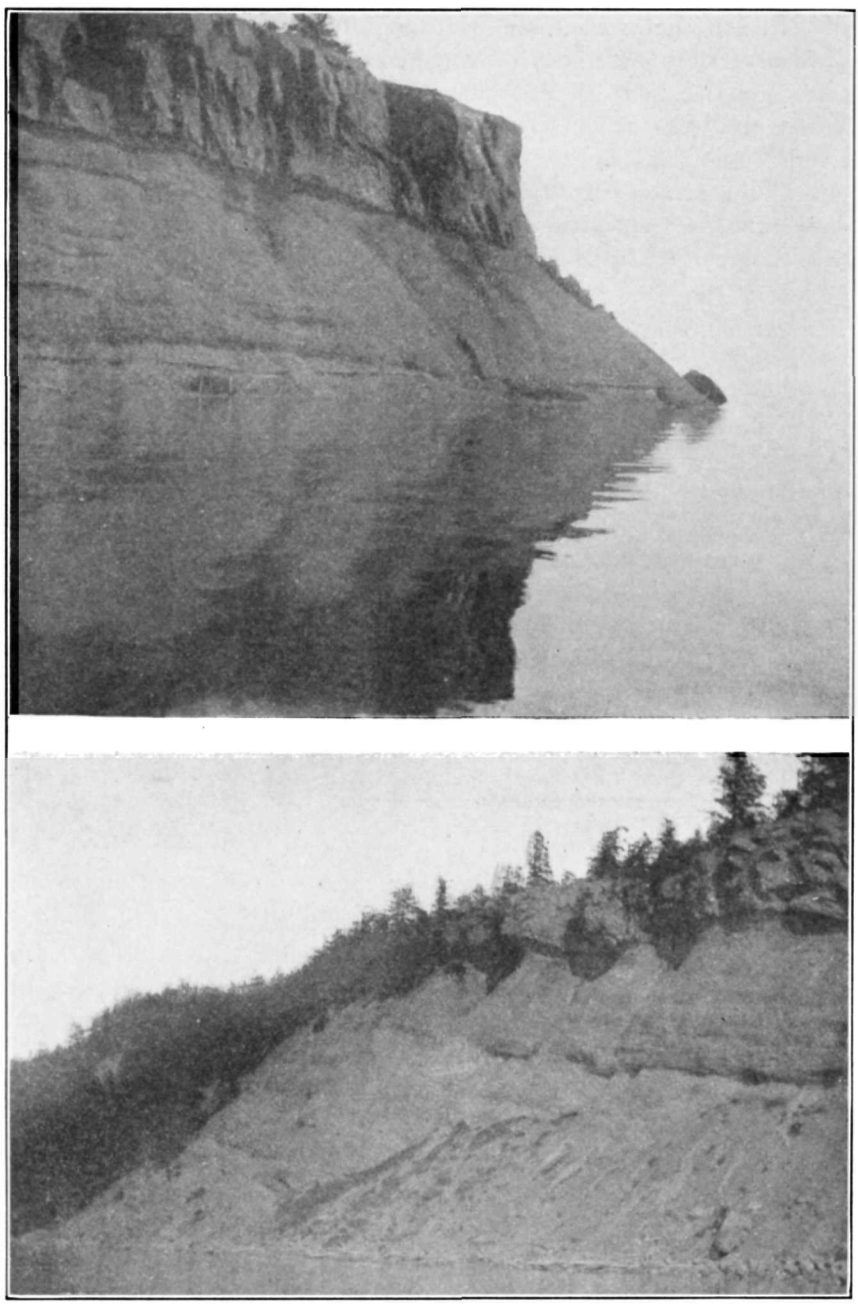


PLATE XVI

Above: Point Disney, Waldron Island, showing the immense conglomerate bed overlain by fossiliferous shaly sandstone. *Below*: The Point Disney conglomerate.

boulders of coarse basic plutonic rocks of several varieties not seen in this region. To the southward, and overlying the Point Doughty conglomerate, there are several thinner beds of conglomerate, sandstone, and lignitic shale. The latter are rich in fossil leaf impressions.

Where the beds are not crumpled by thrusting, the rocks of the Nanaimo series on Orcas Island have a persistent strike of N 65° W, and they invariably dip to the southward. It is not probable, however, that the outcrops all belong to a single monoclinal fold, for the section includes several unexposed horizons of great thickness, and the adjoining areas to the west are faulted and broken.

The section, starting from Point Thompson and proceeding south-westward, is as follows:

Coarse gray sandstone	30	feet
Olive-gray sandy shale with sandstone interbeds	776	feet
Coarse gray sandstone	19	feet
Thin-bedded sandstone and shale	20+	feet
Concealed	1745	feet
Conglomerate with interbedded grit	50	feet
Concealed	1240	feet
Coarse gray sandstone	30	feet
Olive-gray sandy shale with sandstone interbeds	1050	feet
Coarse conglomerate (Point Doughty)	100	feet
Concretionary sandy shale	2	feet
Coarse buff-colored gritty sandstone	3	feet
Carbonaceous sandstone with fossil plants	18	feet
Greenish-gray concretionary shale	25	feet
Fine-grained sandy conglomerate	10	feet
Light gray sandy shale	37	feet
Coarse and fine conglomerate	65	feet
Lignitic shale with fossil plants	400	feet
Coarse buff-colored sandstone	25	feet
Total	5645+	feet

The lignitic shale containing the fossil plants is crumpled and broken.

Still farther southward the rocks are concealed for a distance of half a mile. At this point a coarse conglomerate bed about 35 feet thick outcrops at the water's edge. The conglomerate bed which forms the greater part of Freeman Island evidently belongs to the same horizon. The sandstone and shale strata on Freeman Island strike N 55° W, dip 65°-75° SW, and overlie the conglomerate. The corresponding strata on Orcas Island are crumpled and broken.

Point Kimple, which is located about three-quarters of a mile south of Freeman Island, is composed of medium-textured conglomerate with thin interbeds of sandstone and shale. There are five horizons of this conglomerate and their general strike is N 80° W. They dip to the southward at angles of 20-30 degrees.

The rocks of the Nanaimo series form a submarine shelf or platform that extends from Orcas Island to Parker Reef. The sandstones and sandy shales which form Parker Reef strike N 65° W and dip to the northward at an angle of 60 degrees. Apparently they represent part of the northern limb of

the anticlinal fold, the southern limb of which is exposed on the north shore of Orcas Island.

WALDRON ISLAND

The upper Cretaceous rock exposures on Waldron Island are largely confined to the higher southeast side, and to scattered points along the northern margin. The elevated region extending northeastward from Point Disney is composed of bluish-gray sandstone, coarse conglomerate, and fossiliferous shaly sandstone. The boulders of the conglomerate frequently attain a diameter of several feet. Altered andesite, granodiorite, and chert are the most abundant constituents of the conglomerate boulders, although the older rocks of the region are well represented. In addition, the conglomerate contains many boulders of coarse-textured basic plutonic rocks, and also nephelite and cancrinite syenites, all of which are foreign to this locality.

The rocks composing the southeast side of Waldron Island are folded into a basin-shaped fold. The structure has been complicated by the fact that the formations have slipped on each other with a sort of rotational motion.

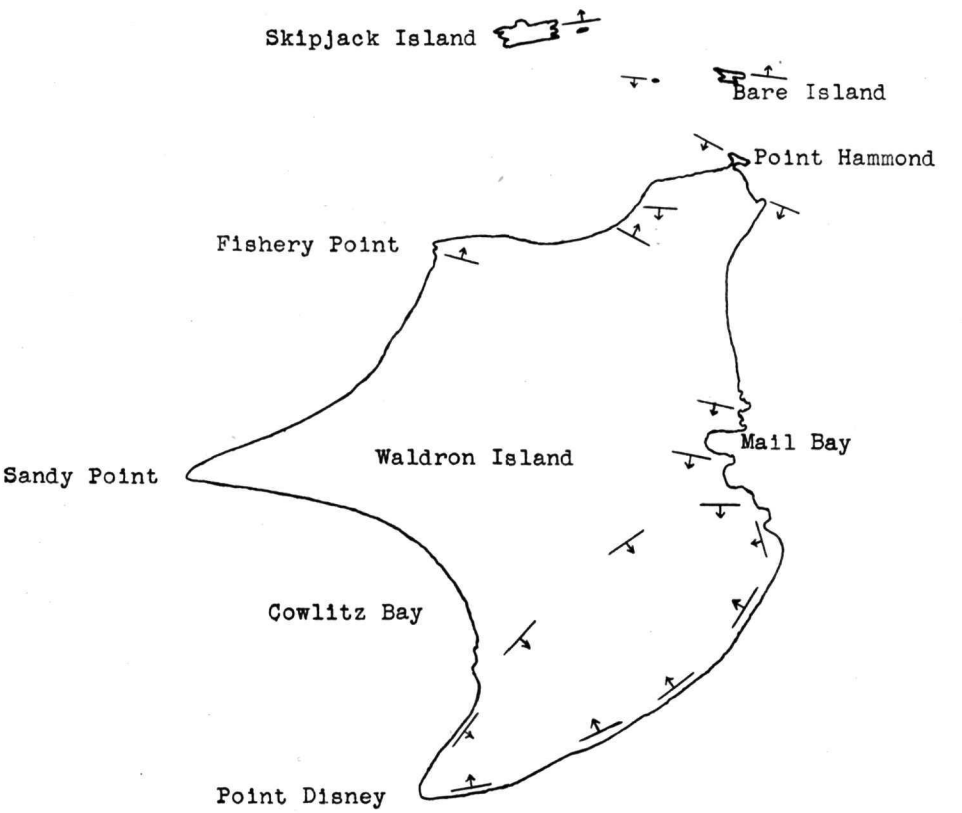


Figure 4. Outline map of Waldron and Skipjack Islands.

Scattered outcrops occur along the north shore of Waldron Island, but they cannot be followed inland because of the thick covering of glacial drift.

These outcrops are composed of buff-colored sandstone with a minor amount of conglomerate. The sandstones contain abundant remains of fossil *Ostrea.*

There is an anticlinal fold between Waldron and Bare islands, while between Point Hammond and Fishery Point, there is a synclinal fold. The average strike is about N 65° W. On the east side of the island, immediately north of the elevated region, there appears to be an anticline with an axis that would intersect the opposite side of the island to the south of Fishery Point. Just how the fold was produced in the elevated portion of the island is not clear.

Several years ago a hole was drilled in the east central part of Waldron Island, to a depth of nearly 1500 feet. The writer has not been able to secure the log of the drill-hole, but the greater part of the core is still on the island. The location of the hole was unfortunate, for the drill penetrated through several hundred feet of conglomerate and sandstone the section of which was already well exposed along the shore-line.

BARE ISLAND

Bare Island is composed of alternating beds of conglomerate, grit and buff-colored sandstone. The rocks are cross-bedded, with a strike of N 70°-80° W and dip about 80° NE. Fossil *Ostrea* are found on this island.

SKIPJACK ISLAND

Skipjack Island is composed of alternating beds of coarse and fine conglomerate, grit, and shaly sandstone. The sandstone is relatively soft, and it is eroded with sufficient rapidity to form embayments with parallel sides between the conglomerate strata. The section on Skipjack Island is about 500 feet thick. The beds strike from N 85° E to nearly east and west, and dip to the northward at an angle of about 70 degrees.

WHITE ROCKS

White Rocks, which are located about a mile to the south of Waldron Island, are composed of grit and conglomerate with some interbeds of coarse sandstone. The beds strike N 30° W and dip 41° NE.

GULL ROCK

Gull Rock is composed of coarse conglomerate with an interbed of less resistant sandstone, the latter being largely eroded away. The beds strike N 65° E. and dip 65° SE.

FLATTOP ISLAND

Flattop Island is composed of about 250 feet of coarse conglomerate, which is underlain by at least 35 feet of thin-bedded dark-gray shale and shaly sandstone. The beds strike N 65°-70° E and dip 25°-26° SE.

RIPPLE ISLAND

The formations exposed on Ripple Island are evidently equivalent to those occurring across the channel on Johns Island. A formation consisting of thick

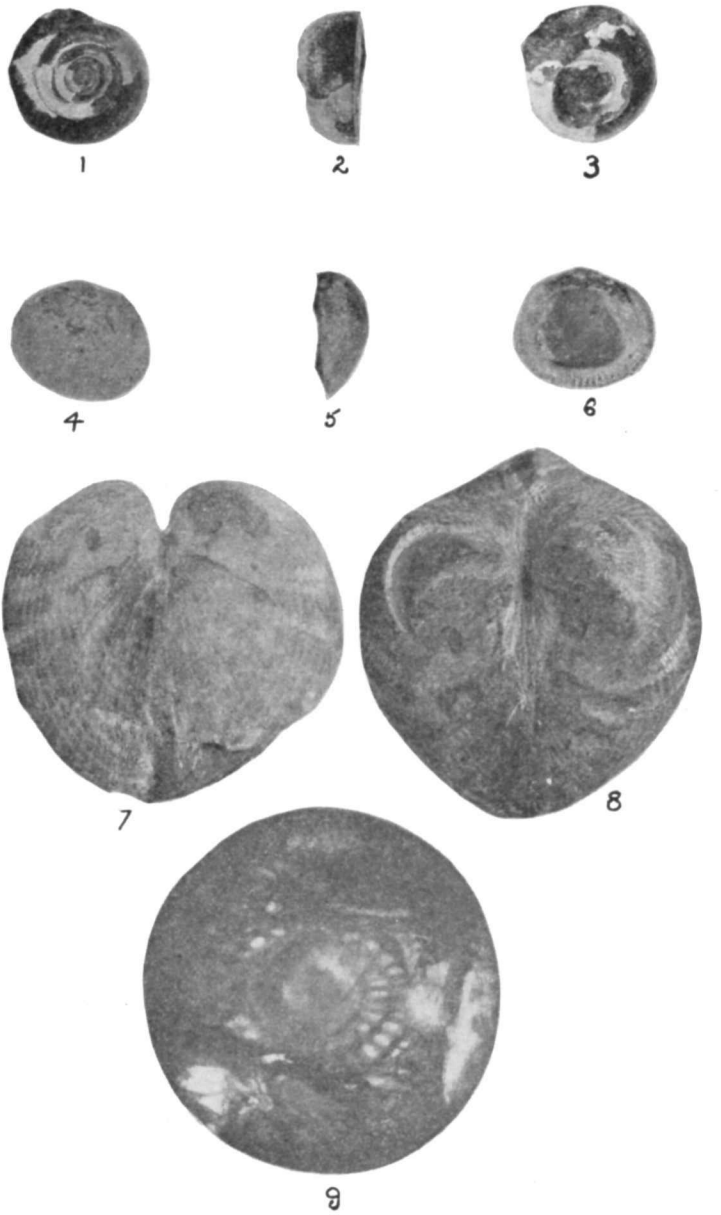


PLATE XVII

Figs. 1, 2, and 3. *Condonella suciensis* n.sp. Type specimen. Figs. 4, 5, & 6. Type specimen. Figs. 7 & 8. *Cucullaea suciensis* n.sp. Type specimen. Fig. 9. *Fusulina sp.* Enlarged specimen from the limestones of the Leech River group, Orcas Island.

and thin-bedded buff-colored sandstone is overlain by about 125 feet of conglomerate. This in turn is followed by thin-bedded shale and sandstone. The beds strike N 80° W and dip 45° SW.

CACTUS ISLANDS

Cactus Islands are composed of conglomerate, cross-bedded sandstone, and shale. The generalised section exposed on East Cactus Island is as follows:

Massive buff-colored sandstone	170+	feet
Conglomerate	25	feet
Massive buff-colored cross-bedded sandstone	160	feet
Thin-bedded shale and sandstone	40	feet
Cross-bedded sandstone and conglomerate	300+	feet
Total	695+	feet

At the east end of Cactus Islands the average strike of the rocks is N 73° W and the dip is 55°-63° SW. At the west end of the group the average strike is about N 65° W and the dip is 60°-66° SW.

JOHNS ISLAND

The generalised section exposed on Johns Island is as follows:

Conglomerate and cross-bedded sandstone	320+	feet
Thick-bedded sandstone with some shale interbeds	300	feet
Conglomerate and cross-bedded sandstone	360	feet
Shale and shaly sandstone	130	feet
Conglomerate	40	feet
Rapidly alternating sandstone, shale, and conglomerate	400+	feet
Total	1550+	feet

At the east end of Johns Island the beds strike N 65° W and dip about 35° SW. At the west end of the island the beds have an average strike of N 60° W and a dip of 50°-55° SW.

STUART ISLAND

The rocks on Stuart Island have been closely folded into an anticline and a syncline whose general trend is N 70° W (See Fig 4.) About 1500 feet of conglomerate with irregular patches of cross-bedded sandstone are exposed on the north limb of the anticline. Underlying the conglomerate there is a great thickness of alternating layers of dark carbonaceous shale and light gray sandstone. The shale strata usually have a thickness of one to six inches, while the sandstone layers are generally somewhat thicker.

The south limb of the anticline, which is at the same time the north limb of the syncline, is represented most prominently by the conglomerate formation mentioned above. This conglomerate forms a ridge that extends from one end of the island to the other, and it connects the two main parts of the island. The same conglomerate formation expresses itself on the south limb of the syncline, where it forms Tiptop Mountain, the highest elevation on the island. Reid Harbor is located in the axis of an elongated structural basin. Along the shore to the southwest of Tiptop Mountain, the rocks are compressed into chevron folds.

