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GEOLOGY AND MINERAL DEPOSITS OF SOUTHEASTERN ALASKA

BY

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AND

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CONTENTS

ILLUSTRATIONS

GEOLOGY AND MINERAL DEPOSITS OF SOUTHEASTERN ALASKA

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INTRODUCTION

SCOPE OF REPORT

The object of the present report is to give a summary of all available data on the general geology of southeastern Alaska. The report is accompanied by a reconnaissance geologic map of the southern and eastern part of southeastern Alaska, which is the only part of that area so far covered in sufficient detail to warrant the publication of such a map. This report is not and can not be a comprehensive treatise on the geology and mineral deposits of this extensive area of Alaska, as the information now available is utterly inadequate for such a treatise.

Practically all the geologic work so far carried on in southeastern Alaska has been of a reconnaissance nature, and because of the small number of workers, the great area to be covered, and the dense undergrowth which clothes the mountains up to timber line and practically buries the bedrock except along very steep slopes, this reconnaissance has been confined chiefly to the coast. The strip along the coast has been mapped geologically by making landings at intervals averaging about half a mile. On the mainland certainly not more than 10 per cent of the Coast Range batholith in southeastern Alaska and the adjoining territory of British Columbia can be said to have been sampled in even the roughest reconnaissance fashion; that is, by the study of one hand specimen and one thin section for each 16 square miles of intrusive rock. About 125 batholiths and stocks are shown on the map, and there are many more stocks and sheets too small to be shown; yet only four of these have been studied in more than a superficial manner, many are known only by one or two thin sections, and many have not been studied at all.

A few areas in southeastern Alaska have been mapped in detail. These include the Kasaan Peninsula, 86 square miles, and the Copper Mountain region, 45 square miles, on Prince of Wales Island; 200 square miles in the Eagle River region; 50 square miles in the Berners Bay region; 103 square miles in the Juneau area, of which 35 miles was subsequently resurveyed on an even more detailed scale; and 130 square miles in the Hyder district.

The strip of southeastern Alaska north of Cross Sound and the geology of Chichagof and Baranof Islands are referred to only briefly in this report.

A section containing many details concerning the intrusive rocks of the Coast Range is included because of their possible bearing on the origin and distribution of mineral deposits.

NATURE OF THE FIELD WORK

The field work done by both authors was conducted from a motor boat of sufficient size to serve for living quarters. The outcrops available for examination consisted of the wave-eroded rock beach, which is more or less continuous around the coast except at the heads of bays and inlets, where the rocks are usually concealed, and the ridges above timber line that were more or less free from moss covering. The examination of the rocks along the shore line was made from a rowboat fitted with an outboard motor. In some places it was possible to traverse the shore on foot for some distance, in other places this was impracticable, and in yet other places it was impossible even to land except in favorable weather.

The United States Coast and Geodetic Survey charts were used as a base for the geology. Actual examination of the geologic formations was confined almost exclusively to the coast line, though in the Ketchikan district Chapin made a few trips inland.

In the years 1915 to 1917, in a total of 9½ months' field work, Chapin completed an areal geologic map of the Ketchikan district south of latitude 55° 40′ and an investigation of its mineral deposits. His map and completed report on this area, though unpublished, were available to Buddington when he began work in southeastern Alaska. In the years 1921 to 1925 Buddington spent a total of 13 months in reconnaissance areal geologic mapping of the coast of the northern half of the Ketchikan district, the Wrangell and Petersburg districts, and the southern half of the Juneau district. In addition, he investigated mineral deposits at numerous places throughout southeastern Alaska, mapped the west coast of Dall, Suemez, and Baker Islands, and covered in considerable detail the northern part of the Hyder district.

RESPONSIBILITY OF AUTHORSHIP

In 1918 Chapin resigned from the United States Geological Survey, and it devolved upon Buddington to write the present report, which includes the results of his own work and most of the general geology of Chapin's report. It has therefore been difficult to accredit responsibility for the statements and descriptions in the chapter on stratigraphy and yet maintain a coherent account for the reader. The stratigraphy that had been worked out by Chapin in the southern part of the Ketchikan district before Buddington entered the field has been found applicable, in the main, to the region farther north and has only been amplified and slightly modified by Buddington. Wherever possible, appropriate sections have been taken bodily from Chapin's report and credited to him. Where Chapin is cited as authority for certain statements or descriptions, without any specific reference, the source is Chapin's original report. Except where material in this report is credited to Chapin or others, Buddington is responsible for the statements or descriptions. But it will be readily understood that Buddington's views must necessarily have been influenced to a considerable extent by Chapin's work, and that he is thus indebted to Chapin even where the obligation is not specifically acknowledged. There has been no opportunity for conferences between Chapin and Buddington on the report here presented.

ACKNOWLEDGMENTS

In addition to his use of Chapin's material, the writer had access to the following unpublished reports and maps: The geology and mineral resources of the area east of Behm Canal, by Lewis G. Westgate; A geologic reconnaissance of the Glacier and Lituya Bay regions, by F. E. and C. W. Wright; A geologic map of Glacier Bay, by J. B. Mertie, jr.; and Geology of the vicinity of Juneau, by A. C. Spencer and H. M. Eakin. Specific acknowledgment of matter obtained from these reports is made at the appropriate places in the text. The writer has consulted also the many reports and articles by other geologists who have written upon different areas and mineral prospects or mines in southeastern Alaska and is indebted to them for much pertinent material.

Both authors are indebted to Mr. A. H. Brooks for the benefit of his broad knowledge of the geology of Alaska. In 1916 Mr. Brooks was in the field with Chapin for a conference and field examination of critical localities, and in 1924 he accompanied Buddington for three weeks in an investigation of mineral deposits in the Juneau and Sitka districts. The authors are indebted also to Messrs. W. H. Dall, Edwin Kirk, G. H. Girty, Arthur Hollick, T. W. Stanton, J. B. Reeside, jr., and Rudolf Ruedemann for determination of fossils.

Mr. Walter Waters, of Wrangell, served very ably and satisfactorily as navigator for both Chapin and Buddington through seven field seasons. In the field the authors were the recipients of favors

from many operators and prospectors, whose assistance they gratefully acknowledge. Buddington is indebted to those who served as his assistants—Messrs. Ben Larson, of Ketchikan, in 1921, George A. Wiggan in 1922 and part of 1923, Chauncey Deming in 1923, and Willard B. Jewell in 1924 and 1925, all of whom rendered consistently efficient service in furthering the work.

Buddington had the use of 2,500 thin sections of rocks collected from southeastern Alaska by F. E. and C. W. Wright, and rough volumetric mineral analyses were made on about 50 of these rocks by the Rosiwal method for this report. Particularly valuable was a collection of sections made from specimens obtained by F. E. Wright across the Coast Range batholith along Stikine River.

EARLIER EXPLORATIONS AND SURVEYS

By Theodore Chapin

The geographic features of the coast of southeastern Alaska first became known to the civilized world through the explorations of the English navigators Cook and Vancouver and the Spaniards Pérez, Quadra, and Arteaga. Capt. James Cook with his assistants made extensive and accurate surveys of this coast in 1778, and after his death George Vancouver, one of his midshipmen, continued the survey of the coast of southeastern Alaska in 1793 and 1794. The accuracy of Vancouver's work is attested by the fact that some of his charts made over a hundred years ago have hardly been changed by the recent surveys made under modern conditions and improved methods.

The influence of the Spaniards is suggested by the large proportion of Spanish names retained in southeastern Alaska. The first of the Spanish explorers was Pérez, who, in an expedition sent out from Mexico, discovered Queen Charlotte Islands in 1774. Bodega y Quadra explored the coast in 1775, and again in 1779 with Arteaga he made explorations on the west coast of Prince of Wales Island. Since the transfer of Alaska to the United States the Coast and Geodetic Survey has been engaged yearly in surveying the coast line and publishing sailing charts and navigation aids.

Casual observations on the geology of southeastern Alaska appear in the writings of some of the travelers who visited the region during the Russian occupation. The most valuable of the early papers is one by Dr. Constantin Grewingk, a Russian, who, although he never visited Alaska, published in 1850 a paper[1] which contains many geographic and some geologic data concerning southeastern Alaska,

[1] Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nord-west-Küste Amerikas mit den anliegenden Inseln: Russ. k. mineral. Gessel. St. Petersburg Verh., 1848–49, 76–342, 1850.

based largely on collections and data obtained by a Russian naval officer.

The first knowledge of the geology of southeastern Alaska published in English was obtained from a report made by William P. Blake,[2] who in 1863 accompanied a Russian expedition sent to Stikine River to establish the boundary between Russian and English possessions.

In 1891 Reid[3] described Muir Glacier in Glacier Bay, and Cushing[4] made a geologic map of the vicinity. The Juneau gold belt was briefly described by Garside.[5]

Among the geologic investigations touching southeastern Alaska were those conducted by George M. Dawson,[6] of the Geological Survey of Canada; C. Willard Hayes,[7] William H. Dall,[8] George F. Becker,[9] and Alfred H. Brooks,[10] of the United States Geological Survey; B. K. Emerson[11] and Charles Palache,[12] of the Harriman Alaska Expedition; and others, all of whom contributed valuable information regarding the broader geologic features, the glaciers, and the coal, mineralogy, and ore deposits.

A brief discussion of the Ketchikan district by Brewer[13] was published in 1901.

In 1901 Brooks[14] made a reconnaissance of the Ketchikan district and outlined the main structural and stratigraphic features of southeastern Alaska. The correlations suggested and conclusions drawn in this hasty reconnaissance of 60 days, made primarily to describe the ore deposits, have proved substantially correct and have been but slightly amended as the result of later, more detailed geologic work.

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[2] Blake, W. P., Notes upon the geography and geology of Russian America and the Stikeen River: 40th Cong., 2d sess., H. Ex. Doc. 177, pt. 2, 1868.

[3] Reid, H. F., Studies of Muir Glacier, Alaska: Nat. Geog. Mag., vol. 4, pp. 21–55, 1892.

[4] Cushing, H. P., Notes on the geology of the vicinity of Muir Glacier: Idem, pp. 56–74.

[5] Garside, G. W., The mineral resources of southeast Alaska: Am. Inst. Min. Eng. Trans., vol. 20, pp. 815–823, 1893.

[6] Dawson, G. M., Report on an exploration in the Yukon district and adjacent northern portion of British Columbia: Canada Geol. Survey Ann. Rept., new ser., vol. 3, pt. 1, pp. 1–277 B, 1888; Geological record of the Rocky Mountain region in Canada: Geol. Soc. America Bull., vol. 12, pp. 57–92, 1901.

[7] Hayes, C. W., An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, pp. 99–162, 1892.

[8] Dall, W. H., Coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 763–908, 1896.

[9] Becker, G. F., Gold fields of southern Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 1–86, 1898.

[10] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 374–376, 1900.

[11] Emerson, B. K., Notes on the stratigraphy of igneous rocks: Alaska, vol. 4, pp. 11–66, Harriman Alaska Expedition, 1904.

[12] Palache, Charles, Notes on the minerals collected: Idem, pp. 92–96.

[13] Brewer, W. T., The Ketchikan mining district: Eng. and Min. Jour., vol. 72, pp. 630–632, 1901.

[14] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, 1902.

In 1903 A. C. Spencer,[15] assisted by C. W. Wright, made a study of the ore deposits in the vicinity of Juneau, and Wright[16] made a reconnaissance of Admiralty Island and studied the placer deposits on Porcupine Creek.

In 1904 and 1905 F. E. and C. W. Wright[17] made geologic investigations, including in their two seasons of work a reconnaissance of the Ketchikan and Wrangell mining districts, structural studies of the Coast Range, stratigraphic investigations on Admiralty, Kuiu, Kupreanof, and Baranof Islands, and studies of the principal mining districts of southeastern Alaska.

In 1906 a geologic reconnaissance survey was carried northwestward from Lynn Canal to Lituya Bay by F. E. and C. W. Wright,[18] and C. W. Wright[19] made further economic and stratigraphic studies.

In 1907 C. W. Wright[20] and Sidney Paige began the detailed geologic mapping and study of the ore deposits of Kasaan Peninsula and Copper Mountain, on Prince of Wales Island.

In 1908 C. W. Wright[21] continued his annual reconnaissance of the mining camps of southeastern Alaska and completed his study of Kasaan Peninsula and Copper Mountain, the report on which is a valuable contribution to our knowledge of the occurrence of the ore deposits of the Ketchikan district, especially the character of the contact deposits.

In 1906 and 1908 some investigations of mineral deposits were carried out in the Sitka district, and in 1909 Adolph Knopf[22] made a reconnaissance survey. In 1909 Knopf[23] made a geologic survey of the Berners Bay district, and in 1909 and 1910 he completed the detailed geologic mapping of the Eagle River region.

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[15] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, 1906.

[16] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, pp. 138–154, 1906; The Porcupine placer district: U. S. Geol. Survey Bull. 236, 1904.

[17] Wright, F. E. and C. W., Economic developments in southeastern Alaska: U. S. Geol. Survey Bull. 259, pp. 47–68, 1905; Lode mining in southeastern Alaska: U. S. Geol. Survey Bull. 284, pp. 30–54, 1906; The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 1908. Wright, C. W., Nonmetallic deposits of southeastern Alaska: U. S. Geol. Survey Bull. 284, pp. 55–57, 1906.

[18] Wright, F. E. and C. W., A geologic reconnaissance of the Glacier and Lituya Bay regions (unpublished manuscript).

[19] Wright, C. W., Lode mining in southeastern Alaska: U. S. Geol. Survey Bull. 314, pp. 47–72, 1907; Nonmetalliferous mineral resources of southeastern Alaska: Idem, pp. 73–81.

[20] Wright, C. W., Lode mining in southeastern Alaska, 1907: U. S. Geol. Survey Bull. 345, pp. 78–97, 1908. Wright, C. W., and Paige, Sidney, Copper deposits of Kasaan Peninsula, Prince of Wales Island: Idem, pp. 98–115.

[21] Wright, C. W., Mining in southeastern Alaska: U. S. Geol. Survey Bull. 379, pp. 67–86, 1909; Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, 1915.

[22] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, 1912.

[23] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 1911; The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 1912.

In 1909 and 1910 Knopf,[24] incidental to other geologic work in southeastern Alaska, made brief visits to the operating mines in the Ketchikan district.

In 1912, after a lapse of one year, geologic work was resumed in the Ketchikan district by E. F. Burchard, who made a study of the marble deposits of the Ketchikan and Wrangell districts [25] and in the following year extended his studies to the Juneau, Skagway, and Sitka districts.[26] A complete report on the marble resources of southeastern Alaska was published in 1920.[27]

In 1913 stratigraphic studies of the Ketchikan district were carried on by Philip S. Smith.

In 1915 and 1916 Chapin continued the stratigraphic studies, and in 1917 he spent five weeks in a reconnaissance of mineral deposits in this district. The result of this work was Chapin's report and map of the Ketchikan district south of latitude 55° 40′, previously mentioned.

In 1915 Gerald A. Waring [28] studied the mineral springs and hot springs of Alaska, and his report included a chapter on those of southeastern Alaska.

In 1917 R. M. Overbeck [29] prepared a geologic map and report on the west coast of Chichagof Island and Peril Strait.

In 1920 L. G. Westgate studied the geology of the coast along Behm Canal in the Ketchikan district and the geology and mineral deposits of the east side of Salmon River in the Hyder district.

In 1916 and 1921 A. C. Spencer and H. M. Eakin made a detailed study of the area in the vicinity of Juneau.

The reports by Westgate, Spencer, and Eakin have not yet been published.

In 1919 J. B. Mertie, jr.,[29a] carried on a reconnaissance of the geology and mineral resources of the Glacier Bay and Lynn Canal regions and visited all the producing mines in the Juneau and Ketchikan districts.

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[24] Knopf, Adolph, Mining in southeastern Alaska: U. S. Geol. Survey Bull. 442, pp. 139–143, 1910; Mining in southeastern Alaska: U. S. Geol. Survey Bull. 480, pp. 98–102, 1911.

[25] Burchard, E. F., Marble resources of the Ketchikan and Wrangell districts: U. S. Geol. Survey Bull. 542, pp. 52–77, 1913.

[26] Burchard, E. F., Marble resources of the Juneau, Skagway, and Sitka districts: U. S. Geol. Survey Bull. 592, pp. 95–107, 1914.

[27] Burchard, E. F., Marble resources of southeastern Alaska: U. S. Geol. Survey Bull. 682, 1920.

[28] Waring, G. A., Mineral springs of Alaska: U. S. Geol. Survey Water-Supply Paper 418, pp. 19–49, 1917.

[29] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 91–136, 1919.

[29a] Mertie, J. B., jr., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, pp. 105–128, 1920; Notes on the Salmon-Unuk River region: Idem, pp. 129–142.

During the field seasons of 1921 to 1925 Buddington was engaged in a reconnaissance survey somewhat more detailed than the older surveys along the coast of the northern Ketchikan, Wrangell, Petersburg, and southern Juneau districts, together with a reconnaissance of mineral deposits at numerous places throughout southeastern Alaska.

In addition to the reports already cited, special reports on individual mineral prospects and mining developments in southeastern Alaska are contained in the following yearly reports on the mineral resources of Alaska, by A. H. Brooks and others, published as bulletins of the United States Geological Survey: 1912, Bulletin 542, pages 31–34; 1913, Bulletin 592, pages 75–117; 1914, Bulletin 622, pages 95–102; 1915, Bulletin 642, pages 53, 73–104; 1916, Bulletin 662, pages 66–100; 1917, Bulletin 692, pages 85–89; 1918, Bulletin 712, pages 27–30, 53–90; 1919, Bulletin 714, pages 15–19, 69, 70, 76, 105–142; 1920, Bulletin 722, pages 34–38; 1921, Bulletin 739, pages 20–22, 51–75; 1922, Bulletin 755, pages 23–25; 1923, Bulletin 773, pages 10–12, 71–139; 1924, Bulletin 783, pages 41–62; 1926, Bulletin 797, pages 8–11.

NOTES ON HISTORY OF MINING DEVELOPMENT

Most of the data for the following brief notes on the history of mining development in Alaska are taken from Government reports on the several districts.

The Russians were aware of the occurrence of gold in Alaska while they owned the Territory, prior to 1867, but they did no mining. The first mineral location in southeastern Alaska is reported [30] to have been made in 1867 on a copper deposit near New Kasaan, on Prince of Wales Island, by Charles Vincent Baranovich, a Russian trader.

In 1869 Mix Sylva and other disappointed miners from the Cassiar gold district, on the Canadian side of the international boundary, traveled northward from Fort Wrangell and discovered placer deposits at Windham Bay and on Powers Creek at Holkham Bay.[31] It is reported that $40,000 was extracted from these placers in 1870–71 and that this represents the first considerable quantity of gold produced from Alaska. The first attempts at lode mining in Alaska under the American régime were made in the vicinity of Sitka in

[30] Ulmer, Joseph, Mining in the Ketchikan district: Min. and Sci. Press, vol. 121, p. 493, 1920.

[31] Wright, C. W., in Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 2, 1906.

1871.[32] By 1880 many auriferous ledges had been discovered in the district around Silver Bay, but they have been little worked to the present time, and none have been put on a productive basis. In 1880 placer gravel was found near the mouth of Gold Creek, Gastineau Channel, and auriferous quartz veins were found on what is now the property of the Alaska-Juneau Co. by Joe Juneau and Richard Harris, who had been sent out from Sitka by N. A. Fuller on the strength of a favorable report by John Muir relating to the mainland of southeastern Alaska. The first official record of the Treadwell property is dated 1881, and most of the properties in the Juneau district which proved of value were discovered between 1881 and 1885.

The beach gold placers east of Lituya Bay were found and worked in the early nineties.

One of the first recorded events in the development of the gold lode mining industry of the Ketchikan district is the discovery by James Bowden of gold-bearing rock on Annette Island in 1892. In 1897 and 1898 came the discovery of the Gold Standard lode, on Helm Bay; the deposits near Dolomi; the Sea Level lode, on Thorne Arm, Revillagigedo Island; and the mineralized area back of Hollis on Twelvemile Arm, Prince of Wales Island.

From 1896 to 1906 intensive prospecting was carried on throughout southeastern Alaska, and many of the copper, gold, and marble properties which have proved valuable were discovered. Placer gold was first discovered in the Porcupine area of the Skagway district in 1898; the total output from this area up to and including 1916 is estimated at about $1,200,000. During 1900 and 1901 considerable work was done on gold deposits on Woewodski Island, in the Wrangell district. The gold lodes on which the Chichagoff mine, in the Sitka district, is still operating were found in 1905. In 1920 gold veins were discovered on Lisianski Inlet, Chichagof Island, from which the first gold was produced in 1924 by the Apex-El Nido Co.

Between 1897 and 1901 many copper and gold properties were located in the Ketchikan district. Between 1899 and 1905 the mineralized belt east of Wrangell was discovered, systematic mining was carried on, and smelting of copper was begun. Copper ore was produced in the Ketchikan district first in 1905, to the amount of 30,400 tons, with an average value of $10.79 a ton. The average quantity of copper obtained from the ore was about 3 per cent. In 1906 there were 10 producing copper mines in the Ketchikan district; in 1924 there were only 2. The total production from 1905 to 1920 is given below.

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[32] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, p. 8, 1912.

Production of copper mines in the Ketchikan district, 1905–1920

	Quantity	Value
Mixed ore............tons..	550,787	....
Copper............pounds..	33,102,689	$6,107,202.00
Gold............ounces..	26,896.6	566,802.00
Silver............do....	242,677	159,000.00
Average value of ore per ton............	....	12.41

The first nickel-copper deposits were found in 1911 on an island off the west coast of Chichagof Island. In 1921 and 1922 other nickel-copper lodes were located on Yakobi Island, also on the west coast of Baranof Island and on Funter Bay, Admiralty Island. No ore has yet been shipped.

Metal-bearing lodes, chiefly of gold and silver, were found at the head of Portland Canal in British Columbia in 1898, and similar discoveries were made on the Alaskan side between 1898 and 1901. They received little attention until 1909, when a small boom was started on the Canadian side. This boom subsided in a few years, but interest was again revived in 1917 by the discovery of rich silver ores on the Canadian side. In 1918 large bodies of rich silver ore were found at the Premier mine. In 1923 gold-silver-lead ores were discovered on the West Fork of Texas Creek in the Hyder district, and in 1925 the Riverside mine, in the Salmon River Valley north of Hyder, produced gold-silver-lead ore.

A little marble was quarried in the early nineties on Ham Island, in the Wrangell district, and worked up into tombstones, which were sold at near-by localities. Marble tombstones were in considerable demand by the natives, who substituted them for the crudely carved wooden totems. The first shipments of marble from Alaska were made in 1902 from quarries opened at Calder, on Prince of Wales Island, and since 1904 there has been a steady increase in the output, practically all of which has come from a few quarries in the vicinity of Shakan, on Prince of Wales Island.

Gypsum has been produced since 1906 from the deposit on Chichagof Island.

GEOGRAPHY

LOCATION AND EXTENT

Southeastern Alaska, which is often called the panhandle, extends southeastward from Mount St. Elias on the north to Dixon Entrance on the south and is bordered on the south, east, and north by British Columbia. This coastal belt, with its contiguous islands, has an area of nearly 40,000 square miles and is included between parallels 54° 30′ and 60° 30′ and meridians 130° and 141°. It forms a strip 400 miles long and 100 to 150 miles wide, with a narrow extension northwest of Mount Fairweather 100 miles long and 25 to 50 miles wide. More than one-third of the land surface of southeastern Alaska is comprised in the 1,100 islands of the Alexander Archipelago. The seaward islands, Chichagof, Baranof, and Kruzof, together with a few smaller ones, have a total area of about 4,500 square miles. Prince of Wales Island is the largest island, with an area of 2,800 square miles. The other large islands are Admiralty, about 1,500 square miles; Revillagigedo, 1,120 square miles; Kupreanof, 1,080 square miles; and Kuiu, 750 square miles. There are many smaller islands, such as Dall, 275 square miles; Etolin, 330 square miles; Mitkof, 200 square miles; Zarembo, 180 square miles; Kosciusko, 160 square miles; Annette, 133 square miles; and Gravina, 102 square miles.

The territory under consideration (see pl. 1) is covered by the charts of the United States Coast and Geodetic Survey listed below, each of which is published on a scale of 1:200,000, except Nos. 8152 and 8002, which are on smaller scales. No. 8002 covers all of southeastern Alaska. Large-scale charts of most of the harbors and channels can also be obtained.

8200. Frederick Sound and Sumner Strait.
8300. Lynn Canal and Stephens Passage.
8102. Hecate Strait to Etolin Island.
8152. Dixon Entrance to Chatham Strait.
8250. Chatham Strait and Baranof Island.
8002. Dixon Entrance to Cape St. Elias.

There are two national monuments in southeastern Alaska. The Sitka National Monument comprises about 57 acres of great natural beauty and historic interest. The Glacier Bay National Monument comprises some 1,820 square miles and includes a number of tidewater glaciers of the first rank in a setting of magnificent snowcapped mountain ranges.

POPULATION AND SETTLEMENTS

The population of southeastern Alaska is mostly concentrated in the mining and fishing centers. About 160 of the small islands are now being utilized for fox ranches, and permanent caretakers live on them.

Skagway is the northernmost town and is the terminus of the White Pass Railway. Juneau is the capital of the Territory, the distributing center for the north end of the panhandle region, and the location of the Alaska-Juneau Mining Co. Douglas is opposite Juneau, across the Gastineau Channel, and near it was the plant of the Treadwell Mining Co. Sitka, on the west coast of Baranof Island, was the first capital of Alaska and contains many points of historic interest and valuable relics of the Russian occupation. The agricultural experiment station is here, and the town is the general supply point for the adjacent region. Wrangell and Petersburg are the supply centers for the central part of the region, and Wrangell is the outfitting station for expeditions up Stikine River. Ketchikan is the distributing point for the southern part of the region; it is the first port of entry in southeastern Alaska. The population of the principal towns, as given in the 1920 census, is as follows: Juneau, 3,058; Ketchikan, 2,458; Sitka, 1,175; Wrangell, 821; Petersburg, 879; Skagway, 494.

There are several small native villages, including Klawak and Hydaburg, on Prince of Wales Island, and Kake, on Kupreanof Island. Craig is a small village on the west coast of Prince of Wales Island. There are also scores of small settlements at or near canneries or mines, to which regular mail service is maintained and where boat supplies, fuel, food, and clothing can be purchased.

TRANSPORTATION

Regular service is maintained by coastwise steamers all the year round from Seattle and Vancouver to Skagway, Juneau, Sitka, Wrangell, Petersburg, and Ketchikan. Freight rates are reasonable, and costs compare favorably with those at Seattle. In the summer season tourist boats leave Prince Rupert for the major ports of southeastern Alaska.

Boats run regularly from Ketchikan carrying mail, passengers, and freight to settlements on the west coast of Prince of Wales Island. Similar service is maintained from Juneau to Fanshaw Bay, Windham Bay, Sumdum, Snettisham, and Taku; from Petersburg to Kake; from Juneau to Auke Bay, Tee Harbor, Eagle Landing, Comet, and Skagway; and from Juneau to Tenakee, Gypsum, Hooniah, Chichagof, Cape Edward, and Sitka.

Four rivers of considerable size—the Alsek, Chilkat, Taku, and Stikine—have their sources in the interior plateau and reach the sea after traversing the Coast Range. During the open season regular sailings are maintained on Stikine River by high-powered river boats between Wrangell and Telegraph Creek, British Columbia, at the head of navigation, a distance of about 170 miles. Chickamin and Unuk Rivers can be ascended with difficulty in small boats to points well within the heart of the Coast Range.

Transportation facilities on land are poorly developed. The rugged nature of the land, with its many swampy areas and luxuriant growth of vegetation, and the numerous deep fiords and channels that cut into or separate the islands, preclude the extensive construction of railroads or even of wagon roads, except at unwarranted expense. The need of railroad construction is in large part obviated, however, by the intricate system of waterways which penetrates the entire region, providing excellent highways for deep-sea vessels and numerous deep-water harbors in sheltered bays.

CLIMATE

The climate of southeastern Alaska is characterized by moderate temperature the year round, including mild winters and cool summers, and by heavy precipitation, except at the head of Lynn Canal and in an area bordering Frederick Sound, including the north end of Kupreanof Island and the southwest end of Admiralty Island. The ports are open to navigation the year round. Near sea level the first frosts occur in September or October and the last in May or June. The average length of the growing season is about 180 days. The snowfall is slight except on the mountains and the inland areas. Near sea level, except at the heads of the mainland fiords, even in winter, the precipitation is mostly in the form of rain, which is heaviest in the fall and winter. The heavy precipitation, although it is disagreeable and occasions considerable inconvenience in travel and prospecting, is a very valuable asset in providing water power.

The prevailing winds at most places are from the south and southeast. At Sitka the winds are prevalently from the east, and in the vicinity of Calder and Kake they may in some years be prevalently from the west. A change from a southeast to a north wind almost invariably brings fair weather. During the winter fierce land winds often blow down the fiords and at their height interrupt the normal passage of coastwise traffic.

Tables presenting the average monthly and annual precipitation and the average annual mean temperature at stations in southeastern Alaska and an adjacent part of British Columbia are given below. The averages for Alaska have been computed from data given in publications of the Weather Bureau, United States Department of Agriculture, for 1923 and earlier years. The data for Stewart, British Columbia, are taken from records by the Dominion Meteorological Service.[33]

Except at the head of Lynn Canal, near Skagway and Klukwan, the minimum temperature is rarely below zero and very rarely below −7°. On the average zero readings occur less than twice a year at Juneau and less than once a year at Sitka. The maximum recorded temperature is 99°. The winter temperature commonly ranges from 10° to 20° above zero and the summer temperature from 70° to 80°.

[33] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, p. 7, 1922.

The total snowfall at Skagway averages about 3½ feet; at Juneau, 9 feet; at Sitka, a little over 4 feet; and at Stewart, British Columbia, a little over 18 feet.

The number of rainy days averages about 200, except at the head of Lynn Canal, where it is less than 100. With few exceptions the rains are gentle, mostly in the form of drizzle or mist.

Average monthly precipitation, in inches, at stations in southeastern Alaska and at Stewart, British Columbia

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Length of record (years)
Annex Creek, near Juneau	8.9	8.0	5.41	5.14	4.3	3.0	5.2	12.0	12.94	15.81	11.78	9.52	99.62	7
Calder	9.97	8.02	7.92	9.12	6.11	3.69	4.48	7.05	12.63	16.03	15.9	-------	-------	16
Fortmann Hatchery	11.54	11.24	11.36	12.12	8.25	5.72	6.83	8.98	14.64	22.44	21.13	16.79	147.4	19
Kake	4.37	4.02	2.62	1.73	2.97	1.80	2.00	4.69	5.49	5.47	4.59	5.72	49.65	5
Ketchikan	12.90	11.44	12.11	12.84	7.84	5.71	8.07	14.35	13.20	21.52	22.96	15.62	159.9	12
Killisnoo	4.93	4.17	4.02	3.02	2.64	2.00	3.36	4.14	6.57	7.46	5.69	5.11	53.34	29
Juneau	6.88	5.27	5.10	5.28	5.14	3.76	5.06	7.38	10.68	10.31	8.31	7.46	80.6	29
Sitka	7.36	6.13	5.25	3.57	4.00	3.30	4.00	7.12	9.98	11.94	9.20	8.78	80.82	56
Skagway	1.53	1.35	1.11	1.36	.67	.89	1.26	1.86	3.63	4.38	4.16	2.36	24.68	16
Speel River	10.48	10.55	10.34	8.45	5.79	4.51	5.23	14.31	20.99	20.94	20.35	11.46	143.33	7
Wrangell	7.65	6.94	3.94	5.04	3.33	3.04	3.38	4.63	10.02	9.17	13.22	8.33	78.69	8
Stewart	7.23	5.87	4.59	3.69	2.07	1.99	3.24	7.88	7.72	11.35	8.42	9.68	73.73	11

Average monthly and annual mean temperatures, in degrees Fahrenheit, at stations in southeastern Alaska and at Stewart, British Columbia

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Length of record (years)
Annex Creek, near Juneau	-------	-------	29.7	40.2	45.5	53.7	55.3	53.7	49.0	40.8	32.8	23.9	-------	7
Calder	27.7	31.3	34.2	39.0	45.0	50.0	52.8	53.4	49.4	42.4	35.6	-------	-------	16
Fortmann Hatchery	25.4	30.2	34.5	40.4	47.3	54.1	58.1	58.1	52.3	44.8	37.3	31.3	42.8	19
Juneau	26.9	29.8	33.4	40.8	47.9	54.2	57.3	55.1	50.1	43.1	35.1	30.9	42	29
Sitka	31.8	34.1	36.5	42.8	46.9	51.4	54.8	55.6	51.8	45.9	38.4	35.3	43.8	56
Skagway	19.1	24.6	28.0	39.9	48.8	55.6	58.4	55.7	49.7	41.1	31.8	25.4	39.8	16
Wrangell	27.1	30.6	31.6	42.4	47.9	55.1	58.3	57.2	52.0	44.7	37.3	30.3	42.9	11
Stewart	19.3	25.9	30.5	39.2	48.2	54.4	57.4	55.8	50.0	41.9	31.7	26.0	40.0	11

VEGETATION AND TIMBER SUPPLY

By Theodore Chapin

Most of southeastern Alaska lies within the Tongass National Forest, formerly known as the Alexander Archipelago National Forest. The hillsides, where not too steep, from sea level up for many hundred feet are covered with a luxuriant vegetation, which is so dense that it effectively conceals the underlying rocks, tends to confine prospecting to the stream courses, and renders detailed geologic mapping slow and expensive. Up to an altitude that may reach about 2,500 feet but is dependent upon local conditions, the lowlands and slopes are forested with a heavy growth of timber. Among the conifers of the forests are species of hemlock, spruce, cedar, pine, and balsam fir. An estimate of their relative abundance furnished by W. G. Weigle, former forest supervisor of Alaska, is given in the following table:

	Per cent
Western hemlock (*Tsuga heterophylla*)	60
Black hemlock (*Tsuga mertensiana*)	
Sitka spruce (*Picea sitchensis*)	25
Western red cedar (*Thuya plicata*)	7
Yellow cedar (*Chamaecyparis nootkatensis*)	5
Lodgepole pine (jack pine) (*Pinus contorta*)	3
White balsam (*Abies lasiocarpa*)	

As seen from this table hemlock is the most abundant, and of the two species noted the western hemlock is much more plentiful. The hemlock is less susceptible than spruce to the borings of the teredo worm, and for this reason and on account of its superior weight it has been in great demand for piling used in fish traps and wharf and dock construction, purposes for which it is well adapted, as it tapers but little in the length required for piles. It is now used extensively also for planking, for which use it is better adapted than fir, as it does not splinter so badly and lasts longer. A great amount of planking is used in wharf, road, and tram construction, as the streets of most towns in southeastern Alaska are built of planks placed upon piling. Hemlock makes a very satisfactory grade of newsprint paper, and the trees, which range from 18 inches to 3 feet in diameter, are said to be especially well adapted to this use.

For general purposes spruce has found the most universal use. It grows to fine proportions, reaching 225 feet in height and 4 feet in diameter 100 feet from the butt. It averages 2,500 board feet to the tree, and exceptional trees yield 20,000 feet. On account of its toughness and lightness the Sitka spruce is suitable for airplane construction and during the World War was used in England and France as well as in the United States.

The western red cedar is used for shingles and for boat timber. The yellow cedar also is used in boat construction and is suitable for furniture and pattern making but is not easily obtained, as there is but little of it found below an altitude of 500 feet above sea level.

Among other trees common to this region may be noted mountain ash, cottonwood, quaking aspen, crab apple, and varieties of willow and alder. From sea level to a height of 1,500 feet or so the forests have a dense undergrowth of berry bushes and other shrubs which in places form an impassable barrier except where trails are cut. The most objectionable of these shrubs is the devil's club, a luxuriant bush whose stalks and stems are thickly covered with sharp, fine thorns. Salmonberry is the most abundant and forms impenetrable thickets. Huckleberries are plentiful; they include two varieties with blue berries and one with red. There are also high-bush cranberries and black currants.

The best timber is found on the well-drained areas, which are confined to the steep hillsides and the vicinity of the large streams. It is not likely that in the near future much timber will be cut for export, but there is an ample supply suitable for mine timber and other local requirements. There is, moreover, a great quantity of poorer-grade timber suitable for paper pulp, and it is believed that this region, with its abundant water power and large deposits of high-grade limestone, will become a pulp and paper producing region.

AGRICULTURAL LAND

Owing to the mountainous character of the topography, few of the flat or gently sloping tracts well adapted to agriculture are large. All the indented arms of the sea, however, are being gradually filled with material brought down by rivers. Except for some low-lying flat islands and low valleys on the larger islands these deposits constitute practically the only large areas of level land in the region. A number of homesteads have been taken up on the deltas of the mainland, and there is opportunity for many more. The largest available tract is that of the Stikine River delta, which is 1 to 3 miles wide and extends upstream for 20 miles or so. This tract contains between 12,000 and 15,000 acres of land apparently suited for diversified agriculture. North of the mouth of Stikine River, on the old, slightly uplifted delta of Patterson River, there is an additional 2,000 acres or more. There is also a considerable acreage available on the islands and mainland at the mouth of Glacier Bay. These areas are suitable for growing berries and vegetables.

WATER POWER

The heavy precipitation insures an abundance of water, and the deep lakes in many of the troughlike valleys form natural reservoirs whose capacity could readily be increased. Many of the streams have an abrupt descent at or near the coast line, thus affording many fine water-power sites. The abundance of water power, the cheap water transportation, and the proximity of forests suitable for pulp wood afford opportunity for the present and future development of pulp and paper mills. One such mill is already in operation on the north arm of Port Snettisham, and others are contemplated.

Investigations by the Geological Survey and the Forest Service indicate a potential water power of more than 450,000 horsepower in southeastern Alaska. Only a small percentage of this is now utilized, but each year shows increased development of power for mining, milling, and other uses.

OUTLINE OF GEOLOGY

MAIN STRUCTURAL FEATURES

All of southeastern Alaska is a rugged mountainous region lying within the Pacific Mountain system, which, as defined by Brooks,[34] includes a broad zone of ranges forming a concave belt parallel to the southern coast of Alaska.

Farther southeast, in the vicinity of Vancouver Island, this system includes two prominent ranges—the Coast Range of the mainland and the Vancouver Range of Vancouver Island—which, according to Clapp,[35] are separated by the submerged northern part of the Pacific coast downfold that extends from the Gulf of California through British Columbia and Alaska and includes Haro, Georgia, Johnstone, and Broughton Straits and Queen Charlotte Sound. Hecate Strait constitutes a further extension of this downfold and separates the Queen Charlotte Range of Graham Island from the mainland.

Within southeastern Alaska the dominating feature of the mainland is the Coast Range, a high mountain mass many peaks of which rise to altitudes of 6,000 to 8,000 feet. Brooks[36] describes it as follows:

> The Coast Range extends from near the boundary of Washington northward through British Columbia into southeastern Alaska, where it lies partly in Alaska and partly in Canadian territory. Following the coast line for nearly 900 miles, it passes inland behind the St. Elias Range near the head of Lynn Canal. Thence it can be traced northward, decreasing in altitude and gradually losing definition until it finally merges with the interior plateau near Lake Kluane, in longitude 138° 30′. This range has no well-defined crest line but is rather a complex of irregular mountain masses, occupying a coastal strip between the Pacific Ocean and the Central Plateau region.

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[34] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, p. 14, 1902.

[35] Clapp, C. H., Sooke and Duncan map areas, Vancouver Island: Canada Geol. Survey Mem. 96, pp. 23–24, 1917.

[36] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 28, 1906.

Chapin describes Clarence Strait, Revillagigedo Channel, Nichols Passage, and the lowlands bordering them as occupying the site of a down-warped trough. This trough extends northwestward beneath the Tertiary formations of Eagle, Zarembo, Kashevarof, Prince of Wales, Kupreanof, Kuiu, and Admiralty Islands. It is evidently one of the series of basins constituting the Pacific coast downfold. Tertiary formations are exposed at least locally in or on the borders of all the basins of the downfold that are not completely submerged.

The mountainous islands and peninsulas to the east of this Tertiary belt may, in the absence of more definite knowledge, be grouped with the Coast Range of the mainland.

To the west of the trough lies what is here named the Prince of Wales Range, dominated by a complex group of short, rugged mountains that reach an altitude of about 4,000 feet. This range includes Prince of Wales Island, all of Kuiu Island except the eastern part, and the island groups lying west of Prince of Wales Island, with the probable exception of Forrester Island. The Prince of Wales Range is composed almost wholly of Paleozoic formations with associated intrusive rocks of Upper Jurassic or Lower Cretaceous age.

The trough between the Coast Range and the Prince of Wales Range appears to be terminated by Chatham Strait. Chatham Strait and Lynn Canal, according to the Wrights,[37] constitute a great fiord eroded along a faulted zone. This fiord is 250 miles long, 3 to 6 miles broad, and 1,000 to 2,900 feet deep. It traverses the general trend of the mountain ranges and of the bedrock structure at an angle of about 30°.

To the north there is no satisfactory means for discriminating between the Coast Range on the one side and the mountain ranges of Admiralty and Chichagof Islands, the Glacier Bay region, and the peninsula west of Lynn Canal on the other.

Mount Fairweather and the associated mountains, which are part of the St. Elias Range, lie along the line of trend of the ranges of the Alexander Archipelago, but are much higher, 8,000 to 15,000 feet, and probably in part of later origin. Their youth is indicated by the fact that in the vicinity of Mount St. Elias Pleistocene beds have been uplifted on their flanks and folded and faulted.[38]

BEDROCK GEOLOGY

The predominant features of the bedrock geology of southeastern Alaska (pl. 2) comprise the composite Coast Range batholith of the mainland and the associated outlying intrusive bodies on the islands

[37] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 21–22, 1906.

[38] Russell, I. C., Second expedition to Mount St. Elias, in 1891: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 1–91, 1892. Maddren, A. G., Mineral deposits of the Yakataga district: U. S. Geol. Survey Bull. 592, p. 132, 1913.

of the Alexander Archipelago and in the Glacier Bay region; a metamorphic-complex belt that lies adjacent to the Coast Range batholith and consists of injection gneiss, crystalline schist, marble, phyllite, and highly schistose greenstone; three belts of Mesozoic formations—one through Juneau and Mitkof Island, one through Keku Straits and Gravina Island, and one through the west coast of Chichagof and Baranof Islands; a belt of Tertiary formations on Zarembo, Kupreanof, Kuiu, and Admiralty Islands, and another along the outside mainland coast northwest of Icy Point; and Paleozoic formations which form probably two-thirds of the country rock of the Alexander Archipelago and the Glacier Bay region. The metamorphic complex is in part of Carboniferous age but may include beds ranging from Ordovician to Upper Jurassic or Lower Cretaceous. Recent lava flows form Mount Edgecombe, on Kruzof Island, and are found in several small separated areas in the vicinity of Thorne Bay, on Revillagigedo Island, and the east side of Behm Canal and along the Lava Fork of Unuk River.

Paleozoic beds form practically all of the Prince of Wales Range, the northeastern part of Chichagof Island, and the area in the vicinity of Glacier Bay. These beds are of pre-Ordovician (?), Ordovician, Silurian, and Devonian age. A considerable part of Kupreanof and Zarembo Islands is composed of middle Paleozoic formations. Carboniferous formations are found within the Alexander Archipelago, in the Keku synclinorium on the northeast end of Kuiu Island and the northwest end of Kupreanof Island and on Admiralty Island. They are also exposed on the mainland along both borders of the Juneau synclinorium in the Juneau and Skagway districts and locally along the borders of the Gravina synclinorium in the Ketchikan district.

The Prince of Wales Range and the mountain ranges on the northeast end of Chichagof Island and in the Glacier Bay region are characterized by the predominance of middle and lower Paleozoic formations, in contrast to the Queen Charlotte Range of Graham Island, where only Mesozoic formations are reported to be present, and the Vancouver Range, where there are Mesozoic and upper Paleozoic formations. The only parts of the Pacific Mountain system south of Alaska which are known to be composed in considerable part of rocks as old as the middle Paleozoic are the San Juan Islands,[39] the Klamath Mountains of California and Oregon, and the northern part of the Sierra Nevada.[40]

Tertiary formations are found in and adjacent to the great trough between the Coast Range and the Prince of Wales Range. This

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[39] McLellan, R. D., The geology of the San Juan Islands: Washington Univ. Pub., vol. 2, pp. 91–99, 1927.