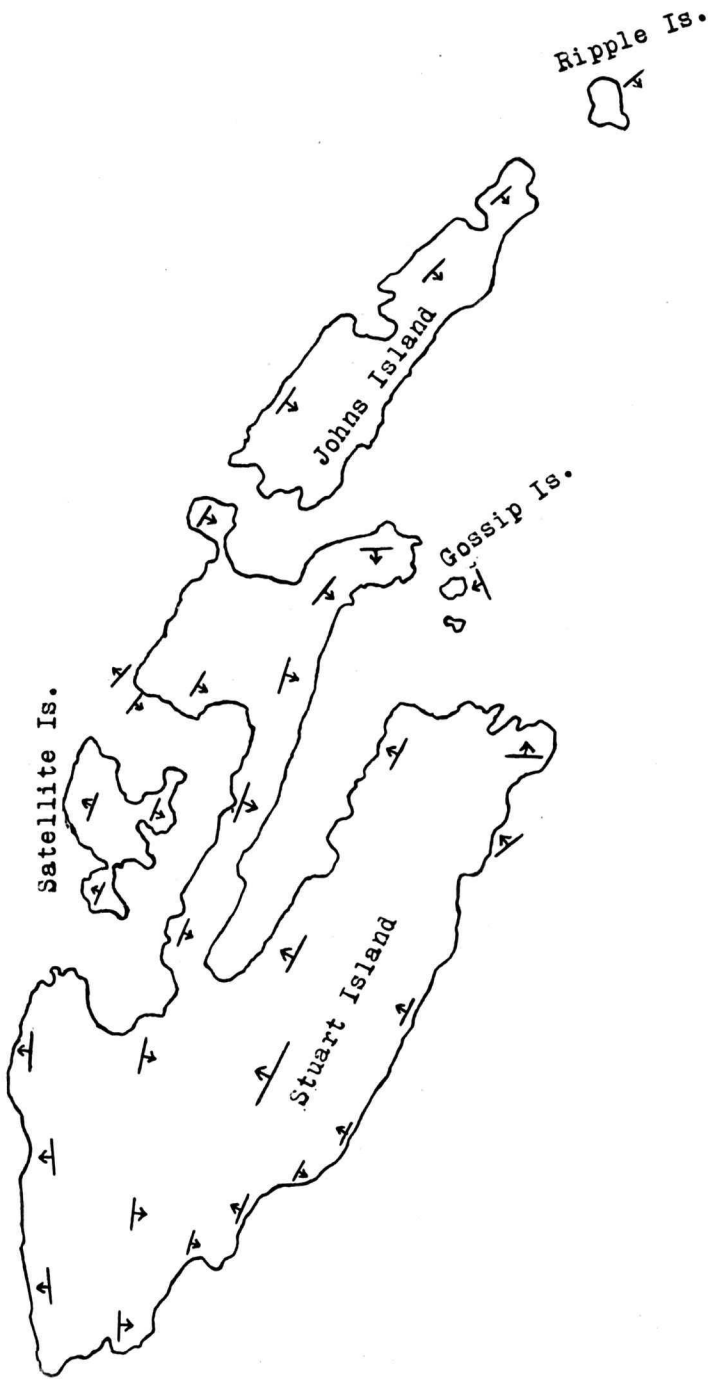


Figure 5. Outline map of Stuart, Satellite, and Johns Islands.

SATELLITE ISLAND

Satellite Island is composed of the same formations as those outcropping on Stuart Island. The anticline occurring on Stuart Island extends across Prevost Harbor and embraces the rocks on Satellite Island. The rocks have an average strike of N 80° W.

Age and Correlation. The lignitic shales occurring south of Point Doughty on Orcas Island have been described by Newberry.[24] He considered the fossil plants to be identical with those occurring in the sandstones in the vicinity of Bellingham, and all of these formations were referred to the Cretaceous. Some of these lignitic beds contain a large thick-shelled species of *Ostrea,* which also occurs on Waldron Island in association with known marine upper Cretaceous fossils.

The best known fossil beds of this region are those occurring on the Sucia Islands. Species from this locality were described and figured by Meek[25] in 1876, by White[26] in 1884, and by Whiteaves[27] in five volumes, 1876-1903.

The fossiliferous formation on the Sucia Islands is 700 feet thick and the fauna contains a great variety of species. The formation, as a whole, may be characterized by the abundance of the following species:

Inoceramus vancouverensis Shumard
Cinula obliqua Gabb
Baculites chicoensis Trask
Crassatellites conradiana Gabb
Trigonia evansana Meek
Margarita ornatissima Gabb
Cyprimeria lens Gabb
Glycimeris suciensis n. sp.

The fossiliferous horizon on Skipjack Island is not more than a foot thick. It is especially characterized by the following:

Perna excavata White
Trigonia evansana Meek
Cinula obliqua Gabb
Glycimeris suciensis n. sp.

At Point Hammond on Waldron Island, a large thick-shelled species of *Ostrea* occurs in association with *Trigonia evansana.* The same species of *Ostrea* occurs near Fishery Point on Waldron Island, on Bare Island, and at various points on Orcas Island. The richest fossil-bearing horizon on Waldron Island is located just above the Point Disney conglomerate. Although a large variety of species is present, it is characterized by *Cucullaea ponderosa Whiteaves, Cucullaea truncata Gabb, Glycimeris suciensis* n.sp, *Cinula obliqua Gabb,* and *Trigonia evansana Meek.*

[24] Newberry, J. S., Description of the Fossil Plants Collected by George Gibbs, Geologist to the United States Northwest Boundary Commission under A. Campbell: *Jour. Boston Soc. Nat. Hist.,* vol. 7, pp. 506-525, 1863.

[25] Meek, F. B., Descriptions and Illustrations of Fossils from Vancouver and Sucia Islands, and other Northwestern Localities: *U. S. Geol. and Geogr. Survey of the Territories, Bull.,* vol. 2, pp. 351-376, 1876.

[26] White, C. A., Cretaceous Fossils from Vancouver Island Region: *U. S. Geol. Survey, Bull.,* pp. 33-48, 1884.

[27] Whiteaves, J. F., *Geol. Survey Canada, Mesozoic Fossils,* vol. 1-5, 1876, 1903.

DESCRIPTION OF NEW GENUS AND NEW SPECIES

GASTROPODA

GENUS CONDONELLA, NEW GENUS

Shell small, discoidal, each whorl being coiled upon the preceding one; umbilicus broadly conical, converging towards the posterior side; anterior side convex; posterior side flat or somewhat concave; each whorl slightly and obliquely emarginate upon the preceding one; aperture sub-ovate to crescent-shaped.

Named in honor of Herbert T. Condon, comptroller of the University of Washington.

CONDONELLA SUCIENSIS n. sp.

Plate XVII. Figs, 1, 2, 3.

Shell consisting of six whorls, increasing rather slowly in size; test thin, sub-nacreous, and crossed obliquely by numerous fine transverse lines.

Dimensions.

	Diameter	Height
Type specimen	13 mm.	5.5 mm.

Locality. The only specimen known was collected on Sucia Island at a point about 300 feet above the base of the fossil-bearing shales.

Disposal of Type. Paleontological collection of the U. S. National Museum, Washington, D. C.

The specimen was examined by Dr. Stanton and Dr. Dall, who said that it resembled the fresh-water genus, *Planorbis,* more than any marine form they had ever seen. Since the specimen was found in strata that were rich in strictly marine fossils it cannot be considered as a variety of that genus.

Superfamily ARCACEA Deshayes

GENUS GLYCIMERIS DA COSTA

GLYCIMERIS SUCIENSIS n. sp.

Plate XVII. Figs, 4, 5, and 6.

Shell small, moderately compressed convex, equilateral, and almost round in outline; beaks small, nearly central and incurved, projecting but little above the superior border; outer surface marked by a close, regular net-work of radiating and concentric raised lines.

Dimensions.

	Length	Height	Thickness
Type specimen	13 mm.	11.5 mm.	8 mm.

Locality. The type specimen was collected on the Sucia Islands where it is fairly abundant. It is also found on Skipjack and Waldron Islands.

Disposal of Type. University of Washington Paleontological Collection.

G. suciensis was classified by Whiteaves as *Glycimeris veatchii.* The writer examined a large number of specimens from the Sucia Islands, Skipjack Island, and Waldron Island, and none were seen that exceeded the type *G. suciensis* in size. The type *G. veatchii* is much higher in proportion to its length, than any of the specimens observed.

GENUS CUCULLAEA LAM.

CUCULLAEA SUCIENSIS n. sp.

Plate XVII. Figs. 7 and 8.

Shell moderately large, ventricose, rounded and equilateral; anterior and posterior ends rounded without any pronounced shoulder; beaks prominent, broad, fairly close together, curved inward and a little forward, placed nearly central; cardinal area moderately large, broad, and marked with well defined, divergent, ligamentary grooves; shell thick, but tapering rapidly at the ventral margin; surface marked by moderately coarse, well defined radiating lines and by irregular and less strongly defined coarse concentric lines.

Dimensions.

	Length	Height	Thickness
Type specimen	43 mm.	about 42 mm.	42 mm.

Locality. Collected on the Sucia Islands at the south margin of Fossil Bay.

Disposal of Type. University of Washington Paleontological Collection.

C. suciensis is distinguished from *C. ponderosa,* and from *C. fruncata,* by its rounded, equilateral shape, and by the character of its surface markings.

Fossils Occurring in the Nanaimo Series	Sucia Islands	Waldron Island	Skipjack Island	Vancouver Island & Vicinity
Fishes				
Lamna appendiculata Agassiz	..	..	..	*
Crustacea				
Callianassa whiteavesii H. Woodward	*	..	..	*
Enoploclytia minor H. Woodward	..	..	..	*
Eryma dawsoni H. Woodward	*	..	..	*
Hoploparia bennetti H. Woodward	..	..	..	*
Linuparus canadensis Whiteaves	*	..	..	*
Linuparus vancouverensis Whiteaves	*	..	..	*
Meyeria(?) harveyi H. Woodward	..	..	..	*
Palaeocorystes harveyi H. Woodward	*	..	..	*
Plagiolophus vancouverensis H. Woodward	*	..	*	*
Cephalopoda				
Anisoceras cooperi Gabb	*	..	..	*
Anisoceras subcompressum (Forbes)	*	..	..	*
Baculties chicoensis Trask	*	*	*	*
Desmoceras selwynianum Whiteaves	*	*	..	*
Diplomoceras notabile Whiteaves	*	..	..	*
Gaudryceras denmanense Whiteaves	..	..	..	*
Gaudryceras maclurei (White)	*	..	..	..
Hamites obstrictus Jimbo	*	..	..	*
Hauericeras gardeni (Bailey)	..	..	..	*
Heteroceras elongatum Whiteaves	..	..	..	*
Heteroceras hornbyense Whiteaves	..	..	..	*
Hoplites vancouverensis (Meek)	*	..	..	..
Nautilus campbelli Meek	*	..	..	*
Nautilus suciensis Whiteaves	*	..	..	..
Pachydiscus binodatus Whiteaves	..	..	..	*
Pachydiscus haradai Jimbo	..	..	..	*
Pachydiscus multisulcatus Whiteaves	*	..	..	*
Pachydiscus neevesii Whiteaves	*	..	..	*
Pachydiscus newberryanus (Meek)	*	..	..	*
Pachydiscus otacodensis (Stoliczka)	*	..	..	*
Pachydiscus perplicctus Whiteaves	..	..	..	*
Pachydiscus suciensis (Meek)	*	..	..	*
Phylloceras forbesianum (d'Orbigny)	..	..	..	*
Phylloceras ramosum Meek	*	*	..	*
Pleuropachydiscus hoffmanni (Gabb) var.	*	..	..	..
Pseudophyllites indra (Forbes)	..	..	..	*
Ptychoceras vancouverense Whiteaves	..	..	..	*
Tetragonites timotheanus? (Mayor)	..	..	..	*
Gastropoda				
Amauropsis suciensis Whiteaves	*	*	*	*
Anchura callosa Whiteaves	..	..	..	*
Anchura exilis Gabb	*	..	..	..
Anisomyon meekii Gabb	..	..	..	*
Bela cretacea Whiteaves	..	..	..	*
Capulus corrugatus Whiteaves	..	..	..	*
Cerithium harveyi Whiteaves	..	..	..	*
Cerithium vancouverense Whiteaves	..	..	..	*
Cinulia obliqua Gabb	*	*	*	*
Cinuliopsis typica Whiteaves	*	..	..	..
Cirsotrema tenuisculptum Whiteaves	*	..	..	..

Fossils Occurring in the Nanaimo Series—(Continued)	Sucia Islands	Waldron Island	Skipjack Island	Vancouver Island & Vicinity
Gastropoda—Continued				
Condonella suciensis n. sp.	*	..	..	..
Cylichna costata Gabb	..	..	..	*
Cypraea suciensis Whiteaves	*	..	..	..
Epitonium mathewsonii (Gabb)	*	..	..	..
Eunema cretaceum Whiteaves	..	..	..	*
Fusus kingii Gabb	*	*	*	*
Gyrodes conradiana Gabb, var. canadensis	*	*	*	*
Haminea hornii? (Gabb)	*	..	..	*
Helcion giganteus Schmidt, var. vancouverensis	..	..	..	*
Helcion tenuicostatus Whiteaves	*	..	..	*
Hindsia nodulosa Whiteaves	*	*	*	*
Littorina compacta? Gabb	..	..	..	*
Lunatia shumardiana? Gabb	*	..	..	*
Lysis suciensis Whiteaves	*	*	..	*
Margarita ornatissima (Gabb)	*	*	*	*
Mesostoma? intermedium Whiteaves	*	..	..	*
Mesostoma? newcombii Whiteaves	*	..	..	..
Mesostoma suciense Whiteaves	*	*	..	*
Nerinea dispar Gabb, var.	..	..	..	*
Odostomia? cretacea Whiteaves	..	..	..	*
Odostomia? inornata Whiteaves	..	..	..	*
Perissolax brevirostris Gabb	*	*	*	*
Phaneta? decorata Whiteaves	..	..	..	*
Potamides tenuis Gabb	..	..	..	*
Potamides tenuis, var. nanaimoensis Whiteaves	*	..	..	*
Serrifusus dakotensis, var. vancouverensis Whiteaves	..	..	..	*
Solariella occidentalis Whiteaves	*	..	..	*
Surcula hornbyensis Whiteaves	..	..	..	*
Surcula suciensis Whiteaves	*	..	..	..
Sycodes glaber (Shumard)	*	..	..	*
Tessarolax distorta Gabb	..	..	..	*
Trochactaeon semicostatus Whiteaves	..	..	..	*
Vanikoro pulchella var. Whiteaves	*	..	..	*
Vanikoropsis suciensis White	*	..	..	..
Volutoderma navarroensis (Shumard)	*	*	..	*
Pelecypoda				
Anatina quadrata Gabb	*	..	..	*
Anatina subcylindracea Whiteaves	..	..	..	*
Anatina sulcatina? Shumard	*	*	*	*
Anatina tryoniana Gabb	..	..	..	*
Anomia vancouverensis Gabb	..	..	..	*
Arca equilateralis Meek	..	..	..	*
Arca vancouverensis Meek	*	*	..	*
Clisocolus cordatus Whiteaves	*	*	*	*
Clisocolus dubious Gabb	*	..	..	*
Corbula minima? d'Orbigny	..	..	..	*
Corbula traskii Gabb	..	..	..	*
Crassatellites conradiana Gabb	*	..	..	*
Crassatellites conradiana, var. tuscana	..	..	..	*
Cucullaea ponderosa Whiteaves	*	*	..	*
Cucullaea suciensis n. sp.	*	..	..	..
Cucullaea truncata Gabb	*	*	..	*
Cuspidaria suciensis Whiteaves	*	..	..	..
Cyprimeria lens Whiteaves	*	*	*	*
Cyprimeria tenuis Meek	..	..	..	*
Cyprina? anthracicola Whiteaves	..	..	..	*

Fossils Occurring in the Nanaimo Series—(Continued)	Sucia Islands	Waldron Island	Skipjack Island	Vancouver Island & Vicinity
Pelecypoda—Continued				
Cyprina denmanensis Whiteaves	*	..	..	*
Dosinia gyrata? Gabb	*	..	..	..
Dosinia inflata Gabb	*	..	..	..
Eriphyla umbonata	*	..	..	*
Exogyra parasitica	*	..	..	*
Glycimeris suciensis n. sp.	*	*	*	..
Glycimeris veatchii (Gabb)	*	..	..	*
Goniomya borealis Meek	..	..	..	*
Gryphaea vesicularis Lamarck	..	..	..	*
Inoceramus digitatus (Sowerby) Schmidt	..	..	..	*
Inoceramus subundatus Meek	*	..	..	*
Inoceramus vancouverensis Shumard	*	*	*	*
Laevicardium suciense Whiteaves	*	..	..	..
Lima suciensis Whiteaves	*	..	..	*
Linearia meekana Whiteaves	..	..	..	*
Lithodomus nitidus Whiteaves	..	..	..	*
Lucina nasuta Gabb	*	..	..	*
Lucina subcircularis? Gabb	*	..	..	..
Mactra warrenana Meek & Hayden	*	*	*	*
Martesia clausa Gabb	..	..	..	*
Martesia parvula Whiteaves	..	..	..	*
Meleagrina antiqua Gabb	..	..	..	*
Meretrix arata Gabb	*	*	..	*
Meretrix nitida Gabb	*	*	..	*
Modiola siskiyouensis Gabb	*	*	*	*
Mytilus pauperculus Gabb	*	*	*	*
Nucula hornbyensis Whiteaves	..	..	..	*
Nucula richardsoni Whiteaves	..	..	..	*
Nucula traskana Meek	..	..	..	*
Nucula truncata Gabb	*	*	..	*
Opis vancouverensis Whiteaves	..	..	..	*
Panopaea concentrica Gabb var	..	..	..	*
Pecten traski Gabb	..	..	..	*
Perna excavata White	*	*	*	*
Pholadomya subelongata Meek	*	..	..	*
Pinna calamitoides Shumard	*	*	*	*
Protocardia scitula Meek	..	..	..	*
Tellina nanaimoensis Whiteaves	*	*	*	*
Tellina occidentalis Whiteaves	..	..	..	*
Tellina quadrata Gabb	..	..	..	*
Teredo suciensis Whiteaves	*	..	..	*
Thracia subtruncata Meek	*	..	..	..
Thyasira cretacea Whiteaves	..	..	..	*
Trigonia evansana Meek	*	*	*	*
Trigonia tryoniana Gabb	..	..	..	*
Veniella crassa Whiteaves	*	*	..	..
Yoldia diminutiva Whiteaves	..	..	..	*
Yoldia striatula Forbes	*	..	..	*
Brachiopoda				
Kingena occidentalis Whiteaves	..	..	..	*
Rhynchonella suciensis Whiteaves	*	*	*	*
Terebratula harveyi Whiteaves	..	..	..	*
Anthozoa				
Smilotrochus vancouverensis	*	..	..	*

EOCENE SYSTEM OR SERIES

Chuckanut Formation

Principal Features. The coal-bearing sandstones and conglomerates occurring on the northern part of Lummi Island and in the vicinity of Bellingham Bay to the eastward are here referred to as the Chuckanut formation. These rocks form the lower part of White's Puget group.[28]

The sandstones of the Chuckanut formation are generally cross-bedded and somewhat arkosic. They are usually cemented less firmly than the sandstones belonging to the Nanaimo series and they contain more interbedded lignitic material. As a general rule the Chuckanut sandstones are lighter in color than those of the Nanaimo series. The conglomerate strata occurring in the Eocene and Upper Cretaceous formations appear to be identical with regard to the nature of the materials composing their boulders and pebbles.