[40] Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (No. 138), p. 1, 1906.

trough must have originated in late Cretaceous or early Tertiary time, for its northwestward continuation forms the lowland area upon which lies the belt of Tertiary beds of Union Bay, on the Cleveland Peninsula, Eagle Island, the west side of Zarembo Island, the Kashevarof Islands, the northeast side of Prince of Wales Island, the west side of Kupreanof Island, the east half of Kuiu Island, and the southwest end of Admiralty Island. The Tertiary deposits of Kasaan Bay, Duncan Canal, and Ernest Sound indicate the sites of Tertiary erosion valleys which lead into the major trough.

PHYSIOGRAPHIC HISTORY

The mountain ranges of the Pacific system are commonly referred to as resulting from the deep dissection of an elevated plateau or uplifted and warped peneplain[41] of Tertiary age. In the southern part of the Coast Range[42] the upwarping of this peneplain is assumed to have taken place at the end of the Pliocene or in early Pleistocene time. The upwarping of the peneplain at the south end of the Vancouver Range is placed by Clapp[43] in the early Pliocene.

Wright[44] has offered an alternative explanation of the approximate uniformity of summit level within the Coast Range:

> It is possible that both the observed tendency toward planation in the uplands and also in the forelands noted above owe their present character to ice action. It is significant in this connection that the upper limit of ice action coincides with the upland base level. If the ice sheet remained long enough at approximately the same level its surface might well have functioned, like a large water surface, as a datum plane toward which the exposed masses tended to be beveled. Sufficient evidence has not yet been gathered to determine definitely the rôle which such ice-cap beveling may have played in the formation of the observed upland surface.

The Pleistocene ice cap was undoubtedly an important factor in the modeling of the present upland surface. The data, however, are inadequate for a satisfactory discussion of the relation of peneplains, of cycles of erosion, and of the former ice cap to the present physiography of the mountains.

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[41] Spencer, A. C., The Pacific Mountain system in Alaska: Geol. Soc. America Bull., vol. 14, pp. 117–132, 1903. Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 286–290, 293, 1906. Dawson, G. M., On the later physiographical geology of the Rocky Mountain region in Canada: Roy. Soc. Canada Trans., vol. 8, sec. 4, pp. 3–74, 1891. Clapp, C. H., Geology of the Victoria and Saanich map areas, Vancouver Island, B. C.: Canada Geol. Survey Mem. 36, p. 8, 1913. Hanson, George, Reconnaissance between Kitsault River and Skeena River, B. C.: Canada Geol. Survey Summary Rept. for 1922, pt. A, p. 38, 1923.

[42] Cairnes, C. E., Coquihalla area, B. C.: Canada Geol. Survey Mem. 139, p. 29, 1924.

[43] Clapp, C. H., Sooke and Duncan map areas, Vancouver Island: Canada Geol. Survey Mem. 96, p. 363, 1917.

[44] Wright, F. E., Excursions in northern British Columbia and Yukon Territory: Twelfth Internat. Geol. Cong. Guidebook 10, Prince Rupert-Skagway section, pp. 41–51, 1913.

Schofield and Hanson[45] state that in the Salmon River district, B. C., the Coast Range was worn down to a condition of peneplanation during the Cretaceous period and that the present valleys were eroded during the Tertiary period.

In the Ketchikan district Eocene sediments occur at and below sea level on Union Point, Cleveland Peninsula, and on Coal Bay, Prince of Wales Island. The pre-Eocene rocks in this general vicinity reach altitudes of 2,800 to 3,300 feet. There is no evidence of faulting between the formations, but there may have been some slight warping. It seems very probable, however, that the Eocene rocks were formed for the most part in a great downwarped basin but also in small part in deep valleys eroded in a mountain range. It therefore follows that an adolescent or mature topography had been developed, at least locally, within this region prior to the deposition of the Eocene sediments and volcanic rocks.

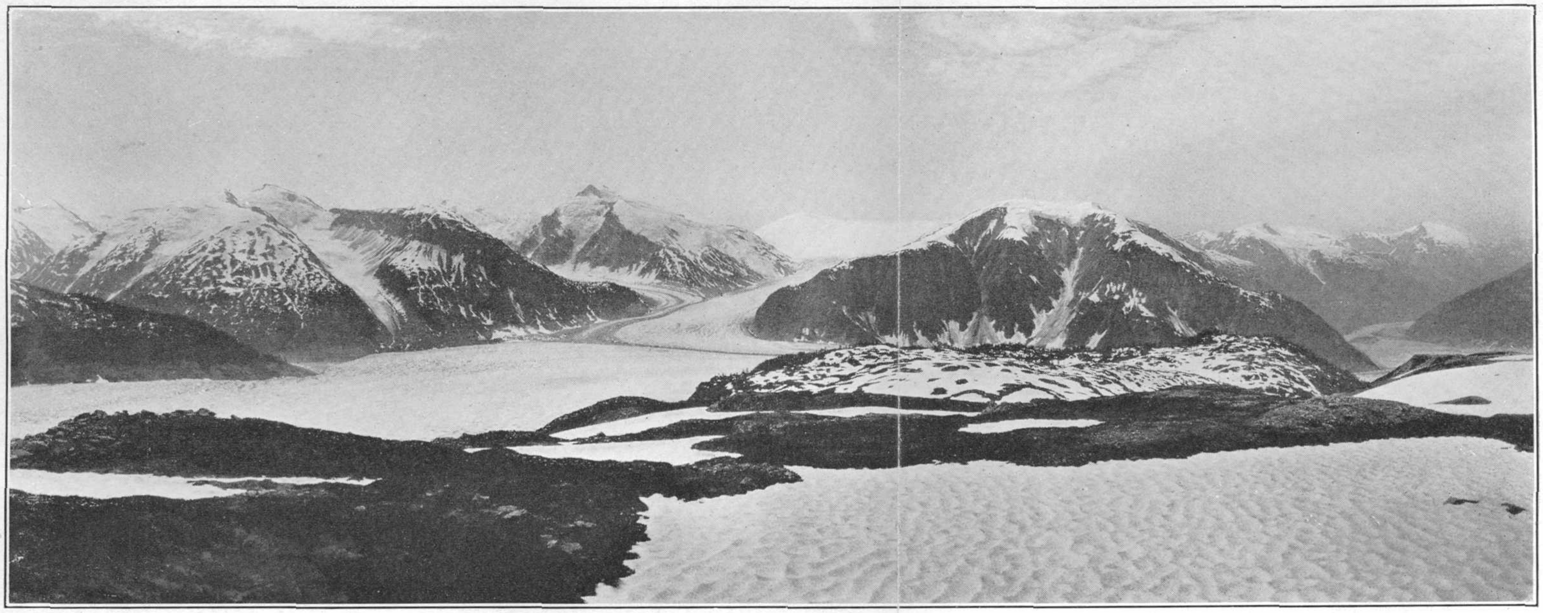
There is little evidence available from which to determine the date of the uplift of the Coast Range in southeastern Alaska. It must have been post-Eocene and may have been Pliocene or early Pleistocene, as seems to be indicated farther south in British Columbia. The uplift of the St. Elias Range certainly went on throughout the Pliocene and Pleistocene and has probably continued to the present time, as indicated by faulting on Yakutat Bay.

TOPOGRAPHY

GENERAL FEATURES

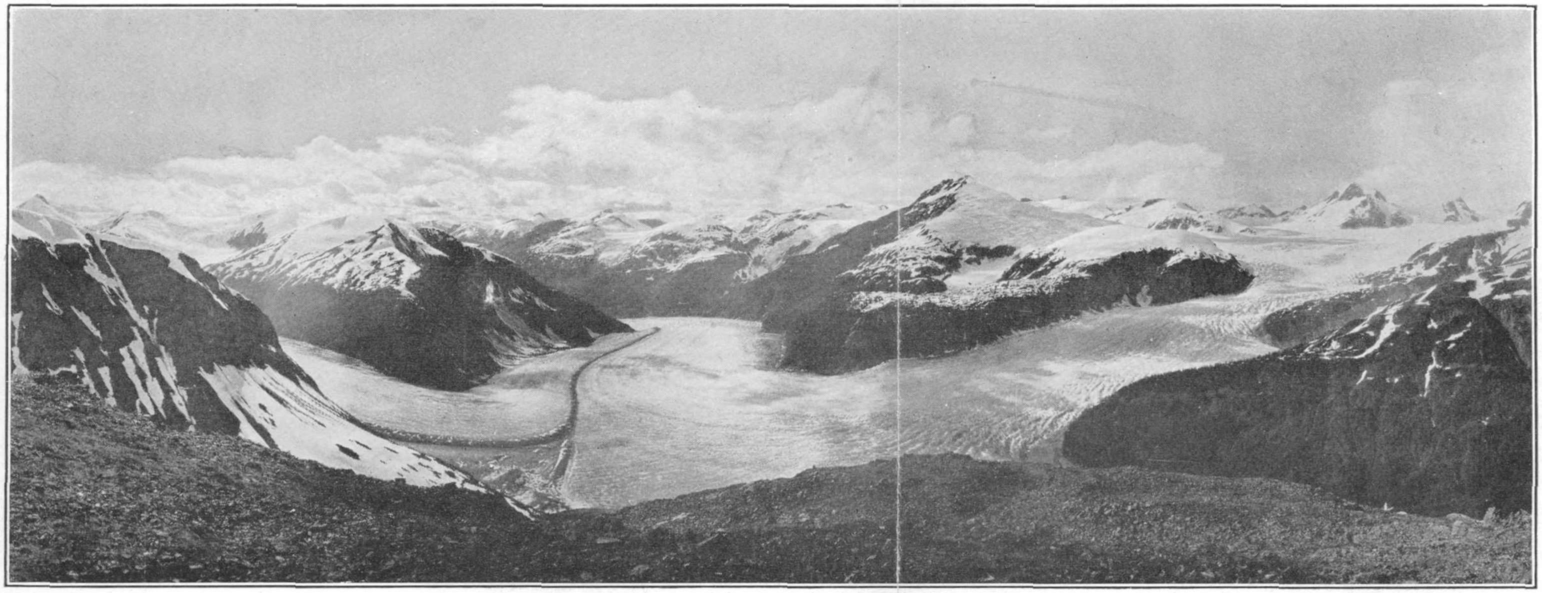
The mountainous topography of southeastern Alaska, with its associated forests, glaciers, waterfalls, and fiords, has a scenic beauty that is one of the great economic assets of the region. A maze of deep, intricate inland waterways thread among the thousands of islands of the Alexander Archipelago. Skagway may be reached from Seattle, 1,000 miles away, through the "inside passage," without once entering the open ocean. The archipelago consists in part of flat, low-lying islands, forested practically to the water's edge; in part of smooth, rolling mountains, likewise completely forested, that rise to a height of several thousand feet; and in lesser part of high ranges composed of bare rounded mountains gouged by cirques or of bare serrate peaks with talus slopes. On the mainland magnificent fiords, equivalent in origin and scenic character to the famous fiords of Norway, penetrate into the granitic heart of the Coast Range; at many places cliffs rise sheer from the water's edge to altitudes of 2,000 to 5,000 feet; and a short distance back from the shore snowy

[45] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, p. 31, 1922.



A. VIEW NEAR LOWER PART OF CHICKAMIN GLACIER

The medial moraine is from Through and Greenpoint Glaciers

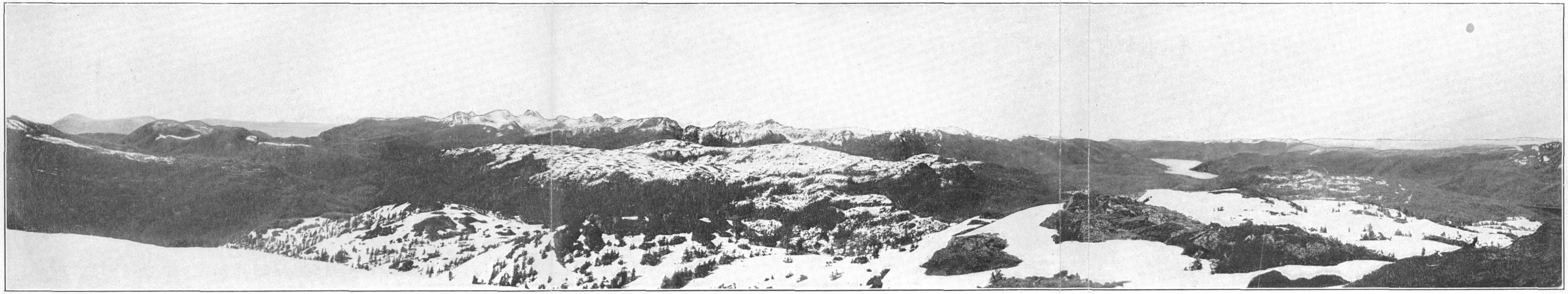


B. VIEW NEAR HEAD OF CHICKAMIN GLACIER

Serrate peaks in background are about 8,000 feet in altitude

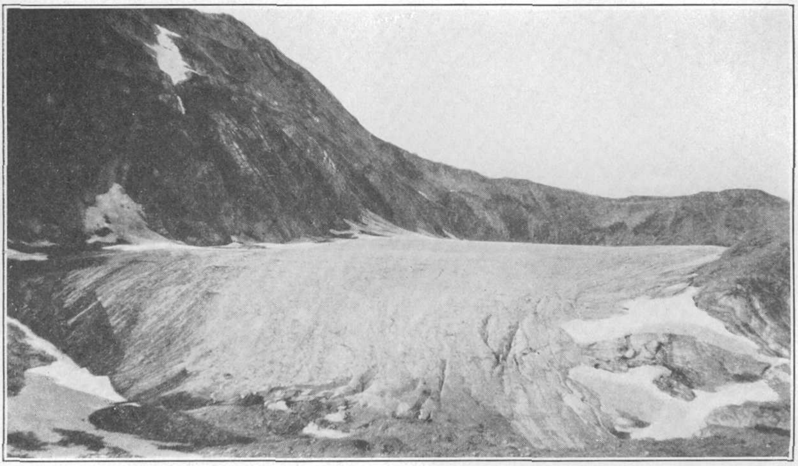
COAST RANGE TOPOGRAPHY, HYDER DISTRICT

A. PANORAMA FROM HEAD OF KLAKAS INLET



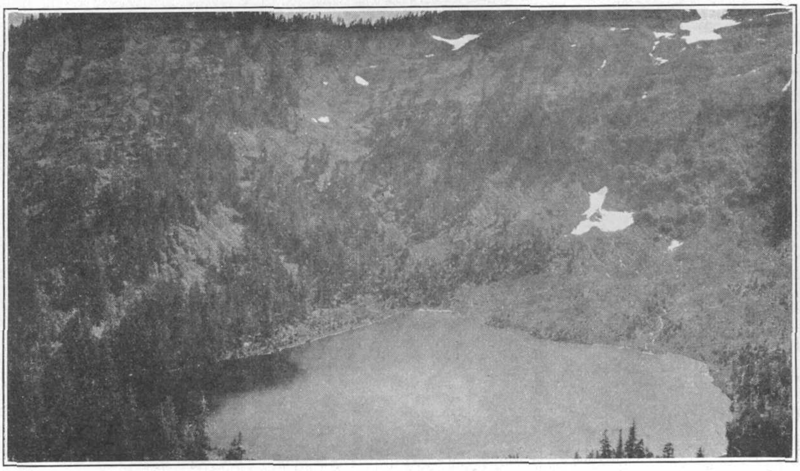
B. PANORAMA FROM HEAD OF TWELVEMILE ARM

MOUNTAINS OF PRINCE OF WALES ISLAND



A. CIRQUE OCCUPIED BY GLACIER 7¼ MILES N. 70° W. OF WHITING POINT, PORT SNETTISHAM

Back wall in crystalline limestone. Altitude 3,000 feet

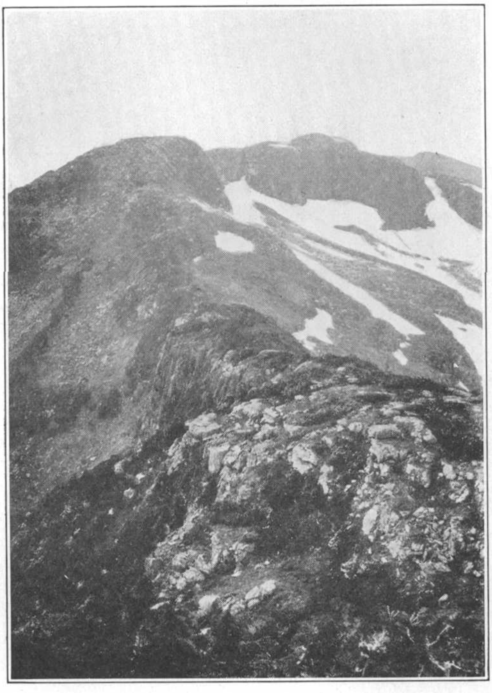


B. CIRQUE OCCUPIED BY LAKE, KANE PEAK, KUPREANOF ISLAND

Back wall in diorite

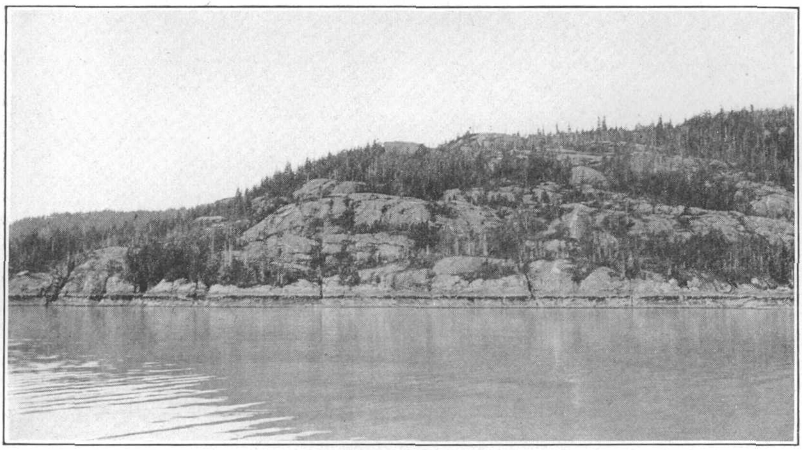
A. ROCK RIDGE FORMING FRONT EDGE OR LIP OF CIRQUE OCCUPIED BY LAKE AT HEAD OF CANN CREEK, LISIANSKI INLET, CHICHAGOF ISLAND

Altitude 1,300 feet. Rock is diorite

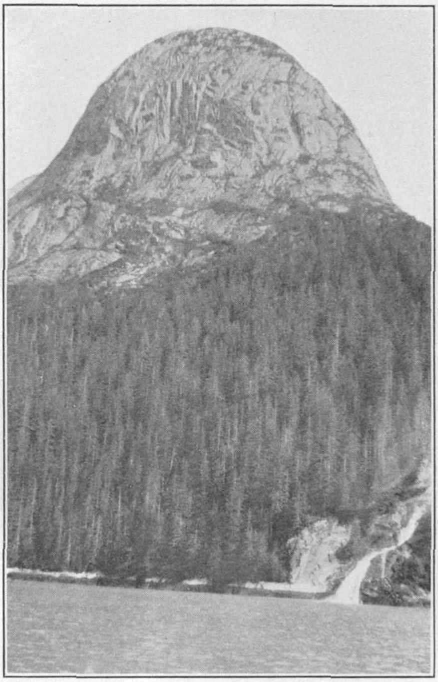


B. RIDGE BETWEEN THE HEADS OF TWO CIRQUES, KANE PEAK, KUPREANOF ISLAND

A. GLACIAL LAKE IN VALLEY OF CASCADE CREEK IN COAST RANGE NEAR THOMAS BAY

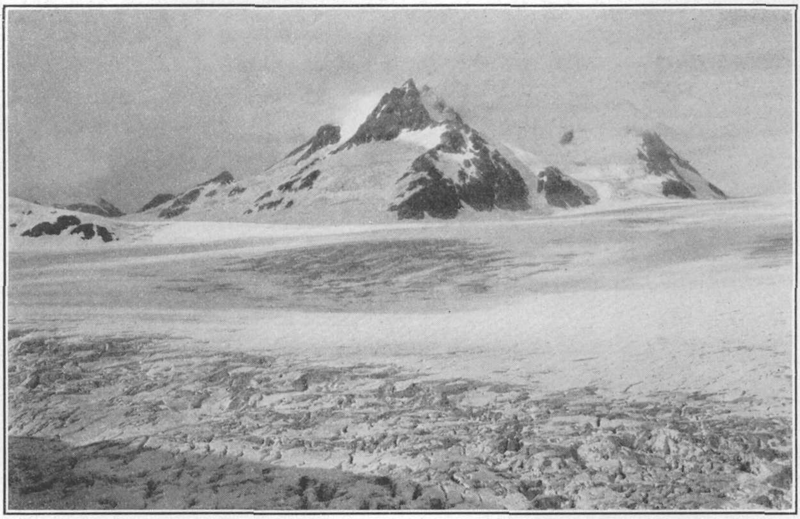


B. GLACIATED SURFACE OF QUARTZ DIORITE SHOWING ROCHES MOUTONNÉES, THOMAS BAY



A. ROUNDED TOP OF MOUNTAIN BELOW LEVEL OF PLEISTOCENE GLACIATION, TRACY ARM, HOLKHAM BAY

Altitude 4,000 feet



B. SERRATE PEAK OF MOUNTAIN ABOVE LEVEL OF PLEISTOCENE GLACIATION, NEAR HEAD OF CHICKAMIN GLACIER, HYDER DISTRICT

Altitude 8,000 feet

peaks 6,000 to 7,000 feet high are common. High peaks like the Devils Thumb, which rises to a height of 9,077 feet, with a shaft projecting more than 1,600 feet above the general level, are visible on a clear day for over a hundred miles. Thousands of small glaciers occur in the mountains, some clinging to slopes so steep as to cause wonder how they can remain there, and some terminating in ice cliffs from which huge masses are continually falling. Some of these valley glaciers discharge icebergs into the sea. Here and there waterfalls, starting hundreds or thousands of feet high on the mountain sides, plunge down in a series of cascades into the valleys or into the sea. So steep are many of the mountain slopes that great landslides are common, and long triangular scars, both old and recent, are a feature of many views. The unusual coastal forms and the contrasts of color afforded by the green of the forest on the lower slopes, the dark to light grays of the bare rock and the talus above timber line, and the white of the snow patches and the glaciers lend variety to the scene.

The topography is that of an adolescent rugged mountainous region, in which the ranges have been deeply dissected by river erosion, modified by the great Pleistocene ice sheet, and sculptured by alpine glaciers of Pleistocene and Recent age. A panorama of part of the Coast Range at the head of Chickamin River, near the international boundary, is shown in Plate 3, *A* and *B*. The highest peak in the Coast Range south and east of Lynn Canal is Kate's Needle (10,002 feet), on the international boundary east of Thomas Bay. The relief is usually several thousand feet. In the general vicinity of the international boundary all the divides are filled with ice and the ridges bear snow or ice caps, from which flow valley glaciers, many of them 20 to 30 miles long, the general effect being that of a snow or ice field with many projecting nunataks. Literally thousands of small alpine glaciers are present on the mainland, and there are many also on Baranof and Chichagof Islands and perhaps on Admiralty Island. The Prince of Wales Range comprises a group of short, rugged glaciated mountains as much as 4,000 feet in height, such as are shown in the panoramas of Plate 4.

The evidences of the great ice flood of Pleistocene time are found in the fiorded coast line, in the modified shape of most of the preexisting river valleys, in the presence of hanging valleys, in polished, grooved, and striated surfaces, and in roches moutonnées. The results of extensive alpine glaciation are seen in the many cirques, tarns or mountain lakes in rock-rimmed basins, knife-edged or comb ridges between cirques, and Matterhorn-like peaks, on both the mainland and the larger islands of the archipelago. (See pls. 5–7.)

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PLEISTOCENE GLACIATION

HEIGHT OF THE ICE SURFACE

During the Pleistocene epoch all the valleys and most of the mountains of both the mainland and the islands were buried under an ice sheet that extended across the whole region to the Pacific Ocean. During the period of maximum flooding ice to the depth of a mile or so must have flowed out through these parts of the mainland valleys that now constitute fiords.

The height of the surface of this ice field was not everywhere the same. In the vicinity of the head of Portland Canal its surface was at an altitude of about 6,000 feet; south of Stikine River and about 14 miles east of Wrangell, 5,000 feet; on Cascade Creek, in Thomas Bay, about 5,000 feet; on Whiting River about 15 miles east of Snettisham, 4,500 feet; and in the Eagle River region, about 3,400 feet.[46] Below the altitudes noted the mountains are smoothed and rounded on their tops (see pl. 8, *A*), though on the mainland and locally on the islands their higher slopes are marked by cirques. But the highest peaks, though furnishing sites for local glaciers and snow accumulations, stood above the surface of the great ice field and are serrate, pinnacled, and frost-riven. (See pls. 3, *B*, and 8, *B*.)

Information as to the rate of decline of the ice surface outward from the centers of accumulation is scanty. On Etolin Island the mountains, about 3,500 feet high west of Mosman Inlet, are rounded and glaciated, whereas the peak, about 4,500 feet high several miles east of Quiet Harbor, on Stikine Straits, is serrate at the top. On the Portage Mountains, Kupreanof Island, glacial striae occur at an altitude of 3,000 feet, and on the Kasaan Peninsula mountains up to 2,840 feet in height are glaciated. On Chichagof Island the mountain 2,800 feet high just west of East Point, Tenakee Inlet, is rounded and glaciated, whereas the 4,000-foot peak back of Tenakee is serrated and probably stood above the ice surface. On Yakobi Island, which lies directly on the Pacific, the mountain back of Bohemia Basin, 2,300 feet high, is rounded, grooved, and polished. Knopf states that Doolth Mountain, on the west side of Chichagof Island, 2,100 feet high, was probably overridden by the ice sheet.

DIRECTION OF FLOW

The ice apparently had, in general, a southwestward flow toward the Pacific Ocean. Observations of the direction of striae made by the ice current near sea level suggest, however, that the flow here was to a considerable extent influenced by the topography. These striae

[46] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 12, 1912.

were doubtless made during the waning stages of glaciation and may therefore indicate a concentrated flow of the ice along former valleys at a late stage of the ice flood. At some places they may be the markings of local valley glaciers. The direction of the striae observed on Kupreanof and Kuiu Islands suggests that an axis extended southwest through the Portage Mountains, the south end of Keku Straits, and the unnamed bay north of Alvin Bay. Northwest of this axis the ice moved to the west or northwest—that is, on the north side of Kupreanof Island, west-northwest; on the west side of Kupreanof Island north of Keku Straits, west; and through Keku Straits, Keku Islands, Threemile Arm, and Port Camden, northwest. Southeast of this axis the ice moved to the west, southwest, or south—that is, across the peninsula at the mouth of Thomas Bay, south-southwest; at the head of Duncan Canal, south; at the mouth of Duncan Canal, southwest; on Level Islands, west through Sumner Strait; north of Point Barrie, southwest; through Alvin Bay, west; and through Sumner Strait, Port Beauclerc, and Affleck Canal, south. The radiating movement of the ice currents is particularly marked in the vicinity of the bay at the south end of Keku Straits. The ice from this area flowed north and northwest through Keku Straits, west-northwest through Threemile Arm, west through Alvin Bay, southwest north of Point Barrie, and south through Sumner Strait. It is also worthy of note that at Kell Bay the ice flowed across the narrow neck of land to join the ice in Chatham Strait.

Erratic boulders of Tertiary conglomerate, breccia, and lava are abundant along the south shore of Mitkof Island and along Frederick Sound southeast of Cape Strait. It seems possible that these boulders were brought down by the Pleistocene glacier that flowed down the Stikine River valley, as similar rocks are now found in place on Iskoot River, a branch of Stikine River. Many fine roches moutonnées on the west coast of Prince of Wales Island show that the ice moved west-southwest across Orr, Tuxekan, and Marble Islands, west through the passages north and south of Noyes and Lulu Islands, and south through the lower end of Bucareli Bay.

VALLEYS

Most of the large valleys on the mainland are broad, flat-floored, and U-shaped as the result of the glaciation, which widened, deepened, and straightened the preexisting river valleys. On the islands there are many "through valleys," with broad, flat floors sloping very gradually up to a divide that is low, broad, and rounded. Such valleys were formed by the passage of ice that flowed up one valley, across the divide, and down another valley, or by valley glaciers that flowed in opposite directions from the same head, planing down the intervening divide.

A valley from which the ice has not yet wholly retreated is shown in Plate 10, *B*. Other such valleys are the one running a little south of west from Petersburg to Duncan Canal, one running northwest from the slough opposite Petersburg to the head of Portage Bay, one on Wrangell Island, and one running from Fools Inlet a little west of north to Eastern Passage.

In some glaciated valleys the profile is not a simple **U**, but the profile of each side may be composed of two or more intersecting curves, concave upward, each successively lower scallop having a steeper inclination. The scallops on one side of the valley may or may not correspond to those on the opposite side. This suggests that the valley is a composite of two or more superimposed **U** valleys, the upper and older one being broader and shallower than the lower and younger ones. This indicates that the history of the waning stages of the Pleistocene glaciation was not one of continuous decline, and it may indicate that there was more than one period of glaciation. The successively narrower valleys suggest successively narrower glaciers, which maintained the same relative size for a sufficiently long time to cut new valleys into the old one. The asymmetric character of the valley can be explained as due to the glacier's eroding its new channel at one side of the old valley, rather than in the middle. Since the glaciers have retreated streams have cut gorges and canyons in the rounded, flat-floored valleys, many of them several hundred feet deep. (See pl. 10, *A*.)

A few valleys show practically the **V** shape resulting from normal river erosion, with only slight glacial modification. An example is the valley on the south side of Tracy Arm, about 12½ miles east of the elbow. The movement of the ice through such valleys must have been slight during the Pleistocene ice flood, and the glaciers apparently did not persist in them sufficiently long during the waning stages of the ice to erode them deeply.

Lakes and broad sphagnum bogs are characteristic features of the glaciated valleys. Many of the lakes occupy deep troughlike basins gouged out of the rock by the ice. The lake in the valley of Cascade Creek, which enters Thomas Bay (see pl. 7, *A*), and the lake in the valley north of Tracy Arm, which is tributary to Port Snettisham, are apparently of this type. Such lakes have great potential value as storage reservoirs in connection with water-power development. Submergence of valleys containing such lakes beneath sea level would produce typical fiords.

FIORDS

The magnificent fiords for which southeastern Alaska has long been justly famous have resulted in part from glaciation. (See pl. 9, *A*, *B*.) These fiords are thought to be former river valleys which were eroded and deepened by the ice currents. Some submergence of the region as a whole may also have accompanied the erosion. As a result of one or both of these factors, the sea invaded the valleys to a greater or less degree upon the melting of the ice, forming passages that are locally called channels, canals, straits, inlets, reaches, coves, bays, sounds, or arms. Those of the mainland are exceedingly important in giving easy access to part of the Coast Range back from the main coast line that would otherwise be relatively inaccessible. Many of the valleys tributary to the fiords enter at high levels, so that their streams have an abrupt descent at or near the coast line. This gives rise to many fine water-power sites.

All the arms of the sea on the mainland are typical fiords with such characters as very steep, straight, parallel walls, truncated or partly eroded mountain spurs, hanging valleys, and a deep central basin or basins with a shallower threshold at the entrance. The walls often show beautiful grooving, fluting, and polishing, and locally a more deeply curved, billowy, flowing type of surface known as roche moutonnée. (See pl. 7, *B*.) Fine examples of fiords are Lynn Canal, Taku Inlet, the north arm of Port Snettisham, Endicott Arm and its branches, Thomas Bay, Le Conte Bay, Bradfield Canal, Rudyerd Inlet, and Portland Canal. The fiords are continued inland by U-shaped valleys with characters similar to the seaward part.

The main channels between the islands, such as Gastineau Channel, Stephens Passage, Frederick Sound, Sumner Strait, Stikine Strait, Zimovia Strait, Clarence Strait, Eastern Passage, Ernest Sound, and Behm Canal, likewise exhibit fiord characteristics but usually not to so marked a degree as those of the mainland, though Blake Channel and Seward Passage are as typical as any of the mainland fiords. Fiords are found also on Etolin, Prince of Wales, Baker, Chichagof, Baranof, and Dall Islands. The other islands show this feature to a much less marked degree.

An idea of the amount of deepening accomplished, at least locally, by the glaciers may perhaps be gained from consideration of the following facts: The lowest point of exit for Clarence Strait is 263 fathoms at the mouth of Dixon Entrance, and throughout much of its course the depth is not over 225 fathoms, yet a depth of 347 fathoms occurs off Lemesurier Point and 369 fathoms in Ernest Sound, east of Brownson Island, a difference of about 100 fathoms (600 feet). If this difference of 600 feet has been excavated in bedrock it might afford an estimate of the minimum deepening due to the ice, as presumably the channel as a whole would likewise have been lowered by erosion.

The north arm of Holkham Bay, Tracy Arm (pl. 9, *A*), is perhaps the most impressive fiord in southeastern Alaska. Its entrance is a narrow channel between a long sand bar always studded with stranded icebergs on the east side and a rocky coast on the west. Through this entrance the strong tide rushes in swirls. The arm makes a right-angled turn 9 miles north of its entrance, practically at the western face of the Coast Range batholith, and then for 13 miles runs directly across the granitic rock of the batholith and into the very heart of the mountains. The arm is only three-quarters of a mile wide, the walls of quartz diorite rise sheer from the water's edge to a height of several thousand feet, and the water has a depth of 1,000 feet or more. So steep are the walls that for a considerable part of their length little or no vegetation has gained a foothold. On the contrary, much of the resistant granitic rock still retains the polished grooving, fluting, and striation produced by the great glacier, 5,500 feet or more thick, which formerly flowed through this arm. Hanging valleys are abundant, and many waterfalls plunge from them down steep declivities to the sea. So deep is the water, even along the shore, that anchorage is impossible except at a few places where the larger streams have built out small deltas. Two great glaciers, each about 20 miles long, enter the head of the fiord and discharge bergs into its waters. The valleys through which these glaciers flow have all the characters of the fiord except that of being submerged, and if the land should subside 2,000 feet their lower parts would become simply two branches of the fiord, extending 5 miles inland.

Another fiord of most impressive grandeur is Fords Terror, which forms a narrow arm extending north from a point near the center of Endicott Arm. Its central part is very narrow, only 1,000 feet or so wide for a couple of miles, with walls of quartz diorite rising almost sheer from the water's edge to heights of 3,000 to 4,000 feet. It is of true canyon or gorge character and yet is an arm of the sea. The entrance to the canyon is particularly impressive, for it is a rock rim across which tidal currents have cut a narrow passage 20 to 25 feet deep, through which the tide rushes with great velocity except at or about slack water. Potholes several feet deep have been drilled in the rock of the rim, between high and low tide levels, by the currents. Inside the rock rim are depths of as much as 500 feet, and outside the rock rim in Endicott Arm, depths of more than 1,200 feet. At one time Brown Glacier entered the east arm of Fords Terror, but it has now retreated so far that it no longer reaches tidewater. At the head of the west arm of Fords Terror is a beautiful hanging valley, with a stream plunging down a steep slope to sea level.

CIRQUES

Cirques, which are horseshoe-shaped basins similar to great stadia or amphitheaters carved out of solid rock, are found at the heads of many of the valleys. These basins are the result of erosion by present or former mountain glaciers. On the mainland the higher cirques are even now occupied by glaciers, but on the islands there are many such basins that are either empty or occupied by lakes. (See pl. 5.) Near the coast many of the cirque floors are at altitudes of 800 to 1,000 feet, as at the head of Bergs and Porterfield Creeks, east of Wrangell, on the mainland; at the head of Jumbo Creek, on Prince of Wales Island south of Hetta Inlet; and at the Apex-El Nido and Pinta Bay prospects, on Chichagof Island. They may, however, be as low as 400 to 500 feet, as on Baker Island.

In the heart of the mountains cirques do not in general occur at altitudes as low as on the islands. For instance, in the Salmon River district, even where the valleys are now free of ice, little or no evidence of cirques is found below an altitude of 4,000 feet. The cirques are believed to have been formed to a very considerable extent during the lowering of the snow line consequent upon the oncoming glacial epoch before the maximum accumulation of snow and ice of Pleistocene time. With the advance of the ice cirques that had been formed at low levels on the slopes of the major valleys of the mainland were almost or completely destroyed, and renewal of cirque formation at low or moderate altitudes was prevented because the valleys were filled with ice to considerable but varying depths up to relatively recent time. Many of these valleys are still partly filled with ice. Cirques at similar altitudes on the islands, however, were merely smoothed and modified. The ice filling the fiords and marine channels between the islands must have been melted away by the relatively warm ocean waters much more quickly than that in the valleys of the mainland, thus affording opportunity for individual glaciers to form or persist for some time at low levels and continue the process of cirque formation.

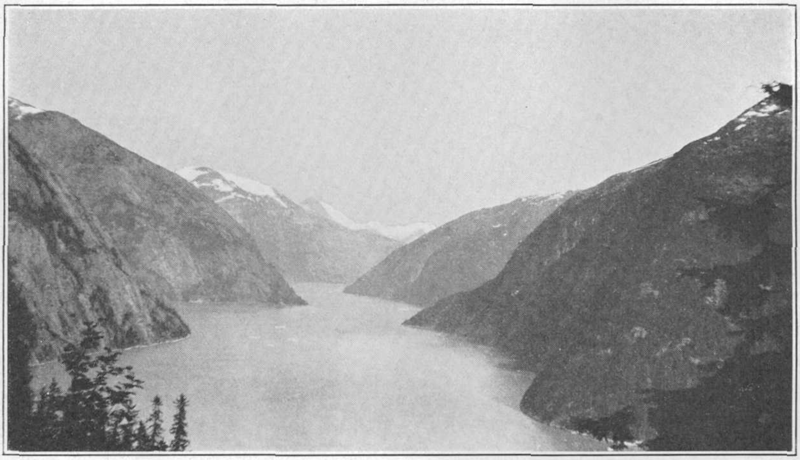
Knifelike ridges remaining between two cirques cut back from opposite directions into the mountains are common (pl. 6, *B*); lateral riblike ridges are abundant; and in high mountains that stood above the surface of the Pleistocene ice, Matterhorn-like peaks, carved by several glaciers, each excavating its basin in the same ridge from a different direction, are conspicuous features of the landscape.

MODERN GLACIERS

Within the Wrangell, Ketchikan, Hyder, and Petersburg districts glaciers are restricted to the mainland, but they constitute there one of the main features of its scenic grandeur. Thousands of small glaciers occupy cirques or cling to the precipitous faces of the mountains. There are many valley glaciers ranging in size from those which barely flow out from their sites of accumulation to those like Chickamin, Baird, Dawes, Sawyer, and Taku Glaciers, which extend 20 to 30 miles. Le Conte Glacier is the southernmost of the glaciers that reach the sea. Other tidewater glaciers in this district include Dawes Glacier, at the head of Endicott Arm; the two Sawyer Glaciers, at the head of Tracy Arm; and Taku Glacier, at the head of Taku Inlet. The two arms of Baird Glacier, Dawes Glacier, and the Sawyer Glaciers head in what is practically the same snow and ice field, with the divides at 5,500 to 6,500 feet. The glacier flowing into Knygs Lake, on Stikine River, several other glaciers draining toward Stikine River, and Le Conte and Popof Glaciers are supposed to head in the same field of ice.

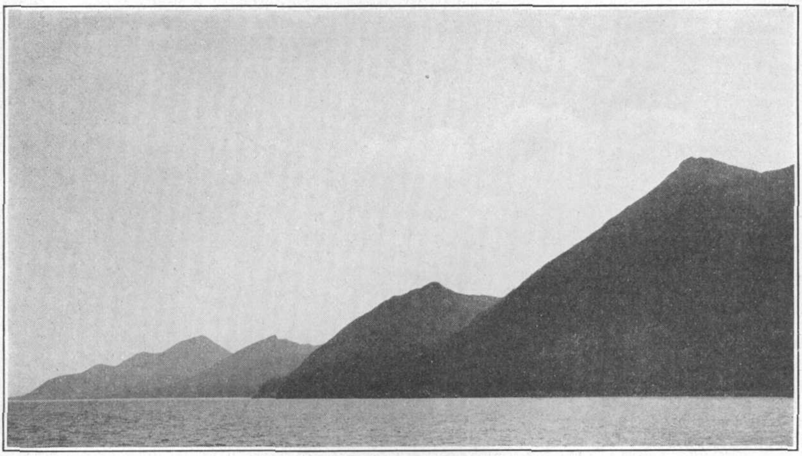
All the glaciers seen by the writer in the area described show evidences of recent retreat within the last score of years, except a very few tidal glaciers, which maintain essentially their former position, and Baird Glacier, which was advancing a little in 1922 and 1923.

Baird Glacier, as shown on the map of the International Boundary Survey, consists of two arms. The southern arm has a maximum length of 30 miles, heading at an altitude of about 6,000 feet on the east side of Mount Ratz, in British Columbia, where it forms a through glacier with the ice that flows into Stikine River through Flood Glacier. The northern arm has a length of about 16 miles. Several through valleys filled with ice connect it with Dawes Glacier. The altitude of the surface of this ice field ranges from about 4,300 feet to 6,500 feet. The glacier does not enter tidewater but reaches within about a mile of it. An outwash plain about a mile wide stretches in front of the ice and is being built forward into the bay. (See pl. 11, *A*.) In 1922 observations showed that between June 25 and August 24 the front of the ice had advanced in general 10 to 15 feet, with a slight retreat at some points. The retreat was particularly noticeable on the south side, where the ice had melted back from a group of trees which it had previously overridden, probably in the preceding spring. At one place the ice about 12 feet above the ground had been thrust forward 5 feet over that below and had produced overthrust folds in the lower ice. The whole lower part of the ice was black from incorporated detritus. Only a very small ridge of terminal moraine, 15 feet or so high, was present at the edge of the ice. The ice in the forward part of the glacier showed many deep crevasses. On June 3, 1923, the glacier was slightly in advance of its position in 1922. On the south side spruce trees 7 inches in diameter had been overthrown by the advancing ice. (See pl. 11, *B*.) On the north side a big snowslide, remnants of which were

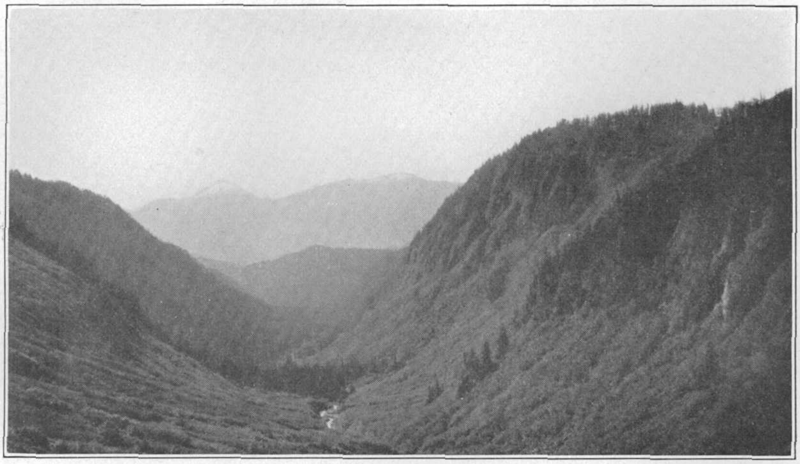


A. TRACY ARM, A FIORD IN SOUTHEASTERN ALASKA

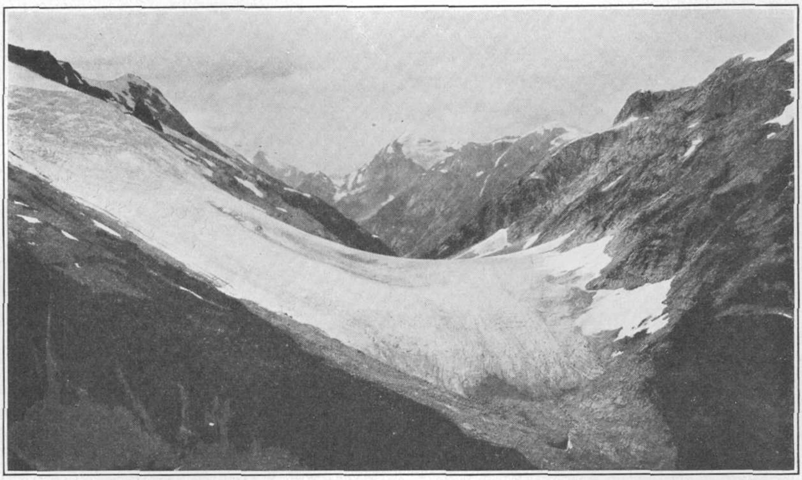
View looking east. Three-fifths of a mile wide at sea level, 1,000 to 1,200 feet deep; walls more than a mile high



B. GLACIER-FACETED HEADLANDS ALONG FIORD ON EAST SIDE OF BAKER ISLAND

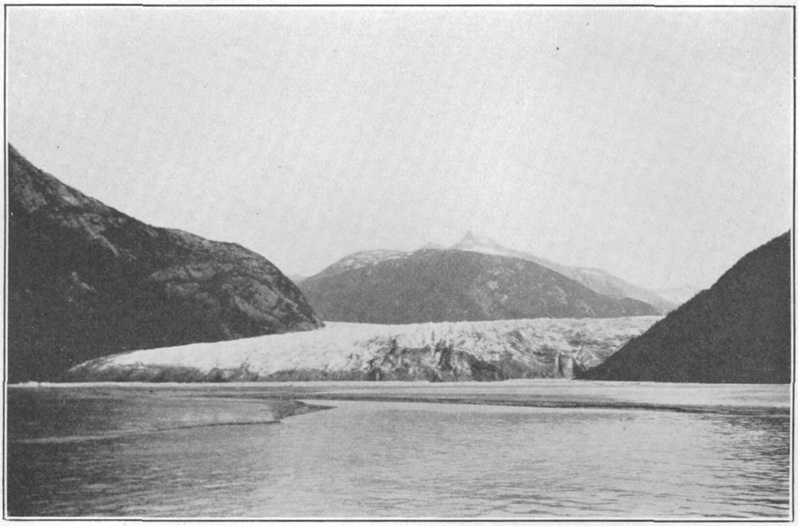


A. U-SHAPED GLACIATED VALLEY WITH RECENT GORGE IN THE BOTTOM, BERGS CREEK, WRANGELL DISTRICT



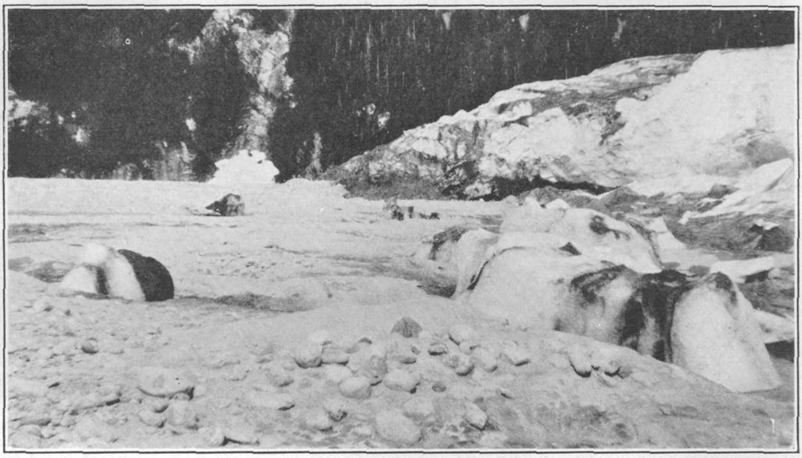
B. PASS AT HEAD OF GOAT CREEK, HYDER DISTRICT

View looking into drainage basin of middle fork of Chickamin River. Divide at head of a through valley from which the glacier has not wholly retreated

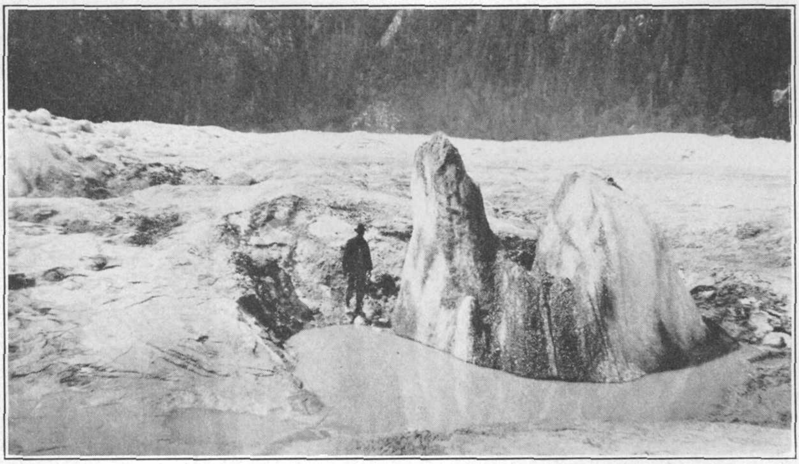


A. BAIRD GLACIER AND OUTWASH PLAIN, THOMAS BAY

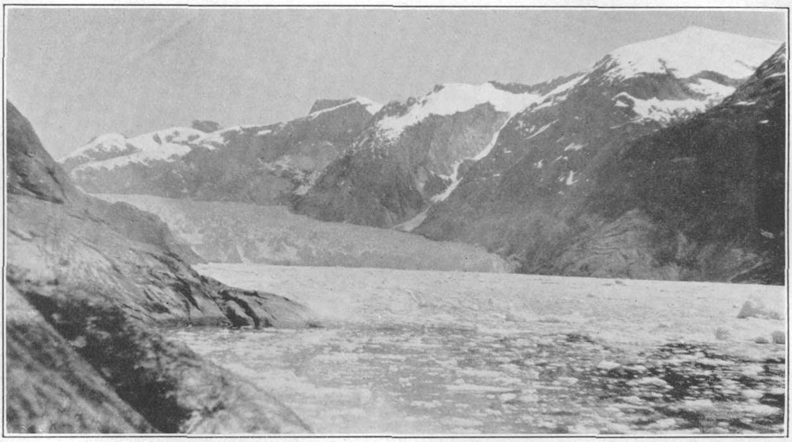
B. TREES OVERTHROWN BY ADVANCE OF BAIRD GLACIER IN 1923



A. ICEBERGS FROM BAIRD GLACIER BURIED IN OUTWASH PLAIN

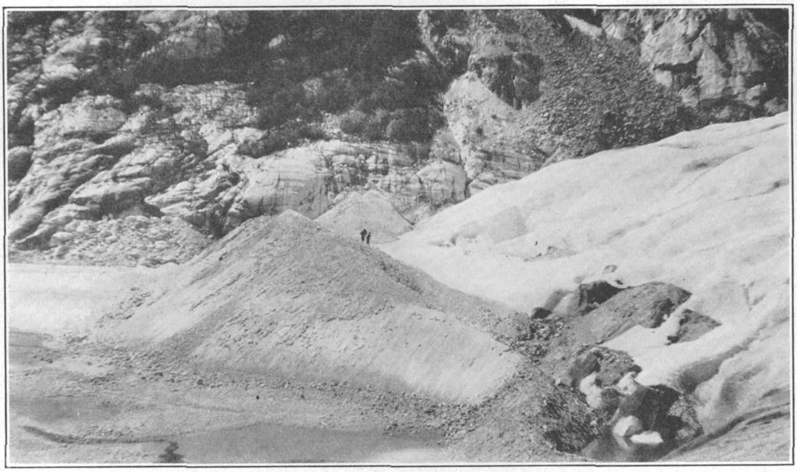


B. PIT LAKE BEING FORMED IN OUTWASH PLAIN OF BAIRD GLACIER BY MELTING OF ICEBERG



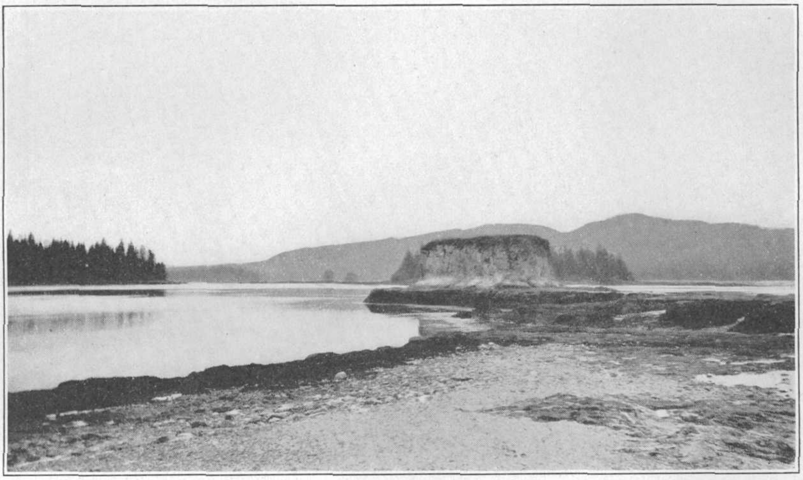
A. DAWES GLACIER, ENDICOTT ARM

View from the south headland of the north arm in June, 1923

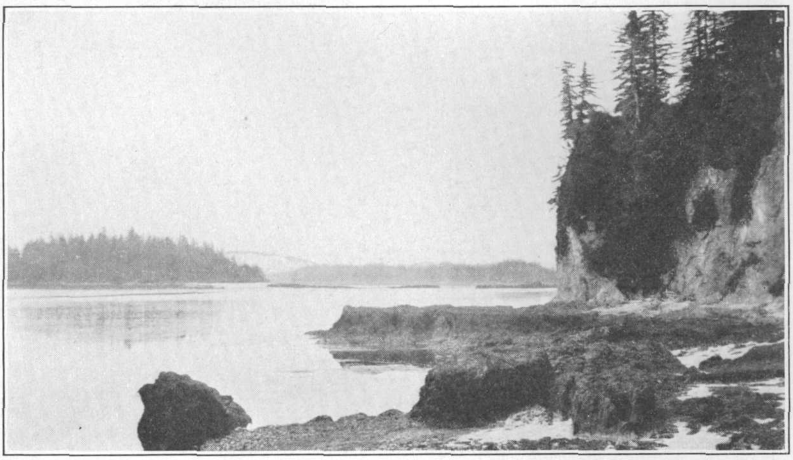


B. NORTH DAWES GLACIER, AT THE HEAD OF ENDICOTT ARM

View showing high terminal moraine and glaciated walls of valley. Appearance in June, 1923



A. REMNANTS OF THREE UPLIFTED WAVE-CUT TERRACES IN LIMESTONE, KEKU ISLETS



B. ELEVATED WAVE-CUT BENCH IN LIMESTONE, CORNWALLIS PENINSULA, KUIU ISLAND still present, appears to have dammed the river temporarily and resulted in a flood that tore away from the north edge of the glacier huge blocks of ice as much as 20 feet in diameter, scattered them along all the way to the sea, and spread over them a deposit of coarse gravel, which built up the outwash plain at least 10 feet higher than it was in 1922. (See pl. 12, *A*.) In June may of the blocks of ice were partly or completely melted and had formed pit lakes. (See pl. 12, *B*.) The cobbles and boulders of the outwash plain are similar in size to those of the present river channel. Only little patches of moraine were present in front of the ice on June 3, 1923. On September 29, when the glacier was revisited, the ice front was found to be in essentially the same position, but a moraine whose surface ranged from sea level to a height of 30 feet (average about 15 feet) lay in front of the ice and marked the maximum advance of the summer. On the north side the stranding of icebergs in the river channel had diverted the river so that it flowed for a quarter of a mile along the front of the ice and cut a new channel to the bay. The glacier was again visited on July 28, 1924. At that time the moraine lay in about the same position as on June 3, 1923; the ice front was slightly behind the moraine; the icebergs that had remained buried in the outwash plain on June 3 were all gone, and their sites were marked by sand-covered pits in the coarse gravel. Otto J. Klotz,[47] of the Canadian Boundary Survey, made some very interesting observations on Baird Glacier in 1894. He found that the slope at the front was 1 to 3, whereas for 15 miles inland it was only 1 to 20; that between May 15 and August 11, 1894, the mass of the glacier at the ice front was lowered through ablation a little more than 2 feet a day; and that its rate of motion was a fraction over a foot a day.

The most conspicuous case of glacial retreat seen by the writer on the mainland is that of Brown Glacier, at the head of the east arm of Fords Terror. As shown on Coast and Geodetic Survey chart 8200, published in 1920 but based on surveys made several years prior to that date, this glacier entered tidewater. In June, 1923, the position of the ice front was about 2 miles behind the position marked on that chart and about 1,100 yards from high-tide level. An old terminal moraine, breached by the river, lies several hundred yards from the beach. Beginning at the position formerly occupied by the ice front, as indicated by the chart, remnants of lateral moraine may be seen along the steep slopes of the east side of the arm and thence to its head. The moraine is deeply trenched by the side streams and is overgrown with alder as far as the point where the arm turns eastward. Beyond that point the moraine is of comparatively recent

[47] Klotz, O. J., Experimental application of the phototopographical method of surveying to the Baird Glacier, Alaska: Jour. Geology, vol. 3, pp. 512–518, 1895.

origin. Near the present terminus of the ice there is one lateral moraine at a height of somewhat more than 200 feet above sea level and another at a height of about 80 feet. The latter is still underlain by ice. The glacier lies in the valley, with lateral branches, buried under moraine extending up the side hills. The whole south arm of Brown Glacier is buried under an ablation moraine. The rock of the valley walls, recently exposed by the retreat of the glacier, is excessively shattered and is sloughing down rapidly.

The front of Dawes Glacier, on Endicott Arm (pl. 13, *A*), appears to be in essentially the same position as that indicated on the coast chart, but Eugene Owens, a prospector familiar with the region, reports that it has decreased in height considerably, and this statement is confirmed by the zone of barren rock immediately above the glacier. The head of the arm was filled with ice in June, 1923, and approach could not be made nearer than the east headland of the north arm.

North Dawes Glacier does not reach tidewater. A high terminal moraine (pl. 13, *B*), with outwash plain, lies between the ice front and the sea.

The Sawyer Glaciers enter the head of Tracy Arm, and both were actively discharging ice in August, 1923. South Sawyer Glacier heads in the same snow field as Sawyer Glacier and North Dawes Glacier. The altitude of the ice in the through valleys is about 5,500 feet. South Sawyer Glacier has a length of about 22 miles and Sawyer Glacier about 20 miles. A field of broken ice was jammed in front of South Sawyer Glacier, and it could not be approached closer than the island. Ice was falling into the sea from Sawyer Glacier about every 15 minutes, but the current was sufficiently strong to keep the arm in front clear of bergs, and a boat could be taken practically to the edge of the ice.

Le Conte Glacier is reported to have retreated a considerable distance within the last 10 years. In June, 1922, the bay was so full of ice that approach could not be made closer than Thunder Point.

Great Glacier lies in a valley about 3 miles east of Popof Glacier, along the valley of Stikine River. A lake lies between the ice front and an old terminal moraine breached by the river that drains the glacial valley. A second moraine lies below the first, and an outwash plain of sand and gravel occupies the space between the two. It is reported that as late as 1870 this glacier bordered the river.

Mendenhall Glacier, north of Juneau, has been described by Knopf.[48]

[48] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 11–13, 1912.

In the Hyder district Boundary Glacier, which is shown on the International Boundary Survey maps as a tributary of Salmon Glacier, now fails to join Salmon Glacier by several hundred feet.

The west front of Chickamin Glacier is reported to have retreated 4,600 feet between 1902 and 1925, and 600 feet between July, 1923, and July, 1925.

As already stated, all the glaciers on the mainland that do not reach tidewater, with the single exception of Baird Glacier, so far as known, show marked evidences of recent retreat. In addition to actual observations on the retreat of the ice evidences of this retreat are found in old concentric terminal moraines hundreds or thousands of feet in front of the present ice front, old lateral moraines scores to hundreds of feet above the present ice level, and bare rock surfaces above the present glacier surfaces upon which vegetation has not yet gained a foothold.

MARINE EROSION

The characters of the coast line are influenced to a marked degree by the nature and structure of the rocks, both in the results of erosion by glaciers, rivers, and weathering and in erosion by the ocean waters themselves. The granitoid rock of the Coast Range is massive and resistant, and in the fiords which cross it deep water occurs right up to the shore line. As a result, little or no erosion by the sea has taken place in this rock; indeed, at many places not even the glacial polish or striations have yet been worn off. But here and there, where the granitic rock occurs in small outlying stocks and is much jointed, reentrants, coves, sea stacks, and terraces have been carved out by the sea; examples of these are found at the north headland of the entrance to Hobart Bay and in the first cove to the east.

The gneiss, as a result of recrystallization and injection and permeation by aplitic and pegmatitic solutions, has acquired an essentially uniform character and therefore resists erosion by the sea in much the same way as the granitic rocks.

The less uniform schist, phyllite, and graywacke have a tendency to develop offshore reefs whose linear extension is parallel to the foliation or bedding. The tendency to develop reefs, however, is most pronounced in the slate and phyllite. These two types of rock are structurally and physically weak, so that erosion by the sea has in many places been extensive, resulting in a multitude of dangerous low-lying reefs along the coast and uplifted wave-cut terraces inland. Rocky Bay, at the south end of the northwest half of Etolin Island, and the islands and reefs in Seymour Canal and Pybus Bay, Admiralty Island, are typical examples of erosion in the Jurassic and Cretaceous slate and graywacke. Ordovician and Silurian graywackes, with intercalated slates, likewise give rise to a coast characterized by dangerous reefs. The beds of slate weather away, and the more resistant beds of graywacke stand up as long, narrow reefs. Most of the borders of Kuiu Island, much of the northwest coast of Prince of Wales Island, and Kashevarof Passage, off Lake Bay, Prince of Wales Island, show this development.

Where the slates, phyllites, and graywackes are intruded by Tertiary basalt dikes the dikes have weathered out in relief at many places, forming narrow linear reefs. They are particularly conspicuous in the vicinity of the Barrier Islands, which lie off the northwest coast of Prince of Wales Island, and near the south end of Brownson Island and Windy Bay, Etolin Island.

Bad as the slate, phyllite, and graywacke are as reef formers, however, the Tertiary volcanic rocks are uniformly worse. Without exception, the coast line developed from them is bordered by a wide fringe of jagged reefs. This is the result of the irregular jointed character of the lava. Many of the rhyolites have a platy structure that renders them an easy prey to the sea, but the basalts are the rocks out of which the more peculiarly treacherous reefs have been carved. Intricate passageways and coves have been cut in the lavas by the sea working along fracture zones. Along the entire south end of Kupreanof Island, for 2 miles offshore, there is a multitude of reefs in part above water and in part submerged. Keku Straits, from 1 to 2 miles wide, between Kuiu and Kupreanof Islands, is a maze of basaltic islands and reefs; the channel is tortuous and is passable only for small boats.

Some of the older lavas likewise tend to develop reefs, as exemplified in the Silurian andesitic volcanic rocks in Labouchere Bay and just east of Lake Bay, in Prince of Wales Island.

Along the islands off the west coast of Prince of Wales Island the sandstone and conglomerate show everywhere a most pronounced development of reefs, as along San Christoval Channel, Naukati Bay, Tuxekan Passage, the bay northeast of Point Ildefonso, Nossuk Bay, Tonowek Bay, and the south side of Marble Island.

The limestone, as a result of solution, has a finely pitted to coarse pockety surface, with many irregular needlelike or knifelike projections. Potholes are very common. So characteristic is the weathered surface of the limestone that it may be distinguished as such from considerable distances offshore. Marine erosion of massive limestone, such as the Silurian, takes place along joints, with the resultant development of chasms and long, straight, narrow channels. A peninsula may thus be dismembered into a string of islands, such as those off the north headland of Cone Bay, Heceta Island, or south of Cosmos Pass, Kosciusko Island. Nearly vertical bluffs, with deep water at the foot, are very common in the massive limestone. This is exemplified on the charts by such names as Bluff Island, at the mouth of Shipley Bay; White Cliff, on the southwest end of Heceta Island; and White Cliff Island, in Davidson Inlet. In the thin-bedded limestone erosion proceeds parallel to the bedding.

On the outer coasts of the islands, where they are exposed to the full force of the waves, a most conspicuous feature is the number of long, deep, narrow, gorgelike chasms, which have been driven into the cliffs, and are still being cut in, by the waves working along two or more closely parallel joints.

SEA-CUT BENCHES AND PLATFORMS

Both on the mainland and on the islands rock benches or remnants of rock benches are common, except in the massive quartz diorite and injection gneisses of the mainland, where they are rarely found because of the recent glaciation and more resistant character of these rocks and because along the fiords which penetrate it the water is deep right up to the shore. The most pronounced and best developed benches are found in the limestone, slate, phyllite, and Tertiary volcanic rocks.

At low tide, broad rock benches with a very gentle seaward slope are exposed at many localities. These benches have been cut largely by wave erosion and are of recent origin. (See pl. 21.)

Benches that are conspicuous because they are very obvious from a boat lie within a zone several feet above and below high-tide mark.[49] Benches at this height appear to be developed locally on all the islands and on the mainland. (See pls. 14, and 15, *B*.) Very good examples may be seen along the south side of Taku Inlet; the south side of Holkham Bay; the southeast side of the Cornwallis Peninsula, on Kuiu Island; Totem Bay, on Kupreanof Island; Rocky Bay, Etolin Island; and near Dolomi.

A number of explanations have been advanced for coastal benches which occur at about high-tide level. They have been ascribed to protection offered by seaweed below high-tide mark;[50] to control by approximately horizontal structural features[51] such as bedding or joints; to recession of cliffs due to atmospheric weathering down to a ground-water level, which has a direct relation to high-tide level;[52] to wear by storm waves at and near the time of high tide; to the interference of tide rips with storm waves except at slack tide;[53] and to uplift.

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[49] Buddington, A. F., Abandoned marine benches in southeastern Alaska: Am. Jour. Sci., 5th ser., vol. 13, pp. 45–52, 1927.

[50] Dawson, G. M., Report on the Queen Charlotte Islands: Canada Geol. Survey Rept. of Progress, p. 96, 1878.

[51] Ferrar, H. T., and others, The geology of the Whangarei-Bay of Islands subdivisions: New Zealand Geol. Survey Bull. 27, new ser., 1925.

[52] Bartrum, J. A., "Abnormal" shore platforms: Jour. Geology, pp. 793–807, 1926.

[53] McLellan, R. D., The geology of the San Juan Islands: Washington Univ. Pub., vol. 2, p. 24, 1927.

Except for a few benches obviously due to structural control or to a coincidence of a glaciated level topographic surface with the present high-tide level, all the benches at about the level of high tide are believed by the writer to be due primarily to erosion by the sea and, where the tidal range is greater than 10 feet, to a relative uplift by an amount somewhere between 10 and 16 feet. The mean tidal range in southeastern Alaska, except in the vicinity of the outer coast, is 11 to 14 feet. At a level just above high tide there are many broad, flat rock benches, some of which bear numerous sea stacks. Though storm waves at high tide will completely cover such benches, it does not seem probable that they could have been cut under the present relations of land and sea. Other benches occur just below high-tide level or just below the upper limit of the rockweed growth, and some of these benches also bear sea-cut arches or sea stacks. These benches are interpreted as resulting from the partial erosion of relatively uplifted benches that formerly stood at slightly higher levels. The coincidence of many benches with the level of the approximate upper range of the rockweed is explained by the greatly retarded rate of erosion due to the protection afforded by this rank growth of vegetation. The benches several feet above or below high-tide level, as a whole, are therefore believed to be due to erosion and uplift, followed by erosion which has lowered them in varying amounts. It seems highly probable that some former benches of similar origin have been entirely destroyed by subsequent erosion. Chapin suggests that as the benches occur only locally, it is probable that the uplift was of a differential character and that parts of the region are sinking below sea level and others are rising, owing to the warping nature of the movement. Buddington found no evidence in the Juneau and Wrangell districts to substantiate this idea, but the data are not sufficiently accurate to be decisive one way or the other.

Benches considerably above low-tide level are present also on the outer coast, where the mean tidal range is about 8 feet. These have not been carefully studied, and their origin is not known.

Extensive lowlands are developed locally on the softer rocks, such as slate, phyllite, and limestone. The groups of islands, such as those of Keku and Zimovia Straits, Seymour Canal, Kashevarof Passage, Saginaw and Security Bays, on Kuiu Island, Rocky Bay, on Etolin Island, and the Keku group, all have relatively flat surfaces at low altitudes. The extreme south end of Etolin Island, the south end of its northwestern part, and the north shore of Kupreanof Island all show low-lying land near the coast. The part of Gravina Island south of Dall Head, the bold promontory that marks the south end of the highlands of the island, is a flat that stands a few feet above sea level at the coast and slopes gently upward toward the highlands that rise abruptly from the plain. Similar features are found on the south end of Annette Island. (See pl. 15, *A*.) Too little is known of these lowlands to make any specific statement as to their character and altitude; but they appear to rise to altitudes of several hundred feet and locally have wide, relatively flat areas at a height of 160 to 200 feet. The low plains here referred to are in part coincident with those considered by Gilbert[54] to be low partial peneplains. It seems probable that they may be in large part the product of subaerial erosion and glaciation, subsequently modified by marine erosion between successive relative uplifts. That recent uplift to the amount of 600 feet has taken place in this region is indicated by deposits of postglacial clay, sand, and gravel containing a marine fauna, which have been found up to this height.

KARST TOPOGRAPHY

A typical karst topography has been developed on some of the large belts of uniform limestone. A very good example is the belt of sink holes in the form of crevasses, wells, pits, and deep longitudinal depressions, interspersed with narrow ridges and pinnacles, which occurs within the band of limestone extending from Grace Harbor to Waterfall Bay, on Dall Island. Practically the whole drainage is underground. So difficult to traverse is this belt that even deer trails are absent.

RELATION OF TOPOGRAPHY TO STRUCTURE

The structural factor that has most strongly influenced the topographic development of this region is the prevalent northwest strike of the formations. This is reflected in the general northwesterly trend of the major physiographic features as well as of many of the minor features.

The relatively flat-lying Tertiary volcanic rocks, where they occupy large areas, have tended to result in a plateau type of topography, but one which is reaching a mature stage of dissection. Buttelike forms are, however, developed here and there, as well as cuesta scarps and dip slopes. The outlying masses of granitoid igneous rock intrusive into the sediments form resistant bosses and usually constitute a group of high mountain peaks.

The Tertiary sandstone, conglomerate, and volcanic rocks on the southwest side of Port Camden, with their low dips of only about 8° SE., have been so eroded as to develop a marked set of steep cuesta scarps and gentle dip slopes.

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[54] Gilbert, G. K., Glaciers and glaciation: Alaska, vol. 3, p. 131, Harriman Alaska Expedition, 1904.

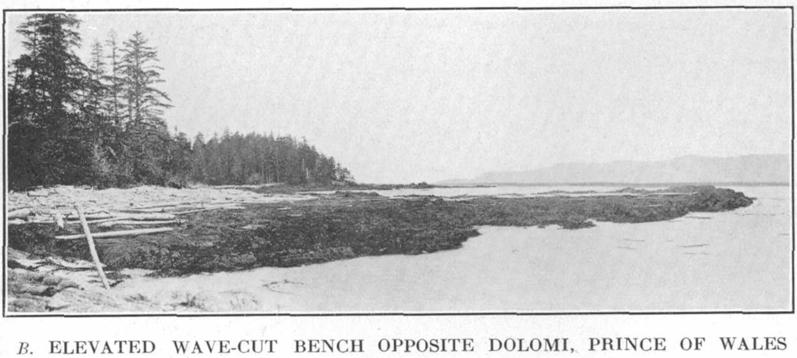
Most of the bays in a belt comprising the west coast of Prince of Wales Island and the islands adjacent thereto, the area adjoining Keku Straits, and the south end of Admiralty Island in the vicinity of Pybus Bay have been eroded along synclinal troughs, and the youngest formations appear on the islands in the bays.

A very striking example of a depression eroded out of the trough of a syncline of Silurian limestone is shown by Davidson Inlet and Sea Otter Sound. Taken in a rough general way, the west half of Kosciusko Island, the line of islands running south to Whale Head, Heceta Island, Tuxekan Island, Orr Island, and Marble Island, which are composed predominantly of Silurian limestone, together form the rim of the basin. The basin is almost separated into two parts by Orr, Marble, Hoot, Owl, and Eagle Islands, which together form a minor anticline or dome within the major syncline. Along the northwest-southeast axis of the basin, on the east side, there are several outcrops of upper members of the Silurian, comprising sandstone and conglomerate, as in the bay at the south end of Tuxekan Passage, along Karheen Passage, on the north side of the east end of Heceta Island, and at the south end of Orr and Marble Islands. Heceta and Kosciusko Islands are essentially cuestas, with steep scarps along the south and north sides, respectively, as on Bald Mountain and Mount Francis, and gentle though irregularly eroded dip slopes into and beneath Sea Otter Sound and Davidson Inlet. The two landmarks Mount Francis and Bald Mountain are outcrops of the same formation at opposite borders of the basin.

Other examples of lowlands or valleys which have been worn out of the troughs of synclines or synclinoria are the lower half of Pybus Bay, on Admiralty Island, the bay at the north end of Keku Straits, Shakan Bay and the lowland of the Barrier Islands, at the northwest end of Prince of Wales Island, Edna Bay, on Kosciusko Island, Tokeen Bay, the bay at the south end of Marble Island and the southwest end of Orr Islands, the south end of El Capitan Passage, Naukati Bay and the wide expansion of Tuxekan Passage, the bay at the south end of Tuxekan Passage, Karheen Passage, Nossuk Bay, San Christoval Channel, St. Nicholas Channel, Portillo Channel, Klawak Inlet and the lowland to the west and north ends of San Alberto Bay, Bucareli Bay, the basin at the head of Port Refugio, on Suemez Island, Trocadero Bay, Soda Bay, Cordova Bay, and Tlevak Straits.

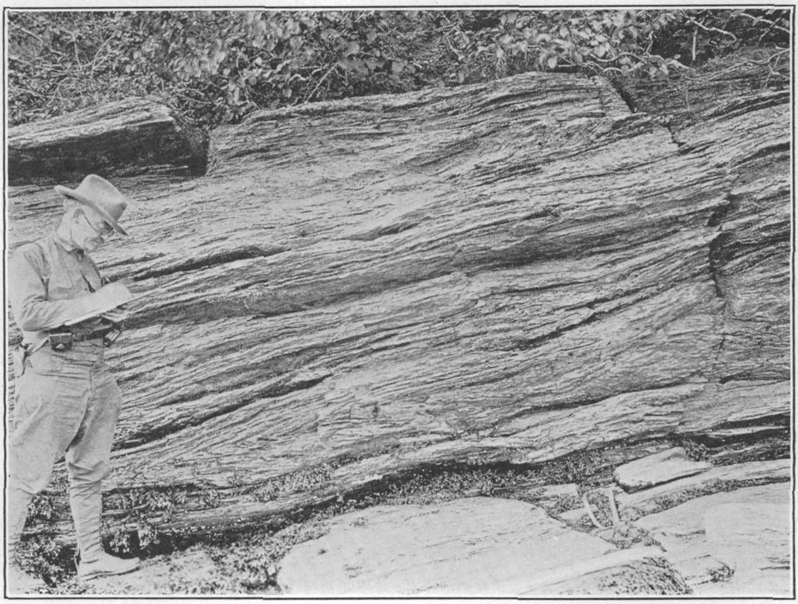
Some channels and bays originated as valleys eroded along the arches of anticlines. Frederick Sound appears to have been eroded along the broad dome of an anticlinal arch in Tertiary volcanic rocks. Other examples are the channels lying east of the line of islands southwest of Kake, on Kupreanof Island, Kashevarof Passage, Port Protection, Labouchere Bay, and Warmchuck Inlet, on Heceta Island.

A. COASTAL PLAIN ALONG SOUTHWESTERN COAST OF ANNETTE ISLAND



B. ELEVATED WAVE-CUT BENCH OPPOSITE DOLOMI, PRINCE OF WALES ISLAND

A. CLOSELY FOLDED LIMESTONE OF THE WALES GROUP, DALL ISLAND



B. GREENSTONE SCHIST OF THE WALES GROUP, PORT JOHNSON, PRINCE OF WALES ISLAND

View showing recumbent folds

Evidences of marked and profound faulting are common throughout the area west of the mainland, but the writer saw no place where faulting had had a direct influence on the present topography. The indirect results from faulting, however, are very evident in many places. The weaker rock of shear and breccia zones is more easily eroded, and faulting brings into contact rocks of unequal resistance. The straight deep marine channel formed by Chatham Strait and Lynn Canal, which extends for 250 miles and forms one of the most conspicuous features of southeastern Alaska, is thought to have been eroded along a fault zone. A good discussion of this feature is given by Martin and Williams.[55]

Other places where the results of faulting were especially noted are the east side of San Christoval Channel between San Fernando Island and the west coast of Prince of Wales Island; the east side of Bocas de Finas, on the southwest side of Heceta Island; the east side of the lower half of Orr Island; the west face of the Mount Calder limestone range, on the northwest end of Prince of Wales Island; and the south end of Zarembo Island.

Many of the features of the topography have been controlled by the presence of great fractures and intersecting fracture systems along which there has been only slight movement. The location of many erosion features such as river valleys and fiords, with their numerous abrupt changes of direction, is due primarily to such planes of weakness. Additional data would be needed, however, for an adequate discussion of this subject.

THE ROCKS

STRATIGRAPHIC COLUMN

By Theodore Chapin and A. F. Buddington

The stratigraphic column in southeastern Alaska comprises a very thick series of formations, which includes the Wales group (metamorphic rocks) and beds of Lower and Middle Ordovician, Silurian, Middle and Upper Devonian, Mississippian, Pennsylvanian (?), Permian, Upper Triassic, Jurassic, Lower Cretaceous (?), Eocene, Pliocene, and Quaternary, with a possible total maximum thickness of about 50,000 feet. The stratigraphic sequence is shown in the accompanying table. The general distribution of the systems and formations is shown on Plates 1 and 2. The Wales group comprises a series of metamorphosed beds whose age and relation to fossil horizons are not definitely known. They were classified as pre-Silu-

[55] Martin, Lawrence, and Williams, F. E., An ice-eroded fiord; the mode of origin of Lynn Canal, Alaska: Geog. Review, vol. 14, pp. 576-596, 1924.

rian by Chapin, before the presence of Ordovician beds in the Ketchikan district was known. Their relation to the Ordovician beds has not yet been ascertained. The group as mapped may be in part pre-Ordovician and it may in part include Silurian beds or even some Devonian, owing to a failure to recognize and properly separate the Devonian. Other metamorphic rocks, mapped as the "Wrangell-Revillagigedo belt of metamorphic rocks," probably range in age from Ordovician to Jurassic or later.

Stratigraphic sequence in southeastern Alaska

[By A. F. Buddington and Theodore Chapin]

System	Series	Character	Thickness (feet)	Distribution
Quaternary.		Chiefly sand and gravel deposited by streams.		
		Basaltic lava and tuff.		Mount Edgecombe, Kruzof Island; Canon Creek and Blue River, tributary to Unuk River; Revillagigedo Island; mainland, Ketchikan district.
		Glacial drift and marine bench and terrace deposits of interstratified gravel, sand, and clay.		Douglas Island, Funter Bay, Port Snettisham, Wrangell, Gravina Island, Salmon River at head of Portland Canal, west coast Prince of Wales Island, Stikine River.
		Unconformity		
Tertiary.	Pliocene (?).	Conglomerate, sandstone, and shale, with coal seams.	1,000±	Lituya Bay.
		Basaltic and obsidian lava.		Suemez Island.
		Unconformity		
	Eocene.	Basaltic and andesitic lava with minor amounts of interbedded breccia and conglomerate, associated with thin coal seams at Murder Cove, Admiralty Island. Tentatively assigned to Eocene.	2,500±	Kupreanof, Kuiu, and Admiralty Islands.
		Rhyolitic and andesitic volcanic rocks and conglomerate.	1,500±	Gravina, Zarembo, Kupreanof, and Kuiu Islands.
		Coarse sandstone with basal and intercalated beds of conglomerate. Associated with thin coal seams in Port Camden, Kuiu Island; Hamilton Bay, Kupreanof Island; Kootznahoo Inlet, Admiralty Island; and Coal Bay, Prince of Wales Island.	1,350±	Coal Bay, Prince of Wales Island; Union Bay, Cleveland Peninsula; Kupreanof, Kuiu, and Admiralty Islands.
		Unconformity		

Stratigraphic sequence in southeastern Alaska—Continued

System	Series	Character	Thickness (feet)	Distribution
Cretaceous(?).	Lower Cretaceous (?).	Slate and graywacke, with a few chert nodules and thin layers of impure limestone; locally with intercalated beds of conglomerate.		Pybus and Herring Bays, Admiralty Island; northern part of Kupreanof Island; Rocky Bay, Etolin Island; Gravina Island; and northwest part of Annette Island.
Jurassic or Cretaceous.		Schistose greenstone; porphyry breccia, predominantly hornblende, rarely augite, with intercalated beds of tuff, lava flows, black slate, and graywacke.		East side of Lynn Canal; Douglas Island; Glass Peninsula, Admiralty Island; Fanshaw Peninsula; Vank Island; Anita Bay, Etolin Island; Onslow Island; Cleveland Peninsula; Gravina and Annette Islands; Cape Fox.
		Graywacke, dark-gray slate, and conglomerate with sparse intercalated beds of tuff and thin layers of impure limestone. May be in part the same as the Lower Cretaceous (?) slate and graywacke.		Point Young, Seymour Canal, Admiralty Island; Fanshaw Peninsula; north end Kupreanof Island; west coast Chichagof Island; Salmon River district.
		Unconformity		
Triassic.	Upper Triassic.	Andesitic rocks, including breccia with limestone matrix and lava flows (in part with pillow structure), locally interbedded with slate and other sediments.	1,400+	Northwest end of Kupreano, Island; east side of Hamilton Bay; Hound Island; northeast side of Kuiu Island.
		Unconformity		
		Conglomerate, sandstone, and limestone; in the Ketchikan district includes considerable black slate in upper part.	1,600±	Gravina, Revillagigedo, and Annette Islands; Keku Islets; northwest end of Kupreanof Island; Pybus Bay, Admiralty Island; Screen Islands.
		Unconformity		
Carboniferous.	Permian.	Thick-bedded limestone; with common to abundant intercalated layers of white chert.	1,000	Saginaw Bay, north side of Kuiu Island; Keku Islets; Pybus and Gambier Bays, Admiralty Island; eastern end of Suemez Island; Taku Harbor.
		Conglomerate, limestone, sandstone, andesitic and basaltic lava, tuff, and, locally, rhyolitic volcanic rocks.	3,000±	Saginaw Bay, north side Kuiu Island; Keku Islets; Snettisham Peninsula, mainland; Windfall Harbor, Admiralty Island.
		Unconformity		
	Pennsylvanian (?).	White massive limestone.	100+	Soda Bay, west coast of Prince of Wales Island.
	Mississippian.	Interbedded coarsely crystalline limestone and black chert, overlain by interlayered dense gray quartzite and cherty limestone; sparse conglomerate.	1,000	Suemez, Madre de Dios, and Robber Islands; Soda Bay, Prince of Wales Island; Klawak; Saginaw Bay, Kuiu Island; Iyoukeen Peninsula, Freshwater Bay, and Port Frederick, Chichagof Island.

Stratigraphic sequence in southeastern Alaska—Continued

System	Series	Character	Thickness (feet)	Distribution
Devonian	Upper Devonian.	Basalt, andesite (in part pillow lava), tuff, limestone, sandstone, slate, and conglomerate.	1,000	Freshwater Bay, Chichagof Island; Suemez and San Juan Bautista Islands; northern part of Kupreanof Island.
		—Unconformity (?)—		
	Middle Devonian.	Limestone.	600+	Long and Round Islands, Kasaan Bay; San Alberto, Clam, Coronados, and Fish Egg Islands; north end of Kupreanof Island.
		Andesitic green to gray tuff (locally cherty) and graywacke, with locally, fine conglomeratic layers, intercalated limestone, and a minor amount of andesitic lava and breccia.	2,400+	Northwest side of Kupreanof Island; islands in Saginaw Bay, Kuiu Island; Prince of Wales Island.
		Andesitic lava (in part pillow lava), breccia, tuff, conglomerate, and, locally, rhyolitic lava.	2,000	Prince of Wales, Dall, Sukkwan Baker, Suemez, and Noyes Islands.
		Interbedded limestone, slate, chert, andesitic lava, breccia, tuff, and, locally, conglomerate.		Duncan Canal and northwest end Kupreanof Island; north side of Noyes Island; Baker Island.
		Conglomerate and graywacke-like sandstone, with, locally, interbedded limestone.	2,000	San Christoval Channel, head of San Alberto Bay, north side San Fernando and Lulu Islands.
		—Unconformity—		
Silurian.		Green-gray graywacke with sparse conglomerate beds. Interbedded red, green-gray, and gray graywacke-like sandstone with a small amount of shale.	5,000+	North half Prince of Wales Island, Tuxekan Passage, Naukati Bay, east end Heceta Island.
		Green-gray shale with intercalated red beds and thin-layered fine-grained gray sandstone, shale, and dense limestone.	500+	West of Edna Bay, south side of Kosciusko Island.
		Predominantly thick-bedded dense limestone; intercalated with thick beds of coarse conglomerate, thin-layered limestone, nodular and shaly argillaceous limestone, and sandstone. Limestone, 3,000 ± feet; conglomerate, 1,500 ± feet.	4,500±	Dall Island; north part of Prince of Wales Island; Kosciusko, Heceta, and Tuxekan Islands; southwest side of Saginaw Bay and locally on east side of Kuiu Island; Kashevarof Islands, Tenakee Inlet and Freshwater Bay, Chichagof Island; Glacier Bay.
		Andesite (in part pillow lava) and andesite porphyry lava; conglomerate; with some associated graywacke, tuff, breccia, and limestone.	3,000±	Kashevarof Islands; Prince of Wales Island; El Capitan Passage; Kuiu and Sumner Islands.
		—Unconformity (?)—		
		Indurated graywacke with associated black slate and sparse conglomerate and limy sediments.		San Fernando, Lulu, Dall, and Noyes Islands; Klakas Inlet, Prince of Wales Island; Glacier Bay (?).
		—Unconformity (?)—		

Stratigraphic sequence in southeastern Alaska—Continued

System	Series	Character	Thickness (feet)	Distribution
Ordovician.	Middle Ordovician.	Indurated graywacke with associated black slate and sparse conglomerate and limy beds; locally andesitic pillow-lava and volcanic rocks.		Thorne, Stevenson, Lulu, Heceta, and Kuiu Islands; El Capitan Passage and Klawak Salt Lake.
	Lower Ordovician.	Thin-layered black chert with black graptolitic slate partings, graywacke, and, locally, andesitic volcanic rocks.		Kuiu, Lulu, and San Fernando Islands; mouth of Klawak Salt Lake; head of Van Sants Cove, Kosciusko Island.
Probably pre-Ordovician to Devonian	Wales group (metamorphic rocks).	Greenstone schist with intercalated or interbedded limestone. Limestone. Schist with beds of limestone and slate. Schist.		Long Island and southern part of Dall and Prince of Wales Islands.

GENERAL LITHOLOGY

Volcanic rocks.—Volcanic rocks, predominantly andesite or basalt, form a considerable part of the Wales group and of the Lower and Middle Ordovician, Middle and Upper Devonian, lower Permian, Upper Triassic, Jurassic, Lower Cretaceous (?), Tertiary, and Quaternary divisions. Rhyolite is present but very sparse in the Silurian, Middle Devonian, and lower Permian but is an important member of the Eocene and Pliocene (?) volcanic rocks and occurs within the Wales group.

Many of the volcanic rocks of the Paleozoic and Mesozoic eras are closely folded and metamorphosed and constitute greenstone schist, whereas those of the Tertiary are relatively flat-lying and unaltered. Pillow lava is abundant in the Lower and Middle Ordovician, Silurian, Middle and Upper Devonian, lower Permian, and Upper Triassic formations, where it is invariably associated with marine fossils. No pillow lava whatever was found in the Tertiary volcanic flows, which are associated with beds carrying fossil land plants. These facts suggest that submarine conditions are distinctly more favorable than land conditions to the development of pillow structure in basic lava.

Graywacke.—Aside from the volcanic rocks, sheared graywacke and slate form the bulk of the rocks classified as Jurassic or Cretaceous. Highly indurated graywacke, with a little slate, forms most of the Ordovician and a considerable part of the Silurian formations. Massive tuffaceous graywacke of great thickness also forms a large part of the Devonian formations. Indeed, the vast quantity of greenish graywacke with associated slate, possibly over a third of the total section, is the most striking and peculiar feature of the entire stratigraphic sequence of southeastern Alaska. Graywacke is found in every system of the Paleozoic and Mesozoic and in many places presents a problem of correlation difficult or impossible of solution without extremely careful detailed work. The abundance of graywacke is doubtless the result of the widespread and active volcanism throughout most of the geologic time interval represented by formations in southeastern Alaska.

Sandstone.—Relatively clean quartzose sandstone is practically absent. Red beds of any description are likewise very sparse and restricted to local areas, such as the west coast of Prince of Wales Island in the vicinity of Tuxekan, Karheen, and El Capitan Passages, where beds of graywacke-like red and green sandstone are prominent. Some typical consolidated but unmetamorphosed sandstones are found in the Eocene section.

Limestone.—Limestone forms a very considerable part of the Paleozoic systems with the exception of the Ordovician, but it is unimportant in the Mesozoic except for the Upper Triassic, and is absent from the Cenozoic. The most widespread, most uniform, and thickest formation of limestone is of upper Silurian age, but thick uniform beds are found also in the Middle Devonian. Cherty limestone of considerable thickness forms a part of the Carboniferous system. The limestone is almost wholly calcite limestone, and that of the upper Silurian is for the most part a very high calcite limestone.