The Chuckanut formation was evidently laid down in brackish or even fresh water, and fossil leaves and plants are very abundant in many of the strata.

Lithology and Structure. The rocks of the Chuckanut formation exposed on Lummi Island consist of cross-bedded and poorly consolidated arkosic sandstones and conglomerates. The conglomerates are indistinguishable from those occurring in the Nanaimo series. The sandstones are composed of undecomposed fragments of granitoid and volcanic rocks mixed with fragments of chert and argillite. Quartz is frequently a subordinate constituent only, although in some horizons it is very abundant. Lignitic material derived from fossil palm trees is found interbedded with and scattered through the sandstone strata.

On Lummi Island the rocks belonging to the Chuckanut formation trend northwesterly. They occupy the bottom of a distorted syncline, the greater part of which has been eroded away. The Chuckanut sediments have been laid down upon the eroded surfaces of the Eagle Cliff porphyrites.

Age and Correlation. The sedimentary strata occurring on the northern part of Lummi Island are identical in lithology and plant remains with those outcropping on the mainland to the eastward. The rocks of the Chuckanut formation are well exposed along the Chuckanut Drive on the Pacific Highway.

It is interesting to note that the rocks of this district contain several plant species which are also found in the upper Cretaceous rocks to the south of Point Doughty on Orcas Island. Newberry[29] compared the fossil plants from both localities and decided that they were identical and of upper Cretaceous age.

Recent work on these fossil plants by Dr. Knowlton has placed the rock

[28] White, C. A., On the Puget Group of Washington: *Amer. Jour. Sci.*, 3rd ser., pp. 443-450, 1888.

[29] Newberry, J. S., Description of the Fossil Plants Collected by George Gibbs, Geologist to the United States Northwest Boundary Commission under A. Campbell: *Jour. Boston Soc. Nat. Hist.*, vol. 7, pp. 506-525, 1863.

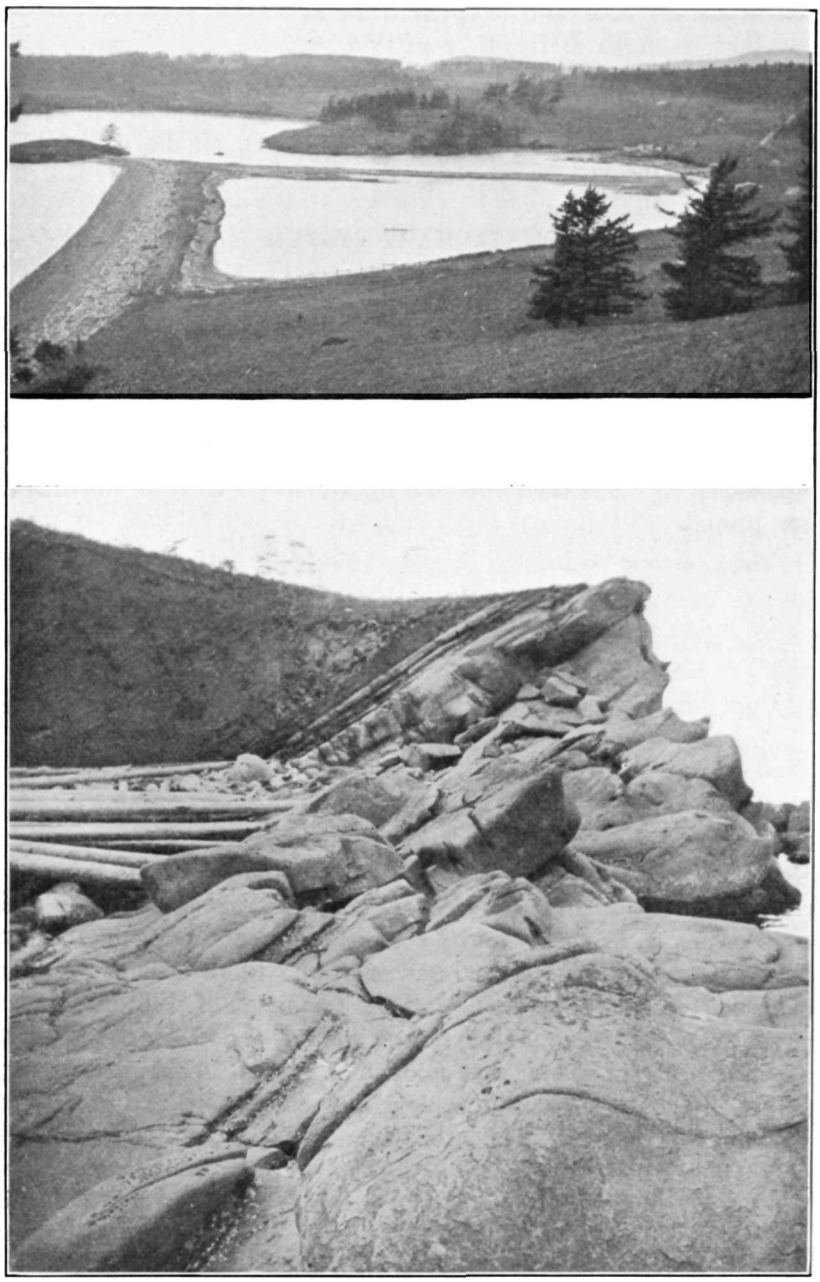


PLATE XVIII

Above: The sandspit and lagoon at Argyle, San Juan Island. *Below*: The Upper Cretaceous rocks at Point Thompson, Orcas Island.

formations in the vicinity of Bellingham Bay in the lower Eocene. According to Dr. Knowlton the beds do not represent the lowermost portion of the Eocene, and their flora is much different from that occurring on Orcas Island. The writer found that the fossil leaves occurring on Orcas Island are interbedded with strata which contain a marine upper Cretaceous fauna.

The Chuckanut flora is very different from the middle or upper Eocene flora occurring in the vicinity of Seattle.

QUATERNARY SYSTEM

In many places the islands of the San Juan group are covered with a deep mantle of glacial till and sediments. The glacial geology of Puget Sound and vicinity has been discussed at some length by Bretz[30] and a bibliography of previous writers on the subject may be found in his report.[31]

Although at least four major periods of glaciation are recognized in many parts of North America, but two have been established as occurring in the Puget Sound region. The sediments and till derived from these glacial invasions have been grouped as follows;

(1) The Colwood sediments, deposited since the retreat of the last glacier.

(2) The Vashon till and sediments, deposited by the last glacier.

(3) The Puyallup sediments, deposited during the interval of time between the Admiralty and Vashon glacial periods.

(4) The Admiralty till and sediments, deposited during the next preceding glacial period or epoch.

A number of small remnants of strongly indurated tillite occur on Burrows Island and also on Allan Island. These remnants of tillite do not occur in contact with the more recent glacial till or sediments. They are found only on the south or protected slopes of the hills, and they occur as pockets on the underlying rocks of the Fidalgo formation. The fragments of the tillite are as strongly cemented as those of the conglomerates occurring in the Nanaimo series. The cementing material or matrix of the tillite is light gray in color and somewhat calcareous. Whether these remnants of tillite belong to the Admiralty glacial period, or to an earlier glaical period, is not known.

The glaciers performed a large amount of erosion in the general region of the San Juan Islands, overriding the highest mountain tops and greatly modifying the earlier topography. The glacial erosion was noticeably more intense at the southern ends of the islands, while the northern ends are often covered with glacial drift. The great bulk of these sediments was deposited during the Puyallup interglacial epoch, and they are usually covered with a thin layer of Vashon till. In places the Vashon till and sediments contain huge erratic boulders.

The direction followed by the upper portions of the glacial ice in this

[30] Bretz, J. Harlen, Glaciation of the Puget Sound Region: *Wash. Geol. Survey Bull.*, 8, 1913.

[31] *Ibid.*, pp. 10-12.

region was not controlled by the underlying topography. The courses of the deepest glacial erosion were partly determined by the presence of fault or fracture zones or by previously existing valleys or channels. Near sea-level the glacial striations usually follow parallel to the courses of the present water channels, while at higher elevations the striations trend nearly north and south. In the northwest portion of the map-area the course of the glacier was slightly east of south. In the southwest portion the striations trend almost exactly north and south, and do not give any indication that part of the ice sheet turned southwestward through the Strait of Juan de Fuca.

Glacial grooves with a depth of several feet are encountered in many parts of the region. Perhaps the most remarkable display of glacial grooving is found on the rocky slopes to the east of Iceberg Point on Lopez Island. Here the glacial striations trend almost at right angles to the strike of the upturned strata of the Leech River group.

On the southeast portion of Orcas Island, to the north of Obstruction Pass, the rocky hills are drumlinoidal in shape and polished by glacial action.

On San Juan Island Bretz recognized two localities, Cattle Point Hill and Bald Hill, as the best examples of recessional moraines occurring in the Puget Sound region.

The sediments occurring on Waldron Island, Lopez Island, Guemes Island, Sinclair Island, Portage Island, and Decatur Island belong largely to the Puyallup inter-glacial epoch. In most cases these sediments are overlain by a layer of till deposited as recessional morainal material by the Vashon glacier.

Since the last glacial period there has been a general uplift throughout all of the area previously covered by the ice. At several localities high above the present sea-level on Waldron Island, the Sucia islands, San Juan Island, Lopez Island and Orcas Island, there are abundant marine fossils. Of these, *Pecten hastatus, Cardium corbis, Paphia staminia,* and *Saxidomus giganteous* are the most abundant. At one locality near Deer Harbor Bretz found marine shells in a well at an elevation of 290 feet.

The San Juan Islands exhibit abundant and excellent examples of recently upraised beaches. These usually occur at elevations of 15 to 25 feet above present high tide.

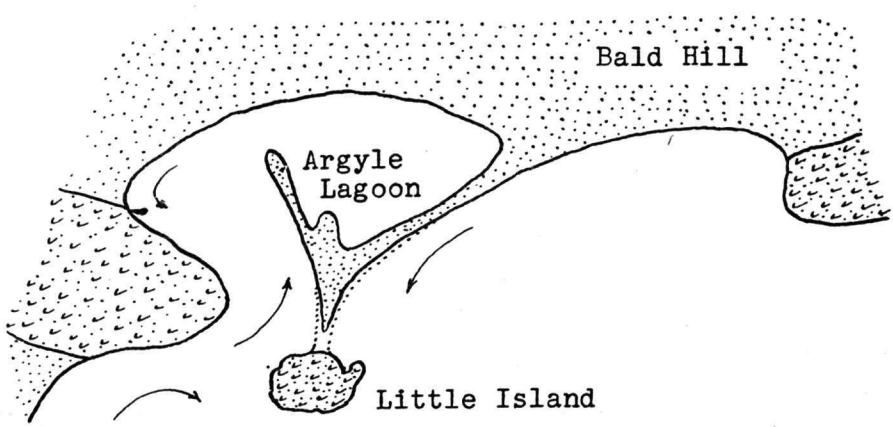
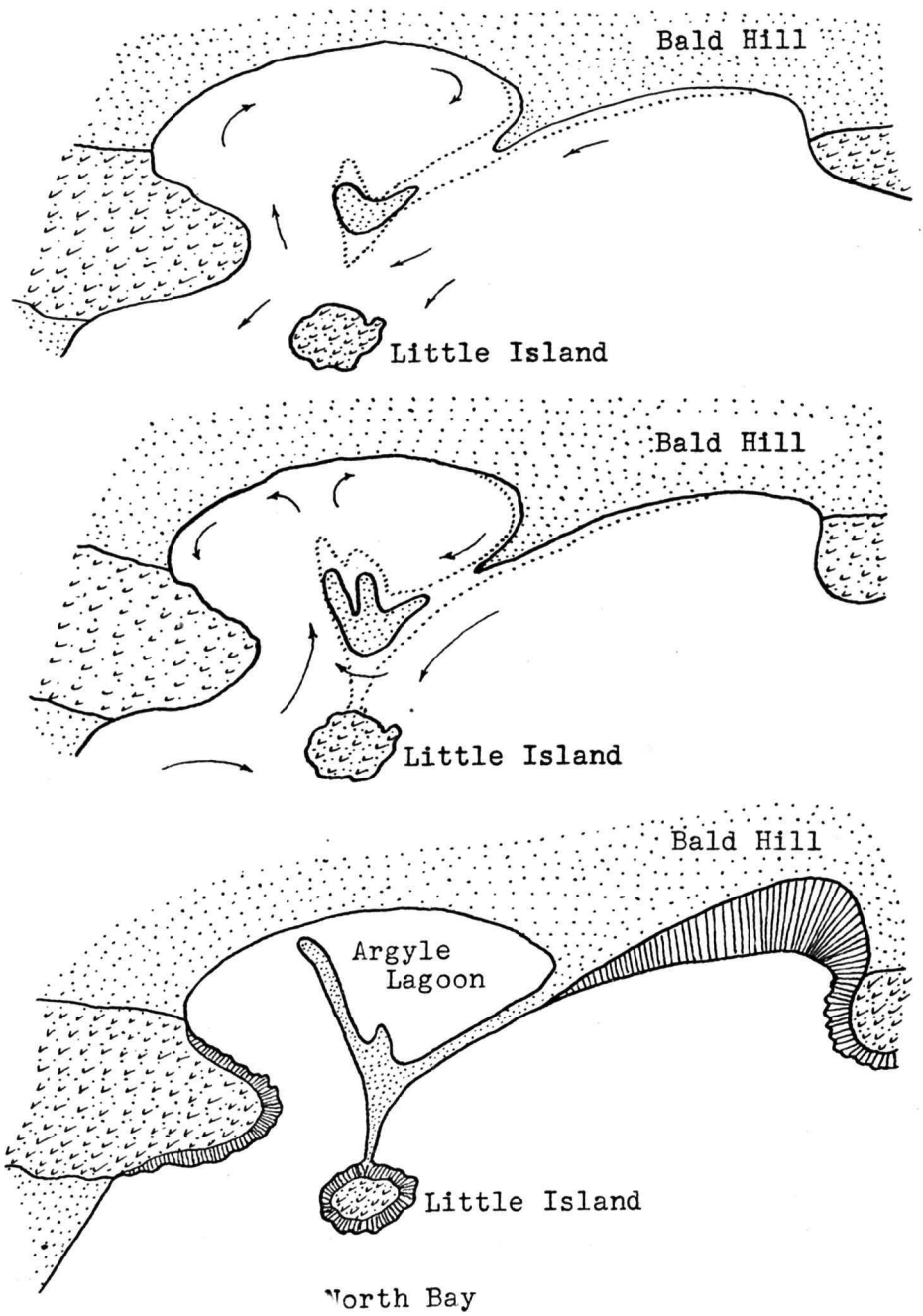


Figure 6. The Argyle Lagoon and sandspit.

At the present time, some interesting sandspits and lagoon lakes are being formed in the San Juan Islands. Among these, the Argyle Sand Spit and Lagoon on San Juan Island, and Fisherman Bay on Lopez Island, are the most interesting.



Figures 7, 8, 9. Three stages in the evolution of the Argyle Lagoon. The arrows show the direction of the prevailing currents.

The Argyle sand spit would have closed the entrance to the bay had it not been for the presence of Little Island which is composed of solid rock. Practically all of the materials composing the sand spit and sandy hook were derived from Bald Hill.

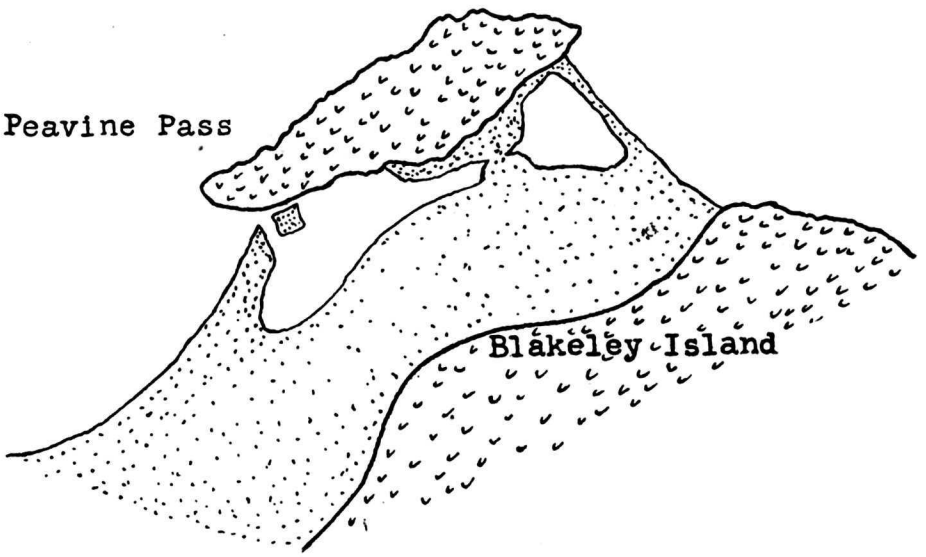


Figure 10. The lagoon and sandspit at the north end of Blakeley Island.

At the north end of Blakeley Island a small rock mass has been tied to the main island by means of sand spits. A similar physiographic feature is encountered on the south shore of Orcas Island about three-quarters of a mile to the east of the village of Orcas.

Double sand spits converging to a point and containing a shallow lagoon between them, are of very common occurrence in the San Juan Island area. In many cases the lagoons have been filled up with sediment so that they no longer contain any water.

At several places along the shores of the San Juan Islands, clam beds uplifted above the present high tide-level are seen to grade downward into beds that now contain living clams of the same species. Care must be used that such deposits are not confused with the so-called "kitchen middens," or shells left by the Indians who formerly camped along the shores.

At the eastern margin of the map-area the deltas of the Samish and Nooksak rivers are at the present time encroaching on some of the San Juan Islands. The Samish delta has already encroached to such an extent that shallow water and luxuriant growths of eel-grass extend almost as far west as Guemes Island. Nooksak River, with its distributary, Lummi River, are supplying so much sediment that a submerged sand bar connecting Lummi Island with the mainland is now in the process of formation.

IGNEOUS ROCKS

GENERAL STATEMENT

The sedimentary rocks of the San Juan Islands have been intruded, and in many places nearly destroyed, by dikes, sills, and irregular masses of igneous rocks. The latter range in composition from ultrabasic dunites and pyroxenites to the most acid aplites and pegmatites. The bulk of the igneous material was apparently derived from the late Jurassic batholith, and the character of the rocks composing the Turtleback complex would indicate that the roof of the batholith was fairly close to the present surface.

The pre-batholithic intrusions took the form of dikes, sills, and large irregular masses which are probably laccolithic in character. The later off-shoots from the late Jurassic batholith took the form of an injection breccia, and the study of the interrelationships of these rocks is an exceedingly complicated and difficult one.

The late Jurassic batholith outcrops along the shore of the Saanich Peninsula on the west side of Haro Strait.[32] Many of the igneous off-shoots occurring in the Turtleback complex in the San Juan Island map-area are identical with dike rocks which cut the granodiorite of the Saanich batholith.

In the eastern part of the San Juan Island map-area large masses of peridodite have been intruded into the sediments of the Leech River group.

The most widespread of all of the igneous rocks of this region are the Eagle Cliff porphyrites. Although these rocks are commonly ellipsoidal in structure, they are clearly intrusive into the older rocks and likely served as feeders to flow rocks which have since been removed by erosion. It is probable that these rocks are to be correlated with the Vancouver volcanics.[33]

Effusive igneous rocks which have actually reached the surface are now probably lacking in the San Juan Island region.

FIDALGO FORMATION

A number of intrusive masses of serpentized dunite, called here the Fidalgo formation, outcrop in the eastern portion of the map-area.

The Fidalgo formation occurs on Fidalgo Head and at several localities in the southeast part of Fidalgo Island. The following islands are composed entirely of this formation: Burrows Island, Young Island, Allan Island, Williamson Rocks, Saddlebag Island, Dot Island, and Hat Island. It forms the major part of Cypress Island.

Petrographic Details. The Fidalgo formation is composed of three distinct rock types which are invariably associated with each other: (1) Large irregular masses of extremely coarse-grained dunite, which weathers to a dark green or dark brown color. (2) Thin irregular off-shoots of fine-grained

[32] Clapp, C. H., Geology of the Victoria and Saanich Map-Areas, Vancouver Island: *Geol. Survey Canada,* Mem. 36, pp. 71-93, 1913.

[33] Dawson, G. M., Report on a Geological Examination of the Northern Part of Vancouver Island and Adjacent Coasts: *Geol. Survey Canada, Ann. Report,* 1886, p. 10B, 1887.

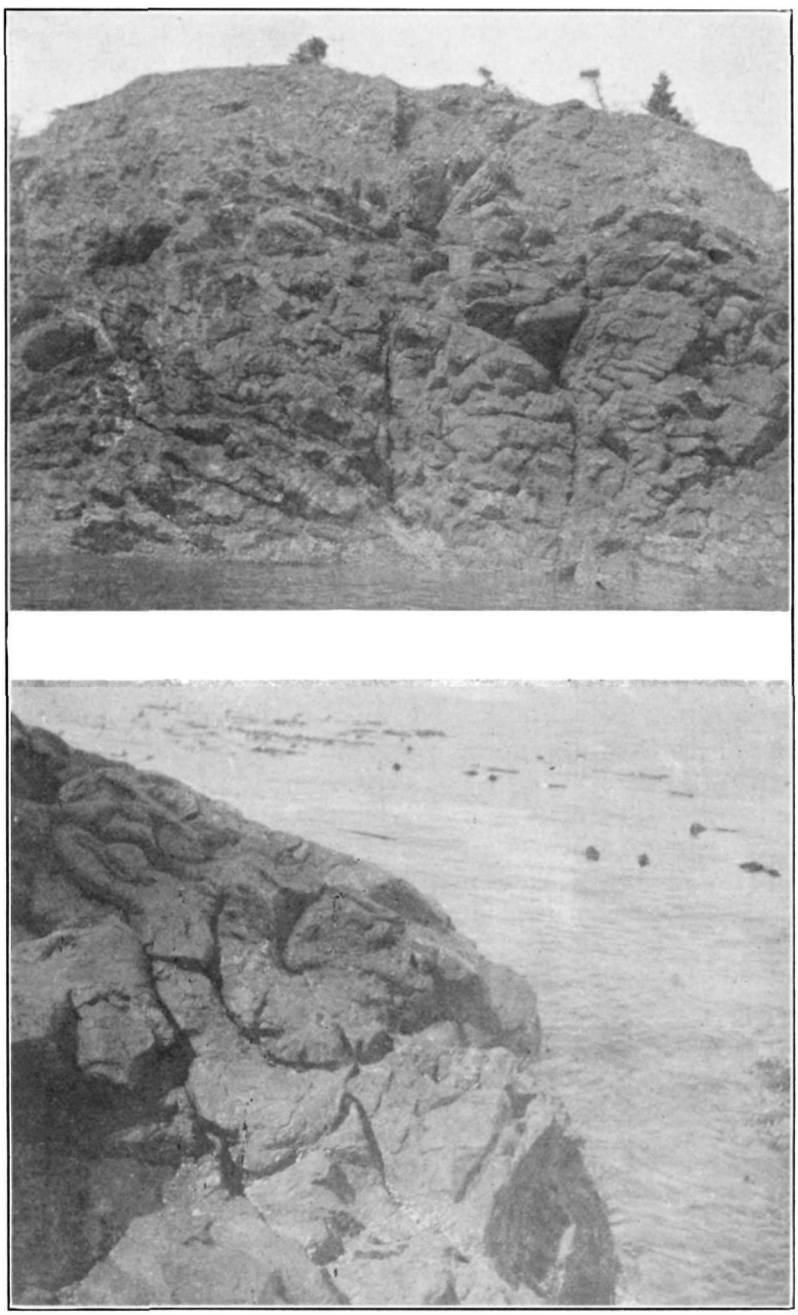


PLATE XIX

Above: Ellipsoidal Eagle Cliff porphyrite at the east side of Davis Bay, Lopez Island.
Below: Ellipsoidal Eagle Cliff porphyrite near Cape St. Mary, Lopez Island.

dunite, injected into the joint-cracks of the coarse-grained variety. These offshoots weather first to a light brown or buff color, and on further disintegration, to a bright orange-red. (3) Both types of dunite are everywhere cut by thin stringers (rarely exceeding two inches in thickness) of serpentinized pyroxenite. The latter is composed almost entirely of altered diallage, the crystals often being as large as the width of the stringer permits. Of the three rock types the pyroxenite is the least resistant to alteration and erosion.

The injected fine-grained dunite often contains schlieren-like segregations of chromite. The latter have been mined to some extent on Cypress Island, in spite of the fact that each ore-body usually contains only a few tons of chromite.

At the southeast corner of Cypress Island, a cone-shaped hill, called Olivine Hill, rising to an elevation of 600 feet, is composed almost entirely of fresh vitreous olivine. Individual crystals of the olivine measure up to two inches in length.

A chemical analysis of the fresh olivine rock, made by the writer, gave the following composition:

SiO_2	42.4%
Al_2O_3	1.1
FeO	5.2
Fe_2O_3	0.6
CaO	0.7
MgO	49.2
Cr_2O_3	0.4
Total	99.6%

Coarse-grained Types

The coarse-grained dunites contain crystals of altered olivine that average half an inch in diameter. The freshly-broken surfaces are dark green in color, but on longer exposure they change to dark brown or black. When exposed, the rock surfaces are differentially etched by erosion, and the individual crystals stand out in relief. The spaces between the crystals, being the first to alter to serpentine, are more easily and quickly eroded. An occasional crystal of altered diallage is seen on the freshly-broken surfaces. The diallage has been altered largely to a lamellar variety of serpentine which possesses a silvery-gray color and a silky lustre.

Thin sections of the dunite occurring at Olivine Hill on Cypress Island show that 90 to 95 per cent of the rock is composed of olivine. Small scattered crystals of diallage, enstatite, and chromite make up the balance of the rock. The rock is remarkably fresh, and the average section shows almost no trace of serpentine. The diallage is likewise fresh, and shows maximum extinction angles of 38 to 45 degrees. Chromite occurs in subhedral crystals, but more commonly it forms irregular grains.

In all other localities the dunites have been serpentinized. The freshest samples obtained show the alteration to have reached the point where the serpentine exceeds the olivine in abundance. Each crystal of olivine has been crossed

by cracks which have been produced by the pressure of crystallization of the serpentine. The alteration has proceeded outward in every direction from the cracks, and isolated remnants of olivine surrounded by serpentine, are all that remain of the former olivine crystals. In many places the alteration has reached the point where all of the olivine has disappeared.

Near the surface, the iron oxide released in the alteration of olivine to serpentine is partially changed to limonite. The chromite oxidizes sufficiently at the surface to kill off the plant life where it is not deeply rooted. The diallage and enstatite alter to bastite, chlorite, and antigorite.

Fine-grained Types

The fine-grained dunites are identical in mineral composition with the coarse varieties. They are intruded into the earlier dunites along zones of weakness, particularly along joint cracks, and their widespread distribution indicates that the coarse dunites had not solidified to any great depth when the intrusion took place.

In general the fine-grained dunites contain a larger percentage of chromite. Apparently the magma supplying the dikes was derived from the lower portions of the original magma, whose chromite had been enriched by gravitative differentiation.

The two types of dunite appear to be almost identical in thin section. The large crystals of the coarse varieties are so badly cut up by cracks filled with serpentine that they are almost indistinguishable from the fine-grained dunites. In both cases the typical section shows small remnants of olivine crystals completely surrounded by serpentine. Iddingsite is often present in small quantities, especially in the more highly altered specimens.

The weathered surfaces of the fine-grained dunites are usually buff-colored, and on still further weathering they become orange-red in color. The reddish-colored hill-sides are noticeable at all localities where the Fidalgo formation comes to the surface. The color is due to the chromium chlorite, kotschubeite, together with iddingsite and a chromium-bearing limonite.

Pyroxenite Dikes

The dunites of the Fidalgo formation are everywhere cut by thin stringers of coarse-grained diallage rock which is now largely altered to a variety of serpentine resembling bastite. In was first supposed that the stringers were composed of chrysotile formed during the process of the alteration of the dunites. Some of the stringers of serpentine no doubt formed in this manner, but the majority of them apparently had a quite different origin.

An examination of thin sections of the materials composing the stringers reveals the presence of unaltered remnants of diallage and hornblende. The serpentine occurs typically in the form of a pseudomorph after diallage. It is quite apparent, therefore, that the stringers of this type were derived from pyroxenites intruded into the dunites in the form of an injection breccia. The pyroxenites were evidently charged with a large amount of volatile constituents at the time of their intrusion.

Age Relations. The rocks of the Fidalgo formation are intrusive into the sediments of the Leech River group and consequently they are at least post-Carboniferous, and probably post-Paleozoic in age.

On Fidalgo Head, across the channel from Burrows Island, a dike of the Eagle Cliff porphyrite has intruded the Fidalgo formation. Similar intrusive dikes occur at several localities on Cypress Island. Since the Eagle Cliff porphyrites are probably of late Triassic or early Jurassic age, it appears that the Fidalgo formation was intruded during the Triassic period.

The fresh vitreous dunite occurring on Olivine Hill on Cypress Island is apparently much younger than the serpentinized dunites. It is possible that the fresh dunite is equivalent to the dunites of late Tertiary age which occur in the Skagit and Hozomeen Ranges.

Eagle Cliff Porphyrite

Intrusive dikes of porphyrite, referred to here as the Eagle Cliff porphyrite, are to be seen in all parts of the map-area where pre-Cretaceous rocks are exposed. The porphyrites are the most widespread and abundant of all igneous rock types occurring on the San Juan Islands.

At Eagle Cliff, on the north end of Cypress Island, the ellipsoidal porphyrites form immense dikes, cutting the Leech River slates and graywackes on one side and the Fidalgo formation on the other.

On Lopez Island the porphyrites are practically free from the late Jurassic intrusives. On San Juan and Orcas islands they have been metamorphosed and in places destroyed by later intrusions. In the eastern part of the map-area, the porphyrites are usually free from the later intrusions, and in such cases the rocks are remarkably fresh.

The rocks occurring on the following islands are composed largely or entirely of the Eagle Cliff porphyrites: Turn Island, Cliff Island, Spindle Rock, Black Rock, Small Island, Fortress Island, Ram Islands, southern part of Decatur Island, Richardson Rock, Castle Island, Boulder Island, Bird Rocks, Belle Rock, the larger or eastern members of the Cone Island group, and Vendovi Island. Excellent outcrops of the Eagle Cliff porphyrites occur on Lopez Island, Orcas Island, San Juan Island, Blakeley Island, Cypress Island, Guemes Island, Lummi Island, and on many of the lesser island and reefs.

Petrographic Details. The Eagle Cliff porphyrites are typically ellipsoidal in structure, the pillow-shaped masses varying from two inches to several feet in diameter. They clearly occur as dikes and sills, and probably served as feeders to flow rocks that have since been removed by erosion. The rocks resemble basalts and basic andesites, both microscopically and structurally, and it is apparent that they solidified near the surface. From their occurrences, it seems probable that the surface of the ground at the time of the intrusion was not far from the elevation of the present surface.

On the southern part of Lopez Island there are excellent exposures of the contacts of the porphyrites where they intrude the sediments of the Leech River

group. The sedimentary rocks are fractured and silicified on both the upper and lower contacts of the porphyrites.

On San Juan and Orcas islands, where the porphyrites sometimes cut the limestones of the Orcas group, the latter are silicified and irregular nodules of flint make their appearance. More rarely, crystals of grossularite, epidote, vesuvianite, and wollastonite are present in the limestones, but some of these minerals are probably due to the late Jurassic intrusives.

The porphyrites are usually medium to fine-grained in texture, and in areas where they have not suffered from later intrusives they are green in color. In the vicinity of the intrusive dikes of the Turtleback complex the porphyrites are often reddish-brown in color, and sometimes highly metamorphosed. The ellipsoidal masses are fine-grained at the margins and they become increasingly coarse in texture as the center is approached. The spaces between the ellipsoids are usually filled with fine-grained andesitic or basaltic material which is often silicified. Small radially arranged vesicles are almost invariably present within the ellipsoids.

Thin sections of the porphyrites at Eagle Cliff show a typically basaltic texture. The interstices between the long reticulated laths of acid labradorite or andesine are filled with augite. Both common augite and titaniferous augite are usually present in the porphyrites. Although olivine is present in the rocks at the type locality, it is generally lacking in the other parts of the map-area. Basaltic hornblende occurs in some of the porphyrites and ilmenite and pyrite are usually present in relatively large amounts. In many instances the coarser-grained porphyrites contain varioles of mingled fine-grained plagioclase and pyroxene. The varioles are relatively rich in pyroxene.

While the porphyrites appear to be quite fresh in the hand specimen the microscope reveals the fact that a considerable amount of alteration has taken place. The plagioclase has been somewhat altered to saussurite and the pyroxene has partly altered to chlorite, serpentine, and epidote. The alteration of the olivine has reached the point where about 50 per cent has changed to serpentine. Streaks of calcite, probably derived from the alteration of the andesine or labradorite, occur in the typical section. Where vesicles occur they are usually filled with serpentine and calcite, but in some cases, chalcedony or zeolites form the chief filling material.

The filling between the ellipsoids is composed of glass with plagioclase microlites. The margins of the ellipsoids contain a considerable amount of glass in the interstices between the plagioclase laths. Towards the center of the pillows the rocks are holocrystalline but never coarse-grained.

The Eagle Cliff porphyrites belong, on the whole, to the more acid type of basalt porphyrites, and they grade into diorite or andesite porphyrites. Some of the more acid facies, e.g., the ellipsoidal porphyrites on the north end of Lummi Island, show a semi-andesitic texture and a relatively large percentage of acid or intermediate andesine. In many places in the western part of the map-area the rocks are porphyritic with rounded phenocrysts of andesine or labradorite up to three-eights of an inch in diameter. The groundmass in the

porphyritic varieties is identical in texture and composition with the non-porphyritic types. Vesicles are occasionally present in the porphyritic types.

On Orcas Island where the porphyrites have been cut and largely destroyed by intrusions of the Turtleback complex, the textures are somewhat coarser. The alteration has been such that little remains of the orginal rock except its texture. The feldspars have altered to kaolin, calcite, and zoisite, and later they became silicified and albitization took place. The augite and other femic minerals have changed, first to uralite and later to chlorite with minor amounts of serpentine and epidote. Tremolite and actinolite are usually present, especially near the contacts with later intrusives.

Age Relations. Owing to the fresh appearance and ellipsoidal nature of the porphyrites in the eastern part of the map area, the author first supposed that they belonged to the Metchosin volcanics (middle or upper Eocene). However, a contact with the sandstones and conglomerates of the Chuckanut formation (lower Eocene), occurring on the north end of Lummi Island, shows that the latter were laid down upon the eroded surfaces of the dikes of the Eagle Cliff porphyrites.

The rocks of the Leech River group serve as the most common host for the porphyrite dikes and sills. The texture and ellipsoidal nature of the porphyrites would naturally indicate that they were flow rocks. Nevertheless they clearly occur as dikes and sills intruding the Leech River and Orcas sediments. The sediments are metamorphosed and brecciated on both the upper and lower contacts of the intrusive sills.

The field evidence indicates that the porphyrites were feeders to former flow rocks, and the present outcrops represent the uppermost portions of the dikes.

The porphyrites intrude the Fidalgo formation at several localities on Cypress and Fidalgo islands. On Orcas and Blakeley islands the metamorphosed remnants of somewhat coarser-textured ellipsoidal porphyrites are intruded by the off-shoots from the late Jurassic batholith. It is probable that the Eagle Cliff porphyrites are of late Triassic or early Jurassic age and related to the Vancouver volcanics.