Where the limestone is intruded by stocks of granitoid igneous rock it is locally metamorphosed to marble. On the mainland and in the Glacier Bay region most of the limestone has been coarsely recrystallized as a result of contact metamorphism on a regional scale due to the vast volume of the intrusive rock.

Conglomerate.—Beds of coarse cobble and boulder conglomerate form conspicuous and thick members of the Silurian formations. They are prominent also in the lower Permian and Tertiary formations and locally in the Jurassic or Cretaceous. Pebble and coarse conglomerate beds are also prominent locally at the base of the Middle Devonian section. A peculiar and characteristic conglomerate composed of andesite and limestone pebbles and cobbles in a greenish tuffaceous matrix is very common in the Silurian and Middle Devonian formations associated with the volcanic rocks. Conglomerate composed chiefly of lava boulders forms very thick beds in the Eocene formations.

Intraformational conglomerate.—A characteristic feature of the Paleozoic systems in southeastern Alaska is the abundance of coarse waterworn intraformational limestone conglomerate. Beds occur in the Silurian, Devonian, lower division of the Permian, and Triassic, in all of which the cobbles of limestone were found to carry the same fauna as the formation to which the conglomerate belongs. Limestone conglomerate of intraformational origin occurs in beds 100 feet or more in thickness in the Silurian. The prevalence of intraformational conglomerate is probably genetically connected with movements accompanying local volcanic activity during these periods.

Slate.—Black slate and argillite are widely distributed and occur interbedded or intercalated in practically all the Mesozoic and Paleozoic formations. Black slate is particularly prominent in the Jurassic or Cretaceous beds. Rarely shale is present.

Chert.—Thin-layered black chert several hundred feet thick occurs in the Ordovician and Mississippian formations. Thick-bedded chert and cherty tuff occur in the Middle Devonian, intercalated thin black chert layers are common in the Mississippian limestone, and layers and beds of white chert are common in the upper Permian limestones. Chert which has been described by some geologists as quartzite is locally prominent in association with the lower division of the Permian beds. Small cherty nodules are found in the Lower Cretaceous (?) slate.

Phyllite, schist, and gneiss.—Two types of metamorphism prevail throughout southeastern Alaska. One has resulted mainly in the formation of a slaty or schistose foliation in the rocks, without marked coarse recrystallization or the formation of high-temperature minerals. It was caused in large part by intense nonuniform stresses and occurred chiefly in the beds away from large bodies of the Mesozoic intrusive rocks. The other type affected particularly a wide belt adjoining the Coast Range batholith. It resulted in the formation of phyllite, schist, and gneiss, with marked recrystallization and change in character of the constituent minerals, caused by the higher temperature and permeating hot solutions attendant upon the emplacement and solidification of the vast volume of magma, in addition to nonuniform stresses as intense as those effective in the other type. The contrast between the rocks produced by the two types may be illustrated by the slate and schistose greenstone that are common in the Alexander Archipelago, as compared with the phyllite and the biotite, hornblende, and garnetiferous schists in the Wrangell-Revillagigedo belt of rocks of the mainland.

WALES GROUP

By THEODORE CHAPIN and A. F. BUDDINGTON

The Wales group comprises a series of metamorphic rocks, including crystalline schist, quartzitic and slaty beds, limestone, and greenstone. The greenstone is predominantly schistose (pl. 16, *B*), and much of the limestone is crumpled (pl. 16, *A*), cleaved, and sheared or metamorphosed to marble. On Prince of Wales Island the Wales rocks occupy a semicircular area extending across the island from Dolomi to Sulzer and along the east shore of Hetta Inlet to Lime Point. The other main area covers all of Long Island, in Cordova Bay, and the southern part of Dall Island. The stratigraphic horizons to which the divisions of the group should be assigned are uncertain, owing to lack of fossils and difficulty in recognizing the formations because of metamorphism, and formations of more than one period are very probably included. Their age is probably Silurian and older, but perhaps some Devonian is included. The structurally lowest schist members can not be correlated certainly on lithologic grounds with any beds of the known Ordovician formations, and they may possibly be of pre-Ordovician age.

The schists include quartz-mica schist and related types derived from sedimentary rocks, greenstone schist including epidote and chlorite schists derived from basic lava flows and tuff, and some light-colored schist derived from altered rhyolitic volcanic rocks. Both tuffaceous rocks and flows are interbedded with limestone which passes into the greenstone schist by an increasing amount of intercalated igneous material. Slate and other argillaceous rocks are interbedded with mica schist and greenstone. The limestones are white crystalline rocks and contain many beds of workable marble. Where they are interbedded with igneous rocks a great variety of colored and variegated marbles have been formed.

The base of the Wales group is nowhere evident. The lowest part exposed is a thick series of crystalline schist, predominantly of sedimentary origin but containing beds of limestone and altered basic and rhyolitic volcanic rocks. In the upper part of the schist series limestone is more abundant and ranges in thickness from less than 100 feet to more than 1,000 feet. There is at least one thick massive bed of pure limestone several hundred feet thick and a great many smaller ones. In its upper part the limestone contains a great deal of intercalated greenstone tuff into which the limestone member seems to grade. The general sequence is schist, schist and limestone, limestone, greenstone and limestone, in a gradationally conformable series in which the limestone intergrades with both schist and greenstone. The greenstone schist associated with the limestone is largely altered to secondary quartz, epidote, chlorite, hornblende, calcite, mica, zoisite, talc, serpentinous material, and other secondary minerals.

The schists were originally sandstone, shale, lava flows, and tuff. They are interbedded with the limestone and were evidently laid down on the sea bottom. The greenstone probably represents submarine lava flows and volcanic ejectments collected in the sea. Even the coarser tuff and breccia are well stratified and apparently waterlaid. The alteration of these rocks is regarded as largely regional metamorphism produced by tectonic forces, in combination with magmatic intrusions. The intrusive rocks are only partly exposed at the present surface.

In 1925 Buddington spent 18 days in mapping the formations along the west coast of Dall Island. His observations follow. In the southern half of the island the oldest rocks are almost exclusively schist, which forms a belt through the center of the island from a point midway between Port Bazan and American Bay southeastward through the Essowah Lakes and the head of Security Cove to and including the Cape Muzon peninsula and McLeod Bay. The schist is light colored and includes very little if any limestone. A belt of light-colored feldspathic quartz schist forms the island and adjacent headland on the north side of McLeod Bay. It can be traced northward as far as the mountains at the head of Port Bazan and crops out also along the shore at the head of Security Cove. This schist can be identified in part as highly sheared, plicated, and folded rhyolite porphyry, and it is probable that a considerable part of this belt consists of metamorphosed rhyolitic volcanic rocks. Biotite metacrysts are common and, locally, crushed phenocrysts of plagioclase, orthoclase, and quartz. The Cape Muzon Peninsula consists almost wholly of thick-bedded schist with a very little limestone. The schist comprises quartzite schist, dark micaceous siliceous schist, and, locally, black hornblende schist. Dikes of quartz diorite, also pegmatite and aplite, are common. Locally black graphitic phyllite is present.

The schist core of the south end of the island is flanked on each side by a belt of schist with intercalated or interbedded limestone. The schist comprises light-gray to greenish quartzose varieties, sericitic schist, and greenstone schist, the last in minor amount.

North of Port Bazan the belt of schist and limestone is overlain by a thick band of limestone with intercalated schist in minor amount. This passes upward into schist and limestone, the schist largely of greenstone origin, and then into greenstone schist with only a little limestone. A similar belt of greenstone and limestone forms the area between the bay north of American Bay and Coco Harbor.

In the schist derived from sedimentary rocks quartz is the predominant mineral, though feldspar, epidote, and mica (sericite and biotite of two kinds, one a dark green) are in places very abundant. Garnet, sillimanite, hornblende, magnetite, and pyrite are common accessory minerals.

The limestone is in general fine-grained crystalline material.

The greenstone schist associated with the limestone is largely altered to secondary quartz, epidote, chlorite, calcite, hornblende, mica, zoisite, talc, serpentine, and other secondary minerals, which have entirely replaced the original minerals of the rock.

On American Bay there are beds of crystalline schist with large radiating clusters of hornblende crystals on the foliation planes in a light-colored groundmass composed of quartz with sillimanite or of plagioclase, muscovite, and epidote. Associated beds consist essentially of hornblende and epidote, feldspathic quartz-mica schist, hornblende schist, and mica schist, with many narrow quartz seams parallel to the foliation planes, and beds of dense limestone.

The schist on the east coast of Dall Island south of the harbor north of American Bay has the appearance of having been formed as a result of metamorphism associated with igneous intrusions. This applies also to the beds on the west side of the island as far north as Port Bazan. There are a number of small intrusive dikes and sills throughout this belt and, locally, an injection gneiss. In the bay south of Gooseneck Harbor, in Gooseneck Harbor, and in Coco Harbor and Rose Inlet the pronounced metamorphism found is the effect of dynamic metamorphism only. The relative sparseness of exposed intrusive masses, however, is in contrast to the widespread crystallinity of the schist, and more extensive bodies of intrusive rocks doubtless underlie the south end of the island at no great depth The limestone beds between Cape Lookout and View Cove and between Diver Islands and Eolus Point are believed to belong to the same formation. The limestone of the southern band is foliated, and that of the northern band is practically massive, indicating that the dynamic metamorphism decreased toward the north.

Chapin considered the limestone of the belt between Waterfall Bay and Grace Harbor a member of the Wales group, but Buddington questions this. The rock is foliated and metamorphosed but not more so than the similar bed of limestone extending from the Diver Islands to Eolus Point. The latter Chapin considered to be of Silurian age, as it occupies a synclinal relation with respect to fossiliferous Silurian slate. The limestone of Waterfall Bay Chapin considered to be overlain by the greenstone and limestone of the Wales group. The strike and dip of the greenstone would indeed appear to indicate that the limestone bears an anticlinal relation to it; but the lithology of the limestone and the presence of crinoids ally it to the limestone of Silurian age on Dall Island, and it has been mapped as such by Buddington. The extension of this belt of limestone to the southeast through Long Island and also the belt along the northeast coast of Long Island have been mapped as Silurian by Buddington, though originally assigned to the Wales group by Chapin. If the greenstone does overlie the limestone belt near Waterfall Bay it is probably of Devonian age and does not belong to the Wales group. The actual relations are not known.

The fossils collected from the rocks of the Wales group were examined by Edwin Kirk, who reports as follows:

15 ACh 150. East coast of Prince of Wales Island, 5 miles south of Chasina Point:

Organic remains are present, but it is impossible to determine what they are.

15 ACh 192. Lime Point, Prince of Wales Island:

Possibly fragments of coral but not determinable. Lithologic appearance like Silurian.

15 ACh 66. Cholmondeley Sound, first cove west of Cannery:

Crinoid columnals. Paleozoic.

The lithology and poorly preserved fossils are not diagnostic but suggest that some of the limestone intercalated with the greenstone schist is of Silurian age. The schist and the schist and limestone are pre-Silurian but are not lithologically similar to the known Ordovician beds and may be of pre-Ordovician age.

WRANGELL-REVILLAGIGEDO BELT OF METAMORPHIC ROCKS

CHARACTER AND DISTRIBUTION

A great belt of metamorphic rocks occurs adjacent to the Coast Range batholith. It includes injection gneiss; crystalline schist with interbedded marble or medium to coarsely crystalline limestone; schistose greenstone and green phyllite with interbedded black and gray sericitic slaty phyllite and, locally, sparse limestone and schistose chert; phyllite with interbedded black slate; and, intermingled in all to a minor or major extent, intrusive masses of quartz diorite (with variations toward granodiorite). These rocks are for convenience called the Wrangell-Revillagigedo belt of metamorphic rocks, in contradistinction to the Wales group of metamorphic rocks, which is restricted to Long Island and the southern part of Prince of Wales and Dall Islands.

The belt is in general narrower at the north, with relatively fewer masses of intrusive rock, and pinches out toward the northwest; in the vicinity of Thomas Bay and the Lindenberg Peninsula the number of intrusive masses is much greater, and their volume increases toward the southeast, where the belt is wider. The Coast Range batholith probably underlies the southern part of the belt more or less continuously at no great depth. The present surface relations are comparable to those that would appear if the batholith at the southeast end of the metamorphic belt had a highly irregular but gentle surface slope to the southwest beneath the belt.

At the south end of the belt in the vicinity of Revillagigedo Island and Bradfield Canal there is a width of 30 to 35 miles, measured across the strike, of intermingled schist, injection gneiss, and intrusive quartz diorite; near Wrangell there is 15 miles of phyllite, crystalline schist, and gneiss, with some intrusive masses of quartz diorite; along Thomas Bay, 6 miles of phyllite, schist, and gneiss, or, if the phyllitic rocks of the Lindenberg Peninsula are included, 20 miles. On the mainland the width of phyllite and crystalline schist, measured across the strike, is 15 miles in the vicinity of Port Houghton, 10 miles near Endicott Arm, 5 miles near Holkham Bay, 3 miles at Taku Inlet, and 2 miles in the Eagle River region.

Much of the western boundary of the Wrangell-Revillagigedo belt of metamorphic rocks is formed by the resistant Mesozoic greenstone, as along Revillagigedo Channel, Gravina Island, the west side of Cleveland Peninsula, the west side of Etolin Island, Glass Peninsula, Onslow Island, and Douglas Island. It is not, however, a natural boundary, for the contact type of metamorphism fades out gradually, though very irregularly, toward the areas with the least number of intrusive bodies. The irregularity is in part caused by the great differences in strength and character of yielding or response to stress of the very different lithologic units and by the localization of shear zones.

The rocks of the belt are the result of contact metamorphism on a regional scale combined with the effects of dynamic metamorphism, or intense stress. Rocks that have been mechanically metamorphosed and sheared and schist that has been dynamically metamorphosed under intermediate temperature are very common in the islands to the west of this belt of metamorphic rocks; but outside the belt highly crystalline schist and marble are restricted to local zones adjacent to intrusive bodies.

The crystalline schist of the Wrangell-Revillagigedo metamorphic belt comprises in general varieties of hornblende and feldspathic hornblende schist, micaceous quartz schist, garnetiferous quartz-mica schist, and quartz-feldspar schist. Sillimanitic schist is found occasionally. Garnetiferous, staurolitic, cyanitic, and ottrelitic phyllites are locally abundant.

The map of the southeastern part of the the Ketchikan district by Wright[56] does not discriminate between gneiss and schist; the boundary lines between these rocks as shown on Plate 1 of this report are therefore based merely on Wright's descriptions and on the general relation of the rocks to the number and volume of the intrusive masses.

[56] Wright, F. E., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pl. 2, 1908.

Injection gneiss forms a belt between the crystalline schist and the main batholith on Thomas Bay and to the southeast or is intermixed with the outlying intrusive masses in the southern part of the belt; but north of Thomas Bay it practically dies out west of the batholith and is restricted to bands within the batholith. On Port Snettisham the injection gneiss adjacent to the border of the batholith is only 600 feet wide, whereas on Thomas and Le Conte Bays and on Stikine River it is 1½ miles wide.

The veins associated with the belts of rocks that show varying degrees of metamorphism show a corresponding progressive change in general character as the batholith is approached. In the dynamically metamorphosed but relatively slightly recrystallized rocks in the Juneau and Funter Bay-Hawk Inlet gold belts and in the slate and schistose greenstone of the Prince of Wales Island belt the quartz veins are commonly milky, with some associated carbonates, and are in places metallized with sulphides or free gold or both. In the belt of phyllite the quartz veins are predominantly milky, with some carbonates, and only a few are metalliferous. In the crystalline schist the quartz veins are usually glassy and thin lenticular, and many of them form injection schist. In the belt of injection gneiss adjacent to the main batholith the veins or vein dikes are aplitic or pegmatitic, and oligoclase is one of their major constituents in addition to quartz and potash feldspar. The injection gneisses are thus mixed rocks consisting in part of igneous material and in part of recrystallized and altered sediments.

The predominant new mineral formed in the early stages of metamorphism is mica, with which are associated disseminated graphitic dust, and locally garnet and ottrelite. Andalusite is commonly associated with muscovite, which in part replaces it and is wholly restricted to local contacts of small intrusive bodies with slate.

The phyllite and crystalline schist consist of biotite, muscovite, quartz, cyanite, staurolite, garnet, sillimanite, and feldspar in the light-colored varieties and of hornblende, quartz, andesine, oligoclase, garnet, and calcite in the dark-colored varieties. The graphitic dust tends to be segregated in streaks, threads, clots, or lenses. Sillimanite occurs only in the crystalline schist where there has been intense metamorphism. Cyanite later in origin than the sillimanite is found occasionally. Cyanite, staurolite, and garnet occur predominantly as metacrysts but are in small part oriented parallel to the foliation. Biotite, muscovite, and hornblende are predominantly oriented parallel to the foliation but here and there, especially biotite, occur also as metacrysts. One specimen shows epidote in rods and grains contemporaneous with biotite and quartz and oriented parallel to the foliation. Magnetite and pyrrhotite are common accessory minerals and usually occur in irregular elongate blebs parallel to the foliation. Pyrite and magnetite also occur as disseminated crystals. The sulphides are in part later than the silicates and occur along fractures.

In the injection gneiss the graphite is in crystalline flakes intergrown with biotite or disseminated through the rock with orientation parallel to the cleavage. The aluminum silicate minerals, such as andalusite, cyanite, sillimanite, staurolite, and ottrelite, are wholly absent from the injection gneiss, presumably because of reaction with the permeating alkalic solutions. Rarely, adjacent to or within aplite veins the hornblende of the injected hornblende schist has been altered to pyroxene. Garnet, though one of the early metamorphic minerals to form, is found through the entire range of metamorphic environment and is even common in the form of disseminated crystals in the igneous rocks themselves where they have disintegrated and reacted with schist inclusions, though it may have persisted here as an unstable relic.

Tourmaline is sparse to abundant as minute crystals in the phyllite and crystalline schist but is practically missing from the injection gneiss, pegmatite, and igneous intrusive rocks. Apatite, on the other hand, is more abundant in the crystalline schist and injection gneiss than in the phyllite. The magmatic solutions appear therefore to have carried the tourmaline to greater distances than the apatite before depositing their load. The tourmaline occurs as perfectly formed crystals apparently replacing any or all of the other minerals and later than the foliation.

KETCHIKAN DISTRICT

Westgate [57] has given the following descriptions of the rocks and their relations at the south end of the Wrangell-Revillagigedo belt of metamorphic rocks:

> The following rock varieties occur within the metamorphic complex: Biotite gneiss, mica schist, quartzite and quartzitic schist, crystalline limestone, calcareous schist and gneiss, and phyllite. These are all metamorphosed sediments, so thoroughly metamorphosed that not a trace of original fragmental structure or of fossils has been found in them east of Behm Canal. Amphibolite is also included within the complex, although its relations to the other rocks are uncertain.
>
> A belt of gneiss and schist with interbedded crystalline limestone and quartzite lies between the belts of greenstone east of Revillagigedo Channel and the diorite of the Coast Range batholith. The western boundary against the greenstone is sharply defined. The eastern boundary against the diorite is much harder to draw because the transition is through a broad belt in which the diorite has penetrated the metamorphic rocks along their structural planes in broad dikelike bands, giving a lit-par-lit structure on an immense scale. As

[57] Westgate, L. G., The geology and mineral resources of the area east of Behm Canal (unpublished manuscript).

one passes from the metamorphic rocks northeast he goes from an area of essentially all metamorphosed sediments through a belt with an increasing amount of quartz diorite in bands between the successive strips of metamorphic rocks until he comes to an area where the rock is a quartz diorite but still contains isolated bands of metamorphic rocks. Still farther northeast is the pure quartz diorite. This progress is irregular rather than steady; along the Boca de Quadra the transition belt is 10 miles in width.

Biotite gneiss.—Biotite gneiss is the most common rock of the metamorphic complex. The most characteristic variety is a red biotite gneiss, usually well bedded and rusty in outcrop. Freshly broken pieces are reddish gray, fiue grained, and indistinctly bedded. Biotite is abundant in oriented separate flakes. The microscope shows quartz, plagioclase (oligoclase-andesine), no orthoclase, and chestnut-red biotite. Garnet occurs in irregular orbicular grains. Graphite is common with the biotite. Pyrite occurs abundantly in crystals filmed with hematite and has caused the rusty color of the weathered ledges. Apatite and zircon are also present as accessories. The average size of grain is 0.25 to 0.5 millimeter; the texture is mosaic; no granulation is found. Though the biotite gneiss shows no trace of original fragmental structure, its constant association with limestone and the general presence of graphite make its sedimentary origin reasonably certain.

With this red biotite gneiss are other varieties, less constant in mineral character. Some are more banded (possibly injection gneisses), carry muscovite or hornblende, and tend toward schist. Some of these, like the red biotite gneiss, carry abundant graphite.

Mica schist and phyllite.—Mica schist is one of the common types of the metamorphic complex. It ranges from nearly white to dark gray in color. Lenses and bands of quartz are in places abundantly developed in the structure planes of the rock. The most abundant minerals are muscovite, biotite, and quartz; hornblende and chlorite are less abundant. Garnet is common, and sillimanite, staurolite, pyrite, and black carbonaceous matter are also present. The rocks are closely folded at many places.

Along the west side of Kanagunut Island, at its north end, the schist gives place to black thin-bedded and evenly laminated phyllite. This is exceptional in the metamorphic complex.

Quartzite.—At several points in the general vicinity of Kah Shakes Cove beds of massive, nearly pure quartzite occur. The rock is light gray to white, glassy, with an indistinct cleavage marked with small amounts of sericite, green mica, and limonite. The thin section shows a mosaic of sutured grains of quartz as much as 1 millimeter in size and a few small flakes of white mica. No sand grains are recognized.

Besides the pure quartzite, rocks are found intermediate between quartzite and gneiss and schist—quartzose gneiss and schist.

Crystalline limestone.—Beds of crystalline limestone a few feet to perhaps several hundred feet in thickness occur within the metamorphic complex. They are most abundant in a belt which makes the shore of Revillagigedo Channel for 3 miles, beginning at a point 1½ miles south of Point Sykes. The belt bears inland and comes to the shore of Boca de Quadra at Quadra Point It is well developed on Kah Shakes Cove and farther south along Very Inlet. Beyond that it was not traced. The belt is not exclusively limestone but includes limestone in beds of such size and number that it can fairly be mapped as a limestone band. It is impossible to say to what extent the different limestone bands represent different beds and to what extent they are repeated by folding. Outside this mapped belt narrow bands of limestone are found at many places in the gneiss, even in the narrow bands of metamorphic rocks that exist as xenoliths cut in the granite. The rock in the ledge is a cream-colored coarse-grained rock; on the freshly broken surface it is white or gray-white, in places averaging a quarter of an inch in size of grain. The rock is quite pure and almost wholly without metamorphic lime silicates.

Calcareous gneiss and schist.—Calcareous gneiss passing into schist is associated with the limestone at Kah Shakes Cove and to the northwest, on the shore of Behm Canal. The constituent minerals are quartz, in places feldspar (usually plagioclase, though orthoclase occurs), calcite, muscovite, commonly chlorite, biotite, and hornblende. Zoisite and colorless epidote are abundant in grains and short columnar crystals. The accessory minerals that may occur are titanite, rutile, garnet, apatite, magnetite, pyrite, and zircon. The rocks are clearly metamorphosed calcareous sediments or impure limestone and mark a gradation from limestone into gneiss. In the field alternating beds of pure limestone and calcareous gneiss and schist are common.

Amphibolite.—Amphibolite is abundant in a belt which can be followed from Sitklan Island north-northeastward by Naket Inlet, Vixen Bay, Weasel Cove, and Badger Bay to the shore of Behm Canal, near the entrance of Smeaton Bay. Between Weasel Cove and Behm Canal the belt appears to separate into two, one of which comes to Behm Canal south of Point Nelson, the other east of Point Nelson in Smeaton Bay. The former is continued by amphibolite bands on the west shore of Behm Canal north of Smeaton Island.

Amphibolite does not constitute the whole of this belt but occurs in bands as much as several hundred feet wide in the schist and gneiss of the metamorphic complex and with the gneissoid diorite of the batholith. Four miles south of Point Sykes it is interbedded in limestone. It is dark gray to black, well bedded, much of it platy and breaking into thin slabs. The banding strikes north-northeast with the course of the belt and has commonly a steep eastward dip, though in places vertical or even steep west.

In hand specimens the amphibolite is dark gray to black and of fine grain (1 to 2 millimeters). It contains commonly hornblende, plagioclase (oligoclase-andesine), biotite, epidote, and quartz. Accessory minerals that may be present are apatite, magnetite, titanite, rutile, zircon, and pyrite. They are allotriomorphic granular in texture and show no evidences of crushing.

The amphibolite is older than the diorite, which cuts it in lit-par-lit fashion on both a large and a small scale. At places on Smeaton Bay alternating bands are only an inch or two in width. The diorite also cuts the amphibolite irregularly, producing a breccia of dark rock cemented by the diorite.

The relations of the amphibolite to the other members of the metamorphic complex are not clear. From its mineral character and general field appearance it is believed to be an igneous rock rather than a member of a sedimentary series. It is then intrusive into the metamorphic rocks. Whether it represents a distinct intrusion from the diorite or an earlier intrusion belonging to the general magmatic period of the diorite was not determined.

Along Ernest Sound and Bradfield Canal there are good exposures of the metamorphic rocks showing all gradations from slate and phyllite on the southwest to injection and relic gneisses on the northeast.

The western border of the belt is taken to be the highly schistose to massive greenstone of Lemesurier Point and Onslow Island. Between the diorite mass of Etolin Island and the quartz diorite of

Eaton Point there is a belt of phyllitic beds including sheared sandstone, phyllitic graywacke, and phyllite. Adjacent to the greenstone on Union Bay there are beds of slate with a 150-foot bed of limestone. The phyllite is gray, and much of it has a paper-thin fissility; it is cross crinkled and very susceptible to weathering and erosion. Near the pyroxenite and diorite mass on Union Bay there is a local contact zone of more intense metamorphism where the beds are severely contorted, puckered, sheared, and injected by aplitic veins. The sandstone is changed to mica schist, and calcareous nodules to banded zoisite and epidotic quartzite. Within the phyllite there is conspicuous evidence of isoclinal folding with very steep axes. Beds with garnet or biotite metacrysts are present but rare. Toward the Eaton Point mass of quartz diorite the phyllite shows the effects of sintering and baking and becomes harder, and many beds contain biotite metacrysts. Adjacent to the intrusive mass itself the beds are injected by abundant quartz veinlets.

Northeast of the phyllite is a belt characterized by crystalline schist and beds intermediate between schist and phyllite. This belt includes the beds between the quartz diorite masses of Eaton Point and Santa Ana Inlet, the borders of Brownson and Deer Islands, and the southern half of Wrangell Island.

Between Eaton Point and Santa Ana Inlet the rocks are predominantly quartz schist with intercalated layers and beds of cyanite schist. Thin layers of hornblendic quartzite and local beds of staurolite and garnetiferous schist are present. Muscovite eyes are abundant in much of the schist. On Deer Island the rock predominant around the quartz diorite mass is a quartz-mica rock intermediate between a phyllite and a schist with beds and layers of garnet-sillimanite-mica schist. The sillimanite crystals in many of the beds average an inch in length and are very conspicuous. A few of them are 6 inches or more in length. At Point Peters staurolite crystals are associated with the sillimanite. At the northeast end of the island zones several feet wide shot through with glassy quartz veins and knots are common, and at the southeast end many narrow pegmatite veins and sills of quartz diorite are intruded in the schist. Some of the veins are crumpled with the schist.

On the south end of Wrangell Island and along Zimovia Straits there are thick beds of quartz-mica phyllite and a series of thin-bedded quartz-mica phyllite interbedded with staurolitic phyllite. Along Zimovia Straits staurolite, cyanite, and cyanite-staurolite phyllite are interbedded with micaceous quartz phyllite. North of Deserted Village, where the phyllite abuts against a mass of quartz diorite, sillimanite schist is formed. Amphibole layers are common, and near intrusive masses the crystallinity is noticeably increased.

East of the belt characterized by beds intermediate between phyllite and schist, along Bradfield Canal as far east as Duck Island, there is a belt of crystalline schist, marble, and injection gneiss.

The marble and interbedded schist are exposed on the flanks of the nose of a northwestward-pitching overturned anticlinal fold whose axial plane dips steeply northeast. The marble is exposed on the shore of Humpback Bay, where it has a northwest strike; it appears again on Ham Island in Blake Channel, and extends to the east for several miles a little north of the shores of Bradfield Canal. Along Bradfield Canal as far east as the intrusive mass of Mount Kapho the predominant rocks are aplitic or pegmatitic quartzose micaceous or hornblendic injection gneiss with here and there sills of granodiorite. The rocks for several miles west of Duck Island consist dominantly of amphibolite injection gneiss, with associated quartz-mica injection gneiss, hornblende schist, thin beds of marble, and sills of granodiorite. The amphibolite injection gneiss ranges in composition from beds of hornblende schist or coarse amphibolite several hundred feet thick, with sparse pegmatite veins, to beds in which pegmatite veins form almost the entire rock, but beds intermediate in composition are the most abundant. The pegmatite veins at some places are as much as a score of feet in width and contain muscovite and biotite as accessories. The beds of marble range from several feet to a score of feet in thickness. The granodiorite sills are also injected by pegmatite and are locally garnetiferous as a result of assimilation. The gneiss has many bands which weather to a rusty color due to disseminated pyrite and pyrrhotite. The quartz-mica varieties usually have intercalated beds of hornblende schist or hornblende injection gneiss and marble.

At the head of Bradfield Canal, within the outer edge of the main batholith, is a belt of mixed gneiss with several thin beds of marble. The mixed gneiss consists of relic injection gneiss and thick sheets of quartz diorite. Rusty-weathering beds are common. The relic injection gneiss is the result of the almost complete disintegration of a belt of schist by intrusive pegmatitic material, so that only relics of the original matter are left. On some large surfaces a coarse breccia structure is very evident, yet the rock is almost wholly pegmatite, and only a ghost of the original blocks of schist remains to tell the story of their former presence. To the west of the belt of mixed gneiss the quartz diorite contains layers of gneiss and thin beds of marble. Where thus interbanded with sedimentary material pegmatite veins roughly parallel to the foliation of the quartz diorite are abundant. In masses of the quartz diorite that are more uniform, with a less pronounced gneissic structure, the veins of pegmatite are sparse and do not conform to the foliation but cut across and intersect at sharp angles.

VICINITY OF WRANGELL ISLAND

Along Stikine Straits, the north end of Wrangell Island, and Mill Creek, Virginia Lake, and Porterfield Creek on the mainland the increase in the intensity of metamorphism toward the Coast Range batholith is again well shown.

The beds at the northwest end of Etolin Island consist of black slate, sheared graywacke, and sheared to massive greenstone, produced largely through dynamic metamorphism. The effects of contact metamorphism are shown locally where intrusive stocks are present.

On the north end of Wrangell Island, from the cove north of Chichagof Peak on the west side around to the headland on the east side of the island that lies southwest of the mouth of Mill Creek on the mainland, the rocks forming the coast line comprise a series of recrystallized, more or less foliated, prevailingly gray sandstone, usually biotitic, with intercalated layers of black slate, much of which is ottrelitic. The quartzose beds are too much metamorphosed and recrystallized to be called sandstone, too micaceous and foliated and in places too impure to be called quartzite, and not so much sheared and recrystallized as the typical quartz schist farther east, nearer the mainland batholith. Some of the beds comprising Point Shekesti are typical micaceous quartz phyllite. Southward along Eastern Passage and Zimovia Straits the rocks show an increasing degree of metamorphism due to the presence of stocks of quartz diorite that probably form much of the interior of the island. Many of the quartzose beds were originally argillaceous, and some calcareous beds are intercalated within the series.

Along the west side of Wrangell Island the quartzose beds are usually fine to medium grained and 1 foot to 10 feet thick. There are also beds of slate that are usually not over several inches thick but may be several feet, with quartzose, highly biotitic layers. Intercalated calcareous beds weather with a characteristic rounded corroded surface.

In thin section quartz is seen to be the predominant mineral in the recrystallized argillaceous sandstone members. The quartz occurs in elongate grains in a matrix of very fine white mica, both minerals oriented parallel to the foliation. The amount of micaceous matrix is highly variable, depending upon the original argillaceous character of the rock. A little feldspar is commonly present as an accessory mineral. Biotite is very abundant in many of the beds and is especially prominent in the thin quartzose partings within the slate beds. It is uniformly disseminated through the rock as chunky equidimensional grains pleochroic from pale greenish brown to brown and bears the relation of a metacryst to the other minerals.

Black carbonaceous dust is abundant but more or less segregated in small lenticular areas. In the highly quartzose beds the quartz is in a very fine granular aggregate with a denticulate texture and local lenticles of coarser grain. Pyrrhotite is a sparse to abundant accessory mineral replacing the siliceous material in the form of small irregular grains elongate parallel to the cleavage. Small euhedral tourmaline crystals are a constant though sparse accessory mineral later than the other minerals. A trace of ottrelite or magnetite is present in some of the beds.

The slate has a dull black surface usually marked by the reflecting black cleavage surfaces of abundant disseminated ottrelite crystals. These range from 1 to several millimeters in diameter. In thin section the rock is seen to consist of an exceedingly fine aggregate of quartz and white mica thoroughly pigmented with disseminated black carbonaceous dust. There is a trace of small biotite metacrysts and a few small grains of pyrrhotite. The platy ottrelite crystals are in part parallel to the cleavage but for the most part oriented at all angles to the cleavage as replacing metacrysts. They are black and opaque in thin section because of the great quantity of included carbonaceous dust. A few are surrounded by a zone of clearer recrystallized quartz. A little tourmaline is present as a microscopic accessory constituent. Pyrrhotite also occurs as a thin film, surfacing fractures across the cleavage.

The rocks on the east side of Wrangell Island from Rock Point southeast along the coast for about 5 miles show a slightly greater metamorphism than those on the west side, although the fine-grained facies have not passed beyond the stage of slate. A characteristic specimen of the slate consists of black garnetiferous ottrelitic slate with thin partings of biotitic recrystallized sandstone. The ottrelite and garnet crystals are uniformly and abundantly disseminated through the slate and average about 1.5 millimeters in diameter. Pyrrhotite is locally an abundant accessory mineral. The cleavage surface of the slate here is not as dull as that of the ottrelitic slate on the west coast, but it is not as lustrous as a typical phyllite.

From the middle of the cove east of Babbler Point to the east end of Lake Virginia the rocks are predominantly gray micaceous quartz phyllite with thin black or mottled gray layers of hornblendic quartzite and quartzose hornblendic limestone from several inches to a foot in thickness and local beds of black ottrelitic phyllite and of dull dark-gray phyllite. Many narrow quartz veins and a number of narrow granite sills occur in these rocks.

The quartz phyllite is in part a thinly cleavable gray fine-grained rock with a conspicuous brown sheen from the mica which forms a more or less uniform coat over the cleavage surfaces though the individual flakes are indistinguishable or indistinct. A typical specimen in thin section is found to consist predominantly of quartz (average diameter 0.5 millimeter) with abundant brown biotite. Hornblende crystals oriented at various angles in the plane of the foliation are common as an accessory mineral. Magnetite grains are common, and there is a trace of garnet. The rock is pigmented with disseminated graphitic dust more or less segregated in streaks. In part the quartz phyllite is a similar fine-grained thinly cleavable rock with the brown biotite uniformly disseminated as abundant chunky metacrysts. Rods of tourmaline are found in these rocks, in places oriented at right angles to the cleavage.

The hornblendic layers are gray with disseminated black hornblende crystals or black hornblendic layers. They have a more massive appearance than the phyllite and are not so thinly cleavable. In thin section a typical gray specimen is found to be a calcareous hornblende quartzite with hornblende and quartz constituting the major minerals. The hornblende crystals are oriented in the plane of the cleavage. Calcite is an abundant accessory mineral, and there is a trace of feldspar. A specimen of the black phase is found to consist of alternating thin layers of highly hornblendic material and quartzose limestone. Both are black and thoroughly pigmented with disseminated carbonaceous dust.

Toward the southeast in the direction of the large masses of quartz diorite along Blake Channel, there is a marked increase in the degree of metamorphism. The phyllite passes into beds intermediate between phyllite and schist or into typical schist. In the vicinity of Madan Bay the beds are staurolite and muscovite-cyanite schist with interbedded quartz schist and a few thin layers of amphibolite. The beds of Port Madan itself are staurolite phyllite. The rocks along the east side of Bergs Cove and along Aarons Bay are very much plicated. Beds of marble, with many narrow quartz veins and considerably sheared, crop out on the west side of the bay. The predominant rocks are quartz-mica schist.

LE CONTE BAY

The shores of Le Conte Bay give a diagrammatic illustration of the change from phyllite to injection gneiss. A sill of porphyritic quartz diorite forms the north headland at the mouth of the bay. This is adjoined on the east by a belt of phyllite 1½ miles wide. On the western border of this belt the phyllite has a sheeny surface and almost parallel cleavage. On the south side of the bay the predominant rock is quartz phyllite with intercalated beds of crinkled black slate. The quartz phyllite is hard and tough when fresh, more like a micaceous quartzite, but on weathering becomes fissile.

To the east the phyllite is somewhat more crystalline and crinkled. The phyllite is adjoined by a belt of quartz-mica schist about three-quarters of a mile wide. On its eastern border the schist is intercalated with thin layers of marble and is penetrated by aplite and pegmatite veins, which still farther east become so numerous as to make of the schist an injection gneiss. The injection gneiss forms the belt adjacent to the Coast Range batholith. It comprises hornblende and biotite gneisses and is conspicuous because of the many rusty beds. The aplite and pegmatite also carries disseminated sulphides.

Quartz veining is abundant in both the phyllite and the schist. In the phyllite the quartz veins tend to occur along localized shear zones, whereas in the schist they occur as thin flat veinlets along the foliation planes and form what might be called a quartz injection gneiss. The quartz veins in the phyllite usually form a series of more or less parallel narrow veins, for the most part an inch to several inches wide but locally larger, with associated knots or lenses of quartz. Many of the quartz veins are themselves involved in folds.

THOMAS BAY

The inlet of Thomas Bay cuts across three different belts of rock, and two additional belts in the mountains on the north side of Cascade Creek were examined.

The first belt on the outer side comprises a series of crystalline schists, which are well exposed on the peninsula west of Ruth Island and along the west coast of Ruth Island itself. The rocks that form the peninsula are predominantly micaceous quartz schist with intercalated beds varying toward a quartzite on the one hand and toward a typical quartz-mica schist on the other. They show an increasing degree of crystallinity toward the east—that is, toward the main batholith. The beds along the southwest side of Ruth Island are rusty-weathering plagioclase-mica schist with accessory staurolite, cyanite, garnet, pyrrhotite, and pyrite. Tourmaline and apatite in perfectly formed small crystals are common to abundant accessories in these rocks and, with the pyrite and pyrrhotite and a few glassy quartz veins, appear to have been the only foreign materials introduced during the metamorphism.

The second belt is about 1$\frac{3}{5}$ miles wide at the head of the southern arm of Thomas Bay and about 4 miles wide northeast of Spurt Point. The thinning of the belt toward the southeast is due in part to the crosscutting of the quartz diorite mass on the east. The belt comprises a series of mixed rocks in part of igneous and in part of sedimentary origin. The rocks that form the north shore of the bay from the base of Point Vandeput almost to Wind Point, those that form the major part of Ruth Island, and those south of Cascade Creek in the south arm are predominantly hornblende plagioclase schist, much of it in various stages of injection and partial replacement by aplite veins or aplitic material and associated with narrow intrusive sheets of quartz diorite. Intercalated with the schist just east of the base of Point Vandeput, in the cove on the northwest side of Ruth Island, along the southeast shore of the northeast half of Ruth Island, and at intervals along the shore north of Cascade Creek are thin beds of medium-crystalline limestone. On Ruth Island the limestone is interbedded with fine-grained white quartzite resembling sheared and recrystallized chert and with intercalated hornblende schist. Blue-gray quartzite also occurs interbedded with hornblende schist overlying the series of beds of white quartzite and hornblende schist. Other common intercalated beds are, for the most part, aplitized mica schist with accessory graphite. Along the shore east of Spurt Point there are all stages of gradation between a schist composed almost exclusively of hornblende and a quartz diorite with accessory garnet. Along the west side of the north arm of Thomas Bay, from a point a short distance south of Wind Point to the quartz diorite belt, the rocks are interbedded garnetiferous quartz-mica schist or quartz-mica schist, with garnetiferous hornblende schist or hornblende schist. These beds are in all stages of injection or replacement by aplitic material or aplite veins and are intruded by sheets of quartz diorite. Many of these beds are impregnated with pyrite and pyrrhotite and weather to a conspicuous rusty-brown color. Many of them carry as an accessory mineral, graphite in crystalline flakes, conspicuous for its silvery appearance on the foliation planes. Quartz veins and veinlets are common in this belt of mixed gneisses. Shear zones shot through and through with quartz veins are also seen. The veins are in general composed of a glassy quartz characteristic of high-temperature veins. Many of the beds show small slips and slickensided surfaces along which mica has developed.

The third belt is the intrusive mass of quartz diorite, about 3 miles in width. The whole mass is more or less contaminated with inclusions, remnants, or assimilation products resulting from the breaking up or disintegration of the schist. Along the east side of the south arm of the bay from Cascade Creek north the quartz diorite contains narrow included blocks of the schist with intercalated beds of crystalline limestone. The eastern half of the belt is made up of quartz diorite with many to sparse stringerlike inclusions of gray schist, individualized bands or blocks of gray injection gneiss, and bands consisting of layers of schist disrupted and disintegrated into a host of small separated stringer-shaped inclusions. Locally what at first appears to be clean quartz diorite is found on closer inspection to be garnetiferous. Sparse inclusions are found in even the cleanest of the mass. A few dikes of white quartz diorite aplite cross the foliation.

The fourth belt, about two-thirds of a mile wide where examined in the mountains north of Cascade Creek, comprises alternating sheets of injection gneiss, injected and impure crystalline limestone, and sheets of granite. Both the gneiss and the limestone (dolomite in part) are broken up by granodiorite dikes, and locally the injection gneiss and granite form areas of breccia. The marble is predominantly rich in silicates, though a few thin beds of purer marble were seen. Tremolitic layers are common and occur in beds some of which are several feet thick. Some beds have a close meshwork of disseminated chondrodite. These may contain layers with abundant nodules of phlogopite mica associated with a few small octahedra of lavender-colored spinel. Green pyroxene is very common, disseminated through many of the beds or as masses of coccolite adjacent to injected pegmatite veins. Pegmatite veins are usually common, and locally quartz veins are abundant. The pegmatite veins usually contain abundant disseminated pyroxene resulting from assimilation of the limestone and locally a little titanite. Some of the limestone contains a little disseminated graphite and mica. Graphite occurs also as a local concentration in some of the pyroxene nodules. White plagioclase feldspar and epidote and nodules of garnet are abundant in some beds. Inclusions of limestone with their borders changed to masses of coccolite were noted in some sheets of the granodiorite.

The fifth belt, of unknown width, consists of a very coarsely porphyritic granodiorite.

The rocks that form the peninsula on the south side of Thomas Bay between Wood Point and the channel on the west side of Ruth Island are predominantly micaceous quartz schist, varying toward a micaceous quartzite on the one hand and toward a more typical mica schist or quartz-mica schist on the other. The beds show an increasing degree of crystallinity toward the east.

Two typical specimens taken from a place three-quarters of a mile east of Wood Point are described below. One is a medium-grained gray rock with a coarse foliation roughly parallel to a plane and fine brown mica flakes on the cleavage surfaces. In thin section the rock is seen to consist predominantly of quartz with abundant hornblende rods oriented parallel to the foliation, a little brown biotite, and accessory disseminated pyrite, magnetite, garnet, and apatite. The pyrite is in elongate irregular grains parallel to the foliation. The hornblende is faintly pleochroic pale to light green. Most of the quartz is in finely mashed laminae with a denticular texture and wavy extinction, but some is in narrow lenticles and layers of clear granular recrystallized quartz. The other specimen is a dark-gray garnetiferous, micaceous quartz schist with a roughly plane-parallel foliation. The cleavage surfaces have a conspicuous uniform sheen due to the mica, but only here and there is the mica distinguishable as individual flakes. In thin section the rock is seen to consist predominantly of quartz with disseminated lenticles made up of brown biotite and colorless muscovite with a little quartz. The micas are oriented at slight angles to the foliation in these lenticles. A little mica in the groundmass is oriented parallel to the foliation. Small garnets are common, forming metacrysts with tails of quartz. The rock is thoroughly clouded with disseminated dots of black carbonaceous material, which is particularly abundant in the biotite. Pyrrhotite is common as very much elongated grains parallel to the foliation. Apatite and plagioclase are accessory minerals. One small euhedral crystal of tourmaline is present.

Along the west side of the channel west of Ruth Island the rocks are more markedly crystalline and are locally closely crenulated. A typical specimen is a grayish-white micaceous quartz schist. The cleavage surfaces are marked by well-individualized flakes of brown biotite several millimeters in diameter.

The west side of Ruth Island is formed of rusty-weathering plagioclase-mica schist. Narrow glassy quartz veinlets, some with pyrrhotite and pyrite, are common locally, and the rocks are considerably more pyritic and pyrrhotitic than the underlying schist. In thin section the predominant constituent is seen to be plagioclase in grains elongate to the foliation. One typical specimen is a very closely foliated rock with a fine lenticular texture, the lenticles, about a centimeter in length, being set off by a wrapping of brown biotite or colorless muscovite. Abundant staurolite, cyanite, and garnet crystals are present. The staurolite, cyanite, brown biotite, and plagioclase are in part intergrown and belong to essentially the same period of crystallization; in part they succeed an earlier generation of brown biotite, muscovite, and quartz and contain inclusions of these minerals oriented parallel to the foliation. Small euhedral crystals of brownish-green tourmaline are abundant and replace each of the other minerals but more especially the biotite. The rock is full of disseminated black carbonaceous dust, in places oriented in a fine plicated schistose structure inclosed in the other minerals. Abundant small apatite crystals and a trace of very fine fibrous sillimanite are present. Another specimen consists of layers rich in plagioclase containing abundant inclusions of brown mica oriented parallel to the foliation, separated by highly micaceous laminae made up mostly of biotite but with muscovite common. The pyrite and pyrrhotite are in irregular grains much elongated parallel to the foliation.

Between Thomas Bay and Endicott Arm, for a distance of 40 miles or so, the Coast Range batholith changes from its prevailing northwest trend parallel to the formational strike to a more truly north-south trend and cuts across the strike of the formations at an angle of about 15° to 40°. As a result there is a change in the character of the same group of rocks as distance from the batholith increases. For example, the belt of injection gneiss adjacent to the main batholith on Thomas Bay appears to be represented on Port Houghton, 35 miles distant along the strike and about 5 miles away from the batholith, by a belt of garnetiferous quartz-mica schist, whereas on Hobart Bay, 10 miles farther along the strike and at least 10 miles from the batholith, the rocks are phyllite.

A belt half a mile to 2 miles wide characterized by the predominance of hornblende schist extends from Spurt Point, on Thomas Bay, northwest to Port Houghton, west of Walter Island Arm.

On Thomas Bay, in general, the penetration and replacement of the hornblende schist has been so complete that at many places it is only on a weathered surface that the rock in any way suggests the process of aplitic injection, and there only faintly. Locally the injection character is conspicuous and the narrow veins are well individualized. The schist as a rule has a well-developed cleavage roughly parallel to a plane. It is medium grained, with the hornblende oriented parallel to an axis. The garnets to a slight extent have grown by pushing aside the adjoining laminae, but to a greater extent they bear the relation of replacing metacrysts developed, or at least enlarged, at the time of the introduction of the aplitic material. The hornblende is commonly moderately pleochroic from light to dark olive-green, but may be pleochroic from deep green to blue to yellowish green. The plagioclase ranges from an andesine (Ab_6An_4) to an oligoclase-andesine (Ab_7An_3). The amount of plagioclase varies widely, depending in part upon the degree of aplitization. With increasing abundance of feldspar the rocks assume a gray color of much lighter tone than normally. Minor accessory minerals found in varying amounts in different specimens are brown biotite, quartz, epidote or pyroxene, resulting from the aplitic alteration of hornblende, pyrrhotite, pyrite, magnetite, ilmenite, apatite, and titanite. The feldspars and quartz show a conspicuously wavy extinction.

A very conspicuous rock developed locally as the result of aplitic injection of the hornblende schists crops out along the north shore of Thomas Bay east of the base of Point Vandeput and at the southern tip of Ruth Island. It is predominantly a coarse garnetiferous hornblende-plagioclase (Ab_7An_3) schist with variations across the strike which indicate an original bedded character. The hornblende crystals are prismatic, with a diameter of about 0.5 centimeter and a length of 1 to 2 centimeters, and are oriented parallel to an axis. They are inclosed in a meshwork of aplite that consists of plagioclase associated with a little quartz. The garnets are inclosed in the aplitic veinlets, and some at least are directly the result of the injection of the aplite. It is a common thing for a few of them to contain grains of pyrite or pyrrhotite. Minor accessory minerals found in varying amounts in the rocks are biotite, apatite, epidote, zoisite, pyrrhotite, pyrite, magnetite, and titanite. A few grains of staurolite were found in one thin section examined, which contained also an exceptional number of apatite crystals. The hornblende is pleochroic from deep green to blue-green to yellow-green ($\alpha=1.661$, $\gamma=1.677$).

Another rock is a black hornblende schist mottled with abundant disseminated small red garnets (2 millimeters) and intimately veined parallel to the foliation by paper-thin veins of glassy quartz intercalated between a medium-crystalline limestone below and an epidotic mica schist thoroughly injected by aplite above. Hornblende in long prismatic growth oriented parallel to an axis is the predominant mineral. The garnets are confined to the quartz veinlets. Magnetite in very long grains with irregular borders, oriented parallel to the roughly plane-parallel cleavage, is a common accessory. A few small apatite crystals and a trace of feldspar constitute the other minerals.

Another specimen is a hornblende schist without garnet but with about 20 per cent of plagioclase (oligoclase-andesine) replacing the rock in the form of veinlets and lenticles or disconnected incipient veinlets. Some of the hornblende is in an advanced stage of partial alteration and replacement by epidote, an unidentified high-birefringent aggregate, and an isotropic chloritic-appearing substance. The plagioclase bears a definite replacement relation to the hornblende. Traces of apatite, magnetite, and biotite are present.

The schist that is light colored on fresh surface is predominantly feldspathic, with abundant biotite and locally garnetiferous. In general it carries a higher percentage of sulphides, predominantly pyrrhotite, than the dark hornblende schist and weathers accordingly with a rusty-brown surface. Graphite is a characteristic accessory mineral that is nearly always present, in contrast to its almost complete absence in the hornblende schist, and it is conspicuous because of the silvery luster of its scales disseminated through the rock. Plagioclase feldspar ranging from oligoclase-andesine (Ab_7An_3) to andesine (Ab_6An_4) is the predominant mineral and seems to be mostly of aplitic origin. Quartz is a widely varying constituent, ranging from a minor accessory to considerably more than half the rock. Biotite is constantly present in abundant flakes and gives the characteristic foliated appearance to the schist. In thin section it is usually pleochroic from light yellowish brown to deep chestnut-brown, but a variety pleochroic from light to deep olive-green is also found. Orthoclase is present in some specimens but is usually absent. A specimen collected from one of the least-injected beds is composed of 54 per cent quartz, 20 per cent plagioclase, 9 per cent biotite, 6 per cent graphite, 6 per cent orthoclase, 5 per cent pyrrhotite, and a little accessory apatite; it is a graphitic, micaceous quartz-feldspar schist. The plagioclase feldspar ranges from an oligoclase-andesine to bytownite. Another bed which occurs intercalated within the hornblende schist and crystalline limestone series is an epidotic feldspar-mica schist. This rock consists of an intergrowth of plagioclase, biotite, epidote, quartz, and magnetite, named in order of abundance. The epidote is in long rods and rounded grains oriented parallel to the foliation. The magnetite is in perfect disseminated octahedra and in irregularly bounded grains. The biotite is pleochroic from pale yellowish olive-green to deep olive-green. The graphite is in crystalline flakes in part intergrown with the biotite and in part with the other minerals. Apatite is an abundant accessory mineral, and a trace of muscovite is present.

In other specimens the pyrrhotite occurs in small elongate grains associated with the graphite or in parallel intergrowths with biotite. A trace of zircon is seen occasionally in some of the biotite.

PORT HOUGHTON

The formation on Port Houghton consists of hornblende schist with intercalated beds of limestone several feet thick and a few beds of black slate or phyllite. The schist may vary widely in general aspect and character but is marked by the prevalence or dominance of hornblende as an almost constant accessory. It ranges from hornblendic, garnetiferous, muscovitic, or biotitic quartz schist to very dark hornblende schist with only a very little interstitial groundmass. Locally the crystals of hornblende may average an inch in diameter, but predominantly the rocks are medium grained. All show a highly schistose structure.

Plagioclase is variable in amount, and in the dominantly hornblende schist it is usually restricted to the interstitial groundmass, where it may serve as a matrix for radiating sheaves of hornblende crystals which have grown at an angle to the foliation. The plagioclase is for the most part clear and untwinned, but in part twinned; it was determined in three different specimens as an albite a trifle more sodic than albite-oligoclase (Ab_9An_1). Common accessory minerals in all the schist are biotite and calcite and, in minor amount, apatite, magnetite, epidote, and pyrrhotite.

Thin layers of limestone are here and there isoclinally folded in the schist, which, but for their presence, would show little or no evidence of such close folding.

Much of the hornblende is fibrous, the plagioclase may be crushed or show irregular extinction, and the quartz may exhibit wavy extinction as a result of pressure following the crystallization of the schist.

On the south side of Port Houghton, east of the belt of hornblende schist, there is a wide belt of garnetiferous quartz-mica schist, which is of a surprisingly uniform character and which forms the coast line from a point just west of Walter Island Arm eastward to a point within 2 miles of the bar at the entrance to the Salt Chuck. The beds strike northwest and, except for local folding, have a uniform steep northeasterly dip. The schist is exposed for a width of 6 miles, measured at right angles to the strike. Locally, sills of quartz diorite and dikes of aplite are intrusive in the schist, as in the vicinity of Walter Island Arm, and more rarely a few beds of the schist are intimately veined with narrow quartz veinlets. Layers of hornblendic quartzite as much as 6 inches thick are present in very minor amount in the schist.

The schist is very thinly cleavable, and its cleavage surfaces exhibit a bright brownish sheen and are studded with red garnets showing crystal faces. The garnets are prevalently about three-sixteenths of an inch in diameter but range generally from an eighth to a quarter of an inch and in local beds are as much as half an inch. In the prevalent type of richly garnetiferous schist the garnets form from 10 to 20 per cent of the rock by volume. Locally there are thin layers and beds composed almost wholly of granular garnet, which on weathering has a friable character.

In thin section the predominant mineral is found to be quartz, with garnet and brown mica as abundant major accessories. The quartz may be either granular or in elongate plates, oriented with their longer diameters parallel to the foliation. The mica is predominantly biotite, oriented with its longer diameters parallel to the cleavage. Muscovite is common but usually in minor amount. The garnets have for the most part been formed through a process of replacement, for the banding of the minerals is in general cut off sharply at their edges and the original puckered structure of the schist is still preserved as a relic structure in the garnets. The garnets have to some extent forced aside the adjoining laminae. Black graphitic dust is abundant more or less uniformly disseminated throughout the minerals of the schist. Tourmaline in crystal rods is a common minor accessory mineral, as well as pyrrhotite, which occurs in irregular-shaped grains, oriented with the longer diameter parallel to the foliation. In some beds staurolite, cyanite, or hornblende may occur as a minor accessory mineral.

The rocks forming the south and east sides of the Port Houghton salt chuck are almost uniformly rusty-weathering brown quartz-feldspar schist. In the northern part some aplitic injection is apparent, but usually the rocks do not show any banding. Their general strike is a little west of north and their dip from vertical to 50° W. In thin section they are found to consist predominantly of quartz and plagioclase (oligoclase to oligoclase-andesine), with orthoclase and biotite as major accessories. Garnet, muscovite, pyrite, magnetite, and apatite are common minor accessory minerals. Locally hornblende may be common.

Another belt of quartz-feldspar schist is found on Endicott Arm, about 10 miles from the head. The beds here are intimately injected by quartz lenticles, lenses, and veins. Beds of quartzite, in part chertlike, and hornblende schist are intercalated. Locally the schist consists of alternating thin layers of limestone, quartz, and mica schist. Most of the beds weather rusty.

About 1½ miles west of the bar at the head of Port Houghton there is a half-mile belt of a very peculiar calcareous hornblende schist, which weathers with a pockety cavernous appearance due to the solution of the limestone. Cherty quartzite beds with thin layers of limestone and quartz-feldspar schist are interbedded.

HOBART AND WINDHAM BAYS

A belt of phyllite is well exposed on Hobart Bay and on the west half of Windham Bay. It consists of interbedded dark and light silvery-lustered, sheeny crinkled phyllite, associated with sparse beds of muscovitic limestone and calcareous schist, which are better crystallized than the phyllite. Quartz, biotite, chlorite, sericite, and feldspar are common visible constituents. Hornblende is common in sparse layers. The phyllite on Hobart Bay is intimately veined with quartz, but in much of the belt on Windham Bay only a few strong quartz veins were observed. Masses of dark metadiorite (sills?) are abundant in the phyllite near the contact with the greenstone belt both on Hobart Bay and in parts of the belt on Windham Bay. Similar interbedded gray and black argillaceous phyllite is exposed on Sanford Cove, Endicott Arm.

HOLKHAM BAY AND TRACY ARM

Holkham Bay and Tracy Arm afford an excellent cross section of the Wrangell-Revillagigedo belt of metamorphic rocks, ranging from dynamically metamorphosed, highly schistose fossiliferous beds on Stephens Passage through beds of phyllite and schist to relic and injection gneisses occurring as bands within the western border of the batholith.

On the southwest there is a bed of phyllite and slate with sills and dikes of metadiorite about 2½ miles in width. This belt extends far to the northwest across Port Snettisham and Taku Inlet to a point about 10 miles north of Juneau and just south of Berners Bay, where it merges into a belt of schist adjacent to the batholith. North of Port Snettisham the belt narrows from 1½ miles to half a mile in width. This belt corresponds to the black slate band of Spencer.[58]

On Holkham Bay the beds consist of a series of interbedded whitish sericitic phyllite, green chloritic phyllite, and black argillaceous phyllitic slate, locally with dark-colored metadiorite sills or dikes. Adjoining these beds on the east is green chloritic phyllite with beds of intercalated argillaceous phyllite.

Normal black slate is not found in this area nearer than 5 miles to the batholith. Sheets of aplite are found up to a point 3 miles from the contact. Limestone 6 miles from the contact is highly schistose but not recrystallized.

Between the phyllite and the border of the batholith is a belt of schist 2 to 2½ miles in width. This belt comprises interbedded quartz-mica gneiss, hornblende schist, and a band of chloritic micaceous hornblende schist, all with sheared aplite sills. Adjacent to the batholith glassy quartz veinlets a fraction of an inch to an inch wide are abundantly injected parallel to the foliation, together with aplitic veins. Farther away local shear zones with quartz veins and bunches of quartz are common. Many of the beds weather rusty. The band of aplitic injection gneiss is not more than half a mile wide.

The east branch of Tracy Arm cuts across the Coast Range batholith at an angle of about 60° to its trend for 15 miles. The walls of the fiord here afford a most extraordinary opportunity to study the phenomena of reaction between the magma of the Coast Range batholith and the sediments which it has included and metamorphosed. Most of the rock in this belt is a shatter breccia consisting of quartz diorite and granodiorite with fragments of schist in various stages of assimilation. Many large belts of injection gneiss are also included. It is doubtful if there is exposed anywhere within this 15-mile belt an area as much as 10 feet square which does not contain at least one small inclusion. It seems probable that one-third of the batholith in this section is included country rock. All gradations between blocks of clean sediment without injection, injection gneiss, and reaction or relic gneiss are found. The only clean belt of quartz diorite

[58] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 17 1906.

is on the western border and is about 3¾ miles wide. Even this has abundant small isolated stringers of inclusions throughout, and near the contact these inclusions are common, probably amounting to several per cent of the rock. Pegmatite veins are noticeably absent in this belt of quartz diorite.

Relic or reaction gneiss, together with relatively clean sheets of quartz diorite and beds of gneiss and marble, forms a belt 2 miles wide east of the belt of relatively clean quartz diorite, and each of the other belts mapped as quartz diorite is in reality of this mixed character. The relic or reaction gneiss is mostly diorite or granodiorite with a ghostlike breccia or banded structure inherited from the blocks of sediment which have been incorporated as part of the rock through reaction with the magma. Much of the reaction appears to have been brought about by pegmatitic material, and this appears at many places as veins in the inclusions.

The injection gneiss consists predominantly of dark micaceous varieties with more or less pegmatitic injection. Hornblende, actinolite, and quartz schists are intercalated. Medium to coarsely crystalline limestone occurs for the most part as beds several feet thick in the gneiss, but beds of relatively clean marble as much as 100 feet thick are found. Bunches of silicates are common in the limestone; these include green pyroxene, red garnet, yellow chondrodite, scaly brown phlogopite mica, and rarely a little lavender-colored spinel.

JUNEAU DISTRICT

Spencer[59] has described the schist belt in the vicinity of Juneau as follows:

> Beds of quartz sand now indurated to quartzite and strata of limestone now partly changed to marble occur at different horizons, but the great mass of the series is garnet, mica, and hornblende schist, presumably derived for the most part from the crystallization of calcareous and argillaceous sandstones and shales. It has been proved that certain layers of hornblende schist are derived from gabbro rocks, such as are locally found in a relatively unaltered state.

Knopf[60] has described a belt of schist which lies between the slate-graywacke formation and the quartz diorite of the batholith in the Juneau district and ranges in width from a few hundred feet at Berners Bay to 2 miles at Mendenhall Glacier.

> The schists are most highly crystalline in the zone directly bordering the quartz diorite gneiss, but toward the southwest they grade through phyllites and biotitic slates into the clay slates and graywackes of the next adjoining

[59] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 16, 1906.

[60] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 20–22, 1912.

belt of rocks. * * * The schists comprise a variety of rocks, mainly of sedimentary derivation. * * * Biotite, garnet, and amphibole are the most common minerals of metamorphic origin that are easily distinguishable; * * * staurolitic and cyanitic schists are found locally. * * * Coarsely crystalline white limestone is interstratified with the schists in beds ranging up to 50 feet in thickness but is not particularly abundant and is usually restricted to the outlying masses of schist in the gneiss.

SCHISTOSE GREENSTONE AND PHYLLITE BETWEEN PORT HOUGHTON AND JUNEAU

A group of rocks consisting of schistose greenstone and green chloritic phyllite interbedded with black and gray sericitic slaty phyllite and sparse dolomite or limestone beds and schistose chert form the Robert Islands and Point Walpole at the entrance to Port Houghton, the outer coast between Port Houghton and Windham Bay, and several belts on the land between Windham Bay and Endicott Arm. A particularly large belt forms the Harbor Islands and the broad peninsula at the south entrance to Endicott Arm and extends northwest through the Snettisham Peninsula, Limestone and Slocum Inlets, and along the east side of Gastineau Channel, being here well exposed between Point Salisbury and Bishop Point.

Along the coast between Port Houghton and Windham Bay the group consists of interbedded schistose green hornblende porphyry, green schist with aphanitic texture, and black and light-gray phyllite. The green schist does not form the major part of the group of rocks but is characteristic of it. Some beds show conspicuous evidence of having once been fragmental. The fragments are felsitic in texture and andesitic. Pyrite and pyrrhotite are locally disseminated through the black phyllite, which weathers red more commonly than the light-colored phyllite. The group of rocks is excessively veined with quartz, which occurs as bunches, as numerous thin plates and lenticles, and sparingly as strong wide veins. All the quartz is glassy and is associated with varying amounts of calcite. Masses of dark metadiorite cut the beds. Locally the beds are veined and intruded by aplite sills and dikes, which are folded with the series, as are also many of the quartz veins. The beds show every evidence of intense folding and plication. Overthrust isoclinal folds that dip 35° to 40° NE. are evident everywhere.

Most of the Snettisham Peninsula except the eastern part is composed of schistose and phyllitic greenstone with intercalated beds of schistose limestone, black slate and phyllite, and sparse beds of schistose chert and conglomerate. The beds strike about northwest and dip northeast. At the south end of the peninsula the succession of beds from southwest to northeast is as described below. The lowest beds comprise interbedded schistose limestone, black slate, white chert, and a felsitic greenstone that appears to be in part a sheared amygdaloid with flattened calcite amygdules and is in part a yellowish-green chloritic epidotic schist. On the shore of the peninsula northeast of the Midway Islands there is a 100-foot bed of schistose limestone, with many layers full of corals or crinoids or both, of Carboniferous age. These beds are overlain by a thick series of schistose greenstone of felsitic texture. Part of this has a peculiar nodular or lenticular structure, as if formed from shearing of a fragmental rock; the matrix is similar to the nodules except that it is more sheared. Part of the greenstone is apparently mashed amygdaloidal andesite. About 2½ miles due east of Point Coke, at the point at the entrance to Tracy Arm, the greenstone is overlain by a bed of white limestone with intercalated layers of schistose white chert. This bed of limestone is lithologically identical with the Carboniferous limestone of Taku Harbor. It strikes northwest, dips 55° NE., and is overlain by beds of black phyllitic slate with similar strike and dip. The contact between the limestone and slate, however, is faulted.

At the north end of Snettisham Peninsula the cove east of Point Anmer is carved out of limestone with poorly preserved silicified fossils. These beds are underlain by interbedded schistose limestone and greenish-gray schist and are overlain by greenstone with intercalated beds of schist. Eastward, toward Snettisham, the beds are successively quartz-mica schist, schistose conglomerate that consists in part of chert pebbles, and green schist that contains lenticles of limestone and intercalated beds of schistose white chert and black slate. Large sheared coral heads occur in some of the beds of green schist. Some of the greenstone shows what appears to be a well-defined pillow structure. The series is lithologically similar to the Carboniferous beds of Windfall Harbor, on Admiralty Island. The limestone with Carboniferous fossils on Stockade Point, Taku Harbor, has previously been described.[61] It consists of thick, massive beds with rare layers of white chert. On the east this limestone is associated with black graphitic slate or phyllite and nodular limestone in a matrix of black bituminous limestone. On the south there are beds of fragmental schistose greenstone with associated black phyllite.

On the east side of Taku Harbor there is a series of green chloritic or calcareous phyllite with thin beds of limestone and white chert. On Limestone Inlet the greenstone volcanic rocks are more massive and consist of amygdaloidal rock and breccia.

[61] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 55, 1908.

AGE

The determination of the age of the Wrangell-Revillagigedo belt of metamorphic rocks is a very difficult problem. Along the coast between Prince Rupert and the mouth of Portland Canal Dolmage[62] maps it as the Prince Rupert formation, of Triassic or Carboniferous age. The Wrights[63] make the following statement with respect to the Ketchikan and Wrangell districts:

> In view of the comparatively weak paleontologic and stratigraphic evidence bearing on the precise age of these argillites and crystalline schists, it is possible that their period of deposition extended even beyond the Carboniferous period into the Triassic. * * * The evidence thus far gathered, however, indicates Carboniferous age for the greater portion of these crystalline schists and argillites.

Chapin,[64] mainly on lithologic and structural grounds but with some paleontologic evidence, has described the phyllite and crystalline schist with associated conglomerate and limestone on George Arm, Revillagigedo Island, as including both Carboniferous and Triassic formations.

Kirk found fossils that he identified as of Ordovician age in beds at Wrangell, but the organic traces are very imperfectly preserved and to the writer the identifications seem open to question.

Fossils identified by Girty as Carboniferous (lot 5138: *Batostomella?* sp., *Stenopora?* sp., and *Spirifer?* sp.) were collected by Buddington from schistose limestone associated with greenstone on the shore of the Snettisham Peninsula northeast of the Midway Islands. Carboniferous fossils (*Productus* aff. *P. gruenewaldti*) had previously been reported by Kindle from Stockade Point, on Taku Harbor. Eakin found Triassic fossils in the belt of slate east of Juneau. Martin has referred the greenstones or Gastineau volcanic group on the east side of Gastineau Channel to the Upper Triassic and the Thane volcanic group to the lower or Middle Jurassic (?). He refers the schist (Clark Peak schist) east of the slate and phyllite belt to the Paleozoic.

Buddington is of the opinion that the greenstone of the Snettisham Peninsula belt and its extensions to the northwest and southeast is largely of Carboniferous age and is to be correlated with a similar lithologic series of rocks exposed on the east side of Saginaw Bay, Kuiu Island. Both Triassic and Devonian rocks and perhaps some

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[62] Dolmage, Victor, Coast and islands of British Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept. for 1922, pt. A, pp. 9–34, 1923.

[63] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 56, 1908.

[64] Chapin, Theodore, The structure and stratigraphy of Gravina and Revillagigedo Islands, Alaska: U. S. Geol. Survey Prof. Paper 120, pp. 18, 90–91, 1918.

Jurassic may be associated with the Carboniferous in minor amount. North of Taku Inlet most of the greenstones may be younger, as suggested by Eakin and Spencer and by Martin.

On the west side of the south arm of Port Snettisham and the west side of Prospect Cove schistose conglomerate is interbedded with black phyllite. This conglomerate is lithologically similar to the conglomerate in the Jurassic or Cretaceous slate on the west side of Seymour Canal, Admiralty Island.

It seems probable that the Carboniferous and Triassic formations constitute a very considerable part of the Wrangell-Revillagigedo belt of metamorphic rocks, but that possibly beds as young as Cretaceous and as old as Ordovician are included. The areal geology and formational relations in the vicinity of Keku Straits, at the north end of the Kuiu Island, and the northwest end of Kupreanof Island (Tertiary formations excepted) seem to Buddington to represent an approximation to the original character and relations of these metamorphic rocks.

ORDOVICIAN ROCKS

A thick series of beds of graywacke with associated slate and locally with andesitic volcanic rocks forms most of Kuiu Island and a considerable part of Prince of Wales and the neighboring islands. The beds have heretofore been assigned wholly to the Silurian system, but the work done by the writer has shown that they are predominantly of Lower and Middle Ordovician age but also in part early Silurian.

PRINCE OF WALES AND NEIGHBORING ISLANDS

Character and occurrence.—At the south end of El Capitan Passage, north of Cap Island, there is a series of andesitic volcanic rocks 3,000 feet or so thick, overlain by about 1,000 feet of andesite conglomerate, in part with limestone cobbles and boulders. The conglomerate is of Silurian age, as some of the limestone fragments carry Silurian fossils. The greenstone volcanic rocks comprise porphyritic andesitic lava containing pyroxene phenocrysts, in part with pillow structure; andesite porphyry conglomerate, composed of fragments that are only slightly waterworn, or breccia; and some graywacke with associated slate. The graywacke and slate intercalated in the lower part of the volcanic series carry Middle Ordovician graptolites.

Fossiliferous slate of Ordovician age is interbedded with the andesitic volcanic rocks at the head of Van Sants Cove, Kosciusko

Island, and at the south end of a small island in Tonowek Bay, about 2 miles southwest of the west headland of Nossuk Bay. Beds carrying graptolites of Ordovician age are found also on Thorne and Stevenson Islands, the southwest side of Heceta Island, San Fernando and Lulu Islands, and Thorne Bay and Klawak Salt Lake, Prince of Wales Island.

The Ordovician beds on the northeast side of Prince of Wales Island consist predominantly of indurated graywacke, prevalently in beds 1 foot to several feet thick with slate partings, but some of the beds are so uniform in character that the bedding can not be distinguished, even in large outcrops. In part the formation consists of thin-layered graywacke with slate laminae in zones interbedded with the thicker-bedded phases. Fine conglomeratic and gritty layers are common locally in the graywacke, and, sparingly, beds of conglomerate. Calcareous pockets are common in some of the beds of graywacke. Along the shores of the arm northwest of Thorne Island the formation consists predominantly of black slate with thin quartzitic laminae. Limestone nodules are common locally in these beds, and beds of schistose brecciated limestone as much as 20 feet thick occur. On Stevenson Island slate predominates over graywacke, though the beds of graywacke are as much as 40 feet thick. On the east side of the island the beds are fractured and faulted on a minute scale, and breccia zones with thin calcite veinlets are common. Rarely a zone of thin-layered black chert is intercalated in the graywacke-slate series. The predominant fragments in the intercalated conglomerate are limestone, slate, felsite, and andesite porphyry.

Examination of typical specimens of these rocks with the microscope shows a common type to consist predominantly of more or less angular fragments of plagioclase, associated with a little quartz, orthoclase, bits of volcanic rock, including felsite and andesite with very irregular borders, and sparse particles of limestone and chert. The groundmass is in places slightly calcareous. Another less common type lacks quartz but contains plagioclase, abundant fragments of pyroxene, and bits of lava that is for the most part of andesitic type.

The northwest shore of Klawak Salt Lake and the island barrier at its mouth consist of thin-layered black chert with partings of black graphitic graptolitic slate, nonfossiliferous black slate, and intercalated beds of dense banded green quartzitic graywacke and quartzite.

Fossils.—The age of the beds on Prince of Wales and the neighboring islands is based on the dozen collections made by Buddington and identified by Rudolf Ruedemann, of the New York State Geological Survey. The specific identifications are given in the following table:

Ordovician graptolite fauna from Prince of Wales and neighboring islands

[Determinations by Rudolf Ruedemann]

	Lower Ordovician			Horizon undetermined		Normanskill				Trenton	
	1995 (1543)	2001 (2052)	2004 (2164)	2003 (2146)	1997 (1796)	2000 (1904)	2002 (2116)	(658)	(706)	(1076)	1996 (1671)
Diplograptus (Orthograptus) calcaratus cf. var. incisus							×				
Diplograptus (Glyptograptus) teretiusculus var. euglyptus							×				
Diplograptus euglyptus						×					
Diplograptus amplexicaulis											×
Diplograptus inutilis	×										
Climacograptus bicornis var. tridentatus						×	×				
Climacograptus bicornis									×		
Climacograptus pungens	×										
Climacograptus sp.				×							
Climacograptus sp. cf. C. eximius or C. pygmaeus										×	
Climacograptus n. sp.					×						
Leptograptus sp.					×						
Glossograptus cf. G. dentatus		×									
Glossograptus cf. echinatus	×										
Didymograptus sp.		×									
Didymograptus sp. cf. D. nitidus			×								
Didymograptus sagitticaulis							×				
Tetragraptus cf. T. quadribrachiatus			×								
Phyllograptus? cf. P. anna		×									
Dicellograptus sextans							×				
Dicellograptus cf. D. gurleyi						×					
Retiograptus geinitzianus						×	×				
Cryptograptus tricornis cf. var. schäferi						×					
Cryptograptus tricornis							×				
Hallograptus mucronatus cf. var. nobilis							×				
Dicranograptus cf. D. nicolsoni								×			
Dicranograptus sp.							×				

1995 (1543). Kosciusko Island, head of Van Sants Cove; black slate interbedded with greenstone volcanic rocks; last Deep Kill zone, top of Beekmantown or lower Chazy.

2001 (2052). Four localities on the islands forming the barrier at the mouth of Klawak Salt Lake; thin-layered black chert with black slate laminae; third Deep Kill zone, upper Beekmantown.

2004 (2164). South side of Lulu Island at west end of Port Real Marina; black chert with slate laminae.

2003 (2146). South end of San Fernando Island, about 1½ miles north-northwest of Point Amargura; black chert with slate laminae; Ordovician, horizon undetermined.

1997 (1796). South end of small island in Tonowek Bay about 2 miles southwest of the west headland of Nossuk Bay and a little north of true west of large island with hill (altitude 430 feet); graptolitic slate and graywacke interbedded with pillow lava; Ordovician.

2000 (1904). Cove about 3 miles northwest of Point Desconocida, Heceta Island; interbedded black slate and graywacke; Normanskill.

2002 (2116). Northwest side of Klawak Salt Lake, about 4 miles from the head; Normanskill.

(658). About a quarter of a mile southwest of the northeast tip of Thorne Island off the northeast coast of Prince of Wales Island; late Normanskill or younger.

(706). Point one-fourth mile west of Point Barnes, Stevenson Island; interbedded slate and graywacke; Normanskill.

(1076). East headland of cove about the center of the southwest side of the northwest arm of Thorne Bay, Prince of Wales Island; probably younger than Normanskill.

1996 (1671). El Capitan Passage, islets 2 miles west of Hub Rock; graywacke and black slate intercalated in andesitic volcanic rocks; Trenton.

Kirk[65] has reported supposed Ordovician graptolites in the slate and phyllite near Wrangell, as follows:

> On the point forming the south side of Wrangell Harbor graptolites were found that seem to fix the age of this Wrangell series. The graptolites are found both in slate and schist. The slate specimens are unrecognizable unless one knows they are graptolites to begin with. The specimens occurring in the schist, though badly preserved, are easily recognizable as graptolites, and the generic affinities of one individual may be determined with a fair degree of certainty.
>
> The specimen of chief importance and interest is referred with little doubt to *Tetragraptus*. It is very like a large species known in the early Ordovician of Idaho. Other specimens not so well preserved strongly suggest *Phyllograptus*. These fossils clearly point to the Beekmantown age of the sediments.

Kirk's determination thus suggests that the fauna of the beds near Wrangell is older than the fauna of Prince of Wales Island. These apparent organic structures are so poorly preserved, however, that their determination is open to serious question.

KUIU ISLAND

Most of Kuiu Island except the northeast part is formed of beds of graywacke and slate that lithologically resemble the known Ordovician and early Silurian beds of Prince of Wales and adjoining islands. They underlie greenstone-limestone conglomerate belonging to the lower part of the upper Silurian section. No fossils have been found in the graywacke or slates of Kuiu Island and their age is unknown. They are possibly mostly Ordovician, with some associated lower Silurian beds in locally infolded synclinal troughs.

The Kuiu Island beds consist predominantly and characteristically of fine to coarse grained pale-green to whitish-gray graywacke in beds 1 foot to 10 feet thick, with dark-gray slate partings. Intercalated in the graywacke are zones of interlayered limestone and slate, or slate and graywacke, or limestone, slate, and graywacke. In the thin-layered limestone-slate beds the limestone layers are an inch or less thick and the slate a fraction of an inch thick. Fine conglomeratic beds several inches thick are common in the gray-

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[65] Kirk, Edwin, An Ordovician fauna from southeastern Alaska [abstract]: Geol. Soc. America Bull., vol. 29, pp. 143–144, 1918.

wacke, and rarely a bed several feet thick occurs. Black impure limestone occurs sparingly in beds as much as 25 feet thick; also black graywacke. Rarely beds of thin-layered black chert are intercalated.

The graywacke is usually fractured on a minute scale, and the thin-layered zones are crumpled and plicated. Faults of small displacement are common. The beds are highly indurated and brittle. Owing to the fragmental character of the rock, a fine to coarse hackly surface often results from weathering. The weathered surface is usually brown, owing to the oxidation of disseminated particles of pyrite, or pale greenish gray where smoothed and polished by wave action.

On Reid Bay the graywacke is in beds 9 inches to 6 feet thick, commonly between 1½ and 2½ feet, with black slate partings a fraction of an inch to an inch thick. The slate weathers to a reddish hue. Along Affleck Canal and Port Beauclerc the beds are several feet to 10 feet thick with a few fine conglomeratic layers. In part the graywacke is uniform, with only scattered calcareous pockets. In part it is marked by layers of calcareous lenses, which in places grade into calcareous layers an inch or so thick and an inch to several inches apart.

The beds of thin-layered limestone, slate, and graywacke have at many places been infolded with the more competent thick-bedded graywacke. Many of them are isoclinally folded, plicated, overthrust, and brecciated. Locally they have been completely crushed to a fault breccia or even compressed to a schistose aggregate composed of eyes of limestone an inch to several inches in length in an argillaceous matrix. As a rule the thin beds have a much steeper dip than the graywacke. Where least disturbed, the beds range from several feet to 100 feet or more in thickness, but where folded they have a very much greater thickness as a result of duplication. The individual layers usually range from a fraction of an inch to several inches in thickness.

The limestone is dense to very fine grained and nonfossiliferous; it is in part light blue-gray on fresh surface, weathering white, and in part dark gray to black. The slate is black, locally weathering with a reddish hue. The graywacke is similar to that of the thick-bedded phases.

The coarser graywacke is seen in the hand specimen to be composed of fragments of dense felsite, chert, black slate, graywacke, limestone, and particles of plagioclase, pyroxene, hornblende, orthoclase, and quartz. Felsite and plagioclase fragments are most abundant.

The felsite fragments are angular and pearl-gray or pale greenish gray to white, weathering white. In the hand specimen they are distinguished with difficulty from the chert fragments but in thin section they are found to consist almost wholly of abundant microlites of plagioclase in a microcrystalline groundmass. Rarely fragments are found which appear to be composed of quartz and feldspar. The plagioclase laths are commonly in flowage alinement but occur also in crisscross arrangement. The large plagioclase fragments in the graywacke are oligoclase-andesine, and the angle of extinction of the microlitic feldspars in the felsite indicates that they are similar. Chert and slate fragments are next in abundance to the felsite and plagioclase. Limestone particles are practically everywhere present though locally sparse. The particles of pyroxene and hornblende are fresh and angular; rarely an almost euhedral crystal of hornblende is present. The pyroxene is more common than the hornblende, but both are subordinate in amount. Orthoclase and quartz occur only as minor accessory minerals.

The character of the fragments and their subangular to angular shape suggest that the graywacke is composed of more or less waterworn volcanic tuff.

On Reid Bay and extending southeast to Sumner Island there is a synclinal trough of Silurian volcanic and sedimentary rocks overlying the graywacke series. On Edwards Island and along the southwest side of Port Beauclerc there is a basin of similar Silurian beds. The Silurian age of these beds is definitely proved by their local association with beds of limestone that carry Silurian fossils and by the presence of Silurian fossils in boulders in the conglomerates. There is no difficulty in distinguishing the characteristic graywacke of Ordovician (?) age from the typical Silurian beds; but between the two is a series of beds which are usually highly deformed, with structural relations obscured. They consist of thin-layered limestone with layers of slate and graywacke and locally with schistose beds of breccia or conglomerate.

In the narrows at the entrance to the salt lake at the head of the Bay of Pillars thin-layered argillaceous and siliceous limestone overlies the graywacke, and on the inner side of the narrows the limestone is in turn overlain by coarse conglomerate. The thin-layered limestone resembles certain beds of the Silurian and is probably of Silurian age.

SILURIAN ROCKS

DISTRIBUTION

Silurian beds have a wide distribution throughout the Alexander Archipelago and in the vicinity of Glacier Bay. They are exposed on the flanks of anticlinal arches or within subordinate synclines in anticlinoria of Ordovician formations. They comprise beds of widely varying character, possibly 14,000 feet in total thickness. The lowest formation of the system appears to be a series of interbedded black slate and graywacke with sparse limy layers and conglomerate beds. This formation is indistinguishable lithologically from the Ordovician beds, but the slate carries graptolites identified by Ruedemann as of lower Silurian age. Overlying these beds are, in succession, a series of interbedded andesitic volcanic rocks and conglomerate composed of lava and limestone; interbedded limestone and conglomerate or limestone with locally a little conglomerate; shale; and graywacke or graywackelike sandstone. In general the graywacke is composed of particles of rock similar to the kinds that form the pebbles and cobbles in the conglomerate but in a more finely comminuted state and associated with a considerable percentage of plagioclase, potassic feldspar, and quartz. The limestone and higher formations are not older than late middle Silurian, according to identifications of fossils made by Kirk.

On Dall Island Silurian formations occupy practically the whole area between the Diver Islands and the small cove north of Cape Augustine and between Breezy Bay and Coco Harbor. Buddington believes that the belt of limestone between Waterfall Bay and Grace Harbor is also of this age. The Silurian rocks exposed here consist of a lower part made up of dark-gray to black slate with thin calcareous or siliceous layers and sparse intercalated graywacke and thin limestone; and an upper part of white limestone, estimated to be 2,000 feet thick. Graptolites identified by Ruedemann as of lower Silurian age were found by Chapin in graphitic slate at View Cove and by Buddington in slate on the north arm of Sea Otter Sound.

On the northeast end of Forrester Island there is a narrow fringe of conglomerate of Silurian type bordering intrusive granodiorite.

On Long Island, in Cordova Bay, there are two belts of Silurian limestone. It is probable that a part of the Wales group of metamorphic rocks belongs to the Silurian system.

Kosciusko, Heceta, Tuxekan, Orr, and Marble Islands consist for the most part of thick massive Silurian limestone, which in general dips in toward Davidson Inlet and Sea Otter Sound and thus forms the rim of a great major synclinal basin, which is, however, modified by many minor folds. The section of the Silurian exposed around the borders of this basin is very much more complete than that on Dall Island.

Silurian beds form much of the northern half of Prince of Wales Island and are well exposed on the Kashevarof Islands on the nose of a plunging anticline whose core is composed of Ordovician beds. On Kuiu Island they are exposed in several narrow synclinal troughs, as along the west side of Port Beauclerc, in a belt extending northwest from Summer Island, along the southwest side of Saginaw Bay, and at the narrows on the Bay of Pillars. They are also exposed on Tenakee Inlet and Freshwater Bay, Chichagof Island, and around Glacier Bay on the mainland.

If all the beds which on faunal evidence are assigned to the Silurian have been correctly identified, then the Silurian system comprises the most heterogeneous and the thickest set of rocks, about 14,000 feet, in the geologic column of southeastern Alaska.

LOWER SILURIAN SLATE AND GRAYWACKE

The lowest beds of Silurian age are exposed on the southwest side of Heceta Island, the north end of Lulu Island, the east side of Noyes Island, between Cape Augustine and Diver Islands and on View Cove, Dall Island, and on Kassa and Klakas Inlets, Prince of Wales Island.

The predominant beds of this formation consist of dark to black graphitic slate with interbedded graywacke and some associated limy layers and sparse conglomerate. On the north end of Lulu Island layers of slate carrying lower Silurian graptolites are intercalated in conglomerate that contains pebbles of slate, diorite, rhyolite, and limestone. On Dall Island rocks assigned to the lower Silurian form the coast line from the first cove north of Cape Augustine north to the limestone belt of the Diver Islands. This belt extends across to View Cove on the east side of the island but pinches in this direction. The beds consist of dark-gray to black slate, thin bedded, with siliceous or calcareous layers and with sparse intercalated thin limestone. Graywacke is present but sparse. The predominant rock is slate. Slickensided graphitic surfaces are exceedingly abundant. At the mouth of Devils Lake and other places there is several hundred feet of limestone with sparse intercalated beds of black slate.

The age of these rocks is based on graptolites collected by Buddington and identified by Ruedemann and on graptolites collected by Chapin and identified by Edwin Kirk. Chapin found graphitic slate with locally abundant graptolites at Klakas and Kassa Inlets on the west coast of Prince of Wales Island and at View Cove on Dall Island. The fossils from Kassa Inlet (17ACh124) were identified by Kirk as *Monograptus* sp.

Graptolite fauna of lower Silurian age from southeastern Alaska

[Determinations by Rudolf Ruedemann]

	2006 (2345)	2005 (2207)	1999 (1903)	1998 (1902)	2070 (3072)	2071 (3073)
Monograptus?				×		
Monograptus aff. M. raitzhainensis			×			
Monograptus n. sp. aff. M. clingani	×					
Monograptus n. sp. aff. M. undulatus						×
Monograptus n. sp. (fragment)	×					
Monograptus priodon					×	×
Orthograptus sp				×		
Climacograptus sp				×		
Mesograptus sp. cf. M. modestus		×				
Cyztograptus sp. (fragment)			×			
Diplograptus sp. cf. D. (Orthograptus) cyperoides					×	

2006(2345). East side of Noyes Island, about 2 miles southwest of Point San Francisco; interbedded graywacke, black slate, and sparse intercalated limy layers and nodules; Silurian (lower).

2005(2207). Lulu Island, north end, opposite Marabilla Island; thin slate layers intercalated in conglomerate; probably Silurian (near base).

1999(1903). About 1½ miles southeast of White Cliff, Heceta Island; interbedded black slate and graywacke; Silurian (lower).

1998(1902). Dead Tree Point, about 3 miles south of Cape Lynch, Heceta Island; from slabs of black slate occurring as fragments in a conglomerate at the base of a thick Silurian limestone formation; early Silurian (?).

2070(3072). Dall Island, Sea Otter Harbor, near head of north arm on north side; poorly preserved graptolites in slate.

2071(3073). Dall Island, Sea Otter Harbor, south side of north arm in cove north of small island; finely preserved graptolites in slate; these graptolites allow no closer correlation than that they belong to the Clinton of North America and the Llandovery of Great Britain.

VOLCANIC ROCKS AND CONGLOMERATE

The next younger formation is predominantly volcanic and conglomeratic. It is well exposed in narrow synclinal troughs on Kuiu Island; on Prince of Wales Island at Labouchere Bay, Port Protection, the west side of Exchange Cove, and Thorne Bay; and on the Kashevarof Islands. Locally it is found on San Fernando Island, at the south end of El Capitan Passage, on the north end of Cap Island, and on some of the adjacent northern islands. It is believed to be exposed also at other localities. The volcanic rocks on the west side of Van Sants Cove, Kosciusko Island, are probably in part at least of Silurian age.