Turtleback Complex

Throughout areas of considerable size the Paleozoic sediments have been intruded by igneous rocks of so many different types and ages that it is impossible to map them individually. For this composite group of intrusive igneous rocks, which are well exposed on Turtleback Mountain, the name Turtleback complex will be used.

In the areas mapped as the Turtleback complex, the Paleozoic sediments were first intruded by dikes and sills of the Eagle Cliff porphyrite. Intrusions of the still earlier rocks of the Fidalgo formation are seldom found in the areas mapped as Turtleback complex. If these were formerly present they have been almost entirely destroyed by later intrusions.

Some of the rocks belonging to the Eagle Cliff porphyrites are apparently related lithologically to the typical Vancouver volcanics occurring on Vancouver Island. These intrusions did not all occur at the same time. It is probable that they were intruded intermittently during a great lapse of time.

Following the intrusions of the Eagle Cliff porphyrites the region was cut by a great variety of intrusive materials, the greater part of which were probably derived from the late Jurassic batholith. The invaded rocks were so badly broken and shattered that the later intrusions took the form of an injection breccia. The igneous rocks occurring on Turtleback Mountain have the appearance of a scrambled mass or net-work of both acid and basic intrusives in a matrix furnished by the remnants of the Eagle Cliff porphyrites. On Blakeley Island the matrix is usually formed by a fine-grained gabbro diorite which may be laccolithic in nature.

The Turtleback complex is composed of a confused net-work or injection breccia containing the following rock types:

(1) Dunites of the Fidalgo formation.
(2) Basalt and andesite porphyrite belonging to the Eagle Cliff porphyrites.
(3) The Wark gabbro diorite.
(4) The Colquitz quartz-diorite.
(5) Scattered off-shoots of diorite porphyrite.
(6) Scattered off-shoots of rhyolite porphyry.
(7) A series of granodiorite porphyry off-shoots together with aplites, pegmatites, and igneous quartz veins.
(8) A series of lamprophyric off-shoots, ranging from the more basic porphyrites to the ultrabasic pyroxenites and hornblendites.

DUNITES OF THE FIDALGO FORMATION

A few scattered remnants of serpentinized dunite occur on Mount Pickett Range and also on Blakeley Island. These remnants presumably belong to the Fidalgo formation. In lithology they are similar to the fine-grained types of dunite seen on Cypress Island.

EAGLE CLIFF PORPHYRITES

In the western and northwestern portions of the map-area the matrix of the injection breccia is generally formed by the Eagle Cliff basalt and andesite porphyrites. Where they are intruded by the later off-shoots from the late Jurassic batholith the Eagle Cliff porphyrites are often red in color and altered almost beyond recognition.

WARK GABBRO-DIORITE

On Blakeley Island and other smaller islands the matrix of the injection breccia composing the Turtleback complex is formed largely by the Wark gabbro diorite.[34] These rocks are identical in lithology with those occurring in the vicinity of Victoria, B. C., though as a rule they are somewhat finer-

[34] Clapp, C. H., Geology of the Victoria and Saanich Map-Areas, Vancouver Island: *Geol. Survey Canada,* Mem. 36, pp. 57-71, 1913.

grained. In several localities on Blakeley Island the Wark gabbro diorites are intruded by long and extremely thin parallel stringers of diallagite and hornblendite. (See Plate VII-B.) Near the contacts of these stringers the gabbro diorites are profoundly altered and crystals of diallage occur disseminated through them. Where the contact action has been intense, the minerals composing the gabbro diorite are largely replaced by pyrope, andalusite, and vesuvianite. The diallagites and hornblendites were apparently very fluid and contained a high percentage of volatile matter.

The Wark gabbro diorite occurs in all of the larger areas mapped as Turtleback complex. It is particularly abundant on Blakeley Island, but it also occurs on Frost Island, Willow Island, Armitage Island, Pointer Island, Orcas Island, San Juan Island, Guemes Island, Huckleberry Island, and along the shore of Burrows Bay on Fidalgo Island.

COLQUITZ QUARTZ-DIORITE

The Wark gabbro diorite is usually accompanied by later intrusions of quartz-diorite known as the Colquitz quartz-diorite.[35,36] These rocks apparently form a part of the great series of off-shoots derived from the late Jurassic batholiths.

DIORITE PORPHYRITE

Occasional small intrusive masses of diorite porphyrite are seen in the injection breccia composing the Turtleback complex on Orcas Island, Blakeley Island, and Fidalgo Island. The diorite porphyrites have the same mineral composition as the more acid facies of the Wark gabbro diorites, and it is assumed that they are related in origin.

RHYOLITE PORPHYRY

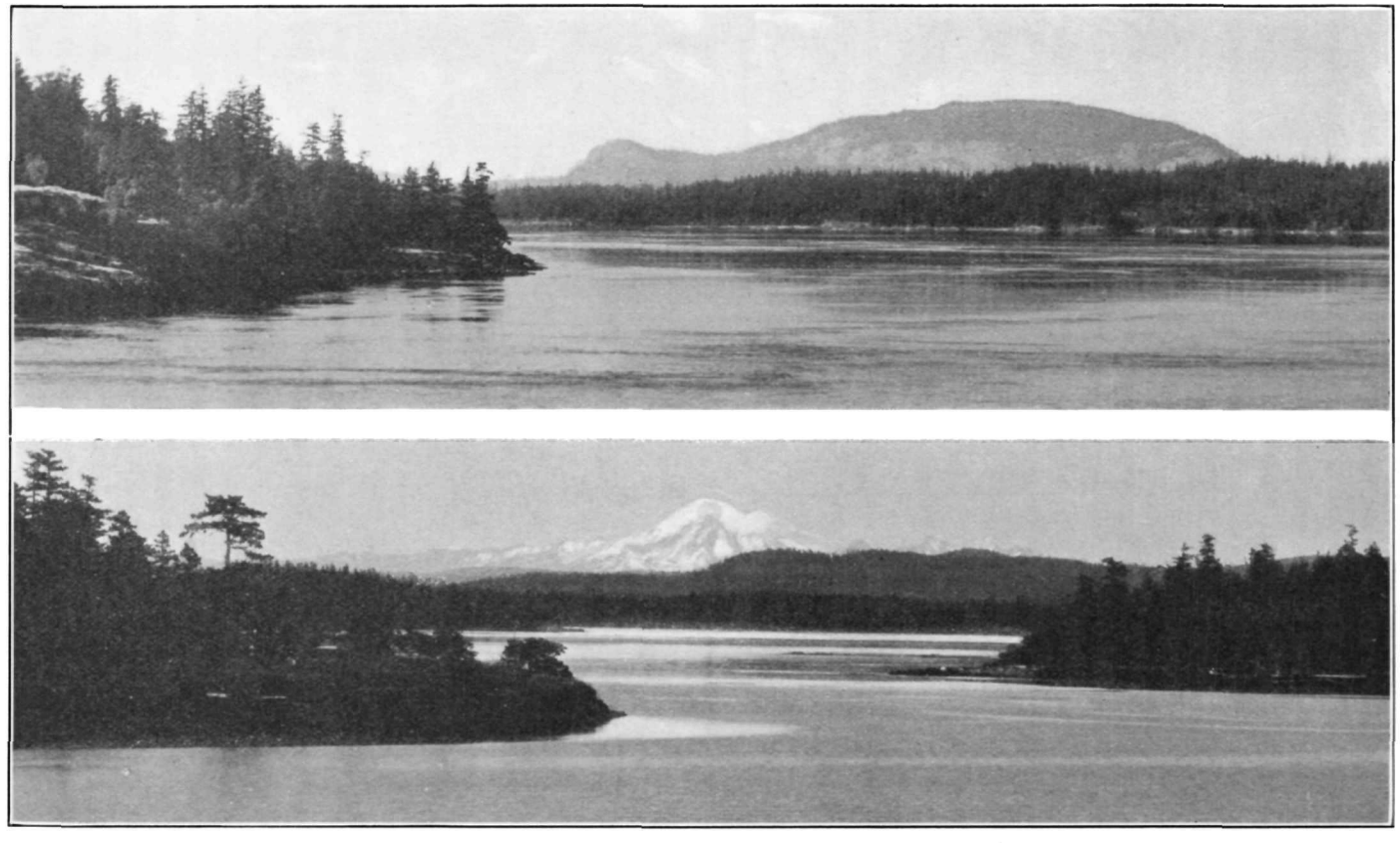
Small isolated intrusions of rhyolite porphyry occur in the Turtleback complex on Orcas Island. They also occur on Jones Island and Barren Island, the latter being composed entirely of rhyolite porphyry.

The rhyolite porphyry is brownish-gray in color with vitreous phenocrysts of quartz. At the surface it weathers to a white color with a pink stain. The groundmass is aphanitic and somewhat glassy in the fresh specimens. The phenocrysts of quartz are usually rounded by resorption, and they measure up to a quarter-inch in diameter.

Under the microscope the rock is seen to consist of a glassy groundmass containing large rounded phenocrysts of quartz and smaller ones of orthoclase. The quartz crystals are cracked by the pressure of crystallization, and they generally contain minute needle-like inclusions of rutile. The orthoclase crystals are much smaller than the quartz phenocrysts, the amount of silica in

[35] Clapp, C. H., Southern Vancouver Island: *Geol. Survey Canada,* Mem. 13, pp. 96-101, 1912.

[36] Clapp, C. H., Geology of the Victoria and Saanich Map-Areas, Vancouver Island: *Geol. Survey Canada,* Mem. 36, pp. 57-71, 1913.



Photograph by J. A. McCormick.

Above: Turtleback Mountain and Orcas Knob as seen from the entrance of West Sound. *Below*: Mount Baker as seen from Friday Harbor, San Juan Island.

the rock exceeding 75 per cent. The orthoclase crystals are somewhat altered to kaolin but they have not been resorbed to any extent.

The groundmass in the rocks on Barren Island is glassy and filled with microlites. On Jones and Orcas islands the rocks usually have a dense aphanitic groundmass showing occasional minute crystals of orthoclase.

The rhyolite porphyries appear to be among the youngest of the off-shoots composing the Turtleback complex.

The Turtleback complex includes a series of porphyry and lamprophyric off-shoots thrown out by the late Jurassic batholith. The earlier intrusions were coarse-grained and very inequigranular quartz-diorite porphyrites. The succeeding off-shoots followed two distinct types of differentiation; the one became increasingly acid and culminated in the aplites, pegmatites, and quartz veins; the other became increasingly basic and formed a series of lamprophyric intrusions.

ACID OFF-SHOOTS

Porphyry Intrusions. The earlier porphyries are very inequigranular and usually coarse or medium-grained. They are composed largely of plagioclase and hornblende.

The earlier off-shoots consist chiefly of andesine, hornblende, orthoclase, and quartz. Biotite occurs in some of the rocks but its presence is not consistent. The plagioclase and hornblende occur in crystals of various sizes, but the orthoclase and quartz crystals are relatively small. The hornblende is generally somewhat altered to chlorite and serpentine.

The succeeding intrusions are less coarsely-textured and the crystals are less inequigranular. Accompanying this change the plagioclase becomes more and more acid and finally culminates in albite or soda orthoclase. The proportions of quartz, orthoclase, and soda orthoclase increase, but the hornblende decreases and is partly displaced by primary biotite.

Each set of off-shoots exerted its effect on the metamorphism of the earlier intrusives.

Later Acid Intrusions. The later porphyry off-shoots become finer and finer grained and grade into the equigranular aplites. The igneous rocks which intrude the aplites are confined to the pegmatites, quartz veins, and the coarse diallagites.

The later porphyry off-shoots consist chiefly of albite, soda orthoclase, and quartz, the latter making up over 25 per cent of the rock. An acid oligoclase sometimes occurs to the extent of about ten per cent. Small crystals of biotite, now largely altered to chlorite, make up the remainder of the rock. Magnetite and pyrite are usually present in small amounts.

The true aplites are medium to fine-grained rocks with an equigranular or sugary texture. In this region they always contain soda-bearing feldspars as the predominating constituents. The percentage of quartz in the aplites is generally well above 25 per cent.

The pegmatites, which are far more abundant than the aplites in this region, are composed of the same minerals as the latter. The variations in the relative proportions of the minerals is much greater in the pegmatites and their textures are usually much coarser. Occasionally the graphic texture is seen in the pegmatites. Some of the pegmatites contain more than 50 per cent of quartz and apparently grade into the igneous quartz veins. The feldspars of the pegmatites are more altered to kaolin than is usually the case with the aplites.

The youngest igneous rocks composing the Turtleback complex are the igneous quartz veins which cut all of the other rocks of the region. It is probable that the quartz veins which almost everywhere cut the sediments of the Leech River group, are a part of the last off-shoots from the Late Jurassic batholith.

LAMPROPHYRIC OFF-SHOOTS

The earlier porphyry off-shoots contain considerable percentages of hornblende. With the earlier off-shoots as a starting-point, a series of basic intrusives have arisen which form an analogy with the acid series. The lamprophyres were apparently thrown off from a portion of the basic differentiate within the batholith. In each succeeding set of off-shoots the percentage of hornblende became larger and larger. As in the case of the acid series the succeeding off-shoots were less inequigranular than the preceding ones.

The later lamprophyres vary greatly in mineral composition. They usually contain hornblende, diallage, biotite, acid plagioclase or soda orthoclase, and occasionally quartz, olivine, and basic plagioclase. Diallage tends to replace hornblende as a primary mineral in the later lamprophyres. Magnetite is the most persistent accessory mineral and it is often quite abundant. Titanite and apatite are usually present in small amounts.

The typical fine-grained equigranular lamprophyres, with a texture similar to that of granulated sugar, apparently correspond with the aplites in the acid series. They were thrown off a little earlier than the aplites which usually cut them.

The succeeding basic off-shoots, which generally cut the aplites, are composed largely of diallage and hornblende with minor amounts of enstatite and olivine. These may be considered as ultrabasic pegmatites, the crystals of which frequently measure six inches in length. At the time of their intrusion these diallagites and hornblendites contained large quantities of volatile constituents which altered the invaded rocks for considerable distances from the contacts. Where these rocks have intruded into the Wark gabbro-diorites, the later have been more or less completely replaced by magnesian garnet, andalusite, quartz, vesuvianite, diopside, and other contact minerals. It is difficult to understand how some of these contact minerals originated. It is very remarkable that sufficient alumina was provided to form andalusite, which is so abundantly present near these contacts. The occurrence of thin parallel

ribbon-like stringers of diallagite and hornblendite in the Wark gabbro-diorite is equally astonishing. (see Plate VII-B.)

The diallagites sometimes show all of the transitional phases from fresh unaltered diallage to light green hornblende pseudomorphic after diallage, and finally to a variety of serpentine resembling bastite. Primary and secondary hornblende may occur in the same rock.

Age Relations. Owing to the fact that the Cretaceous and Eocene sediments occurring in the San Juan Island region are not cut by any igneous materials and since the conglomerate occurring in these sediments include boulders composed of rocks from the Turtleback complex it is evident that the igneous rocks composing the Turtleback complex are pre-Cretaceous in age. The great series of igneous off-shoots must therefore be related to the late Jurassic batholiths and not to those of late Miocene age.

STRUCTURE

In detail the structure of the rocks in the San Juan Island map-area is extremely complicated. A large part of the structural geology of this region will remain long unsolved, for the major fault lines are occupied by deep channels and the islands are often separated so far from each other that the continuity of the structure is broken. The Paleozoic rocks have been subjected to so many periods of folding and faulting, and in addition they have been intruded by igneous rocks of so many periods of igneous activity, that it is indeed remarkable that any continuity can be traced in their structural relations.

The three large islands, Orcas, San Juan, and Lopez, serve as a nucleus to which the structural relationships of the smaller and more isolated islands must be connected. These three islands reveal a structure which in its major aspect is a broad open syncline plunging at a vertical angle of about 35 degrees toward the southeast.

An examination of the topographic maps of the islands fringing the eastern shore of southern Vancouver Island, shows how clearly the rock structure is related to the surface features. The Cretaceous rocks retain an unbroken northwest and southeast trend until the International boundary is reached. Beyond this point the rock structure is broken, and with the exception of the Stuart Island group, the smaller islands show little or no apparent structural relationship to each other. Superficially at least it would appear that Saturna Island and South Pender Island exhibit drag, such as would occur if the San Juan Islands had been thrust to the northward.

The former topography of the San Juan Islands has been greatly modified by glaciation, but the erosion beneath the glaciers was no doubt guided to a considerable extent by valleys and by the fracture zones and fault zones that were already in existence. It is probable that a fault of considerable magnitude occupies each of the major channels.

In an earlier paper[37] the writer described a fault extending from False Bay to Doe Bay, as the Kanaka fault. It now appears that although a fracture zone or fault occurs throughout the greater part of this line, it does not cross the map-area as a single fault. Its movement, in different portions of the fault line, did not have the same direction.

Judging from the soundings, a very profound fault occurs in Haro Strait, quite close to the shore of San Juan Island. Another fault of considerable magnitude follows San Juan Channel and crosses Lopez Island near the village of Lopez. Whether this fault continues on through Lopez Pass, or whether it is cut off by a north-south fault in Lopez Sound, has not been determined. The south side of the fault apparently moved southeastward with respect to the north side.

It is assumed that a fault or fracture zone follows Harney Channel, and

[37] McLellan, R. D., The Devonian Orcas Group of Washington: *Amer. Jour. Sci.*, vol. 8, p. 220, 1924.

before the formation of the San Juan fault, this zone crossed over in a direct line to Rocky Bay on San Juan Island. If such a fault zone occurs, its horizontal displacement cannot be very large.

The line connecting the villages of East Sound and West Sound is probably the location of a pre-Jurassic fault-zone, because of the numerous igneous intrusions along this line. The strike of the rock formations is parallel to this line.

A fault of small horizontal displacement follows East Sound and divides Orcas Island into two almost equal parts. Whether the fault continues on into Lopez Sound is problematical. From evidence occurring on the north shore of Orcas Island the fault is post-Cretaceous in age, and the eastern side moved southward and upward with respect to the western side.

Along the north shore of Orcas Island, from Point Lawrence to the foot of Buck Mountain, the fossiliferous Leech River sediments strike parallel to the shore-line and dip about 65 degrees to the southward. On the top of Mount Constitution the Leech River sediments strike about N 45° E, and dip towards the south-east. The rocks occurring on Mount Constitution Range are clearly overthrust upon the Leech River sediments which outcrop along the shore to the northward. The fault-line between them is visible at several localities at an elevation of about 1000 feet.