At many places this formation is easily confused with the very similar Devonian or Ordovician volcanic rocks unless structural or faunal evidence is available to differentiate them.

This formation has not been recognized in contact with the lower Silurian graywacke-slate series. At some places it is definitely overlain by upper Silurian limestone, but the nearest identified and underlying formation is the graywacke-slate series or volcanic rocks of the Ordovician. Part of the volcanic material has probably been derived from erosion of the Ordovician volcanic rocks. The position overlying the lower Silurian graywacke-slate series assigned to it in the stratigraphic sequence is based in part on paleontologic evidence.

The formation consists chiefly of volcanic rocks and of conglomerate composed of lava pebbles. In one locality it may consist predominantly of lava flows; in another exclusively of conglomerate composed of lava pebbles, and in another of both lava and conglomerate. The beds of conglomerate resemble those at the base of and intercalated in the limestone of the overlying formation.

Several different types of rock are comprised in the formation, including the following:

1. A conglomerate composed almost wholly of well-rounded andesite or andesitic porphyry cobbles and boulders; the matrix may be calcareous, and lenses of limestone are intercalated, but limestone cobbles are sparse.

2. A conglomerate composed almost wholly of limestone cobbles or boulders in a limestone or andesitic tuff-like matrix; this type is rare, but beds 100 feet thick are found.

3. Peculiar conglomerates intermediate between 1 and 2, consisting of pebbles and cobbles of andesite and limestone in a greenish tuff-like matrix.

4. A homogeneous-appearing andesitic rock composed of fragments of andesite in a matrix of the same material; the structure, which is apparently that of a conglomerate or waterworn breccia, can be distinguished only on favorable surfaces.

5. A uniform hornblende andesite porphyry with conspicuous phenocrysts and andesite with small phenocrysts of plagioclase or pyroxene; these form flows and locally show pillow structure.

6. Sparse layers of slate, beds of graywacke, and lenses or beds of limestone as much as 100 feet thick.

Rarely cobbles of diorite or of gray and red felsite are found in the conglomerate. Fragments of slate are locally abundant in some of the finer-grained beds. Rarely, also, the volcanic rocks consist of rhyolite flows and breccias, as at Sarheen Cove, El Capitan Passage. The limestone pebbles, cobbles, and boulders of the conglomerates tend to weather out and leave a characteristic pockety, openwork structure. (See pl. 17, *B*.)

The limestone fragments are usually of a dense-textured limestone typical of the Silurian, and many carry fossils of Silurian age. The fossils are the same as those from the overlying limestone. It is therefore believed that the limestone conglomerates are intraformational and that the limestone fragments are of practically the same age as the volcanic fragments. Vertical movements of the sea bottom, perhaps local, must have accompanied the volcanism and resulted in contemporaneous erosion and submarine slumping of slightly compacted fine lime muds. A part of the volcanic material, at least, must have been erupted from central volcanoes, which were built up above the surface of the ocean and were thus subject to erosion.

LIMESTONE AND CONGLOMERATE

The succeeding formation consists of a very great thickness of limestone with local thick lenses of conglomerate. It is economically important because of its present and potential value as a source of limestone and some marble.

It forms a belt from Breezy Bay to Diver Islands from View Cove almost to Cape Lookout, and from a point opposite Howkan to Waterfall Bay on Dall Island. On Long Island, in Cordova Bay, it forms two belts. Heceta, Tuxekan, Orr, Marble, Eagle, Owl, Hoot, White Cliff, and Kosciusko Islands consist almost wholly of this formation. The east side of Tuxekan Passage from Naukati Bay to Sarkar Cove, El Capitan Passage from Sarheen Cove to El Capitan, the Mount Calder Range running northwest from Calder Bay through the Hole in the Wall to Labouchere Bay, a part of Port Protection, several miles of coast east of Point Baker, Strait Islands, Red Bay, and the coast for several miles to the west, the northern islands of the Kashevarof group, including Bluff, Shrubby, and Bushy Islands, the west side of Exchange Cove and the headland to the north, Prince of Wales Island, are all made up of limestone. On Kuiu Island Beauclerc Peak and the mountain ridge along the southwest side of Saginaw Bay consist of Silurian limestone. On Chichagof Island the marble of Basket Bay, Tenakee, and Freshwater Bay is probably in the same formation. In Glacier Bay a great range of coarsely crystalline upper Silurian limestone runs through Willoughby and Drake Islands and the east side of Rendu Inlet. These belts comprise most of the known Silurian limestone, but many other small areas have been observed, and there are very probably others not yet known.

The limestone-conglomerate formation appears locally to overlie the volcanic rocks conformably. In many places the basal part consists of conglomerate of lava boulders and interbedded limestone and thus grades downward into the conglomerate and volcanic formation; in other places the limestone appears to rest directly on the volcanic rocks, as at Labouchere Bay. In yet other places, owing to possible faulting or erosion, the limestone lies in an unconformable relation directly against an older graywacke formation, as southwest of Saginaw Bay, Kuiu Island, and on the southwest side of Heceta Island. On View Cove and Sea Otter Harbor, Dall Island, the limestone overlies the lower Silurian slate and graywacke.

At Dead Tree Point, about 3 miles south of Cape Lynch, Heceta Island, limestone directly overlies conglomerate. The conglomerate consists of limestone cobbles and boulders; of flakes, slabs, and chunks of black graptolitic slate and graywacke; and of cobbles of andesite porphyry, granite, diorite, and rhyolite. Some of the limestone cobbles carry Silurian fossils, and the slabs of slate carry lower Silurian graptolites. This conglomerate, therefore, must mark an unconformity. On Cap Island, El Capitan Passage, about 1,000 feet of conglomerate of well-rounded andesite boulders intervenes between the limestone and the volcanic rocks. On the Kashevarof Islands and likewise north of Sarheen Cove, El Capitan Passage, conglomerate composed chiefly of lava cobbles is interbedded with the lower part of the limestone formation. This conglomerate includes some limestone cobbles and pebbles.

On the east side of Tokeen Bay beds of conglomerate and intercalated limestone, of probable Silurian age, lie unconformably on indurated isoclinally folded graywacke of probable pre-Silurian age. The conglomerate passes upward into interbedded conglomerate, graywacke, and slate. The graywacke consists of bits of quartz, plagioclase, and andesite, with shreds of chlorite and grains of magnetite.

Conglomerate is not, however, restricted to the basal part of the limestone formation but may appear abruptly as thick or extensive lenses or as intercalated beds within and even at the top of the formation. In some sections conglomerate is sparse or is not present, and beds of limestone as much as 2,000 feet in thickness are wholly free of argillaceous, sandy, or conglomeratic intercalations.

The conglomerate that occurs within the limestone formation is very well exposed in Halibut Harbor where it has a thickness of 1,500 feet; west of Van Sants Cove, Kosciusko Island; on the east side of El Capitan Passage opposite Aneskett Point; at the south end of Tuxekan Passage, Prince of Wales Island; at the Bay of Pillars, Kuiu Island; and on the Strait Islands. Beds 200 to 1,000 feet thick are found at Cone Bay, at the head of Warm Chuck Inlet, Heceta Island, in Nossuk Bay, at the south end of Marble Island, and at Pole Anchorage, Kosciusko Island. Some of the limestone cobbles in the conglomerate at Halibut Harbor carry a Silurian fauna.

Conglomerate occurs at the top of the limestone formation on Bushy Island, in the Kashevarof group, and on Saginaw Bay. At Saginaw Bay it is interbedded with limestone carrying Silurian fossils.

East of Edna Bay, Kosciusko Island, the conglomerate is composed predominantly of red rhyolite porphyry, some of which shows flow structure. Intercalated red rhyolite flows also appear to be present here.

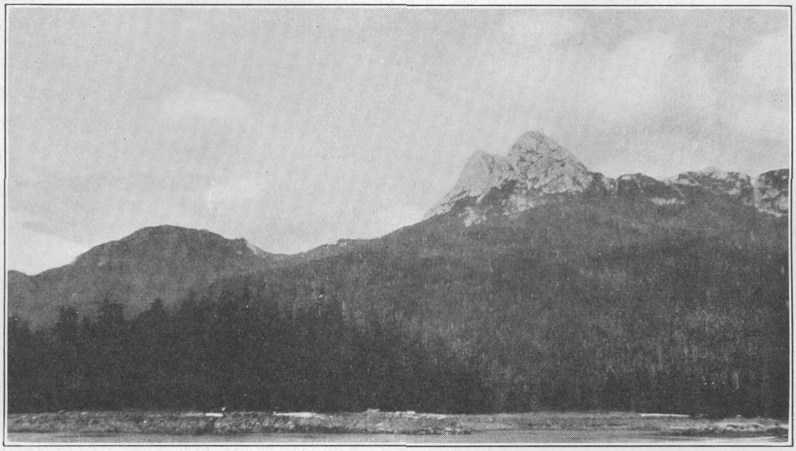
Along the south end of Marble Island about 2,000 feet of graywacke and conglomerate overlying limestone is exposed in a syncline. The lower part consists of very thin-bedded graywacke and shale; the central part of thick-bedded graywacke or grit and pebble conglomerate; and the upper part of medium-bedded fine-grained graywacke and slate. The graywacke beds resemble those of the Shakan syncline, and it is not certain whether they are of Devonian or Silurian age. A specimen of graywacke, examined with the microscope, was found to consist of particles of andesite, felsite, plagioclase, granophyre, quartz, spherulitic rhyolite, and orthoclase. The groundmass is chloritic and slightly calcareous.

On Orr Island Silurian limestone is overlain by interbedded red and green sandstone and coarse conglomerate in apparently unconformable relations. The north arm of Cyrus Cove is cut along the contact between the conglomerate and the shaly limestone. The limestone that forms the west side of the north arm is along the line of strike of the conglomerate. At several places, however, beds of sandstone and conglomerate occur apparently interbedded with the limestone. On the east and west sides of the peninsula at the south end of Orr Island limestone crops out along the line of strike of the conglomerate, even where the two are only a short distance apart. In the lower beds of the conglomerate the major part or even all of the pebbles and cobbles are of limestone.

It is a question whether the conglomerate of Orr and Marble Islands should or should not be correlated with the sandstone of Naukati Bay and Karheen Passage. If so correlated, it is of Silurian age, and the apparently unconformable relations may mean only an abrupt change in conditions within the same general period of time.

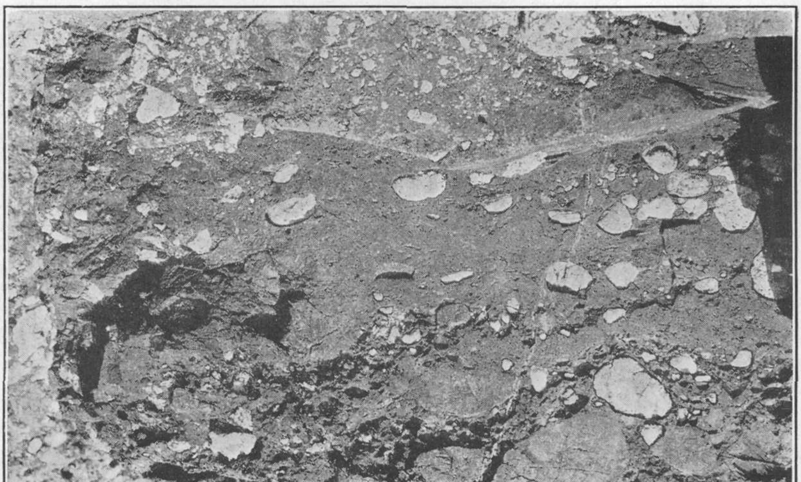
The conglomerate is of a type and character found in southeastern Alaska, so far as the writer's knowledge goes, exclusively in the Silurian system. It is prevailingly coarse pebble to cobble conglomerate with only a minor amount of finer-textured beds and with a few boulders as much as 2 feet in diameter. In some beds the pebbles and cobbles consist almost wholly of red felsite, or of felsite porphyry and limestone; in others, almost wholly of green andesite and andesite porphyry with plagioclase or pyroxene phenocrysts; here and there, almost wholly of limestone; but usually of andesite porphyry, amygdaloidal red basalt, red and gray felsite porphyry, limestone, light-colored and pink diorite, quartz diorite, monzonite, granite, red jasper, and chert in varying proportions. The fragments of granitoid rocks are almost everywhere present, though locally in minor amounts, and resemble very closely the intrusive rocks of the Coast Range, to which they can not possibly have any genetic relation, as the conglomerate beds are locally intruded and metamorphosed by those rocks and are interbedded with or intercalated in fossiliferous Silurian limestone.

Some cobbles and boulders of the limestone carry Silurian fossils and must be of intraformational origin. The pebbles and cobbles of lava are similar to those found in the underlying volcanic formation, but rhyolite appears to be much more predominant in the conglomerate than in the lava flows. This change in proportion may be due in part to superior resistance of the rhyolite, but must be due in part to derivation from a source in which rhyolite was more prevalent with respect to andesite than in any rocks at present exposed in the Silurian or older formations in southeastern Alaska.



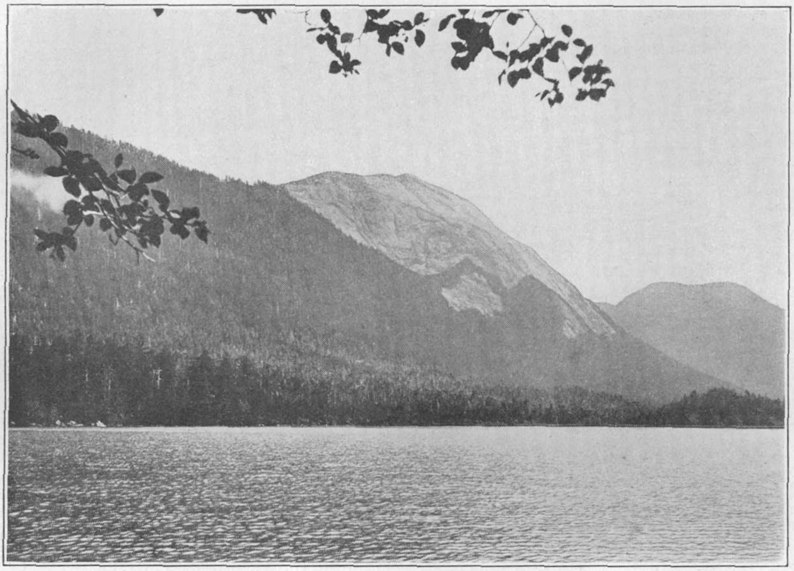
A. MOUNT CALDER, PRINCE OF WALES ISLAND

A mountain of Silurian limestone

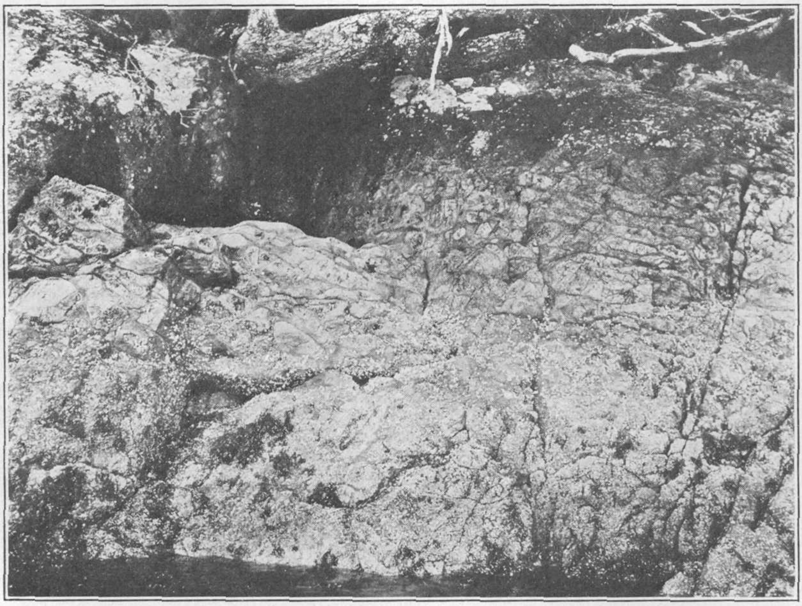


B. SILURIAN CONGLOMERATE, KUIU ISLAND

Rock is composed of limestone and andesite in a waterworn tuffaceous groundmass



A. MASSIVE WHITE SILURIAN(?) LIMESTONE, DALL ISLAND



B. FLOW BRECCIA OF MIDDLE DEVONIAN AGE, HESSA PENINSULA, PRINCE OF WALES ISLAND

Doubtless, however, a large proportion of the lava cobbles were derived from the equivalent of the underlying conglomerate and volcanic formation. The pebbles and cobbles of granitoid rock have not been traced to their source, despite the fact that their size and abundance indicate a near-by local origin. It is possible that pre-Silurian batholithic rocks may yet be found within areas of the Ordovician or pre-Silurian formations. Otherwise it seems necessary to assume that they were derived from a land area composed of older formations with associated batholithic intrusive rocks which formerly stood to the west where now are the depths of the Pacific Ocean.

The association of very thick beds of high-calcium limestone with thick beds of giant conglomerate and graywacke is a most peculiar one. The conglomerate has been interpreted by Kirk [66] as of glacial origin, but Buddington could find no confirmatory evidence of this. It appears possible that the great lens-shaped beds of conglomerate may be local deposits, made by torrential streams, and the graywacke may be in part the more finely comminuted offshore equivalent. The calcareous shale and argillaceous limy beds which are locally intercalated with the clean thick-bedded limestone may also be in part the offshore equivalent of the conglomerate. However, if these beds of conglomerate are simple stream deposits, it is strange that the source from which they were derived is not evident. They may be reworked glacial till. The problem of their origin is not solved, and they need further study.

The limestone is in part dense and massive with only rare, if any, evidence of bedding; in part the massive limestone is interbedded with thin-layered limestone, nodular and shaly limestone, calcareous shaly argillite, dense platy siliceous layers, green-gray shale, and sparse buff-weathering sandstone.

The massive limestone occurs in uniform beds as much as 2,000 feet in thickness. (See pls. 17, *A* and 18, *A*.) The fresh rock is white, but the usual color of the weathered surface is a pallid brown. The rock is usually intensely fractured, and the fracture surfaces are coated with a thin facing of calcite or rarely dolomite, which often weathers out in relief as a network of veinlets.

The thin-layered zones are as a rule highly fossiliferous, but the massive limestone is usually devoid of fossils. Conglomerate lenses are associated with many of the thin beds. In some localities a zone of these interbedded calcareous, argillaceous, and conglomerate beds, as much as 800 feet thick, appears to occupy an intermediate position in the section, as at the south end of Tuxekan Passage. Very rarely

[66] Kirk, Edwin, Paleozoic glaciation in southeastern Alaska: Am. Jour. Sci., 4th ser., vol. 46, pp. 511–515, 1918.

and locally rhyolite or andesitic volcanic rocks occur within the limestone.

On the south side of the Keku Island group there is a string of three long, narrow islands with a general east-west trend. These islands are composed predominantly of dense white limestone with scarcely a trace of bedding, minutely fractured and veined with calcite. There are intercalated beds of coarse conglomerate 20 feet or more thick, composed wholly of fragments of limestone in a limestone matrix. Some of the boulders are 2 feet in diameter. Very many of the boulders and cobbles are fossiliferous or are themselves waterworn coral heads. In addition to other corals, they contain abundant *Halysites*, which have been found nowhere else in southeastern Alaska. The writer is of the opinion that these are intraformational conglomerates and that the beds are of Silurian age.

SHALE

A horizon very high in the Silurian is represented by a formation about 500 feet thick, consisting of pale-green slaty shale with intercalated red beds and thin-layered very fine-grained gray sandstone, gray shale, and dense limestone, which forms the northern part of Edna Bay and the coast about halfway between Edna Bay and Cosmos Pass, on the north side of Kosciusko Island. The beds are gently folded in a synclinorium, with a steep to slightly overturned anticlinal fold on the west side of Edna Bay. The bay itself is carved out of a northward-pitching synclinorium. These beds overlie the limestone conformably.

SANDSTONE AND GRAYWACKE

A thick series of interbedded red, green-gray, and gray sandstone, in part of graywacke type, with a minor amount of shale, forms the trough of a synclinorium on Naukati Bay and for 3 or 4 miles to the south along Tuxekan Passage; similar beds are exposed again along the west side of Karheen Passage, the east end of Heceta Island, and the islands north of the east end. On Naukati Bay the beds of sandstone are folded with a true east-west strike into two anticlines and a syncline. South of Naukati Bay the beds form a broad, gentle syncline. The limbs dip about 25°, the axis strikes N. 80°–85° E., and the trough pitches about 10° E. There appears to be about 3,000 feet of sandstone exposed here. The sandstone overlies the upper Silurian limestone. They have a similar strike, but the limestone occurs at many places directly along the line of strike of the sandstone in a manner suggesting unconformable relations.

On the east side of Heceta Island the sandstone in general strikes northwest and dips 40°–60° NE. In addition to the beds of red, green-gray, and gray sandstone there are sparse beds of fossiliferous white sandstone and conglomerate. Pebble layers are common in the sandstone. The pebbles here as in the Silurian conglomerate are of granite, diorite, and monzonite; red, gray, and white rhyolite; red, green, and black chert; and rarely limestone. Layers of nodular sandstone and beds of fissile limestone are present but very rare. Ripple marks occur on some surfaces and cross-bedding is very common.

A specimen of sandstone from Staney Island is found in thin sections to be composed predominantly of angular bits of quartz in a calcareous groundmass. Plagioclase grains are common, and the matrix is permeated with hematite. Another specimen obtained about half a mile south of Staney Island is a graywacke consisting of angular quartz and plagioclase with a little associated microperthite and grains of epidote and chlorite. The green-gray color is due to the epidote and chlorite with sparse hematite. Another specimen from the northeast tip of Heceta Island appears to be a tuff composed almost wholly of plagioclase with associated pyroxene crystals and abundant grains of magnetite and epidote in a groundmass of epidote.

The relation of these beds to the underlying limestone distinctly suggests unconformable relations, but the fossils obtained from beds on Karheen Passage were identified by Kirk as of Silurian age. The common fossil is *Leperditia* sp.

On the northern part of Prince of Wales Island Silurian limestone is apparently overlain by a thick graywacke formation of doubtful age. The graywacke forms the coast line between Point Colpoys and Exchange Cove, a considerable part of the coast west of Red Bay, and the trough of the Shakan Bay synclinorium. The graywacke occurs in beds 9 inches to several feet thick, with intercalated layers of green-gray slate several inches thick. In the upper part the slate is more abundant and the slate and graywacke are interlayered in beds as much as 9 inches thick. Rarely a bed of pebble conglomerate is found. West of Shakan there is one bed of very coarse conglomerate containing pebbles and cobbles of diorite, black and white chert, limestone, and porphyry. Along the coast, from the contact with the limestone south to the north end of the southeast Barrier Island, the beds have a uniform north-northwest strike and southwest dip, changing from 60° on the east to 25° and less on the west. This would make a thickness of 7,500 feet, which seems too much. Just east of Shakan the beds of graywacke grade downward through slate and calcareous slate into limestone upon which they appear to lie conformably. On the nose of the Kashevarof anticline, on Bushy Island, a great thickness of coarse conglomerate overlies the Silurian limestone; whereas west of Exchange Cove, in a similar structural position, graywacke with intercalated conglomeratic layers 6 inches to a foot thick overlies the limestone. This suggests that the graywacke is the equivalent of the conglomerate formation.

The graywacke resembles the Devonian graywacke formation of Saginaw Bay, but it is also similar in character, though it is without red beds, to the graywacke-like sandstone of Tuxekan and Karheen Passages, which are of Silurian age. It is here tentatively correlated with the Silurian beds.

When examined in thin section the graywacke is found to consist of angular bits of quartz, microperthite, orthoclase, plagioclase, limestone, epidote, chert, slate, and sparse particles of volcanic rock. Locally the groundmass is calcareous.

DIKES

At the north end of Prince of Wales Island numerous dikes of altered basic rock and of felsite cut the Silurian beds and are in turn cut by the intrusive rocks of the Coast Range. The older dikes were doubtless formed during one or more of the several periods of volcanism that intervened between the Silurian and the period of intrusion of the rocks of the Coast Range.

AGE AND CORRELATION

Silurian fossils were found by E. M. Kindle in limestone at a locality just east of the third cove northeast of Meade Point, west of Saginaw Bay, Kuiu Island. The following fossils were identified by him:

Diphyphyllum? sp.
Conchidium knighti.
Whitfieldella sp.
Holopea servus.
Murchisonia sp.

Many small collections were made by Buddington from a great many widely separated localities. Edwin Kirk identified the species which are given in the table below. Kirk states that 933 (2042), 1530 (2023), 1531 (2041), 1536 (2024), 1540 (2025), 1602 (2007), 1625 (2044), 1665 (2036), 1679 (2046), 1680 (2047), 1696 (2029), 1715 (2030), 1719 (2031), 1730 (2032), 1735 (2035), 1748 (2033), 1752 (2034), 1766 (2037), and 1882 (2039) are Silurian and not older than late middle Silurian; 225, 233, 357, 399, 403, 540, 545, 546, 623, 638, 654, 933, 972, 985, 1082, 1130, 1133, 1092, 1172, 1191 are Silurian; and 1562 (2027), 1688 (2045), 2230 (2018), 1761 (2008), 1837 (2010), 1862 (2009), 1912 (2040), 611, and A are probably Silurian.

Collections were made by Buddington and Chapin from the limestone at the head of Waterfall Bay, Dall Island. Edwin Kirk reports as follows on these collections (2069 and 15 ACh 302): "All that remain in this limestone are poorly preserved crinoid columnals and what appear to be *Cladopora*-like corals. Judging from the scant evidence afforded by the lithology and the traces of fossils it would appear that Silurian age is indicated."

Silurian fossils from southeastern Alaska

[Collected by A. F. Buddington; identified by Edwin Kirk]

	1																				2								3								4				5	
	1540 (2025)	1625 (2044)	1665 (2036)	1679 (2046)	1730 (2032)	1735 (2035)	1752 (2034)	1715 (2030)	1719 (2031)	1748 (2033)	1562 (2027)	1688 (2045)	540	545	546	654	985	623	A	140	1092	1172	1191	638	B	1766 (2037)	1602 (2007)	933 (2042)	1530 (2023)	1531 (2041)	1680 (2047)	1882 (2039)	1761 (2008)	1837 (2010)	1862 (2009)	1912 (2040)	403	357	399	1133, 1130	1696 (2029)	973, 223, 233
Stromatopora					X							X				X		X					X															X	X			X
Diphyphyllum		X			X					X	X																															
Ptychophyllum															X									X																		
Cyathophyllum									X									X			X	X	X	X		X																X
Favosites			X								X	X		X	X		X	X	X	X	X		X	X																		X
Syringopora				X										X																												X
Aulopora																							X																			
Cladopora		X									X									X																						
Alveolites?																						X																				
Heliolites																									X																	
Camarotoechia																	X																	X								
Orthoceras														X				X											X	X												
Lissatrypa?				X				X		X		X														X	X	X	X	X	X	X	X									
Hormotoma																												X	X					X								
Sieberella													X																													
Spirifer															X		X											X		X	X											
Atrypa reticularis	X			X				X				X																			X							X	X			
Schuchertella								X																																	X	
Meristina																X	X		X									X														
Athyris																								X													X					
Conchidium	X					X		X									X								X												X		X	X		
Coelospira							X		X																																	
Coelocaulus?														X																												
Trochonema														X					X						X																	
Holopea		X	X				X		X																																	
Harpidium latus						X				X																																
Dalmanites												X																														
Proetus																																			X							
Lichas													X																												X	
Leperditia																	X															X	X	X	X	X						
Conocardium																			X																							
Clorinda																			X	X																						
Cyclonema																			X																							
Idiostroma																																					X	X	X			
Halysites																																										X
Gypidula																																						X				
Gastropods																																								X		
Calymene																																						X				
Capellinia																								X																		

1. Limestone, Prince of Wales and adjacent islands.
2. Limestone interbedded with conglomerate and graywacke, Prince of Wales Island and Saginaw Bay, Kuiu Island.
3. Red and green graywackelike sandstone and shale, Prince of Wales and adjacent islands.
4. Cobbles in Silurian volcanic and conglomerate formation and intercalated slate and limestone, Kuiu and Prince of Wales Islands.
5. Cobble in Silurian conglomerate.

140. About 6 miles east of Cape Bendel, Kupreanof Island.

223. Pair of long islets about 2¼ miles northwest of the conspicuous headland about 10 miles southeast of Point Cornwallis, Kuiu Island.

233. Same as 223.

357. East end of island in unnamed bay on Kuiu Island about 4 miles west of the northwest end of Conclusion Island.

399. Point at southeast end of Sumner Island, Sumner Strait.

403. Three miles west-southwest of the southernmost tip of Conclusion Island.

540. East side of Shrubby Island, Kashevarof Group.

545. South side of the island south of the middle part of Shrubby Island.

546. Islets southwest of point indicated by 1¾-fathom mark on chart 8200, at southwest end of Shrubby Island.

623. Two miles east of Pine Point, north coast of Prince of Wales Island.

638. West headland of Exchange Cove, Prince of Wales Island.

654. Southern island of pair northeast of Exchange Island, off northeast coast of Prince of Wales Island.

933. (2042). Head of Saginaw Bay, west side of Kuiu Island.

973. Same as 223.

985. Southwest end of Shrubby Island, Kashevarof group.

1092. North of Sarheen Cove, El Capitan Passage, Prince of Wales Island.

1130. Islet at head of east arm of Labouchere Bay, Prince of Wales Island.

1133. Head of northeast arm of Labouchere Bay.

1172. South side of Sarkar Cove, near its head, El Capitan Passage.

1191. West side of El Capitan Passage about 1 mile north of Devilfish Bay.

1530 (2023). West side of small cove northwest of Green Island, on south side of Kosciusko Island.

1531 (2041). Point halfway between Edna Bay and Cosmos Pass, south side of Kosciusko Island; interbedded red and green shale.

1540 (2025). Kosciusko Island, east side of peninsula on east side of Edna Bay, about 0.7 mile north of south tip of point.

1562 (2027). Dead Mans Pass, east side of Marble Island, near center.

1602 (2007). Southwest end of Orr Island, west side of peninsula east-northeast of the south tip of Marble Island.

1625 (2044). South tip of Owl Island, off west coast of Prince of Wales Island.

1665 (2036). Head of bay on east side near the center of Orr Island.

1679 (2046). North side of third cove north of south tip of Orr Island.

1680 (2047). North headland of second cove north of southeast tip of Orr Island.

1688 (2045). Arm at north end of Tuxekan Island just east of Cap Island.

1696 (2029). El Capitan Passage, islet about 2 miles north of Cap Island.

1715 (2030). El Capitan Passage, cove southeast of Hub Rock; islet of thin-layered limestone.

1719 (2031). North side of Naukati Bay near entrance.

1730 (2032). East shore of Tuxekan Passage about 2 miles south of Staney Island.

1735 (2035). Southwest tip of islet on east side of Tuxekan Passage, opposite south tip of Tuxekan Island.

1748 (2033). West side of Tuxekan Passage opposite locality 1730.

1752 (2034). West side of Tuxekan Passage opposite Staney Island.

1761 (2008). Islet in middle of bay east of Point Swift, Tonowek Bay.

1766 (2037). Head of cove a little more than 1 mile south of Point Swift, Tonowek Narrows.

1837 (2010). Small islet at north end of group about 2½ miles south of Karheen.

1862 (2009). Southeast tip of island about 2½ miles due west of Karheen.

1882 (2039). West headland of cove on the north side of Heceta Island, about 4½ miles west of Karheen.

1912 (2040). Little islet about a mile northwest of northwest tip of Anguilla Island.

A. Quarry at Tokeen, Marble Island. Collected by E. F. Burchard.

B. Near the middle of the north side of Heceta Island. Collected by E. F. Burchard.

DEVONIAN ROCKS

DISTRIBUTION AND CHARACTER

Rocks belonging to the Devonian system are widespread throughout southeastern Alaska and have been studied particularly on Prince of Wales, Annette, Sukkwan, Suemez, Dall (north end), Baker, Noyes, San Juan Bautista, and Kupreanof Islands and on Freshwater Bay, Flynn Cove, and Port Frederick, Chichagof Island. They comprise great thicknesses of basic volcanic rocks, graywacke, and tuffaceous sediments, considerable limestone, black slate, conglomerate, and a little chert.

The stratigraphic relations of the different formations of the system have not been worked out because there is a great variation in the lithologic character of the Devonian sections from place to place, no complete sequence has been found, fossils are relatively sparse in most of the beds, intense deformation and covered contacts obscure the relations at some places, and no detailed mapping has been done. Part of the tuff and graywacke on the northwest end of Kupreanof Island, mapped as Middle Devonian is certainly of Upper Devonian age, but just how much is not certain.

MIDDLE DEVONIAN ROCKS

SOUTHERN KETCHIKAN DISTRICT

By Theodore Chapin

The stratigraphic relations of the Middle Devonian rocks are not plain. The best evidence at hand points to three conformably gradational groups of rocks—an upper group, purely sedimentary in character; a lower group, purely igneous; and an intermediate group, made up of igneous pyroclastic rocks with interbedded slate and limestone. The rocks of the lower group appear to be volcanic breccias and flows which unconformably overlie the lower Paleozoic and Silurian rocks. Overlying the volcanic rocks is a series of conglomerate; sandstone, and slate, in part tuffaceous, with interbedded flows and breccias, and fossiliferous limestone. The rocks of this group appear to grade upward into the more dominantly sedimentary formations, which culminate in beds of massive limestone several hundred feet thick. The age of the upper and intermediate groups is known positively by the fossils which they carry. No fossils have been found in the lower group of igneous rocks, but from their conformable relations with and similarity to some of the underlying rocks they are regarded as also Middle Devonian, though some may possibly be Lower Devonian.

Middle Devonian rocks exposed on Vallenar Bay on Gravina Island were called the Vallenar "series" by Brooks [67] and were further described by Chapin [68] as the Vallenar formation. The Devonian rocks of Gravina Island are probably the equivalent of rocks that occur on Prince of Wales Island and at other places, but the Middle Devonian section is now known to include considerably more than the rocks exposed on Gravina Island and probably contains a number of formations, although it is not possible to recognize in other parts of the region the exact equivalent of the Middle Devonian rocks of Gravina Island. At no place is the entire section of the Middle Devonian rocks exposed in undisturbed sequence, and the following section is constructed mainly from exposures on Prince of Wales Island.

Stratigraphic section of Middle Devonian rocks in the southern Ketchikan district

Massive limestone.
Conglomerate and limestone.
Conglomerate and graywacke.
Graywacke and slate.
Black slate and tuff.
Tuffaceous conglomerate, sandstone, slate, limestone, and interbedded flows and breccias.
Volcanic breccias and flows.

The flows are fine-grained, dense, green to gray rocks composed essentially of secondary epidote, chlorite, calcite, sericite, quartz, and feldspar. The only evidence of the original character of the rock is found in the few remnants of plagioclase feldspar, probably andesine, and hornblende or pyroxene. The rock was originally andesite.

Interbedded with the lava flows are coarse breccias that consist of a dark-green matrix, of essentially the same composition as the lava, and angular red and black glassy fragments. In places the red ap-

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[67] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, p. 42, 1902.

[68] Chapin, Theodore, The structure and stratigraphy of Gravina and Revillagigedo Islands, Alaska: U. S. Geol. Survey Prof. Paper 120, p. 87, 1916.

pears to predominate. Flow breccia, a type of rock intermediate in origin between the lava and breccia, is of common occurrence. It appears to be composed of fragmental volcanic ejectamenta, but shows flow structure. (See pl. 18, *B*.)

The coarse angular breccias grade into finer-grained breccias and stratified, water-laid tuffs. They are composed of explosive volcanic material, including glass and microlites and fragments of feldspar and hornblende, and were evidently collected in water with little or no transportation by streams. The water-laid tuffs are nearly all calcareous, the amount of limestone varying from minute particles to lenses and beds. Even the coarser breccias are limy and in places contain large blebs of calcite. These calcareous parts of the rock dissolve out easily where exposed along the shore and give to these stratified rocks a slaglike appearance resembling the flow structure of lavas.

The tuffs also grade into tuffaceous conglomerate, sandstone, and slate, which by a decrease of volcanic material pass into purely sedimentary beds. The graywacke and feldspathic sandstone are composed largely of volcanic detritus.

On the southwest coast of Prince of Wales Island sediments and tuffs appear to be conformable on the flows and breccias. On Brownson Bay and Hetta Inlet graywacke carrying Middle Devonian fossils conformably overlies the volcanic rocks. The red and green breccias grade up into finer-grained tuff with Middle Devonian plants overlying graywacke with Middle Devonian marine fossils.

These tuffaceous sediments, which appear to be near the base of this group, contain interbedded black slate and limestone that also carry Middle Devonian fossils. Fossiliferous limestone that appears to occupy this horizon is exposed on Keete Inlet, Max Cove, Klakas Inlet, Hunter Bay, and Tah Bay, and with it are correlated some similar beds of limestone at the head of Nichols Bay. This same horizon is possibly represented also in the limestone interbedded with tuffaceous sediments on Dickman Bay and other places on Moira Sound.

Schistose rocks are associated with greenstone at a number of places. Some of these appear to be contact-metamorphic rocks formed along the borders of masses of intrusive quartz diorite and others are possibly infolded schist of older formations.

Round Island, in Kasaan Bay, is composed entirely of limestone similar in appearance to the limestone of Long Island and of the same age. Berry Island, much of Kasaan Peninsula, and parts of Skowl Peninsula are made up of conglomerate, graywacke, tuff, and interbedded limestone, but the relation of these beds to the fossiliferous limestone of Long Island is nowhere evident. The limestone is a dark-blue brittle rock, similar to the fossiliferous limestone of Long

Island. The conglomerate is made up of pebbles and large cobbles of graywacke, chert, porphyry, rhyolite, and limestone, set in a matrix of angular sand. The graywacke is a banded arenaceous rock composed of quartz and feldspar, angular rock particles, ferromagnesian minerals, and slate. It is essentially the same in composition as the conglomerate, into which it grades by increase of coarse material.

If the synclinal structure of Long Island extends across Kasaan Bay to Kasaan and Skowl Peninsulas the massive fossiliferous limestone of Long Island is stratigraphically the highest of the Middle Devonian rocks known. Some of the thick beds of limestone on Kasaan Peninsula may be correlated with it or they may be even higher but these interstratified limestone, conglomerate, and tuffaceous beds are believed to occupy a position just below the massive limestone of Long Island and are correlated with similar rocks on Skowl Peninsula.

A thick uniform limestone member of the Middle Devonian is exposed on Long and Round Islands, Kasaan Bay, and on Coronados and Fish Egg Islands and the islands to the north, on the east side of San Alberto Bay. Similar limestone of Middle Devonian age is exposed on the north end of Kupreanof Island, where it is very highly sheared, and in Duncan Canal. The limestone is highly fossiliferous and on Long Island it is dark gray to blue and fine grained. The limestone of Long Island was described by Kindle as overlying buff or cream-colored siliceous beds of igneous origin, but these supposed beds are reported by Buddington to be platy rhyolites with local flow structure and spherulitic texture, of Tertiary age, and to rest unconformably on the limestone.

The limestone on the Coronados Islands range from a white crystalline rock to brown and gray beds with a little argillaceous and sandy material. The limestones on the islands on the east side of San Alberto Bay are fine grained, gray, and thin to thick bedded. On the island halfway between Clam Island and East Alberto Island a thick bed of graywackelike sandstone is intercalated in the limestone. All the limestones are very richly fossiliferous, and the fauna has been identified by Edwin Kirk as of late Middle Devonian age.

The basalts are dark-green and black fine-grained rocks with visible phenocrysts of augite, feldspar, and olivine set in a groundmass composed essentially of secondary minerals.

The andesitic pillow lava, breccia, and tuff which overlie Middle Devonian interbedded limestone, slate, and chert on Duncan Canal, Kupreanof Island, may be of Middle Devonian age.

The age determination of the Vallenar formation of the southern Ketchikan district is based upon large collections of fossils made from the massive limestone at the top of the group and from the underlying thin-bedded limestone which is interbedded with the tuffs and lava flows. Edwin Kirk, who has made a study of these faunas, states:

Some of the faunas here referred to the Middle Devonian as represented in the collections might be referred to the Lower Devonian. There are, however, no truly diagnostic Lower Devonian forms present, as there are no truly diagnostic Middle Devonian species. There is in addition a general homogeneity of the faunas from the base of the Devonian as drawn up to the *Stringocephalus* horizon, which elsewhere marks the upper part of the Middle Devonian. There also appears to be a fairly close relation between the faunas of the *Stringocephalus* horizon and the faunas underlying it. For these reasons it has seemed best for the present to refer all the Devonian faunas below the *Stringocephalus* horizon to the Middle Devonian.

The thin-bedded limestone and associated tuffaceous limestone have yielded a number of collections of fossils, all of which are regarded as Middle Devonian.

Fossils collected at Vallenar Bay, Gravina Island, by Brooks in 1901 were determined by Charles Schuchert as Devonian. More collections were made in 1905 and 1906 by the Wrights and E. M. Kindle,[69] who give the following report on a collection obtained 1 mile west of Vallenar Bay, Gravina Island:

The material from this locality, while generally insufficient for specific determination, is much better than that obtained last year (1905) and leaves no doubt as to the Devonian age of the beds west of Vallenar Bay. Several specimens of *Atrypa reticularis* are present. This fixes the horizon as not later than Carboniferous, while the association of *Chonetes* cf. *manitobensis*, *Spirifer* sp., *Proetus* sp., and *Cyclonema* sp. indicates a horizon of Devonian age, probably Middle Devonian.

The following collections made by the writer were also regarded by Kirk as Middle Devonian:

15ACh 9, 21, 22, and 311, Hotspur Island:

Favosites hemisphericus.
Favosites limitaris.
Cladopora sp.
Favosites sp.
Syringopora sp.
Zaphrentis type of Z. gigantea.
Favosites cf F. emmonsi.
Rhipidomella sp.
Alveolites sp.

15 ACh 151, 153, and 155, Clover Bay, Prince of Wales Island:

Cladopora sp.
Syringopora sp.
Favosites hemisphericus.
Cyathophyllum sp.

15 ACh 180, Hessa Inlet, Prince of Wales Island:

Cladopora sp.
Crinoid columnals.

15 ACh 188, Hunter Bay, Prince of Wales Island:

Atrypa reticularis.
Favosites hemisphericus.
Alveolites sp.
Cyathophyllum sp.
Syringopora sp.

[69] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 50, 1908.

15 ACh 203, Max Cove, Prince of Wales Island:

Favosites hemisphericus.
Alveolites sp.

The following collection was made by Kirk:

East shore of Keete Inlet, Prince of Wales Island:

Atrypa reticularis.
Stropheodonta sp.
Reticularia sp.
Martinia cf. M. maia.
Leiorhynchus sp.
Rhynchonella sp.
Chonetes sp.
Orthoceras sp.
Grammysia sp.
Pterinea sp.
Modiomorpha sp.

Most of the species listed above are undescribed.

This fauna is clearly referable to the Middle Devonian as defined in southeastern Alaska. It belongs to a group of faunas found within the great series of argillite, quartzite, and greenstone overlying the Silurian and known not only in Prince of Wales Island but also in the northern part of Chichagof Island.

Fossil plants that occur in the graywacke beds associated with the limestone of Hessa Inlet were submitted to David White, who reports as follows:

The collection which constitutes lot 17339 of the paleobotanic collections of the Geological Survey consists of fragments of a slender, distantly forking algoid type with slender but slightly thickened medial axis. It is probable that the ultimate divisions were more or less distinctly flat and ribbon-like, conforming largely to the characteristics of the genus *Taeniocrada*.

A few of the fragments, as preserved, have facies suggestive of one of the slender forms from the Middle Devonian of Canada, identified in some of the collections under the name *Psilophyton*.

The aspect of the material and the absence of pteridophytic features suggest Middle or possibly even Lower Devonian age for the beds.

The massive limestone beds of the upper part of the Vallenar formation have yielded large faunas of Middle Devonian fossils. Kindle[70] lists a fauna collected in the massive limestone of Long Island, Kasaan Bay, which he considers to be Lower and Middle Devonian. Subsequent collections made by the writer and by Kirk have shown that the faunas of the upper and lower parts of the limestone series are essentially homogeneous and that the limestones form a stratigraphic unit. Kirk's report is as follows:

Many of the species represented in the limestones of Long Island, Kasaan Bay, are either new or are represented by specimens too imperfect for exact specific identification. Because of this there is at present no reason for changing Kindle's original faunal lists. In the lower portion of the limestone series he identified the following fossils:

Stictopora sp.
Cladopora sp.
Spirifer cf. S. sulcatus.
Sanguinolites sp.