The structure of the region to the southeast of Mount Woolard is almost hopelessly complicated. The rocks of the Orcas and Leech River groups appear to be scrambled together in this district.

A local anticline crosses East Sound at its southern end and all of the rocks to the south of Dolphin are affected by it. The southern part of East Sound is located on the axis of the anticline, but to the north of Rosario and Dolphin there is no evidence of such a fold for the rocks on both sides of the channel trend northeasterly and dip towards the southeast.

The Leech River sediments on Lummi Island appear to be structurally related to those on the north shore of Orcas Island, both having approximately the same strike. The south part of Lummi Island is apparently the up-throw side of a fault that cuts sharply across the island.

In the western portion of the map-area normal faults occur in New Channel, Spieden Channel, and on the south side of the point connecting Davidson Head with San Juan Island. Each of these faults trends in an east-west or slightly northwest direction, and in each case the south side is the up-throw side.

It is evident that the sediments of the Nanaimo series at one time extended over all excepting the eastern margin of the map-area. Erosion has removed these sediments from the more uplifted areas.

The small islands in the northern part of the map-area do not display much similarity in structure. The structure of each of these islands has been treated in the description of the rocks of the Nanaimo series.

Presumably the greatest period of folding and faulting occurred during the

late Jurassic. Apparently the Paleozoic rocks were folded into the large plunging syncline at this time, although they probably were folded to some extent at the close of the Paleozoic. If the syncline was formed at the close of the Paleozoic, the Leech River group could not possibly contain any Mesozoic formations for these rocks were all folded at the same time.

The rocks of the Nanaimo series and the Chuckanut formation were evidently folded during the same periods of folding. As no rocks between the Eocene and Pleistocene occur on the San Juan Islands, it is necessary to look to the adjoining districts for evidence as to the periods of folding of the Cretaceous and Eocene rocks.

The first period of marked folding succeeding that of the late Jurassic took place during the late Eocene or early Oligocene. As noticed by Clapp,[38] the deformation, though ranging from British Columbia to California, was intense only in isolated localities. From evidence found on southern Vancouver Island, Clapp considers that the deformation was quite certainly of early Oligocene age.

According to Weaver[39] no sharp break separates the Miocene from the Oligocene, but during the middle or latter part of the Miocene an extensive elevation of the sea floor took place.

Since the last glacial period the whole region has been uplifted to such an extent that marine fossils have been found in glacial sediments 290 feet above the present sea-level. In the San Juan Island map-area there appears to have been a recent uplift of 15 to 25 feet.

[38] Clapp, C. H., Sooke and Duncan Map-Areas, Vancouver Island: *Geol. Survey Canada*, Mem. 96, pp. 254-255, 1917.

[39] Weaver, C. E., A Preliminary Report on the Tertiary Paleontology of Western Washington: *Wash. Geol. Survey Bull.* 15, pp. 25, 1912.

HISTORICAL GEOLOGY

The geological record as revealed in the rocks exposed on the San Juan Islands is fragmental in many respects, but when taken with the records shown in the surrounding areas, a fair conception of the outstanding geological events may be had.

PALEOZOIC ERA

DEVONIAN PERIOD

The geological record, as revealed on the San Juan Islands, opens with the middle or upper Devonian period. Periodically alternating conditions of sedimentation occurred in a wide, shallow, and subsiding epicontinental sea, producing thin alternating layers of fine-grained and semi-colloidal silica sand and layers of mud or silt. The deposition of these alternating layers of sediment continued until a total of many thousand feet of strata were deposited. Colonies of corals, brachiopods, and other sedentary animals were able to establish themselves in the more favored localities during the process of the deposition of the sediments. These gave rise to the limestone lenses which occur intermittently throughout this rock group.

MISSISSIPPIAN PERIOD

The conditions of sedimentation existing in the late Devonian period were continued on into the Mississippian. The dividing-line between the two periods was probably marked by the temporary addition of pyroclastics to the normal sediments. The closing stages of the Mississippian period were probably marked by a second period of volcanic activity in the surrounding regions which contributed pyroclastic material to the sediments. During this time the floor of the sea was being gradually uplifted and the character of the sediments was changing to the coarser-grained varieties. During the stage the basal tuffaceous graywackes of the Leech River group were probably in the process of deposition. The Mississippian period was probably terminated by a general uplift of the region.

PENNSYLVANIAN PERIOD

The Pennsylvanian period presumably opened with a submergence of the region until conglomerates and breccias were deposited upon the surface of the graywackes. A further submergence caused the character of the sediments to become finer and finer-grained until nothing but silt was deposited. Periodically alternating conditions in the sedimentation caused thin alternating strata of light and dark colored carbonaceous mud to be deposited. These alternating conditions of sedimentation continued for a long lapse of time during which an occasional limestone bed was formed. The Pennsylvanian period was probably closed by another general uplift of the San Juan Island region.

PERMIAN PERIOD

The dividing line between the Pennsylvanian and the Permian periods has not been established in the San Juan Island area. If the conglomerates, graywackes, and slates occurring in the upper part of the Leech River group really belong to the Paleozoic, they probably belong to the Permian period. In that case, the whole area was uplifted above sea-level at the close of the Paleozoic era.

MESOZOIC ERA

TRIASSIC PERIOD

It is possible that the movement which resulted in the uplift of the Paleozoic sediments was connected with the intrusion of the dunites of the Fidalgo formation. During the latter part of the Triassic period the area was down-warped, and the sea waters came in and deposited the sediments of the Haro formation. At the same time, tremendous and repeated eruptions of andesitic material occurred on Vancouver Island.

JURASSIC PERIOD

The outpouring of volcanic materials continued on into the Jurassic period. In the San Juan Island region the post-Triassic erosion surface was not far from the present erosion surface. At any rate the intrusions of the Eagle Cliff porphyrite assumed ellipsoidal structures indicating that the intruded rocks were both near to the surface and very moist.

Near the close of the Jurassic the area was uplifted and the Paleozoic and Mesozoic sediments were subjected to a period of intense folding and faulting. The area was intruded by large batholithic masses of granodiorite and the overlying sediments were in many places destroyed by the numerous off-shoot dikes thrown out by the batholiths.

LOWER CRETACEOUS PERIOD OR EPOCH

The intrusion of the late Jurassic batholiths was followed by a prolonged period of erosion and deposition. So great was the lapse of time represented by the lower Cretaceous period, that the batholith was partly de-roofed in some of the neighboring areas by the close of the Knoxville stage. The conglomerates do not contain abundant boulders of granodiorite, however, until upper Cretaceous time.

UPPER CRETACEOUS PERIOD OR EPOCH

Erosion and deposition of the sediments derived from the uplifted land areas continued during the upper Cretaceous period. By this time the batholiths were exposed over considerable areas in the neighboring regions. The conglomerates and arkosic sandstones of the Nanaimo series were laid down upon surfaces that were usually near sea-level. Clapp in his study of the Nanaimo region considers the Nanaimo series to have been laid down upon erosion surfaces that were not far from the present level.

Patos Islands show an excellent though exceedingly fragmental record of the fact that a large river delta existed at that locality during upper Cretaceous time.

CENOZOIC ERA

EOCENE PERIOD OR EPOCH

The Mesozoic era was closed by a general withdrawal of the sea and an accompanying uplift of the whole region. The Cenozoic era began with a gradual submergence of the region, the waters entering both from the northward and from the area now occupied by the Strait of Juan de Fuca. As the submergence continued, the waters encroached farther and farther eastward upon the land areas. The sediments of the Chuckanut formation on Lummi Island were laid down upon the eroded surfaces of the Eagle Cliff porphyrites and the Leech River sediments. During this period the waters occurring in the eastern and southeastern portion of the map-area were brackish. Towards the close of the Eocene period the whole region was uplifted above sea-level and gently folded.

OLIGOCENE PERIOD OR EPOCH

During the early part of the Oligocene period the rocks occurring in the San Juan Island region were still further uplifted and folding and faulting took place. This was apparently followed by a prolonged period of erosion, for no rocks of middle or late Tertiary age are found in the region.

MIOCENE PERIOD OR EPOCH

During the early and middle Miocene the region was exposed to erosion, and the more elevated portions were no doubt reduced to areas of low relief. Towards the latter part of the Miocene period, when the newer Cascade Mountains were in the process of formation, the rocks of the San Juan Island region were uplifted and folded into a mountain range trending in a northwest and southeast direction. At this time the river systems which drained southern British Columbia were probably prevented from reaching the ocean by way of the Strait of Juan de Fuca.

PLIOCENE PERIOD OR EPOCH

In the San Juan Island region the Pliocene period is represented by a long erosional interval during which the uplifted mountain range was deeply dissected by ravines and valleys.

QUATERNARY

PLEISTOCENE PERIOD OR EPOCH

The uplifted mountain range which crossed the San Juan Island map-area was subjected to the erosion of repeated glacial invasions during the Pleistocene period. The region was subjected to at least two distinct glacial advances and future investigations will probably reveal the proof of additional and

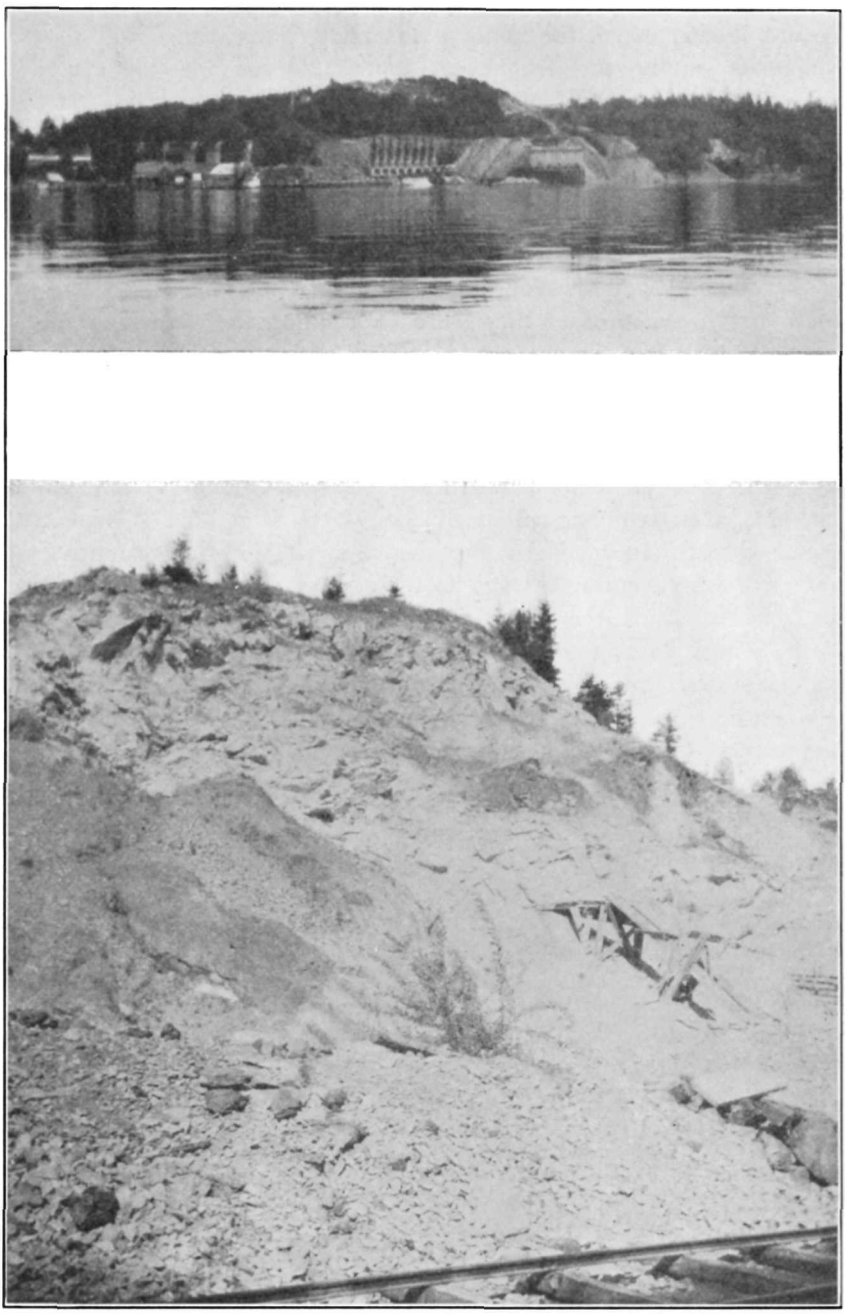


PLATE XXI

Above: Roche Harbor, San Juan Island. *Below*: One of the quarries of Roche Harbor Lime and Cement Company, Roche Harbor.

still earlier glacial invasions. The glacial episodes were separated by intervals of time during which the climate was relatively warm.

While the outline of the present topography of the San Juan Island region is no doubt of pre-glacial origin, the earlier topography has been greatly modified as a result of glacial erosion.

RECENT PERIOD OR EPOCH

The retreat and close of the Vashon glacial invasion marks the beginning of the Recent period. The loose and unconsolidated sediments deposited during the different glacial invasions and interglacial intervals were left in such a position that in some cases they were exposed to the action of the waves. These sediments were rapidly eroded away and often carried considerable distances by the strong tidal currents. High sea-cliffs were developed as the waves cut their way into the deeper and more elevated deposits of glacial material. Sand bars, sand spits, and sandy hooks were formed by the action of the waves and tidal currents. Had it not been for the great strength of the tidal currents, the erosional action of the waves would have been felt to a far greater extent. In many of the channels the tide-rips are more or less active at all times excepting at high tide, and it is therefore at high tide that the storm waves reach the shore without being broken up into interfering components which destroy or limit their eroding power. The abundant wave-cut benches at high tide-level show how efficient the waves are as agents of erosion when they are not broken up by the tide-rips.

The retreat of the last glacier was evidently followed by a general uplift, for excellent examples of recently uplifted wave-cut benches may be seen in all parts of the region at elevations of 15 to 25 feet above high tide-level.

MINERAL RESOURCES

LIMESTONE

The limestone deposits occurring in the San Juan Island region are confined to Orcas Island, San Juan Island, Shaw Island, O'Neal Island, Henry Island, Jones Island, Cliff Island, and Crane Island. These deposits occur in rocks of Devonian, Carboniferous, and Triassic age. They are particularly abundant in the cherty formations of the Orcas group, and occasionally they are found interbedded with the sediments of the Leech River group.

The limestone deposits occurring throughout the whole region have a marked tendency to pinch out rapidly in every direction. They generally occur as small "pockets" in the Orcas cherts, and each deposit is typically lens-shaped.

Origin of the Limestone Lenses

When a rock is crushed or pulverized either by hand or by the natural processes of weathering, and the resulting material is sorted by the action of water, the following products are obtained:

(1) Coarse fragments which in nature are deposited close to shore in the form of gravel.

(2) Finer fragments which are carried farther from shore by the action of waves and currents and finally deposited as sand.

(3) Still finer fragments which are carried far from shore by the action of storm waves and tidal currents and deposited as silt or clay.

(4) Extremely fine particles which form a colloidal suspension in water. The nature of this material is such that it is carried long distances from land. It tends to settle out during quiet weather, but it is again transported in one direction or another by each succeeding storm, until it is finally covered by other sediments.

It is assumed that the cherts of the Orcas group were formed by a semi-colloidal silica silt which was distributed over the bottom of an epicontinental sea far away from the shore. The conditions of sedimentation were such that thin alternating layers of semi-colloidal silica silt and argillaceous silt were being deposited over a wide area.

The bottom of this sea was apparently unfavorable for plant or animal life. Isolated colonies of corals and other sedentary animals and plants occurred here and there but the struggle for existence was apparently very keen. In some cases the colonies of corals were able to thrive temporarily and they grew up higher and higher and spread out rapidly on all sides. Then the conditions changed in such a manner that the struggle for existence became more intense. The animals near the margins of the colonies were evidently less favored than the others and they were unable to survive. In the meantime the siliceous and argillaceous sediments were accumulating, and when the margins of the colonies failed to grow upward, they were covered with

sediment. Thus a colony of lime-secreting animals or plants might gain a foothold on a small area; grow upward and spread outward as the deposition of sediment progressed; after reaching a period of maximum development, to gradually dwindle down to extinction and to be finally covered by later sediment—such is the apparent origin of the lens-shaped limestone beds which occur in the sediments of the Orcas group.

The limestone lenses or "pockets" which often end abruptly without any tapering, are in some cases truncated by faulting, and in others by the intrusion of igneous rocks. The more rounded masses of limestone were apparently produced by the intensity of the forces which folded the rocks of the Orcas group. The original limestone strata were considerably more extensive than the ledges occurring at the present time.

SAN JUAN ISLAND

The largest deposit of limestone occurring within the map-area is located at Roche Harbor near the north end of San Juan Island. The limestone deposit is located on the elevated peninsula which separates Roche Harbor from Westcott Bay. The quarries and the lime-burning plant at Roche Harbor, which belong to the Roche Harbor Lime and Cement Company, are the largest lime producers in the State of Washington.

Under the management of John S. McMillin the lime-burning establishment has been built up until, at the present time, it is equipped with the most modern appliances. The lime-burning plant at Roche Harbor has been described in detail by Landes.[40]

After being newly equipped with eight modern kilns of the bottle type, the plant suffered from a disastrous fire during the summer of 1923. Although this loss was keenly felt and the industry was practically paralyzed at the time, it did not prevent the company from pursuing a continued policy of expansion and enlargement.

Previous to the fire of 1923, many of the buildings were being utilized almost beyond the limit of their capacity. As in the case of most disasters to well established industries, the evil effect was temporary, for the destroyed portions of the equipment are already being replaced by newer and more efficient appliances which eventually will greatly increase the output.

The limestone, which is very compact and completely recrystallized, is broken loose by blasting. (See Plate XXI-B.) The loosened product is then broken by hand into lumps of the desired size, and at the same time it is sorted and classified according to its quality. The classified lumps of limestone are delivered to the nearby kilns by means of railway cars, and these are emptied into hoppers which lead by gravity into the kilns below. The kilns are situated along the shore of Roche Harbor, and large warehouses and shipping docks are located near at hand.