[70] Kindle, E. M., Notes on the Paleozoic faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, pp. 324–327 1907.

Cardiola sp.
Hercynella nobilis.
Hercynella bohemica.
Holopea sp.
Murchisonia angulata.
Murchisonia sp. 1.
Murchisonia sp. 2.
Planitrochus cf. P. amicus.
Loxonema sp.
Holopella sp.
Trochonema sp.
Euomphalopteris? sp.
Operculum.
Beyrichia? sp.
Leperditia sp.
Orthoceras sp.

In the upper portion of the series Kindle lists the following forms as collected from one zone:

Favosites cf. F. radiciformis.
Cyathophyllum sp.
Orthophyllum? sp.
Zaphrentis sp.
Calceola cf. C. sandalina.
Syringopora sp.
Lingula cf. L. bohemica.
Atrypa reticularis.
Atrypa hystrix.
Gypidula optatus.
Gypidula cf. G. intervenicus.
Meristella cf. M. barrisi.
Stropheodonta stephani.
Spirifer sp.
Spirifer hians?
Spirifer thetidis.
Spirifer subcomprimatus.
Spirifer sp.
Spirifer indeferens.
Spirifer sp.
Reticularia? sp.
Rhynchonella cf. R. amalthea.
Rhynchonella livonica.
Pugnax sp.
Dalmanella occlusa.
Schizophora macfarlani?
Schizophora striatula.
Streptorhynchus sp.
Stropheodonta comitans.
Camarotoechia? sp.
Cypricardinia? sp.
Conocardium cf. C. bohemicum.
Conocardium sp.
Lucinia cf. L. proavia.
Leptodesma sp.
Mytilarca sp.
Nuculites sp.
Telinopsis sp.
Holopella? sp.
Loxonema? sp.
Murchisonia sp. 2.
Murchisonia sp. 1.
Naticopsis sp.
Oriostoma sp.
Oriostoma princeps var.
Euomphalus cf. E. planorbis.
Tremanotus cf. T. fortis.
Tentaculites sp.
Ooceras sp.
Gomphoceras? sp.
Orthoceras sp.
Cytherella? sp.
Entomis pelagica.
Leperditia sp.
Cyphaspis sp.
Proetus sp.
Proetus cf. P. romanooski.

Somewhat below the fauna given above he notes the following species:

Cladopora?
Cyathophyllum sp.
Camarotoechia sp.
Meristella cf. M. ceres.
Spirifer sp.
Spirifer cf. S. thetidis.
Spirifer cf. S. cheiropteryx.
Stropheodonta comitans.
Orthonota sp.
Schizodus sp.
Conocardium cf. C. bohemicum.
Euomphalus planorbis.
Oriostoma princeps var.
Tentaculites.
Cyphaspis sp.
Orthoceras sp.
Proetus cf. P. romanooski.

The "*Cardiola*" identified by Kindle in the lowest fauna is *Panenka*. This ranges upward into the higher faunas and was found near the top of the section as shown in Long Island. Fragments of *Hercynella* likewise were seen associated with the higher faunas. In the basal portion of the limestones numerous corals were found, chiefly referable to the genera *Favosites*, *Cladopora*, and *Striatopora*. These are specifically identical with corals associated with the higher faunas referred to the Middle Devonian, not only in this section but also in other parts of southeastern Alaska. There is no good reason then for drawing a stratigraphic line within the limestone series of Long Island.

The question of the age assignment of the limestone series involves then the contained fauna as a whole. Of Asiatic and European affinities as it is, and differing widely from the Devonian faunas of eastern North America, the task is not an easy one. The general aspect of the fauna, and this carries with it even lower faunas found elsewhere in southeastern Alaska, is more Middle than Lower Devonian. In my opinion the best course is to call these faunas Middle Devonian. If Lower Devonian be present in southeastern Alaska it is more apt to be found within the sediments now referred to the Silurian. The final settlement of this question depends in great part, however, on the final disposition of disputed stratigraphic units elsewhere in North America, Europe, and Asia.

Collections were also made by the writer from massive limestone beds of Coronados and Fish Egg Islands and Port Bagial, on the west coast of Prince of Wales Island, which are correlated with the Long Island rocks. Kirk reports:

15 ACh 278. Coronados Island:

Cyathophyllum sp.
Favosites, 2 sp.
Stringocephalus burtini.
Atrypa reticularis var.
Leiorhynchus sp.
Camaratoechia sp.
Productella sp.
Stropheodonta sp.
Straparollina sp.
Bronteus sp.
Stromatopora? sp.

15 ACh 280, Port Bagial, Prince of Wales Island:

Crania sp.
Atrypa reticularis.
Eunella sp.
Ambocoelia umbonata.
Bellerophon? sp.
Murchisonia sp.
Strophostylus sp.
Actinostroma sp.
Amplexus sp.
Aleveolites sp.
Favosites hemisphericus.
Cyathophyllum sp.
Syringopora sp.
Cladopora sp.
Striatopora sp.

The fauna obtained near the east end of Coronados Island is of great interest in that it gives a datum plane for correlation with faunas outside Alaska. Associated with the fauna listed from Port Bagial is found *Stringocephalus burtini* Defrance. This brachiopod marks a well-defined zone in the upper part of the Middle Devonian of Europe. It is also found in the Yukon Valley of Alaska and in the Mackenzie River region of Canada. In southeastern Alaska it has also been found in San Alberto Bay, west of Klawak. Here it occurs almost immediately underlying the Upper Devonian. Another interesting European element in the fauna is the trilobite genus *Bronteus*.

NORTHERN KETCHIKAN DISTRICT

On the southwest side of Saginaw Bay upper Silurian beds consisting of interbedded fossiliferous limestone and conglomerate are overlain by interbedded conglomerate and andesitic lava of probable

Devonian age. Some of the lava is reddish, with abundant phenocrysts of pink plagioclase; it resembles trachyte but in thin section is found to be andesite.

The waters of Saginaw Bay cover the beds intervening between the conglomerate and lava formation and the formation exposed on the adjacent string of islands which parallels the shore. This group of islands is composed of thick-bedded greenish graywacke with intercalated beds of conglomerate and thin-layered platy sandstone and slate. Beds of thin-layered black argillite occur sparsely and also beds of andesitic breccia. The thin-layered argillites carry Devonian fossils, in part marine and in part carbonized plant remains. The conglomerate is composed of bits of red felsite, green andesite, and andesite porphyry; it is usually fine grit, but is rarely coarse and in beds 15 feet thick. The graywacke is in beds 2 to 20 feet thick. There appears to be at least 2,000 feet of this formation exposed on these islands, and the total thickness is probably considerably greater. These beds structurally overlie the lava and conglomerate formation that appears to the southwest, and a few fossils collected from them are reported by Edwin Kirk to be of probable Middle Devonian age.

The predominant rock of Suemez, Baker, St. Ignace, and Noyes Islands consists of andesitic lava (predominantly with pillow structure) and breccia with associated limestone-andesite conglomerate and locally intercalated beds of bright-red shale or thin-bedded dark-gray slate and graywacke. The limestone-andesite conglomerate is composed of limestone and andesite cobbles in a green tuff-like groundmass. Limestone occurs also in great, irregular masses as much as 10 feet in diameter. In one bed the limestone cobbles were found to carry Devonian fossils, and they are probably of intraformational origin. The conglomerate resembles the similar beds of the upper Silurian. The andesite is normally of felsitic texture and sage-green to dark green-gray color. Along Port Real Marina, at the north end of Santa Rita Island, beds of gray and red felsite breccia and tuff with sparse beds of thin-banded green and gray slate overlie the andesitic volcanic rock.

On Baker Island the peninsular headland east of the Gaviota Islands is formed by a syncline of thin-bedded dark and light gray calcareous slate, sandstone, or graywacke and intercalated conglomerate, overlying the andesitic volcanic rocks. There is 500 feet or so of schistose limestone also exposed. The conglomerate consists of pebbles of chert and dense sage-green greenstone. At the extreme northeast end of St. Ignace Island there are exposures of similar interbedded limestone, conglomerate, sandstone, and slate overlying the volcanic rocks. On Noyes Island, between Point San Francisco and

Steamboat Bay, there is a series of interbedded conglomerate, sandstone, graywacke, and dark-gray to black slate, with intercalated limestone and local andesitic lava and breccia. On Steamboat Bay there is a thick chert bed. The limestone carries Devonian fossils.

The beds overlying the andesitic volcanic rocks on the northwest side of Suemez Island are of a different type. They consist of interbedded graywacke, slightly waterworn andesitic tuff, banded dark-gray slate, light-colored dense graywacke, and conglomerate composed of cobbles of limestone and andesite. Beds of limestone, tuff, and breccia are sparsely intercalated. The graywacke is predominant.

On Duncan Canal, Kupreanof Island, there is a series of beds consisting in part of dark-gray slate with intercalated beds of chert and thin layers of black chert and limestone and in part of thick-bedded limestone interbedded with slate, green and white chert, and schistose andesitic volcanic rocks. The slate series appears to pass upward into the more dominantly limestone beds. The limestone carries a Middle Devonian fauna identified by Edwin Kirk. The beds are overlain by sage-green andesitic lava (in part with pillow structure), breccia, and tuff.

A series of beds of conglomerate or graywackelike sandstone or both forms the group of islands at the head of San Alberto Bay and in San Christoval Channel, the north end of San Fernando and Lulu Islands, Blanquizal Island, and a group of small islets west of the north end of Anguilla Island, in the Maurelle group. San Christoval Channel is carved out of a syncline of these beds. The east limb is vertical to slightly overturned toward the west; the slope of the west limb is more gentle. At the north end of San Fernando Island there is exposed about 2,500 feet or more of conglomerate beds that overlie a graywacke series or, locally, conglomerate of typical Silurian aspect. The Silurian (?) part of the conglomerate series is here composed predominantly of limestone cobbles and boulders and of pale-colored rhyolite porphyry. Local beds are composed almost wholly of andesite. Granite and chert pebbles are present. These beds appear to be overlain conformably by pebble conglomerate with interbedded sparse sandstone and shale. The upper conglomerate beds contain many chert pebbles and seem to be less metamorphosed than the lower conglomerate beds, though this difference may be only apparent. Locally conglomerate beds resembling the upper conglomerate overlie a graywacke series with apparent unconformity. At the north end of Lulu Island there is 2,000 feet of the pebble conglomerate in which chert forms a considerable part, limestone pebbles are rare, and slaty fragments are locally abundant. The conglomerate beds are overlain conformably by dense nonfossiliferous limestone at Point Santa Gertrudis.

Blanquizal Island consists of interbedded graywackelike sandstone and conglomerate, with the sandstone predominating. In the conglomerate the pebbles are greenstone, chert, graywacke, quartz, rhyolite, and rarely diorite and granite. There appears to be 1,800 feet of these beds exposed here. About 1¾ miles northwest of Point Ildefonso there are beds of fossiliferous sandstone intercalated in a giant conglomerate, which appears to overlie unconformably a graywacke formation. Some of the sandstone is white, but most of it is gray. The matrix of the conglomerate is calcareous, and the cobbles, which are predominantly 6 to 12 inches in diameter and well rounded, consist of limestone, green, white, and black chert, slate, greenstone, felsite, granite, diorite, and banded dense cherty quartzite. In some conglomerate beds on the islands in San Christoval Channel cobbles of greenstone or diorite or both are abundant.

The age of these beds is uncertain. Structurally they must lie between the Silurian and the Middle Devonian. At the head of San Alberto Bay they pinch out, and Middle Devonian limestone is practically adjacent to Silurian volcanic rocks. As the contacts are covered it is not certain whether this relation is due to a local lenslike character of the conglomerate formation, to an unconformity, or to faulting. The beds probably belong either to the upper part of the Silurian system or to the lower part of the Devonian. Kirk states that the few fossils obtained from the formation at a place 1¾ miles northwest of Point Ildefonso indicate a probable Middle Devonian age. Chert is not a characteristic cobble of the Silurian conglomerate, though it is present in them; but granitoid and volcanic rocks are characteristic both of the beds under consideration and of the known Silurian conglomerates.

Limestone carrying abundant silicified fossils forms Ham Island, a small islet in Karheen Passage. A collection from this locality was identified by Kirk as of Middle Devonian age. This limestone apparently occupies the trough of a syncline in red sandstone with conglomeratic layers. The sandstone locally carries abundant *Leperditia*, which are referred to the Silurian by Kirk. At the head of San Alberto Bay Middle Devonian limestone overlies conglomerate and graywackelike sandstone, as has been described. This suggests a correlation of the sandstone of Karheen Passage and the conglomerate and sandstone of San Christoval Passage and the head of San Alberto Bay. But the sparse fossils from the two formations are referred by Kirk to the Silurian and probably Middle Devonian respectively, and there is considerable difference in lithology. On San Fernando Island at Fern Point Middle Devonian limestone overlies graywacke of probable Silurian or older age. These relations suggest that an unconformity exists at the base of the limestone formation.

A number of collections of fossils, identified by Edwin Kirk as of Middle Devonian age, were made by Buddington from formations north of the southern part of the Ketchikan district. These are listed in the following tables:

Middle Devonian fossils from southeastern Alaska

[Collected by A. F. Buddington; identified by Edwin Kirk]

	1							2						3
	1-P-6	Q-16	R-2	P-3	Z-9	2232 (2019), 2230 (2018)	140	1841 (2038)	2030 (2012)	2031 (2013)	2057 (2014)	2085 (2016)	2132 (2017)	939 (2022)
Favosites		×				×	×	×					×	
Alveolites		×												
Heliophyllum								×		×	×	×	×	
Cyathophyllum	×			×				×	×		×			
Cladopora							×		×		×			
Syringopora								×	×					
Striatopora			×					×		×		×	×	
Pachypora									×		×		×	
Acervularia			×							×				
Stromatopora									×			×		
Zaphrentis		×		×										
Diphyphyllum				×										
Atrypa reticularis								×			×			
Schizophoria striatula								×						
Gypidula								×						
Stropheodonta								×						
Reticularia										×	×			
Cyrtia											×			
Camarotoechia											×			
Spirifer		×				×								
Rhynchonella		×		×										
Proetus				×				×						
Hercynella?														×
Tentaculites														×
Pterinea														×
Orthoceras						×								×

1. Limestone, Kupreanof and Noyes Islands.
2. Limestone, Prince of Wales and adjacent islands.
3. Graywacke, Saginaw Bay, Kuiu Island.

1-P-6. Middle arm of Duncan Canal, Kupreanof Island.

Q-16. East shore of Duncan Canal, southwest of islet northwest of Castle Islands.

R-2. First islet south of peninsula between middle and east arms of Duncan Canal, Kupreanof Island.

P-3. First islet northwest of Duncan point, west arm of Duncan Canal, Kupreanof Island.

Z-9. Head of Emily Island arm of Duncan Canal, Kupreanof Island.

2232(2019) and 2230(2018). Northeast end of Noyes Island, east of Steamboat Bay.

140. About 6 miles east of Cape Bendel, Kupreanof Island.

1841(2038). Ham Island, about 1¾ miles south of Karheen, off west coast of Prince of Wales Island.

2030(2012). Clam Island, north of Fish Egg Island, and Klawak Reef, off west coast of Prince of Wales Island.

2031(2013). Alberto Island, off west coast of Prince of Wales Island.

2057(2014). Island halfway between Clam Island and East Alberto Island, San Alberto Bay.

2085(2016). Small islet off northeast end of the island on which there is a cemetery, north of Klawak.

2132(2017). Fern Point, east side of San Fernando Island.

939(2022). Island about center of Saginaw Bay, Kuiu Island.

A peculiar fauna occurs in a bed of sandstone intercalated in giant conglomerate on the east side of San Christoval Channel. Kirk identified the fossils as *Camarotoechia* sp., *Orbiculoidea* sp., and *Cypricardella* sp. and referred them to a probable Middle Devonian horizon.

MIDDLE (?) AND UPPER DEVONIAN ROCKS OF NORTHERN PART OF KUPREANOF ISLAND

A thick series of beds, predominantly tuffaceous, of known Devonian age, is exposed in the northern part of Kupreanof Island. They are well exposed in the vicinity of Kake and again for 2 miles along Frederick Sound about 2 miles east of Cape Bendel. The fossils included are in part of Upper Devonian age and in part of indeterminate age but either Middle or Upper Devonian.

The formation comprises, characteristically, very thin bedded tuff with sparse chert layers; thick-bedded tuff with intercalated calcareous tuff or tuffaceous limestone; and a few flows of pillow lava with beds of banded chert and beds of slate. It is possible that a series of rocks east of Cape Bendel consisting of black slate and chert with interbedded limestone lying between the typical beds of tuff and Permian limestone belong to this formation. The tuff is in general very fine to medium grained and green to green-gray. Impalpably fine grained beds are very common. One of the most striking and characteristic features of this series is the presence of beds of tuff of a color most unusual in rocks, a light blue to blue green. Beds and layers of white chert are found in minor amount intercalated in the tuff, and black chert is associated with the slate in the belt east of Cape Bendel. The tuff and chert are exceedingly fractured by short cracks and minute offsetting faults, and the rocks break down into small angular fragments. They weather along the coast line with a glazed appearance, the result of the prevalently fine grain, and acquire yellowish-brown, greenish, or reddish-brown hues.

The thin-bedded facies is well shown at Point Macartney, where it consists of greenish tuff with chert in layers a fraction of an inch to several inches thick, with a few beds of tuff several feet thick. Crinoid stems are visible in many hand specimens of the tuff and in practically all specimens when examined in thin section.

A specimen of typical medium-grained green tuff from Point Macartney is found, on microscopic examination, to be a crystal tuff and to consist almost wholly of angular particles of sodic plagioclase with a few grains of hornblende and andesite (plagioclase) porphyry. Cross sections of crinoid stems are very common. The green color is due to disseminated chlorite. A pale greenish-blue tuffaceous limestone from a locality about 5 miles southeast of Kake is found to consist of abundant rounded particles of plagioclase and of andesite porphyry with plagioclase phenocrysts in a calcareous groundmass. Quartz grains occur sparingly. Crinoid stems and corals with well-preserved cell structure are abundant. A few particles of dense green chert are present. A specimen of dense green tuff from a locality about 3 miles southeast of Kake exhibits in thin section a compressed indistinct groundmass with abundant small particles of plagioclase and many traces of devitrified glass shards, some with evidence of a scoriaceous structure. Another specimen from the islet about a mile southwest of Kake is a dense striped green vitric tuff, slightly calcareous, composed almost wholly of fragments of devitrified glass with abundant particles of feldspar in an indistinct groundmass. Many small crinoid stems are seen in thin section. Crystal tuff and vitric-crystal tuff, with accessory fragments of andesite, are thus seen to be the predominant types of rock.

The series is evidently marine, comprising in considerable part tuff consisting of volcanic ash of primary origin and in minor part detrital tuff consisting of volcanic ash washed in from land surfaces, normal mud resulting from weathering processes, calcareous skeletons of organisms, and siliceous precipitates or organic secretions.

The stratigraphic positions and relations of the divisions of the Devonian system are only partly known. The beds described include andesitic volcanic rocks; interbedded conglomerate, limestone, slate, and andesitic volcanic rocks; interbedded slate, chert, andesitic volcanic rocks, and limestone; limestone; graywacke with waterworn andesitic tuff; and interbedded predominantly cherty conglomerate and graywacke-like sandstone. In the absence of fossils and in our ignorance of the stratigraphic sequence it is impossible to distinguish Middle Devonian volcanic rocks from Upper Devonian volcanic rocks on lithology alone; and it is not certain that there is not more than one horizon within the Middle Devonian represented predominantly by limestone, or by graywacke and tuffaceous sediments, or by volcanic rocks.

UPPER DEVONIAN ROCKS OF OTHER PARTS OF SOUTHEASTERN ALASKA

By Theodore Chapin

Rocks of known Upper Devonian age are not extensive in southeastern Alaska, though it is quite probable that, owing to the absence of fossils, rocks of this age have been included with Middle Devonian or Carboniferous formations. They are found on the west coast of Prince of Wales, Suemez, and San Juan Bautista Islands and on Freshwater Bay, Chichagof Island. The rocks comprise melaphyre pillow lava and tuff on Freshwater Bay and limestone, calcareous sandstone with some conglomerate, interbedded limestone and argillite, and basalt on Suemez and San Juan Bautista Islands. The lower yellow impure limestone on Port Refugio, Suemez Island, and the argillite on San Juan Bautista Island contain fossil plants. The limestone contains abundant marine fossils.

The age of the Upper Devonian rocks is known from a number of fossil collections from various places. Fossil plants from the lowest member of the Upper Devonian limestone of Port Refugio, Suemez Island, collected in July, 1917, were submitted for identification to David White, who reports as follows:

7388 (17 ACh 7). Port Refugio, Suemez Island, southeastern Alaska. The limestones contain indistinct fragments of what appears to have been a rather dense filamentose alga resembling somewhat some of the fossils identified by various paleontologists as *Buthotrephis*. These fragments do not seem to admit of more exact determination. Two specimens in the collection appear to belong to vascular types, though they are so macerated as to leave doubt as to their exact affinities. One of them, however, is similar to certain Devonian plant remains from Canada described as *Rachiopteris*. Material of this sort is to be expected from the Middle Devonian, though it might perhaps occur in the lower part of the Upper Devonian.

Marine invertebrates collected from the overlying beds were determined by Edwin Kirk, who reports as follows:

16 ACh 132, 141, 142, 143. Port Refugio, Suemez Island, west coast of Prince of Wales Island:

Spirifer disjunctus.
Schizophoria striatula var.
Productella cf. P. hallana.
Camarotoechia (?) duplicata.
Orthothetes cf. O. chemungensis.
Ambocoelia sp.
Plant remains.

The faunas of all these lots are essentially the same, most of the species being found in each lot. The age of the strata is clearly Upper Devonian.

Fossils collected from San Juan Bautista Island were examined by Kirk, whose report follows:

16 ACh 158:

Cyathophyllum sp.
Syringopora sp.
Aulopora sp.
Atrypa reticularis.
Productella cf. P. hallana.
Pentamerella sp.
Gomphoceras sp.

16 ACh 162:

Productella cf. P. hallana.
Atrypa sp.

Near these two localities Wright made a collection which adds the following species to the above lists:

Productella cf. P. lachrymosa.
Spirifer disjunctus.

These faunas are of Upper Devonian age. Stratigraphically the beds containing them underlie those carrying the faunas listed from Suemez Island.

Fossils collected by Buddington from the west headland of a cove about 2 miles north of Point Refugio, Suemez Island, were identified by Kirk as *Pugnax pugnus*, *Productella* sp., and *Spirifer disjunctus*, of Upper Devonian age. Fossils were also collected by Buddington from green andesitic calcareous tuff beds underlying limestone on Hamilton Bay, Kupreanof Island, about 6½ miles southeast of Kake. These were identified by Kirk as *Fenestella?* sp. and crinoid columnals, of either Upper Devonian or Mississippian age, with the chances rather favoring the former.

CARBONIFEROUS ROCKS

DISTRIBUTION AND CHARACTER

Rocks of the Carboniferous system are distributed throughout southeastern Alaska, but in the Alexander Archipelago they occupy only small, widely separated areas. On the mainland they form a considerable part of the schist series in the Juneau district and are possibly present in the schist of the Ketchikan district.

It seems highly probable that a considerable part of the Wrangell-Revillagigedo belt of metamorphic rocks of the mainland is of Carboniferous age, including the mapped belts described as schistose greenstone, green phyllite interbedded with black and gray sericitic slaty phyllite, and sparse beds of limestone and schistose chert. One such belt forms most of the outer part of the mainland coast line from Port Houghton northwest to Taku Inlet, and other belts lie to the east. On Admiralty Island a part of the belt of rocks that passes through Windfall Harbor is likewise believed to be of this age. A description of the schistose beds of the Wrangell-Revillagigedo belt of metamorphic rocks will be found on pages 49–74.

In the Ketchikan district metamorphic rocks composed of schist and limestone with tongues of intrusive granitoid igneous rocks border the Coast Range batholith. Many of the beds of limestone contain a great abundance of crinoid stems, and on that basis they have been referred by Kindle to the Carboniferous.

The most complete section of the Carboniferous system in the least metamorphosed condition is exposed on Saginaw Bay and the Cornwallis Peninsula, at the north end of Kuiu Island, and on the Keku Islets.

Considered lithologically the Carboniferous rocks may be divided into three groups—a lower group, of Mississippian age, which consists of interbedded coarsely crystalline limestone and black chert overlain by interlayered dense gray quartzite and cherty limestone with sparse sandstone and conglomerate; an intermediate group, of Pennsylvanian or lower Permian age, which comprises conglomerate, limestone, sandstone, andesitic, and basaltic lava and tuff, and possibly at some places rhyolitic volcanic rocks; and an upper group, of Permian age, which consists of thick-bedded limestone with common to abundant intercalated layers of white chert. All three divisions have very richly fossiliferous beds.

MISSISSIPPIAN ROCKS

DISTRIBUTION AND CHARACTER

The Mississippian rocks are exposed over a considerable area in the vicinity of Klawak, on the west coast of Prince of Wales Island. They form the east side of Klawak Inlet, a belt between Klawak Inlet and Klawak Lake, Klawak Island, and the islands to the north up to the entrance of Klawak Salt Lake. They are exposed also at Point Bocas Peninsula, Suemez Island, on small islands at the mouth of Soda Bay, and on Madre de Dios and the Robber Islands, Bucareli Bay.

The beds consist of coarsely crystalline highly fossiliferous limestone and black thin-layered chert (pl. 19, *A*) overlain by interbedded dense gray quartzite and cherty limestone with sparse sandstone, conglomerate, and limestone. The base of the beds is reported by Chapin to be a thin strip of conglomerate and calcareous arkose. Much of the fossiliferous coarsely crystalline limestone has a fetid odor when first broken.

In Saginaw Bay, Kuiu Island, the beds form a long peninsula and its continuation in islands and reefs in the center and at the head of the bay, also the string of islands at the head of the east side of the bay and the outer edge of the coast for over a mile south of Halleck Harbor. On Chichagof Island Mississipian beds form the Iyoukeen Peninsula.

The contacts between the Mississippian and older formations are either covered or obscured by faulting, but all the beds here described as Mississippian overlie Upper Devonian or late Middle Devonian beds.

AGE AND CORRELATION

Fossils collected from Soda Bay by the Wrights[71] in 1905 were determined by G. H. Girty, who reported as follows:

Zaphrentis sp.	Chonetes sp.
Menophyllum? sp.	Productus aff. P. punctatus.
Derbya sp.	Productus aff. P. mesialis.
Schizophoria? sp.	Productus aff. P. setiger.

[71] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 54, 1908.

Productus hirsutiformis.
Productus aff. P. cora.
Productus aff. P. concentricus.
Productus aff. P. burlingtonensis.
Spirifer aff. S. bisulcatus.
Spirifer aff. S. keokuk.
Spiriferina sp.
Reticularia aff. R. setigera.
Athyris aff. A. lamellosa.

This lot clearly belongs to the lower Carboniferous fauna.

The following collections made by Chapin were also identified by Girty, who reports:

1803 (15 ACh 234). Island at entrance to Soda Bay:

Zaphrentis sp.
Lithostrotion aff. L. portlocki.
Productus semireticulatus.
Productus sp.
Spirifer striatus?

1803 a (15 ACh 233). Island at entrance to Soda Bay:

Zaphrentis sp.
Lonsdaleia? sp.
Syringopora sp.
Productus aff. P. cora or P. giganteus.
Reticularia? sp.

1803 b (15 ACh 232). Island at entrance to Soda Bay:

Aulopora? sp.
Lonsdaleia? sp.
Productus giganteus.
Martinia? sp.

1803 c (15 ACh 233). Island at entrance to Soda Bay:

Lithostrotion sp.
Campophyllum? sp.
Productus giganteus.

1803 d (15 ACh 230). Island at entrance to Soda Bay:

Productus giganteus.
Pustula sp.
Girtyella? sp.
Martinia? sp.
Composita? sp.
Edmondia? sp.
Euomphalus? sp.

1804 (15 ACh 238). Northeast coast of Suemez Island 1½ miles southeast of Point Bocas:

Fenestella sp.
Hemitrypa sp.
Batostomella? sp.
Batostomella? sp.
Schizophoria sp.
Orthotetes aff. O. keokuk.
Chonetes aff. C. illinoisensis.
Productus semireticulatus.
Productus aff. P. ovatus.
Avonia? sp.
Pustula aff. P. biseriata.
Pustula sp.
Productella concentrica.
Spirifer aff. S. keokuk.
Reticularia aff. R. setigera.
Composita sp.
Griffithides sp.
Paraparchites aff. P. carbonarius.
Eumetria sp.

Girty says:

The Carboniferous collections represent at least three distinct faunas. One of these belongs in the upper Mississippian and apparently represents the Mountain limestone or *Productus giganteus* zone of European geologists. * * * The Mississippian lots, then, are in ascending order 234, 232, 233, and 230. They belong to the Lisburne fauna and correlate the rocks from which they came with the formation of that name in northwestern Alaska and with the Mountain limestone of Europe. The Mountain limestone is generally correlated with the upper Mississippian of North America. Another collection representing the same fauna is that numbered 238.

2434 a (16 ACh 105). Eastern island of group east of Madre de Dios Island, entrance to Trocadero Bay:

Fusulinella? sp.
Endothyra aff. E. bowmani.
Crinoid stems.
Batostomella sp.
Fistulipora sp.
Fenestella sp.
Polypora sp.
Pinnatopora sp.
Coeloconus sp.
Rhabdomeson sp.
Goniocladia? sp.
Cystodictya aff. C. pustulosa.
Orthotetes? sp.
Streptorhynchus? sp.
Schizophoria n. sp.
Productus semireticulatus.
Productus aff. P. undatus?
Diaphragmus n. sp.
Tegulifera? sp.
Pustula aff. P. eximia.
Pustula aff. P. distorta.
Pustula aff. P. spinulosa.
Pustula sp.
Shumardella missouriensis?
Girtyella sp.
Brachythyris aff. B. suborbicularis.
Brachythyris n. sp.
Spirifer aff. S. pellensis.
Martinia n. sp.
Composita n. sp.
Cleiothyridina aff. C. sublamellosa.
Eumetria verneuiliana.
Edmondia sp.
Sphenotus? sp.
Cardiomorpha? sp.
Caneyella? n. sp.
Leptodesma sp.
Pterinopecten n. sp.
Aviculipecten n. sp.
Aviculipecten sp.
Pleurotomaria sp.
Euomphalus sp.
Naticopsis? sp.
Bulimorpha sp.
Platyceras sp.
Orthoceras sp.
Nautilus sp.
Gastrioceras sp.
Goniatites sp.
Griffithides sp.
Paraparchites sp.
Bairdia sp.

16 ACh 106. Robber Islands, entrance to Trocadero Bay:

Lithostrotion? sp.
Zaphrentis sp.
Stenopora? 2 sp.
Anisotrypa? sp.
Batostomella sp.
Fenestella sp.
Polypora sp.
Cystodictya aff. C. pustulosa.
Orthotetes? sp.
Schizophoria? sp.
Chonetes aff. C. illinoisensis.
Productus giganteus.
Productus semireticulatus.
Productus sp.
Pustula aff. P. magnituberculata.
Pustula punctata.
Pustula sp.
Productella? aff. P concentrica.
Camarotoechia sp.
Spirifer aff. S. striatus.
Syringothyris? sp.
Reticularia aff. R. pseudolineata.
Cliothyridina aff. C. incrassata.
Conocardium sp.
Platyceras sp.
Phillipsia sp.

16 ACh 107. Madre de Dios Island, entrance to Trocadero Bay:

Zaphrentis sp.
Lonsdaleia? sp.
Cystodictya? sp.
Rhombopora sp.
Schizophoria sp.
Productus semireticulatus.
Brachythyris sp.
Ostracoda indet.

16. ACh 115. Klawak Island, a quarter of a mile north of Klawak cannery:

Michelinia sp.
Zaphrentis sp.
Lithostrotion sp.
Lithostrotion sp.
Lonsdaleia sp.
Crinoidal fragments.
Schizophoria aff. S. swallowi.
Orthotetes? sp.
Streptorhynchus? sp.
Chonetes aff. C. illinoisensis.
Chonetes sp.
Productus giganteus.
Productus aff. P. longispinus.
Productus aff. P. gallatinensis.
Productus aff. P. inflatus.
Productus aff. P. striatus.
Productus aff. P. ovatus.
Productus sp.
Pustula aff. P. plicatilis.
Pustula aff. P. pilosa.
Pustula aff. P. spinulosa.
Pustula sp.
Overtonia? aff. O. fimbriata.
Productella? aff. P. concentrica.
Camarotoechia? sp.
Cranaena? sp.
Spirifer aff. S. cameratus.
Spirifer, 2 sp.
Spiriferina? sp.
Squamularia? sp.
Martinia? sp.
Cliothyridina? sp.
Composita sp.
Sphenotus sp.
Nucula? sp.
Pterinopecten sp.
Leptodesma sp.
Bellerophon aff. B. sublevis.
Pleurotomaria? sp.
Platyschisma? 2 sp.
Platyceras sp.
Proetus sp.
Paraparchites sp.
Bairdia sp.

16 ACh 145. East shore of island in Klawak Inlet, 2¼ miles north of Klawak:

Lithostrotion sp.
Lonsdaleia? sp.
Fenestella several sp.
Polypora several sp.
Pinnatopora? (Ptilopora?) sp.
Rhabdomeson sp.
Schizophoria (or Rhipidomella) sp.
Orthotetes? sp.
Productus semireticulatus.
Productus ovatus?
Pustula aff. P. wallacianus.
Rhynchopora sp.
Leiorhynchus? aff. L. greenianum.
Brachythyris aff. B. suborbicularis.
Spirifer aff. bifurcatus?
Syringothyris? sp.
Spiriferina sp.
Reticularia sp.
Martinia? sp.
Hustedia sp.
Conocardium sp.
Naticopsis? sp.
Proetus sp.

The following collections were made by Buddington and identified by Girty, who reports:

930 (5443). Northwest end of long island at head of Saginaw Bay, Kuiu Island, on east side; 40-foot bed of limestone intercalated in series of interlayered chert, slaty quartzite, and cherty limestone:

Endothyra? sp.
Cyathaxonia sp.
Lonsdaleia sp.
Amplexus? sp.
Triplophyllum sp.
Clisiophyllum sp.
Platycrinus sp.
Batostomella? sp.
Leioclema sp.
Glyptopora n. sp.
Cystodictya aff. C. lineata.
Crania n. sp.
Rhipidomella n. sp.
Derbya? sp.
Chonetes aff. C. capax.
Productus n. sp. aff. P. samsoni.
Productus aff. P. cora.
Productus aff. P. gallatinensis.

Productus aff. P. ovatus var. minor.
Pustula aff. P. wallaciana.
Pustula aff. P. curvirostris.
Pustula aff. P. millespinosa.
Pustula aff. P. concentrica.
Pustula sp. a.
Pustula, 3 sp. indet.
Pustula? sp.
Marginifera? cf. M. juresanensis.
Camarophoria sp.
Rhynchopora aff. R. beecheri.
Dielasma aff. D. formosum.
Dielasma aff. D. arkansanum.
Dielasma? sp.
Spirifer aff. S. missouriensis.
Spirifer n. sp.
Spirifer sp.
Brachythyris aff. B. subcardiiformis var.
Spiriferina aff. S. panderi.
Spiriferina aff. S. cristata.
Squamularia aff. S. perplexa.
Martinia? sp.
Composita n. sp.
Hustedia sp.
Schizodus? sp.
Deltopecten aff. D. wyandotte.
Aviculipecten aff. D. similis.
Euphemus? sp.
Euomphalus aff. E. planidoreatus.
Platyceras sp.
Griffithides sp.

932 (5444). Head of Saginaw Bay, Kuiu Island:

Fusulina sp.
Ortonia? sp.
Stenopora sp.
Fenestella several sp.
Semicoccinium? n. sp.
Polypora, several sp.
Septopora? sp.
Acanthocladia n. sp.
Streblotrypa? n. sp.
Chainodictyon? sp.
Coeloconus sp.
Cystodictya? sp.
Crania n. sp.
Crania sp.
Rhipidomella aff. R. carbonaria.
Schizophoria? sp.
Derbya? sp.
Chonetes aff. C. capax.
Productus aff. P. cora.
Productus semireticulatus.
Productus aff. P. koninckianus.
Productus aff. P. ovatus var. minor.
Productus aff. P. sampsoni?
Productus sp.
Pustula aff. P. indianensis.
Pustula aff. P. concentrica.
Pustula aff. P. morbilliana.
Pustula aff. P. pseudaculeata.
Pustula aff. P. rugata?
Pustula sp. a?
Pustula sp. d.
Pustula? sp.
Strophalosia? sp.
Camarophoria aff. C. bisinuata.
Rhynchopora aff. R. beecheri.
Dielasma n. sp.
Dielasma aff. D. formosum.
Dielasma aff. D. arkansanum.
Spirifer aff. S. missouriensis.
Spirifer n. sp.
Spiriferina aff. S. cristata.
Brachythyris aff. B. subcardiiformis var.
Squamularia aff. S. perplexa.
Ambocoelia aff. A. planiconvexa.
Cliothyridina aff. C. orbicularis.
Hustedia n. sp.
Edmondia sp.
Sphenotus, 3 sp. indet.
Sphenotus? sp.
Goniophora? n. sp.
Nucula aff. N. shumardiana.
Leda? sp.
Parallelodon sp.
Aviculipecten aff. A. similis.
Aviculipecten chesterensis?
Aviculipecten aff. A. edwardsi.
Aviculipecten aff. A. edwardsi var.
Aviculipecten aff. A. hardinensis.
Aviculipecten, 2 sp. indet.
Aviculipecten n. sp.
Deltopecten aff. D. caneyanus.
Deltopecten, 2 sp. indet.
Leiopteria? sp.
Conocardium n. sp.
Myalina sp.
Cypricardina aff. C. consimilis.
Cypricardella sp.

200 (4304). About 8 miles southeast of Point Cornwallis, on Keku Strait, just north of conspicuous sea arch in limestone:

Fusulinella sp.
Zaphrentis? sp.
Crinoid.
Polypora? sp.
Diplopora? sp.
Batostomella? sp.
Rhipidomella sp.
Chonetes sp.
Productus ovatus?
Productus n. sp.?
Productus sp.
Pustula sp.
Camarophoria sp.
Spirifer sp.
Spiriferina sp.
Hustedia sp.
Pleurotomaria? sp.
Straparollus? sp.
Griffithides sp.
Bairdia sp.

2053 (5445). About 1 mile northwest of Klawak:

Schizophoria aff. S. swallowi.
Orthotetes? sp.
Productus semireticulatus var.
Productus aff. P. gallatinensis.
Dielasma? sp.
Spirifer aff. S. mosquensis.
Cliothyridina? sp.

2069 (5446). Northwest end of island about 2½ miles north of Klawak:

Triplophyllum sp.
Spirorbis sp.
Fenestella sp.
Schizophoria sp.
Productus giganteus.
Productus aff. R. gallatinensis.
Pustula aff. P. semicostata.
Pustula sp. b.
Marginifera? aff. M. splendens.
Marginifera? n. sp.
Camarotoechia sp.
Spirifer aff. S. mosquensis.
Cliothyridina? sp.
Euomphalus n. sp.

2090 (5446). Small islet about 1¾ miles north of Klawak:

Fusulina sp.
Lithostrotion? sp.
Campophyllum? sp.
Triplophyllum sp.
Rhipidomella aff. R. nevadensis.
Productus semireticulatus var.
Productus aff. P. cora.
Pustula aff. P. pseudaculeata.
Marginifera? n. sp.
Squamularia perplexa.
Composita? sp.
Euomphalus aff. E. utahensis.

2095 (5447). Just east of cemetery on island north of Klawak:

Rhombopora sp.
Rhabdomeson sp.
Cystodictya sp.
Derbya? sp.
Chonetes aff. C. illinoisensis.
Chonetes aff. C. geinitzianus.
Chonetes sp.
Productus aff. P. cora.
Productus aff. P. ovatus var. minor.
Productus sp.
Pustula aff. P. alternata.
Pustula sp. c.
Pustula, 2 sp. indet.
Marginifera? sp.
Camarophoria? sp.
Dielasma? n. sp.
Squamularia aff. S. perplexa?
Griffithides sp.

2108 (5449). Little islet about 1⅓ miles north of Klawak. Gray sandstone with intercalated calcareous beds:

Triplophyllum sp.
Rhipidomella aff. R. nevadensis.
Schizophoria? sp.
Chonetes sp.
Productus semireticulatus.
Productus aff. P. cora.
Pustula aff. P. punctata.
Pustula aff. P. blairi.
Marginifera? aff. M. splendens.
Squamularia? sp.
Ambocoelia sp.
Cliothyridina aff. C. sublamellosa.

Sphenotus, 2 sp. indet.
Parallelodon n. sp.
Cypricardella n. sp.
Schizodus? sp.
Aviculipecten aff. A. similis.
Laevidentalium aff. L. venustum.
Bellerophon sp.
Bucanopsis sp.
Euphemus carbonarius.
Phanerotrema aff. P. grayvillense.
Phanerotrema? aff. P. wortheni.
Solenospira? sp.
Goniatites? sp.
Bembexia aff. B. swallowiana.
Trepospira? sp.
Pleurotomaria sp.
Pleurotomaria n. sp.
Pleurotomaria, 2 sp. indet.
Solenospira? sp.
Anomphalus? n. sp.
Aclisina? sp.
Sphaerodoma sp.
Meekospira sp.
Straparollus aff. S. spergenensis var. planorbiformis.
Naticopsis aff. N. carleyana.
Naticella n. sp.
Naticella? sp.
Zygopleura n. sp.
Orthoceras sp.
Phillipsia n. sp.
Ostracoda indet.

2257 (5450). East side of small islet in Klawak Harbor:

Clisiophyllum sp.
Batostomella sp.
Chainodictyon? sp.
Rhombopora sp.
Schizophoria aff. S. swallowi.
Schizophoria? sp.
Rhipidomella sp.
Derbya? sp.
Chonetes aff. C. illinoisensis.
Productus semireticulatus.
Productus aff. P. gallatinensis.
Productus aff. P. cora.
Pustula aff. P. pustulata.
Pustula aff. P. carringtoniana.
Pustula aff. P. rugata.
Pustula aff. P. pseudaculeata.
Pustula aff. P. spinulosa.
Pustula, 2 sp. indet.
Marginifera? n. sp.
Camarophoria sp.
Camarophoria? sp.
Girtyella? sp.
Dielasma? n. sp.
Spirifer aff. S. incertus.
Squamularia aff. S. perplexa.
Delthyris? n. sp.
Brachythyris aff. B. subcardiiformis.
Spiriferina sp.
Cliothyridina sp.
Hustedia aff. H. remota.
Platyceras sp.

Girty makes the following comments on the collections by Buddington:

I am inclined to refer [them] to the upper Mississippian (Lisburne horizon), yet not without some doubt. Their fauna at least marks a pronounced change from that of the Permian, whether of the dark sandy beds or of the whitish limestone. Nor are they equally open to doubt, for lots 2257 and 2069 I would identify with considerable confidence as Mississippian. The several faunas contained in these collections differ from one another considerably, and all may not belong to the same period. On the other hand, several collections are not without strong suggestions of Pennsylvanian time. In the United States I should regard *Fusulina* and *Squamularia*, and to a less degree *Hustedia*, as indexical of Pennsylvanian, but there the evidence of these forms is not uncontradicted. It is obvious, however, that these Alaskan faunas have no counterpart of any age in the United States, and that the criteria which one would safely employ there can not be employed here. As to *Fusulina*, the form which has been recognized in two of the collections is very rare, very small, and very primitive, and furthermore, not only the related genus *Fusulinella* but *Fusulina* itself is known in the Mountain limestone (upper Mississippian) of Russia. It seems best, then, to refer these eight collections to the upper Mississippian and to account for their diverse facies and their, in some cases, Pennsylvanian leanings by the fact that the upper Mississippian faunas of Alaska are extremely varied, that they are widely different from the Mississippian faunas of the United States, and that they are imperfectly known and have never been described in detail.

Partly for the reasons just given, I have made few if any unqualified identifications of the species collected, and in making comparisons I have employed species best known to me and probably to others most likely to use the faunal lists; or else I have employed less known species that are more similar than the familiar ones. My object has been to convey some notion of the faunas shown by the collections, so that the very diverse and conflicting faunal relations suggested by the comparisons should carry little weight. In fact, not a few of these species of supposed Mississippian age are compared with late Pennsylvanian species figured by Tschernyschew in his monograph on the Gschelian fauna of Russia. This is partly because parallel species were lacking in our own Mississippian and Pennsylvanian faunas. Furthermore, the Gschelian fauna contains many types not found in our own Pennsylvanian faunas at all, some of them even recalling our Mississippian faunas. This is so true that I have not been able wholly to divest myself of the suspicion that some of the collections included in the Gschelian monograph came from Mississippian horizons.