[40] Landes, Henry, The Non-Metalliferous Resources of Washington, Except Coal: *Wash. Geol. Survey,* vol. 1, part 3, pp. 24-27, 1902.

The limestone deposit at Roche Harbor is situated in a region which has suffered from intense folding and faulting. A fault of considerable horizontal and vertical displacement crosses San Juan Island from Rocky Bay to Roche Harbor. The northern end of the Roche Harbor limestone deposit is evidently truncated by this fault, and the northern side of the fault evidently moved westerly or northwesterly with respect to the southern side. If this is true, the northern extension of the limestone strata exposed at Roche Harbor should occur at the bottom of the Haro Strait somewhere to the west of Battleship Island.

To the south of the fault or fault zone, the Orcas cherts are folded into the form of a broad syncline plunging towards the southeastward, and the region in the vicinity of Mosquito Pass is located on the axis of this fold.

The limestone deposit at Roche Harbor is apparently composed of several limestone strata which are separated from each other by interbeds of chert and argillite belonging to the Orcas group. The large accumulation of limestone at this locality is not due to the thickness of individual strata. As a result of the intensity of the folding in this area, the folds have been locally overturned, and as a consequence each limestone layer is repeated at least three times in the quarries making up the Roche Harbor limestone deposit. Although three large quarries, and several small ones, have been developed, the limestone reserves are of considerable magnitude.

The Roche Harbor limestone deposit is relatively free from intrusions of igneous materials and these have in no way injured the quality of the stone. The fact that Bazalgette Point is composed of igneous rocks derived from the late Jurassic intrusions, would indicate that its close proximity to the limestone deposits has been brought about by faulting, for otherwise the limestones would surely have shown the effect of the intrusions. The only igneous material which actually cuts the limestone deposits is some greatly altered sill-like andesitic material. These igneous rocks are possibly a part of the Eagle Cliff porphyrites, and their intrusion apparently occurred prior to the period of major faulting.

The limestones, which are typically coarse to medium-grained and bluish-gray in color, are completely recrystallized. Their purity and uniformity of composition throughout the deposit is remarkable, and it is easily practical for the company to guarantee a content of calcium carbonate in their product exceeding 98 per cent. The percentage of magnesium carbonate in all of the limestones of the Orcas group is very low, usually being less than one per cent. This is all the more remarkable considering the fact that the whole region has been repeatedly intruded by rocks containing high percentages of magnesium.

The following analyses[41] show clearly the remarkable purity of the Roche Harbor limestone:

[41] Landes, Henry, Cement Resources of Washington: *U. S. Geol. Survey Bull.* 285, p. 378, 1906.

	I	II	III
SiO_2	0.44	0.27	0.20
Al_2O_3 } Fe_2O_3 }	1.13	0.21	0.30
$MgCO_3$	....	0.46	1.02
$CaCO_3$	98.21	99.06	98.57
Total	99.78	100.00	100.09

I. Analyzed in 1888 by Moss Bay Hematite and Iron Company (Limited), Workington, England.

II. Analyzed in 1893 by Puget Sound Reduction Company, Everett, Wash.

III. Analyzed in 1902 by C. F. McKenna, New York City.

Small limestone deposits may be traced southward and southeastward from Roche Harbor intermittently for several miles. These lenses do not belong to a definite horizon. The fact that the cherts on Mount Dallas Range contain small lenses of limestone scattered throughout the whole area, would tend to make any correlation of the lenses in the Orcas cherts very doubtful.

In 1923 the Orcas Lime Company, which for several years operated a limestone quarry on Orcas Island, opened up a quarry about half a mile south of that operated by the Roche Harbor Lime and Cement Company. The quarry is located on the peninsula between Westcott Bay and Mosquito Pass. A lime-kiln of the bottle type has been installed and a wharf has been constructed on the shore of Mosquito Pass. The limestone is conveyed from the quarry to the kiln by gasoline-propelled cars. As yet but little development work has been done in the quarry and the size and quality of the deposit has not been proved.

Small scattered lenses or fragments of lenses of limestone occur at Mitchell Bay and along the shore to the southward.

On the west shore of San Juan Island near the foot of Mount Dallas Range, in section 23, T 35 N, R 4 W, there is a large limestone quarry belonging to Henry Cowell & Company. The deposit was known to the earliest settlers and has been quarried for a number of years. The early settlers regarded this deposit as a much larger one than that occurring at Roche Harbor.

Unlike the Roche Harbor deposits it has been silicified to a considerable extent by intrusions of the Eagle Cliff porphyrites. The igneous dikes have added little except silica in the form of flint, to the limestones. The flinty limestones so produced, when mixed with the enclosing country rock and burned, makes a good quality of Portland cement. The unsilicified portions are burned in kilns constructed of Sucia Island sandstone and lined with fire bricks. The quarry is located about two hundred feet above the kilns, and the rock is delivered by means of cable cars using the gravity system.

The remaining limestone deposits are not being worked at the present time. The majority of them are too small to be worth quarrying, while others have been quarried to the point where they are no longer profitable.

A large number of small limestone lenses occur on Mount Dallas Range. In many cases the individual lenses do not exceed fifteen feet in length and

two feet in thickness. An examination of the enclosing chert strata often shows that no faulting has taken place to truncate the limestone layers. Occasionally it is possible to follow the courses of the chert strata from one lens to another and demonstrate that no faulting has taken place between them, and also demonstrate that the lenses do not belong to the same horizon.

Two deserted limestone quarries occur on San Juan Island; one at Limestone Point in section 18, T 36 N, R 3 W, and the other in section 34, T 36 N, R 3 W. A considerable tonnage of limestone still occurs at each of these locations.

Several thin strata of limestone occur in the Haro formation on the narrow arm which connects Davidson Head with the remainder of the island. These limestone beds are too small to be of any commercial value.

ORCAS ISLAND

Although several large deposits of limestone occur on Orcas Island, none of them are being worked at the present time. Probably the largest undeveloped limestone ledge occurring on Orcas Island is found in section 2, T 36 N, R 2 W, and is commonly known as the McGraw-Kittinger limestone ledge. It is of scientific interest because it was formed largely by the Carboniferous coral *Lithostrotion.* The chert beds which contain the limestone strata trend in a northeast and southwest direction and dip towards the southeast. The thickness of the limestone ledge varies from 25 to 40 feet, and it is exposed along the cliff for a distance of about 200 feet.

Across East Sound and apparently in line with the strike of the McGraw-Kittinger ledge, there is a deposit of limestone owned by the Tacoma Smelter. A considerable tonnage of limestone has already been quarried from this deposit but it has not been worked in recent years. This limestone layer outcrops at the shore of East Sound and rises almost vertically from the water's edge to a height of about 50 feet. It then bends abruptly so as to trend approximately N 40° E, and dips towards the southeast. It has been intruded by basic andesite which has since been converted into serpentine schist. The thickness of the limestone layer varies from 20 to 40 feet, and it may be traced, with an occasional small off-set, for a distance of about 300 feet.

Still farther to the northeast there are several small lenses which occur intermittently in the same general strike line. At a distance of about one and one-half miles to the northeast of the Tacoma Smelter deposit, there are three limestone lenses which vary from 15 to 30 feet in thickness. Several attempts have been made to develop these lenses but none of them have proved successful.

Along the shore of East Sound between the villages of Rosario and Olga there are several limestone lenses. One of these deposits (Plate XV-B), is so located that it might be developed with a profit even though its maximum thickness is only 20 feet. This deposit would permit only a limited amount of development for it dips towards the eastward into the precipitous side of Entrance Mountain. A considerable tonnage of limestone could be removed, however, without any danger of falling rocks.

Near the head of East Sound there are several deserted lime kilns with little or no limestone nearby. In one or two cases the kilns were never used, for the builders were not familiar with the typical pocket-like nature of the limestone lenses occurring in the cherts of the Orcas group, and had not previously tested out their deposit. In one instance, after the lime kiln had been completed, the whole limestone lens was blown out by one charge of powder.

The small limestone lenses occurring along the shore of East Sound to the south of Lookout Mountain, are cut by numerous igneous intrusions. None of these lenses are of any commercial importance.

Along the shore of West Sound, to the northeast of Sheep Island, there is a small though persistent limestone layer which trends northeasterly and dips towards the southeast. This stratum can be followed intermittently for several hundred yards. Another small limestone layer outcrops along the shore of West Sound to the southwest of Double Island. A very small lense of limestone outcrops on the east shore of Deer Harbor, about three-quarters of a mile north of Pole Pass.

At the southwest side of Orcas Knob, in section 31, T 37 N, R 2 W, there is a deposit of limestone of good quality belonging to J. Soderberg. This deposit was quarried to some extent several years ago, but unfortunately the limestone layer dips into the mountain face which rises vertically for several hundred feet.

Farther southward, in the same section, the quarries that were formerly operated by the Orcas Lime Company are apparently located on the same limestone layer. Although a considerable tonnage of limestone of good quality yet remains in the quarries, they had to be abandoned because of the height of the overhanging cliffs into which the limestone layer dips. The Orcas Lime Company operated two quarries in this locality, and a fairly modern lime burning plant is still located on the property. The limestone layer trends northeasterly parallel to the shore, and dips steeply towards the southeast into the face of the precipitous slopes which form the shore line.

About a mile to the southwest of the quarries belonging to the Orcas Lime Company, there is another deserted quarry which was formerly operated by the Imperial Lime Company. This quarry is apparently located on the same limestone layer that occurs along the shore to the northeastward. The limestone has been largely removed from this quarry, and the abandoned lime burning plant is now in a dilapidated condition. The limestone occurring in the quarry of the Imperial Lime Company has been intruded by igneous rocks.

Scattered lenses of limestone occur on Orcas Knob and along the shore to the northward, but these are all very small.

Along the northeast shore of Orcas Island, from Point Lawrence to the foot of Buck Mountain, there are scattered though persistent layers of limestone which occur in the rocks belonging to the Leech River group. At one time these *Fusulina*-bearing limestones were quarried and burned at a locality in section 22, T, 37 N, R 1 W. The quarry was deserted partly because of

the fact that the limestone was inferior in quality, and partly because of the cost of quarrying the beds which dip southward into the precipitous hill-sides.

SHAW ISLAND

Several small limestone lenses occur along the southwest shore of Shaw Island, and small scattered limestone deposits occur in association with the Orcas cherts in the west central part of the island. None of these deposits have any commercial importance.

CLIFF ISLAND

A limestone layer with a thickness of 15 to 25 feet follows along the northwestern shore of Cliff Island. The limestone layer trends northeasterly and dips towards the southeast. It is associated with cherty rocks belonging to the Orcas group, but these have been intruded by dikes and sills of the Eagle Cliff porphyrite. About one-half of Cliff Island is composed of reddish colored ellipsoidal Eagle Cliff porphyrite. The limestone bed was quarried to some extent several years ago, but on account of the small tonnage present in the deposit it was abandoned.

CRANE ISLAND

At the southern margin of Crane Island, and almost directly in line with the strike of the bed occurring on Cliff Island, there is a small isolated lens of limestone. The margins of this limestone bed were burned to quicklime by the intrusions of ellipsoidal Eagle Cliff porphyrite, and although they have since been changed back into limestone, they still retain the cracked appearance peculiar to lumps of quicklime. This deposit is too small to be of any commercial importance.

JONES ISLAND

A persistent limestone layer outcrops along the east shore of Jones Island, and trends northwesterly as far as the head of the large harbor which opens toward the northward. From this point the same or a similar bed of limestone trends westerly and outcrops along the west shore of the island. The maximum thickness of this layer of limestone is about 15 feet. It is associated with the Orcas cherts, but in many places it is bounded both above and below by igneous rocks. The limestone has been injured considerably by the intrusion of igneous rocks.

O'NEAL ISLAND

The southern end of O'Neal Island is crossed by a limestone layer which trends northeasterly. It has a maximum thickness of about 15 feet and a length of about 100 feet, and it is consequently too small to have any commercial value. In places it pinches down to a few inches in thickness.

HENRY ISLAND

On Henry Island, on the west side of Roche Harbor, there is a deserted limestone quarry and lime kiln belonging to the Roche Harbor Lime and Ce-

ment Company. A considerable amount of limestone still remains in this quarry. About midway along the west side of Henry Island there is a small isolated deposit of limestone which outcrops along the shore. Several small limestone lenses outcrop near the shores of Nelson Bay and also along the shores of the smaller bay to the northward.

CLAY AND CEMENT MATERIALS

The cement materials other than limestone occurring on the San Juan Islands are practically limited to the clays which are Pleistocene in age and glacial in origin.

The unmetamorphosed sediments of the Nanaimo series do not yield any materials suitable for the manufacture of cement. It is possible that some of the slates and argillites of the Leech River group could be used in the cement industry.

Due to the low percentage of magnesia in the limestones of the Orcas group they are well suited for the manufacture of cement. Many of the smaller limestone deposits have been silicified by igneous intrusions and they are consequently of no value for the manufacture of quicklime. This silicification, however, has not injured the limestones for the manufacture of Portland cement.

ORCAS ISLAND

On the Kimple estate, in section 21, T 37 N, R 2 W, there is a large deposit of glacial clay of good quality. A small brick manufacturing plant has recently been established in this locality, and a wharf or landing is being constructed at Kimple Bay.

The clay is uniform and quite plastic, and on burning it turns to a light buff color. The bricks are light in weight and they hold their shape well. Their surfaces are smooth and pleasing in appearance. The future outlook for this newly established industry is very bright.

A small deposit of plastic clay is located in the lowland to the north of East Sound.

In section 21, T 37 N, R 1 W, there is a deposit of clay and a brick-yard was at one time located there. The clay is light yellowish-gray in color and it possesses a good plasticity. Its chemical composition is as follows:[42]

SiO_2	59.92%
Al_2O_3	21.08%
Fe_2O_3	4.56%
CaO	3.88%
MgO	2.90%
K_2O	1.16%
Na_2O	0.97%
Loss on ignition	4.74%
	99.21%

A. A. Hammer, Analyst.

[42] Shedd, Solon, Cement Materials and Industry in the State of Washington: *Wash. Geol. Survey, Bull.* 4, p. 206, 1913.

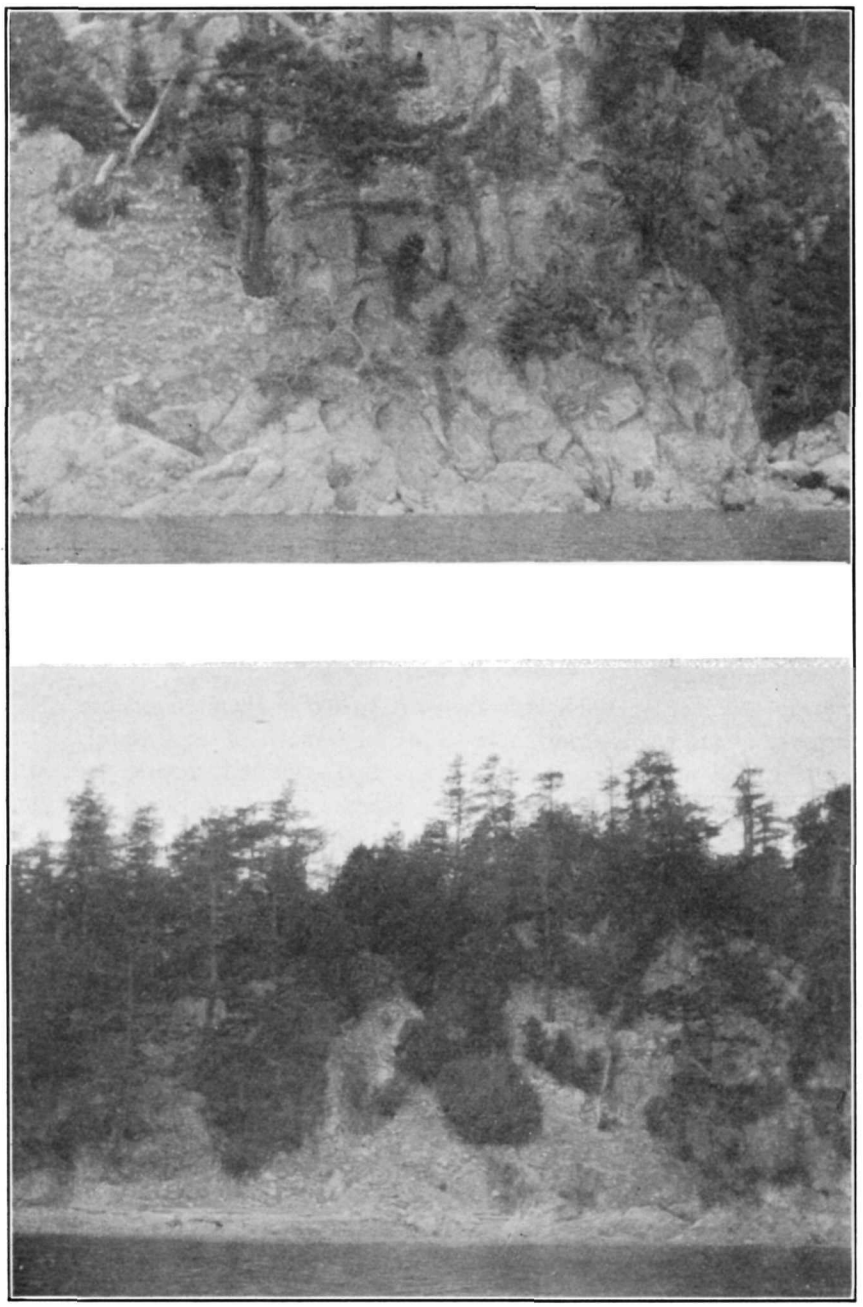


PLATE XXII

Above: Feldspar rock deposit at Deer Harbor, Orcas Island. *Below*: Feldspar rock deposit at Deer Harbor, Orcas Island.

SAN JUAN ISLAND

A deposit of plastic glacial clay occurs at the head of Westcott Bay, almost adjoining the lime works of the Roche Harbor Lime and Cement Company. Small scattered clay beds occur throughout the San Juan Valley.

LOPEZ ISLAND

A large part ot the north end of Lopez Island is covered with glacial sediments which include a layer of clay from 15 to 30 feet thick. This clay is not very plastic for in places it grades off into sandy clays.

GUEMES ISLAND

Probably the largest deposits of plastic clay in the map-area are located on Guemes Island. A well defined layer of lay with a maximum thickness of 30 feet covers the greater part of the island. A large part of this clay is plastic but nothing is known about its burning qualities.

GRAVEL

Near the village of Friday Harbor, in section 13, T 35 N, R 3 W, there is a large deposit of coarse sand and gravel. The material extends from Friday Harbor to Griffin Bay and constitutes what is known as Bald Hill. It was deposited by the last retreating glacier, being temporarily a part of the terminal moraine.

During the year of 1924, bunkers were constructed on the shore of Friday Harbor so that barges are now able to load by gravity. Salt water is pumped up to the gravel pit to be used for washing down and sorting the sand and gravel. Bald Hill contains an enormous amount of coarse sand and gravel.

FELDSPAR

On the west shore of Deer Harbor in section 7, T 36 N, R 2 W, there is a large deposit of feldspar rock belonging to A. D. Tift. Farther westward the same material occurs as a network intermingled with other types of intrusions which make up the injection breccia of the Turtleback complex. Smaller intrusions of white feldspar and quartz occur on the west shore of West Sound, in section 8, T 36 N, R 2 W. They are also found on Turtleback Range.

At the time of its discovery the Deer Harbor feldspar rock deposit was mistaken for limestone. When it was found that it would not make quicklime, the owners sent away samples of the rock for examination and determination. The samples were incorrectly determined as a silica-bearing rock suitable for the manufacture of glass. Several attempts were made to utilize this material in the glass industry. Trial lots were tested on a small scale at Anacortes, and again at Everett, Washington. None of the enterprises met with success though it was not fully realized that the rock was unsuited for the manufacture of glass.

During the summer of 1922, the writer obtained samples of the feldspar

rock, known locally as the glass rock, and discovered that it was composed largely of soda-bearing feldspar. Burning tests conducted by the Ceramics Department of the University of Washington showed that it fused at Seger cone No. 8½ and produced a pure white glassy glaze. It therefore met with the burning requirements of the desired grade of feldspar, and subsequent tests showed that it produced excellent results as an ingredient in the manufacture of the finest grade of porcelain.

The Deer Harbor feldspar rock is composed almost entirely of feldspar and quartz. The bulk of the feldspar is soda orthoclase together with lesser amounts of albite and orthoclase. An occasional small flake of muscovite is the chief accessory mineral. Exceedingly small quantities of magnetite, zircon, tourmaline, titanite, and apatite are sometimes found in the rock. The chief secondary minerals are kaolinite and sericite.

Along the west shore of Deer Harbor there are four injected masses of the feldspar rock which outcrop along a cliff about 75 feet high. They were intruded as pegmatites into the injection breccia which makes up the Turtleback complex. Some of the dikes trend in a northeast and southwest direction and dip towards the northwest at an angle of about 40 degrees. The usual occurrence of the feldspar rock is in the form of irregular masses.

The largest and most northern body of feldspar rock is stained with ferric oxide derived from the alteration of biotite. It is a coarse-grained pegmatite with individual crystals of quartz and feldspar measuring about half an inch in diameter. The thickness of this deposit as it outcrops along the shore is about 60 feet.

The remaining three deposits outcropping along the shore of Deer Harbor are pure white in color. The most southern of these occurs in the form of a dike which is about 25 feet thick at the water's edge, but is not exposed at the top of the cliff. This is the smallest of the four deposits, but the quality of the rock is excellent.

Between these two deposits there are two other large ones of high quality. The latter are very irregular in shape and they blend with each other in places. They may be followed inland with certainty for about 300 feet from the edge of the cliff, but their size diminishes rapidly. The larger of these deposits averages about 45 feet in thickness, and the smaller one is about 35 feet thick. Where the two deposits are fused together they measure more than 300 feet along the face of the cliff. In places they are intermingled with irregular masses of lamprophyric material.

The mineral composition of the deposits of feldspar rock is not constant even within a single deposit. Some portions are relatively high in quartz, others show the eutectic mixture of quartz and feldspar in the formation of a graphic intergrowth of these two minerals, still others are composed largely of feldspar in excess of the eutectic ratio.

Although the feldspar rock is usually medium to fine-grained, it is distinctly pegmatitic in character. It does not show the granular or sugary texture typical of an aplite. The feldspars have suffered considerably from kao-

linization so that the multiple twinning of the albite is partly concealed. For this reason it is difficult to determine the original percentages of albite and soda orthoclase.

The average chemical composition of the Deer Harbor feldspar rock is as follows:

SiO_2	75.26%
Al_2O_3	15.26%
FeO	0.94%
CaO	0.37%
MgO	1.00%
Na_2O	6.61%
K_2O	1.33%
Ignition	0.39%
	101.06%

(Analysis made in 1924 by Carl Woods of the United States Bureau of Mines, Seattle, Wash.)

The feldspar rock fuses at Seger cone No. 8½ or about 1300° C., and it burns to a pure white color. It has been thoroughly tested by the Ceramics Department of the University of Washington, and it proves to be excellent as an ingredient in the manufacture of high grade porcelain.

The Deer Harbor feldspar deposit is situated in an ideal location for transportation, for the shore slopes abruptly to a depth of about 40 feet below sea-level, and barges could be loaded with the minimum of expense.

COAL

Considerable prospecting for coal has been done in the rocks of the Nanaimo series. Several years ago the Northwest Construction Company of Seattle put down a two-inch diamond drill hole on Waldron Island. The hole is located on the property of Ethan Allan, near the shore of Mail Bay. The location selected for the drilling was very unfortunate, for the greater part of the rock-section was already well exposed along the shore. The writer was not able to locate the log of the well, which was nearly 1500 feet deep, but it is said that small amounts of coal were encountered at three different horizons. The greater part of the core of the well is still located on the property of Ethan Allan.

The lignitic leaf-bearing shales occurring on Orcas Island to the south of Point Doughty have been prospected for coal seams, but nothing larger than pockets have been found.

In 1924 a portion of Sucia Island was taken out as a coal claim by Henry Parrott of Seattle. The stratigraphic section on the Sucia Islands is similar to that occurring in the coal measures at Nanaimo, British Columbia, and the erosional valleys with the bed rock concealed by mantle materials are consequently worth investigating.

The Leech River sediments occurring along the northeast side of Orcas Island have been prospected to some extent for coal. A number of small seams of semianthracite have been discovered but no deposits of commercial importance have been opened up as yet. No coal from this source has ever

been shipped but the local blacksmiths have used it in their forges. These deposits of coal are of Pennsylvanian age.

CHROMITE

The dunite dikes of the Fidalgo formation occurring on Cypress Island contain variable amounts of chromite. Sometimes the schlieren-like masses of chromite are sufficiently large to make their exploitation profitable. The deposits are scattered throughout the whole island, but the largest pockets of chromite discovered up to the present time have been located well up on the slopes of Cypress Dome.

In 1922 the Cypress Island chromite deposits were examined by Pardee, whose report[43] is freely quoted in this description.

The total production of chromite to date is 200 tons, most of which contained between 45 and 50 per cent of chromic oxide. The known deposits still contain several thousand tons of material averaging between 10 and 25 per cent of chromic oxide.

The largest ore body is located on the Ready Cash claim on the steep western slope of Cypress Dome. The claim is located about 1100 feet above sea-level, and about three-quarters of a mile from the shore. It was developed by an open cut 10 feet wide, 15 feet long, and six feet deep, from which about 25 tons of ore were mined. In 1918 the Cypress Chrome Company extended this mine and extracted 50 tons of chromite. Ore from the Ready Cash claim consists of coarse granular chromite intergrown with the rose-red chrome chlorite, kotschubeite, a chromium-bearing limonite, and a light green chromium-bearing variety of hornblende.

On the shore of Cypress Lake there are two claims that have been prospected for chromite. Ore taken from the Last Chance claim at the south end of the lake carried about 25 per cent of chromium oxide.

Numerous other deposits of chromite occur on the island but their size is small. The chromite occurs in association with the dunite dikes and in no instance was there any notable concentration of chromite in the original stock-like intrusions. No concentrations of chromite were found on the other islands composed of the Fidalgo formation.

BUILDING STONE

Some of the Cretaceous sandstones occurring in the Nanaimo series are suitable for building purposes. Rocks of this kind occur on Sucia Island, Matia Islands, Waldron Island, and to a certain extent on Stuart and Johns islands.

On Sucia Island the coarse to medium-grained buff-colored sandstone occurring on the north side of Fossil Bay could be utilized for building purposes. At one time a quarry was operated on this sandstone formation and the rock was used in Seattle for paving-blocks. The sandstone proved to be too soft for such a purpose and the quarry was consequently abandoned. A

[43] Pardee, J. T., Chromite Ores in Washington: *U. S. Geol. Survey, Bull.* 725, pp. 61-65, 1922.

certain amount of this sandstone is suitable for the manufacture of grindstones. All of the rock in this formation is easy to extract because it has two good partings at right angles to each other.

A considerable amount of sandstone has been quarried on Waldron Island and shaped into small rectangular blocks. A large amount of this material has been used in the construction of the jetties at the mouth of the Columbia River. The quarries are located on the east side of Point Disney.

Sandstone has been quarried at Reid Harbor on Stuart Island. In general the sandstones occurring on Stuart Island and Johns Island are not as easily accessible as those on Sucia Island.

Some of the graywackes and indurated sandstones of the Haro formation occurring to the south of Davidson Head might be used for building purposes.

The graywackes occurring in the sediments of the Leech River group at Humphreys Head on Lopez Island have been quarried to some extent.

The igneous rocks occurring on the San Juan Islands are not suitable for building purposes.

WATER RESOURCES

The chief supplies of fresh water occurring in the San Juan Island map-area are found in the large and elevated lakes on Orcas, Blakeley, and San Juan Islands.

On Orcas Island, Mountain Lake with an elevation of 915 feet, and Cascade Lake with an elevation of 350 feet, are capable of supplying a moderately large quantity of water at all seasons of the year. Buck Lake, Killebrews Lake, and the Twin Lakes also contain a considerable volume of water. The large bogs occurring on Mount Constitution Range and in other localities in the map-area are capable of retaining a remarkably large volume of water. The water derived from the relatively heavy precipitation which falls on Mount Constitution Range is naturally conserved so efficiently that numerous streams issue from all sides of the range at all seasons of the year. Orcas Island is abundantly supplied with water.

On Blakeley Island, Thatcher Lake with an elevation of 188 feet, and Blakeley Lake with an elevation of 374 feet, are capable of supplying a considerable volume of water.

San Juan Island has three lakes of moderate size, Sportsmans Lake, Trout Lake, and Egg Lake. The water resources of San Juan Island are somewhat limited excepting in the northern portion where the rocks of the Orcas group are encountered. The underground water supply is found especially in the fractured cherts of the Orcas group, and artesian wells have resulted on Shaw Island in some instances when the overlying Leech River sediments were penetrated.

Lopez Lake, with an elevation of 91 feet, is the only body of surface water occurring on Lopez Island. Water can be readily obtained, however,

by penetrating certain impervious strata in the glacial sediments which cover the greater part of the island.

Several small lakes occur on Cypress Island but their combined volume of water is very small.

The smaller islands of the San Juan group are occasionally so lacking in fresh water that a species of prickly cactus may be found growing on them. It is very remarkable, however, that some of the small, bare, rocky islands which are isolated from the others by exceedingly deep channels, have an abundance of freshwater at a depth of 40 or 50 feet below the surface.

AREAS OF THE SAN JUAN ISLANDS

San Juan County	Acres
Orcas	36,431.91
San Juan	35,448.14
Lopez	18,847.21
Shaw	4,936.89
Blakeley	4,435.75
Waldron	2,936.08
Decatur	2,294.20
Stuart	1,786.45
Henry	1,023.05
Sucia group	749.00
Spieden	480.45
Patos group	244.50
Crane	221.66
Obstruction	216.20
Johns	214.55
Jones	200.18
Center	178.25
Matia group	170.11
James	113.65
Satellite	106.15
Frost	69.95
Brown	59.70
Long	58.05
Clark	55.05
Canoe	49.58
Flattop	49.30
Pearl	38.60
Barnes	36.10
Turn	35.15
Charles	32.40
McConnell	31.68
Cactus group	31.40
Trump	29.40
Double	25.94
Skipjack	19.28
Reef	17.25
Cliff	15.61
Sentinel	14.65
Colville	11.48
Yellow	10.27
Willow	9.64
Castle	9.33
Dinner	9.10

San Juan County—Cont'd.	Acres
Ram group	8.80
Sisters group	8.27
Armitage	7.35
Peapod Rocks	6.90
Boulder	6.90
Doe	6.43
Flower	4.60
O'Neal	4.50
Goose	4.25
Hall	3.90
Bird Rocks	3.75
Bell	3.67
Iceberg	3.50
Deadman	3.50
Aleck Rocks	3.25
Ripple	3.25
Fortress	3.21
Battleship	3.20
Victim	3.00
Fisherman	2.75
Skull	2.70
Coon	2.70
Blind	2.25
Sheep	2.00
Barnacle Rock	2.00
Gossip group	1.75
White Rocks	1.45
Barren	1.37
Richardson Rock	1.35
Gull Rock	1.30
Buck	1.25
Indian	1.25
Twin Rocks	1.14
Posey	1.03
Knob	0.80
Whale Rocks	0.75
Low	0.75
Bare	0.70
Guss	0.60
Sear Rock	0.60
Freeman	0.35
Pointer	0.25

Total Acres 111,876.61

WHATCOM COUNTY	Acres	WHATCOM COUNTY—Cont'd.	Acres
Lummi	5,249.12	Lummi Rocks	3.00
Portage	923.25	Viti Rocks	2.75
Eliza	170.00	Eliza Rock	0.40
Total Acres			6,348.52

SKAGIT COUNTY	Acres	SKAGIT COUNTY—Cont'd.	Acres
Cypress	5,501.95	Jack	20.00
Guemes	5,094.95	Huckleberry	11.74
Sinclair	1,054.10	Strawberry	10.50
Samish	931.10	Young	6.76
Burrows	473.70	Cone group	6.50
Allan	287.55	Dot	2.50
Vendovi	218.98	Towhead	2.15
Hat	91.85	Williamson Rocks	1.20
Saddlebag	20.60		
Total Acres			13,736.13

	Acres	Square Miles
San Juan County	111,876.61	174.81
Whatcom County	6,348.52	9.92
Skagit County	13,736.13	21.46
Total	131.961.26	206.19

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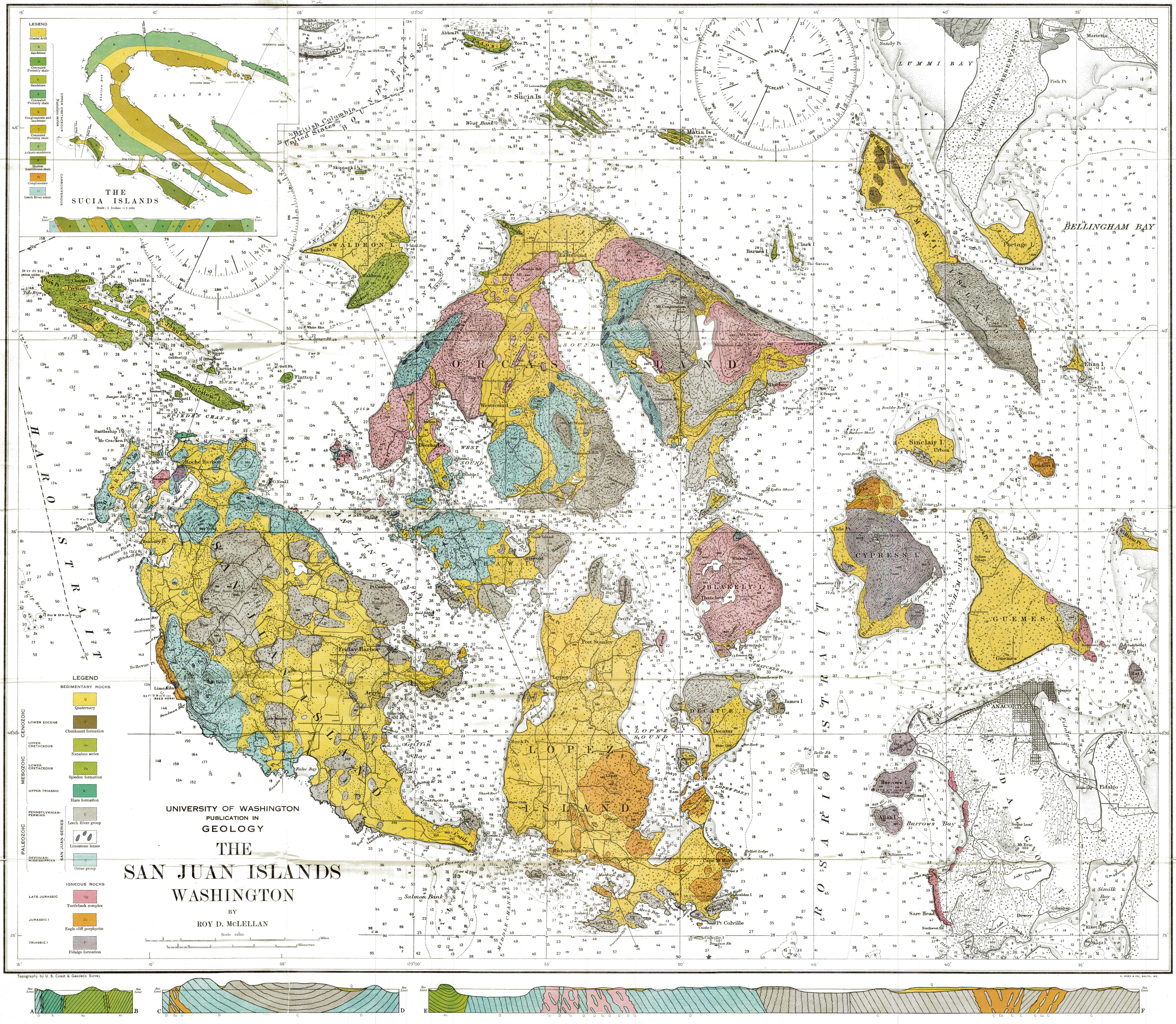
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