PENNSYLVANIAN (?) ROCKS

By Theodore Chapin

The Pennsylvanian (?) fauna occurs in the massive white limestone which is confined to the small bay on the southeast corner of the island in Soda Bay, on the west coast of Prince of Wales Island, about east of the north end of Dall Island. The limestone, which is at least 100 feet thick, overlies conformably the limestone of Mississippian age and appears to occupy the trough of a syncline, the axis of which is about coincident with the axis of the bay. (See pl. 19, *B*.)

The following collection of fossils was identified by G. H. Girty:

16 ACh 228 (1803–e). Southwest corner of island in the mouth of Soda Bay, Prince of Wales Island:

Chaetetes milleporaceus.
Lophophyllum sp.
Lophophyllum sp.
Euomphalus sp.

The highest of the [Soda Bay] collections (228, 1803–e) is probably of Pennsylvanian age. It contains little that is really diagnostic, but we note a complete faunal change from the *Productus giganteus* fauna below. The coral genera *Chaetetes* and *Lophophyllum*, though not really confined to the Pennsylvanian, are especially characteristic of its fauna. In North America the genus *Chaetetes* appears to be practically restricted to rocks of Pennsylvanian age. Indeed, no Mississippian occurrences are generally known, though I have recognized the genus in two or three Mississippian collections, a fact not yet made public. Provisionally, lot 228 may be assigned to the Pennsylvanian, and it may be compared with the Moscovian of Russia. Additional evidence, however, is needed to give force to either correlation.

PERMIAN ROCKS

CHARACTER AND OCCURRENCE

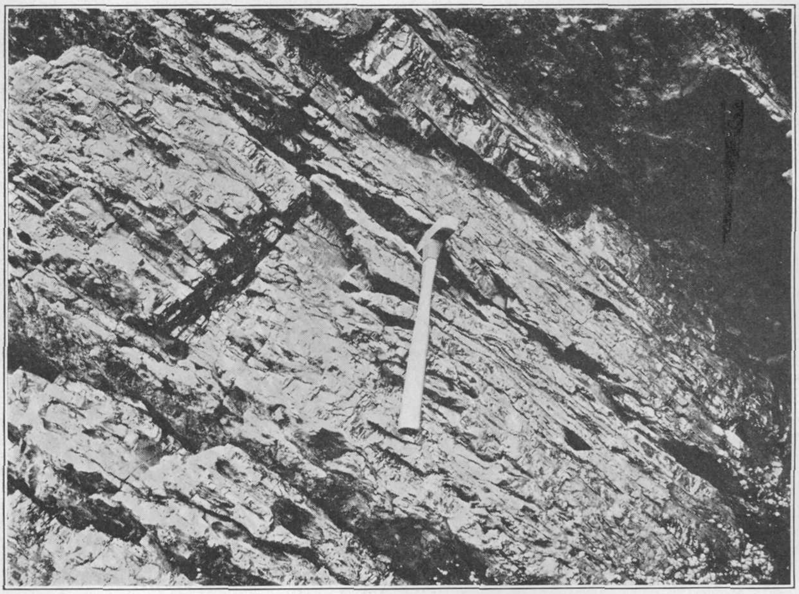
The rocks here classified as Permian comprise two divisions, both of which are tentatively assigned to the Permian by Girty. The lower division comprises a very great variety of rocks, including thick conglomerate; black calcareous shale with layers of brown-weathering limestone or buff calcareous sandstone; basaltic and andesitic lava, in part with pillow structure; andesitic tuff and breccia; thick-bedded medium-grained white limestone with layers of white chert; brownish-weathering thin-bedded dense limestone; sandstone; and perhaps at some places felsite breccias, tuffs, and flows. The upper division is more uniform and consists of white limestone with intercalated layers of white chert.

The most characteristic and most complete sequence of unmetamorphosed Permian beds is exposed on the Cornwallis Peninsula of Kuiu Island and on the Keku Group of islands.

In the Ketchikan district the known Permian is exposed only on the small narrow peninsula at the extreme eastern side of Suemez Island. These beds belong to the upper division of the Permian and are described by Chapin as consisting of about 300 feet of closely folded blue and gray limestone, which appears to have unconformable relations to the older formations. Beds of the lower division of the Permian are found on lower Porcupine Creek in the Skagway district.

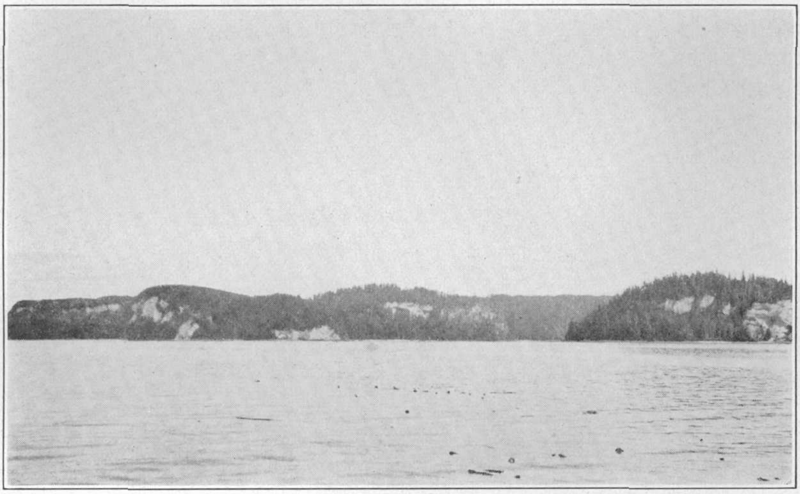
The upper division of the Permian is exposed locally beneath the Upper Triassic formations along the north shore of Hamilton Bay, on the long island several miles south of Kake, and southeast of Pinta Rocks, on the eastern flank of the Cape Bendel syncline, Kupreanof Island. These beds also form the conspicuous mountain about 5 miles north of Kake. On Admiralty Island they are known in Pybus and Herring Bays. On the mainland the upper division of the Permian is found at the south headland of Taku Harbor and about 2½ miles east of Point Coke, at the entrance to Holkham Bay, in the Juneau district.

Highly metamorphosed Carboniferous formations, that may be of Permian age, are found on the west side of Windfall Harbor, Admiralty Island. The rocks consist predominantly of amygdaloidal and porphyritic andesitic lava with zones of chert, black slate, and one thick zone of interbedded conglomerate, limestone, chert, and green andesitic tuff and lava with intercalated red beds comprising shale, sandstone, and conglomerate. Several of the limestone beds, though highly sheared, are coralline and crinoidal, and the fauna was identified by G. H. Girty as of Carboniferous age.

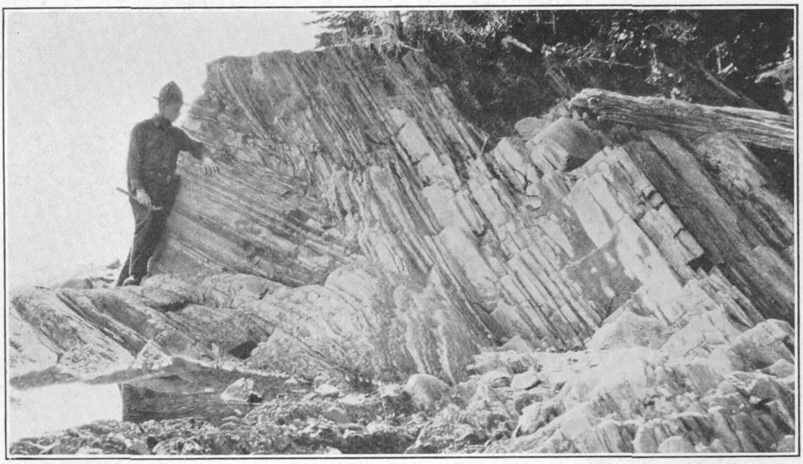


A. BLACK CHERT OF MISSISSIPPIAN AGE, MADRE DE DIOS ISLAND

B. FOSSILIFEROUS MASSIVE WHITE LIMESTONE OF PENNSYLVANIAN AGE, SODA BAY, PRINCE OF WALES ISLAND



A. PERMIAN LIMESTONE BLUFFS ON NORTHEAST SIDE OF SAGINAW BAY, KUIU ISLAND



B. OVERTURNED FOLD IN GRAYWACKE AND PHYLLITE, EAST SIDE OF FREDERICK SOUND

The Snettisham Peninsula on the mainland consists of schistose greenstone volcanic rocks with intercalated beds of limestone, conglomerate, and argillaceous and quartz-mica schists. On the shore northeast of the Midway Islands a 100-foot bed of schistose limestone has many layers containing abundant corals or crinoids. A fauna from this limestone submitted to G. H. Girty was identified as of Carboniferous age. About 2½ miles east of Point Coke, at the point at the entrance to Tracy Arm, there is an exposed bed of limestone with layers of schistose white chert which is lithologically identical with similar Carboniferous beds. The cove east of Point Anmer, at the north end of Snettisham Peninsula, is carved out of limestone which contains poorly preserved silicified fossils and resembles the upper division of the Permian.

At Taku Harbor, in the Juneau district, limestone carrying Carboniferous fossils (probably Permian) occurs in association with schistose greenstone, phyllite, thin beds of limestone and chert, and black graphitic slate.

The stratigraphic succession in the lower division of the Permian appears to be variable. In Saginaw Bay the beds immediately overlying the Mississippian appear to be brown to buff weathering calcareous gray sandstone, with lenses of coarse conglomerate and interbedded limestone and shale. The sandstone predominates, and the beds lie conformably on the Mississippian. The conglomerate consists of cobbles of andesite, red rhyolite, white chert, red jasper, and limestone. At the head of the bay the sandstone beds are overlain by a thick series of black calcareous slate interlayered with buff-weathering siliceous limestone and calcareous sandstone. On the south side of Halleck Harbor the sandstone is overlain by a thick series of basaltic or andesitic breccia with sparse small limestone pebbles and cobbles that carry Carboniferous fossils. To the southeast the volcanic rocks appear to thin out and interdigitate as green tuff with interbedded sandstone, shale, and limestone. On the islands opposite the cannery the cherty dolomite of the upper division of the Permian overlies andesitic pillow lava and tuff with interbedded limestone and calcareous sandstone full of carbonized plant remains. On Halleck Harbor the same beds overlie brownish-weathering sandy limestone and black calcareous shale. The lower Permian beds are cross folded and warped so that estimates of thickness are difficult.

On the northeast side of Cornwallis Peninsula and in the Keku Islets Permian formations are again exposed, but though not more than 4 miles apart across the strike, the lithology of the formations is in some respects quite different. Conglomerate beds predominate. The lowest beds appear to be exposed along the northeast coast of

Cornwallis Peninsula from the point about 10 miles southeast of Point Cornwallis. The beds comprise interbedded conglomerate, conglomeratic limestone, sandstone, and limestone with intercalated basalt and andesite flows. The conglomerate consists of pebbles and cobbles of andesite, white chert, limestone, red jasper, and other rocks. Some of the limestone has intercalated layers of white chert. Rhyolite of unknown age forms part of the coast in this vicinity. About 4 miles southeast of Point Cornwallis there is a series of volcanic rocks and conglomerate exposed locally along the coast for a mile and also on the west side of the long islet. These beds are overlain unconformably by Upper Triassic limestone and are probably of Permian age. They consist of rhyolite breccia and tuff of red, white, and greenish hues, with interbedded lava and conglomerate, and of basaltic breccia and amygdaloidal basalt with many veinlets of brilliant red jasper.

The small islet and reefs about 4 miles southeast of Point Cornwallis, opposite a conspicuous sea arch, are composed of about 400 feet of interbedded conglomerate and brown sandstone overlain by limestone and underlain by limestone with white chert layers. The conglomerate is composed predominantly of fragments of red felsite and green andesite with abundant limestone, chert, and bits of red jasper; many of the limestone cobbles are highly crinoidal. Toward the northeast andesitic tuff is intercalated in the conglomerate. The age of these beds is indeterminate except as indicated by the fact that on the next islet to the east about 250 feet of fossiliferous limestone which belongs to the lower division of the Permian, interbedded with andesitic flows and tuffs, is exposed in a position structurally overlying the conglomerate. On the next large island to the east there is exposed about 1,000 feet of conglomerate, consisting largely of cobbles and pebbles of limestone and chert, with intercalated sandstone. These beds are in a structural position that would place them higher in the series than the limestone and volcanic rocks, and they are in turn overlain conformably by the limestone with intercalated chert layers carrying a fauna characteristic of the upper division of the Permian. The uppermost beds of the conglomerate series are brown-weathering sandstone with intercalated limestone and conglomerate. Some of the limestone cobbles in this conglomerate carry a fauna identified by Edwin Kirk as of Silurian age.

On the large northwesternmost island of the Keku group there is about 1,200 feet of black platy or shaly limestone or calcareous shale with a few intercalated layers of buff-weathering sandy limestone and a 75-foot bed of conglomerate. These beds form a triangular area in the middle of the island leaving only a narrow strip at the west side of the base of the peninsula on the north side of the island

and a wide area on the east. They are adjoined on the west by infolded or infaulted Upper Triassic beds, and on the east by limestone and chert. The beds of buff-weathering limestone are highly fossiliferous with a fauna identified by G. H. Girty as belonging to the lower division of the Permian.

Carbonized plant remains are frequently found in the sandstones of the lower division of the Permian.

The upper division of the Permian is characteristically exposed on the Keku Islets, on Cornwallis Peninsula of Kuiu Island (pl. 20, A) and on Pybus and Herring Bays, Admiralty Island. The formation consists of about 1,000 feet of limestone with intercalated layers or interbeds of white chert. The relative amount of chert is variable in different sections. On the Keku Islands the chert layers usually range from about 9 inches to several feet in thickness and the limestone beds from 5 to 50 feet. Lenticular veinings of chert are also common in the limestone. Many of the chert layers are considerably brecciated. Locally, as on the south side of Admiralty Island west of False Point Pybus, there is as much as 200 feet of white chert with only a very little limestone, and elsewhere there are relatively clean beds of limestone several hundred feet thick. The beds are highly fossiliferous, and faunas collected from many localities have all been identified by G. H. Girty as of Permian age.

AGE AND CORRELATION

The age of the formations listed here as Permian is based on several collections of fossils made by Wright and on later collections gathered from many localities by Buddington. The identifications are all by G. H. Girty.

Girty's report on collections made by Buddington in 1922 from both the upper and lower divisions of the Permian follows:

Where I have seen the Permian rocks of southeastern Alaska, they consist of an upper group of whitish cherty limestones and a lower group of blackish sandy limestones. The faunas also of these two divisions of the Permian, though related, are appreciably different. The existence of this lithologic and faunal distinction raises the question whether, as the upper division is classed as Permian, the lower should not be classed as upper Pennsylvanian. On this question I am inclined to take the negative side, for the present at least. The difference between the lower and upper faunas seems too slight for a boundary as important as that between the Pennsylvanian and the Permian.

He reports further on the collections made by Buddington in 1923:

Lots 5135 (966–c) and 5136 (976) contain the fauna of the white cherty Permian limestone correlated with the Artinsk sandstone of Russia, that is so well exposed on Kuiu Island (Saginaw Bay) and is also found in other parts of Alaska.

The white Permian limestone is underlain by dark sandy limestones which are exposed on Kuiu Island and on the Keku Islets. To this horizon I would refer lots 5126 (918–B), 5127 (920–A), 5122 (921), 5130 (925), 5129 (926), and 5132 (929). This fauna, if well represented, is readily distinguishable from that of the white limestone, though related to it, and should, I am inclined to think, be classed as Permian if the other is. It might well be classed, however, as upper Pennsylvanian if the Pennsylvanian was followed by the Permian without any marked lapse of time or change of conditions. Lots 5124 (913), 5131 (928), and 5134 (965) should also probably be included in this group, though they have a somewhat different fauna; and in the group, though less definitely, should probably be included the small collections 5123 (906) and 5125 (918–A). The paleontologic evidence which 5125 contains is too meager to indicate clearly where its affinities lie. Lot 5128 (905) is unique in consisting largely of Goniatites, but it does not contain enough other species to indicate its geologic age. This lot may go either with 5124, 5131, or 5134, or it may be much older. The Goniatites suggest certain Mississippian types, but they are also related to some that occur in the Pennsylvanian.

The accompanying lists show the species contained in the collections. But few positive identifications have been made. The faunas are so fundamentally unlike any that have been described in the United States proper that comparisons with our own Pennsylvanian and Permian species would be for the most part futile. The faunas most closely related to these, so far as known, are found in Russia, but the Russian faunas are so remote as to cast doubt in a general way upon the exact identity of many of the Alaskan species, and as no Russian specimens are available for direct comparisons, it has seemed best now, as in the past, merely to suggest relationships and to leave such final identifications as can be made to the course of a comprehensive study in which all of our specimens of each species can be employed.

LOWER DIVISION OF THE PERMIAN

The collections listed below were all made by Buddington, except as otherwise specified; the identifications are by G. H. Girty, who makes the following comments:

Lots 917 and 2349 contain a rather characteristic fauna which occurs in dark-colored siliceous and calcareous beds that underlie the whitish Permian limestone of Artinskian age. This fauna differs materially from that of the whitish limestone and at the same time is undoubtedly related to it. This horizon has been included along with the other in the Permian, but it may prove to be highest Pennsylvanian.

917 (5451). East side of peninsula on southwest side of Halleck Harbor, Kuiu Island:

Fenestella sp.
Derbya? sp.
Chonetes aff. C. granulifer.
Chonetes n. sp.
Productus aff. P. mammatus.
Productus semireticulatus var.
Productus aff. P. koninckianus.
Productus cora?
Pustula aff. P. fasciata.
Pustula aff. P. wallaciana.
Avonia aff. A. porrecta?
Marginifera aff. M. splendens.
Marginifera aff. M. splendens var.
Marginifera aff. M. lebedevi?
Camarophoria aff. C. mutabilis.
Camarophoria aff. C. pentameroides?
Rhynchopora sp.
Dielasma? sp.
Spiriferella arctica var.
Squamularia aff. S. perplexa.
Martinia? aff. M. simensis var. substricta.

Spirifer cameratus Tschernyschew [not Morton].
Ambocoelia n. sp.
Cliothyridina? sp.
Aviculipecten aff. A. delawarensis.
Aviculipecten aff. A. montpelierensis.
Aviculipecten sp.
Lima aff. L. retifera.
Bellerophon sp.

Halleck Harbor, Kuiu Island; black carbonaceous shale, calcareous sandstone, and conglomerate; lower division of upper Carboniferous; collected by Wright:[72]

Fusulina aff. F. longissima.
Crania sp.
Schizophoria? sp.
Derbya aff. D. robusta.
Chonetes sp.
Chonetes aff. C. trapezoidalis.
Productus aff. P. humboldti.
Productus aff. P. porrectus.
Productus aff. P. semireticulatus.
Productus aff. P. schrenki.
Productus cora.
Spirifer aff. S. ufensis.
Spirifer cameratus Tschernyschew [not Morton?].
Squamularia n. sp.
Martiniopsis sp.
Rhynchopora aff. R. geinitziana.
Dielasma sp.
Streblopteria sp.
Aviculipecten aff. A. mccoyi.
Aviculipecten, 2 sp.
Entolium aff. E. aviculatum.
Solenopsis? sp.

5125 (918–A). First niche in coast line southeast of the southwest headland of Halleck Harbor, Kuiu Island; thin-layered buff-weathering siliceous limestone underlying 5126 (918–B) either unconformably or in faulted relations:

Lonsdaleia sp.
Productus aff. P. gruenwaldti.
Productus aff. P. undatus.

5126 (918–B). First niche in coast line southeast of the northwest headland of Halleck Harbor, Kuiu Island; gray sandstone underlying conglomerate:

Fusulina aff. F. elongata.
Chonetes aff. C. geinitzianus.
Productus aff. P. ischmensis.
Productus aff. P. ischmensis var.
Productus aff. P. koninckianus.
Pustula aff. P. humboldti.
Rhynchopora sp.
Reticularia? n. sp.

5128 (926). Just southeast of cannery on northeast side of Saginaw Bay; buff-weathering interbedded calcareous sandstone and shale, overlain by conglomerate:

Fusulina aff. F. elongata.
Fenestella sp.
Orthotichia? aff. O. morganiana.
Streptorhynchus sp.
Chonetes aff. C. timanicus.
Chonetes aff. C. granulifer.
Productus aff. P. ischmensis.
Productus aff. P. ischmensis var.
Productus aff. P. koninckianus.
Productus aff. P. mammatus?
Productus aff. P. grueneWaldti.
Productus sp.
Pteria aff. P. longa.
Pinna sp.
Pustula aff. P. humboldti.
Marginifera sp.
Rhynchopora aff. R. nikitini.
Dielasma sp.
Spiriferina aff. S. cristata.
Reticularia? n. sp.
Squamularia? sp.
Spirifer aff. S. cameratus.
Euchondria? aff. E. neglecta.
Aviculipecten sp. a.
Aviculipecten sp. b?
Aviculipecten sp. d.
Aviculipecten aff. A. occidentalis.

[72] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 52, 1908.

5122 (921). First cove southeast of Halleck Harbor, Saginaw Bay, Kuiu Island; shaly limestone overlying interbedded andesitic breccia, tuff, and limestone:

Fusulina aff. F. elongata.
Fenestella sp.
Rhombopora sp.
Orthotichia? aff. O. morganiana.
Enteletes? n. sp.
Derbya aff. D. grandis.
Chonetes aff. C. geinitzianus.
Chonetes aff. C. granulifer.
Productus cora.
Productus aff. P. koninckianus.
Productus aff. P. mammatus.
Productus aff. P. gruenewaldti.
Pustula aff. P. juresanensis?
Pustula sp.
Acanthopecten aff. A. carbonifer.
Lima n. sp. a.
Lima n. sp. b.
Lima aff. L. retifera.
Marginifera aff. M. typica var. septentrionalis.
Marginifera aff. M. aagardi.
Rhynchopora aff. R. nikitini.
Dielasma aff. D. bovidens.
Dielasma aff. D. supracarbonicum.
Spirifer aff. S. cameratus.
Spiriferina aff. S. cristata.
Spiriferina aff. S. holtzapfeli.
Spiriferina sp.
Squamularia aff. S. perplexa.
Euchondria? aff. E. neglecta.
Aviculipecten sp. a.
Aviculipecten sp. b.
Aviculipecten sp. c.
Naticopsis n. sp. aff. N. nana.

5130 (925). North end of round island opposite cannery on northeast side of Saginaw Bay, Kuiu Island; limestone associated with andesitic volcanic rocks:

Orthotichia? aff. O. morganiana.
Derbya aff. D. grandis.
Chonetes aff. C. geinitzianus.
Chonetes aff. C. trapezoidalis.
Chonetes sp.
Productus aff. P. koninckianus.
Productus aff. P. ischmensis.
Productus aff. P. ischmensis var.
Pustula aff. P. humboldti.
Reticularia? n. sp.
Euchondria? aff. E. neglecta.
Phanerotrema sp.

5131 (928). About two-thirds of a mile southeast of cannery on northeast side of Saginaw Bay, Kuiu Island; calcareous slate with many basalt dikes; Tertiary:

Sponge?
Striatopora sp.
Fenestella sp.
Pinnatopora sp.
Rhombopora sp.
Chonetes sp.
Productus aff. P. gruenewaldti.
Productus aff. P. koninckianus.
Marginifera aagardi.
Pustula aff. P. wallaciana?
Rhynchopora? sp.
Ambocoelia? sp.
Anthraconeilo? sp.
Aviculipecten sp. f.
Nautilus? sp.
Phillipsia sp.

5132 (929). Northeast side of Saginaw Bay, about 1½ miles southeast of cannery; buff-weathering interbedded calcareous sandstone and shale:

Fusulina aff. F. elongata.
Zaphrentis sp.
Triplophyllum sp.
Amplexus? sp.
Batostomella sp.
Fenestella, 2 sp.
Polypora, 2 sp.
Crania sp.
Derbya aff. D. grandis.
Chonetes aff. C. geinitzianus.
Chonetes aff. C. trapezoidalis.
Chonetes aff. C. granulifer var.
Productus aff. P. koninckianus.
Productus aff. P. mammatus.
Productus aff. P. gruenewaldti.
Pustula humboldti.
Pustula aff. P. fasciata.
Pustula aff. P. tuberculata.

Pustula aff. P. juresanensis?
Marginifera aff. M. typica var. septentrionalis.
Spirifer aff. S. cameratus.
Spiriferina sp.
Reticularia? n. sp.
Squamularia aff. S. perplexa.
Parallelodon sp.
Aviculipecten sp. b?
Aviculipecten sp. d?
Aviculipecten sp. e.
Pernipecten n. sp.
Lima sp. b.
Conocardium? sp.
Schizodus? sp.
Bellerophon sp.
Pleurotomaria n. sp. aff. P. conulus.
Naticopsis n. sp. aff. N. nana.
Platyceras.
Ostracoda indet.

2349 (5452). Head of Saginaw Bay, east side of cove on east side of bay:

Zaphrentis sp.
Campophyllum sp.
Spirorbis? sp.
Leioclema sp.
Polypora sp.
Thamniscus? sp.
Crania sp.
Schizophoria n. sp.
Derbya? sp.
Chonetes aff. C. granulifer.
Chonetes aff. C. verneuilianus.
Chonetes aff. C. ostiolatus?
Productus cora.
Productus aff. P. tenuistriatus.
Productus aff. P. koninckianus.
Productus aff. P. cancriniformis.
Productus sp.
Productus semireticulatus var.
Productus aff. P. gruenewaldti.
Avonia aff. A. porrecta.
Pustula aff. P. irginae.
Pustula aff. P. subhorrida.
Pustula aff. P. wallaciana.
Pustula aff. P. pseudaculeata.
Pustula sp.
Marginifera aff. M. splendens.
Camarophoria aff. C. pentameroides.
Rhynchopora sp.
Spirifer cameratus Tschernyschew [not Morton].
Spirifer aff. S. nikitini.
Spirifer aff. S. fasciger.
Brachythyris aff. B. ufensis.
Spiriferella? aff. S. artiensis.
Spiriferina sp.
Spiriferina sp.
Squamularia aff. S. perplexa.
Reticularia? sp.
Cliothyridina aff. C. roisayana.
Aviculipecten aff. A. delawarensis.
Aviculipecten aff. A. montpelierensis.
Aviculipecten sp.
Pernipecten aff. P. aviculatus.
Pteria n. sp.
Schizodus? sp.
Pleurotomaria sp.
Naticopsis sp.
Platyceras sp.
Griffithides sp.

4308 (206). Northernmost Keku Islet, west side; black limestone with buff-weathering layers and conglomerate beds:

Derbya? sp.
Chonetes sp.
Productus aff. P. cancrini.
Productus aff. P. mammatus.
Productus aff. P. semireticulatus.
Marginifera aff. M. involuta.
Marginifera aagardi.
Schizophoria sp.
Camarophoria aff. C. crumena.
Spiriferella? arctica var.
Squamularia aff. S. perplexa.
Cliothyridina n. sp.
Aviculipecten sp.
Myalina? sp.

Same as 4308; collected by Wright:[73]

Fusulina aff. F. longissima.
Stenopora sp.
Rhombopora sp.
Meekella? sp.
Derbya? sp.
Chonetes aff. C. trapezoidalis.
Productus aff. P. cora.
Productus aff. P. humboldti.

[73] Wright, F. E. and C. W., op. cit., pp. 53–54.

Productus aff. P. koninckianus.
Productus aff. P. fasciatus.
Productus aff. P. tartaricus.
Productus aff. P. lineatus.
Productus semireticulatus.
Productus aff. P. jakovlevi.
Streblopteria sp.
Aviculipecten aff. A. mccoyi.
Aviculipecten, 2 sp.
Myalina aff. M. perattenuata.
Pinna? sp.
Schizodus sp.
Capulus sp.
Straparollus sp.
Bulimorphia aff. B. peracuta.
Productus n. sp. aff. P. tuberculatus.
Productus sp.
Marginifera aff. M. juresanensis.
Spirifer cameratus Tschernyschew [not Morton?].
Spirifer arcticus?
Spiriferina aff. S. pyramidata.
Squamularia sp.
Pugnax aff. P. utah.
Rhynchopora aff. R. geinitziana.
Rhynchopora aff. R. nikitini.
Camarophoria aff. C. purdoni.
Camarophoria aff. C. superstes.
Pseudomelania sp.
Loxonema aff. L. subgracilis.
Turbonellina aff. T. chatzepovkensis.
Pleurotomaria, 2 sp.
Bellerophon sp.
Medlicottia aff. M. orbignana.
Leperditia sp.

4309 (215). East side of northernmost large Keku Islet; black calcareous shale with intercalated beds of buff-weathering limestone:

Zaphrentis? sp.
Cladochonus sp.
Batostomella sp.
Derbya? sp.
Productus aff. P. mammatus.
Productus aff. P. timanicus.
Productus aff. P. cancrini.
Pustula aff. P. humboldti.
Marginifera aagardi.
Marginifera? aff. M. lebedevi.
Marginifera? aff. M. involuta.
Camarophoria aff. C. crumena.
Rhynchopora aff. R. nikitini.
Dielasma sp.
Spiriferella? arctica var.
Spirifer aff. S. dieneri.
Spirifer aff. S. fasciger.
Spiriferina sp.
Squamularia aff. S. perplexa.
Cliothyridina n. sp.
Aviculipecten sp.
Pleurotomaria? sp.

5128 (905). Kuiu Island, just west of the point on Keku Strait where the coast line turns from north to northwest, limestone overlying conglomeratic limestone, and andesitic lava involved in an indeterminate relation:

Lonsdaleia sp.
Platyceras sp.
Gastrioceras aff. G. nolinense.

5123 (906). Just northwest of locality 5128; coral reefs interbedded with basaltic flows:

Triplophyllum sp.
Striatopora? sp.

4305 (231). Kuiu Island, west of south end of Keku Island group; limestone with interbedded basaltic lava:

Syringopora? n. sp.
Zaphrentis? sp.
Clisiophyllum sp.
Lonsdaleia n. sp.
Lonsdaleia? sp.
Polypora sp.
Rhombopora sp.
Schizophoria sp.
Productus aff. P. gruenewaldti.
Productus cora Tschernyschew [not D'Orbigny].
Camarophoria margaritovi?
Spirifer aff. S. striatus Tschernyschew [not Martin].

5124 (913). North end of long island about 3 miles southeast of Cornwallis Point, Keku Strait; highly crinoidal limestone, lower beds with chert layers:

Lonsdaleia sp.
Fistulipora sp.
Batostomella sp.
Derbya? aff. D. bennetti.
Rhipidomella aff. R. uralica.
Orthotichia? aff. O. morganiana.
Chonetes aff. C. granulifer var.
Productus aff. P. cora.
Productus sp.
Pustula sp.
Pustula aff. P. tuberculata.
Pustula aff. P. pustulata?
Avonia aff. A. porrecta.
Marginifera aff. M. juresanensis?
Marginifera aff. M. aagardi?
Marginifera sp.
Richthofenia aff. R. lawrenciana.
Dielasma? sp.
Spirifer aff. S. marcoui.
Squamularia aff. S. guadalupensis.
Cliothyridina? sp.
Aviculipecten? sp.
Griffithides? sp.

5134 (965). Islet in Keku Strait about 1¼ miles east-northeast of point 4 miles southeast of Point Cornwallis; limestone interbedded with andesitic flows and tuff:

Syringopora sp.
Favosites sp.
Striatopora sp.
Lonsdaleia sp.
Stenopora sp.
Batostomella sp.
Rhipidomella aff. R. uralica.
Orthotichia? aff. O. morganiana.
Productus aff. P. gruenewaldti.
Productus aff. P. koninckianus.
Productus n. sp.?
Marginifera aff. M. juresanensis.
Productus (Marginifera?) sp.
Avonia aff. A. porrecta.
Pustula aff. P. fasciata?
Pustula aff. P. wallaciana?
Dielasma sp.
Spirifer sp.
Martinia? sp.
Squamularia aff. S. perplexa.
Brachythyris sp.
Cliothyridina? sp.
Cypricardinia sp.
Aviculipecten? sp.
Schizodus? sp.
Euconospira? sp.
Platyceras sp.
Euomphalus? sp.

5137. West side of Windfall Harbor, Seymour Canal, Admiralty Island; schistose limestone interbedded with conglomerate, chert, and andesitic volcanic rocks:

Stenopora sp.
Batostomella? sp.
Leioclema sp.
Polypora sp.
Rhabdomesa? sp.

UPPER DIVISION OF THE PERMIAN.

Wright made a collection from beds on Halleck Harbor in Saginaw Bay, Kuiu Island. His description [74] follows:

Beds of white cherty limestone 450 feet or more in thickness overlie a series of black, carbonaceous shales, calcareous sandstones, and conglomerates with an exposed thickness of 125 feet. * * *

[74] Wright, F. E. and C. W., op. cit., pp. 54–55.

In the overlying limestone beds belonging to the upper series Girty reports the following:

Fossils from Halleck Harbor, Kuiu Island; upper division of upper Carboniferous:

Zaphrentis? sp.
Crinoid fragments.
Stenopora sp.
Streptorhynchus aff. S. pelargonatum.
Chonetes, 2 sp.
Productus aff. P. timanicus.
Productus aff. P. aagardi.
Productus aff. gruenewaldti.
Productus aff. P. humboldti.
Productus aff. P. mammatus.
Productus aff. P. lineatus.
Productus aff. P. occidentalis.
Productus sp.
Spirifer aff. S. alatus.
Spirifer aff. S. blasii.
Spirifer articus.
Spirifer n. sp. aff. S. marcoui.
Spirifer aff. S. dieneri.
Spiriferina aff. S. cristata.
Squamularia sp.
Cleiothyris sp.
Camarophoria margaritovi.
Camarophoria aff. C. purdoni.
Rhynchopora aff. R. nikitini.
Rhynchopora aff. R. geinitziana.
Dielasma sp.

The fossils listed in the accompanying table were identified by Girty from collections made by Buddington.

Fossils from upper division of Permian of Kuiu, Keku, and Kupreanof Islands

	4301 (61)	4302 (69)	4303 (75)	4307 (203)	4310 (217)	4311 (234)	4312 (235)	5135 (966-c)	5136 (976)
Stenopora?			×						
Zaphrentis?	×	×							
Leioclema									×
Leioclema?		×	×			×			
Fenestella	×								
Polypora	×								
Productus tartaricus						×			
Productus horridus						×			
Productus tastubensis						×			
Productus aff. P. longus Tschernyschew [not Meek?]	×								
Productus aff. P. inflatus Tschernyschew [not McChesney]									×
Productus aff. P. gruenewaldti		×				×			
Productus aff. P. mammatus				×		×			
Marginifera aagardi	×	×	×		×			×	×
Marginifera involuta						×			
Marginifera	×								
Camarophoria margaritovi	×	×	×	×	×	×	×	×	×
Pustula aff. P. horrida									×
Pustula aff. P. humboldti									×
Pustula aff. P. nikitini		×							×
Dielasma?		×							×
Dielasma n. sp			×						
Spirifer		×							
Spirifer aff. S. fasciger	×			×			×	×	×
Spirifer aff. S. tastubensis						×			
Spiriferella? arctica		×	×		×	×	×		
Spirifer aff. S. schellwieni									×
Spiriferina								×	
Squamularia?									×
Squamularia aff. S. perplexa						×			
Aulosteges aff. A. hispidus									×
Martinia?								×	
Cliothyridina?								×	
Cliothyridina n. sp									×
Hustedia aff. H. meekana								×	
Aviculipecten									×

4301 (61). Little islet with east-west axis about 7 miles southeast of Kake, on Hamilton Bay, Kupreanof Island; 1922.

4302 (69). About 6½ miles southeast of Kake on Hamilton Bay, Kupreanof Island; thick massive white crinoid limestone overlying green tuff; 1922.

4303 (75). Small islet off tip of southeast prong of northern half of long island about 2½ miles south of Kake, Kupreanof Island; limestone with thin conglomeratic layer; 1922.

4307 (203). Reef with conspicuous sea stack about half way between Kuiu Island and the northernmost Keku Islet; 1922.

4310 (217). Northern reef of Keku Islands, about 5 miles west-southwest of Kake; limestone with white chert layers; 1922.

4311 (234). Southern tip of southernmost large island of Keku group; about 5 miles west of Point Hamilton; 1922.

4312 (235). Islet southeast of locality 4311; 1922.

5135 (966–c). Long, narrow island in south-central part of Keku group; limestone overlying conglomerate of the lower division of the Permian; 1923.

5136 (976). Island about 1 mile north-northeast of conspicuous headland 10 miles southeast of Point Cornwallis; from limestone cobbles in a conglomerate probably of Upper Triassic age; 1923.

A collection of fossils was made by Chapin from Suemez Island and identified by Girty as follows:

1805 (15 ACh 240). South shore of east point of Suemez Island:

Zaphrentis sp.
Fistulipora sp.
Stenopora sp.
Leioclema sp.
Chonetes aff. C. verneuilianus.
Productus aff. P. humboldti.
Polypora sp.
Productus cora var.
Productus aff. P. mammatus.
Productus sp.
Dielasma aff. D. bovidens.
Dielasma sp.
Camarophoria aff. C. margaritovi.
Spirifer aff. S. tastubensis.
Spirifer aff. S. interplicatus.
Spirifer aff. S. schellwieni.
Spirifer sp.
Cliothyridina? sp.
Griffithides sp.

Fossils collected by Burchard[75] from the west side of Pybus Bay, Admiralty Island, about 2½ miles from the entrance, were identified by Girty as of Artinskian age:

Batostomella sp.
Camarophoria aff. C. margaritovi.
Chonetes aff. C. morahensis.
Productus aff. P. timanicus.
Productus aff. P. gruenewaldti.
Productus semireticulatus.
Productus aff. P. multistriatus.
Productus sp.
Tegulifera? sp.
Dielasma sp.
Rhynchopora aff. R. nikitini.
Spirifer aff. S. cameratus.
Spiriferella? arctica.
Squamularia aff. S. perplexa.
Modiola? sp.
Murchisonia? sp.

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[75] Burchard, E. F., Marble resources of southeastern Alaska: U. S. Geol. Survey Bull. 682, p. 55, 1920.

The lower limestone, which is exposed on the more northerly of the Screen Islands, in Clarence Strait, yielded the Carboniferous (?) fossils collected by G. C. Martin in 1914, of which Girty says:

Intrinsically they might be Carboniferous, but they are so unlike the usual run of Alaskan Carboniferous faunas that I am disposed to think that they may be Triassic. I have provisionally identified the following species:

Lot 12. Next to the northernmost of the Screen Islands:

Pseudomonotis? sp.
Pleurotomaria? sp.
Aviculipecten? aff. A. fasciculatus.

Kindle also obtained from the lower limestone some fossils concerning which Girty submitted the following statement:

Lot 22A. Screen Islands:

Tegulifera? sp.
Pseudomonotis? sp.

These [lots 22A and 22G] differ from any other Alaskan Carboniferous fauna known to me. Intrinsically, while they contain types that are unusual and interesting, they seem to be without anything which is diagnostic. I am at present unable to say either that they are Carboniferous or that they are not, and as there seems to be a certain amount of extrinsic evidence for supposing that they do represent that period I have accepted them, though only very provisionally.

TRIASSIC ROCKS (UPPER TRIASSIC)

DISTRIBUTION

Fossiliferous Upper Triassic rocks are found on Gravina Island, in the northern half of Kuiu and Kupreanof Islands, on some of the islands at the north end of Keku Strait, on Turnabout Island, Frederick Sound, on the Screen Islands, Clarence Strait, on the south end of Admiralty Island, in Pybus Bay, at Gambier Bay and between Mole and Windfall Harbors, Seymour Canal, and on the mainland near Juneau. Lithologically similar rocks, presumably of the same age, occur on Carroll Inlet, George Arm, and Annette and Hotspur Islands, in the Ketchikan district. Triassic beds form a portion of the schistose greenstone, phyllite, and crystalline schist of the mainland, but fossils of Triassic age have been found in those beds at only one locality in the area covered by this report.

Triassic rocks occur on Gravina Island in a belt along the southwest coast from Threemile Cove, opposite Dall Bay, northward for about 7 miles. On Kupreanof Island they are exposed along the flanks of a southeastward-pitching anticline which passes through the town of Kake and within a major syncline which lies east of the Kake anticline; good outcrops are found on Frederick Sound east of Cape Bendel and on the north shore of Hamilton Bay. On the Keku group of islands they occur within a narrow pinched synclinal trough, in part with isoclinal folds, extending across the two large northeastern islands of the group. They also form Hound Island. On Kuiu Island they extend southeastward for about 2½ miles, with local interruptions, along the northeast side of Cornwallis Peninsula, from a point about a mile southeast of Point Cornwallis. Triassic beds also form the coast west of Hound Island for 7 miles or more.

CHARACTER AND STRATIGRAPHIC RELATIONS

The succession, variation, and thickness of the Triassic formations have not been satisfactorily worked out because of structural disturbances and the interruption of the continuity of the exposures by waterways or by forest cover. The Triassic rocks in the vicinity of Keku Straits include three groups—one consisting of sediments and the two others of volcanic rocks with a little intercalated sedimentary material.

The sedimentary formation of the Upper Triassic here comprises conglomeratic limestone and calcareous conglomerate, calcareous sandstone, and sandy limestone, black shale, and medium-bedded gray limestone. The limestone is usually fine grained and at many places contains black slaty layers. The conglomerate and sandstone are restricted to the basal beds.

The volcanic formations are differentiated on the basis of their faunas; their character and their structural relations over wide areas are insufficiently known and their lithology is too similar to separate them otherwise. They comprise green andesitic flows, breccia, and tuff with local intercalated sedimentary beds. The lava predominantly shows a pillow structure but is in part amygdaloidal and in part polygonally jointed. Much of the breccia has a limestone matrix and is in considerable part the result of a primary disaggregation of the radial-jointed pillows—an autoclastic structure. The basal part of the volcanic rocks on Kuiu Island consists of interbedded limestone and green andesitic tuff and lava with local conglomeratic beds. On Kupreanof Island the other volcanic formation has locally a bed of conglomerate 150 to 200 feet thick at its base. The volcanic rocks of Kuiu Island rest directly on the lower division of the Permian beds, whereas the volcanic rocks of Kupreanof Island rest on the sedimentary division of the Upper Triassic.

On Gravina Island Chapin includes in the Upper Triassic a series of slate with interlayered graywacke-like sandstone which he describes as overlying the conglomerate, fossiliferous limestone, and slate of the basal part of the Upper Triassic. To Buddington it seems possible that this formation may be, at least in part, of Jurassic age.

GRAVINA AND REVILLAGIGEDO ISLANDS

By Theodore Chapin

On Gravina Island the Upper Triassic rocks fall naturally into three main divisions—one composed essentially of conglomerate, one essentially of limestone, and one of interbedded black slate, sandstone, conglomerate, and limestone. These three conformable terranes are shown by fossils to be probably Upper Triassic. Overlying the Upper Triassic sediments, with apparent conformity, are volcanic agglomerates and intercalated sedimentary beds which are, at least in part, of Upper Jurassic or Lower Cretaceous age and possibly in part of Upper Triassic age.

The exposed basal member of the series on Gravina Island is a coarse conglomerate that extends along the southwest coast of the island from Conglomerate Point northwestward to Open Bay and occupies three narrow strips whose continuity is broken by Fivemile Cove, Thompson Cove, and Threemile Cove. The conglomerate is a heavily-bedded, massive rock. The boulders are essentially of angular coarse-grained granite, and the matrix is quartz-feldspar sand presumably derived from the same source as the boulders. Intercalated with the coarse conglomerate are thin beds of sandstone, which are composed of the same material as the matrix of the conglomerate, and gradational beds of grit. Thin beds of fossiliferous limestone and black slate with pronounced cleavage occur sparingly. The conglomerate and intercalated sandstone beds are strongly indurated and break with prominent fractures across the boulders.

On a small cove south of Threemile Cove[76] the conglomerate is finer grained toward the top and passes upward into grits, sandstone, and slate, which are overlain by a large block of fossiliferous massive limestone. There has been some movement along this contact, so that the relations are confused, but the limestone is apparently above the conglomerate and sandstone. On Thompson Cove the conformable relations of the limestone to the conglomerate, sandstone, and slate are more evident, although here also there has been some faulting.

In the upper part of the conglomerate the beds are thinner and the material is much finer grained and contains more sandstone, slate, and thin beds of limestone, which are conformably overlain by the massive limestone.

The limestone varies in appearance from place to place. On Thompson Cove and Open Bay it is a soft gray fossiliferous rock, in which corals are especially abundant. On Threemile Cove it is more closely folded, is considerably silicified, and weathers out brick-

[76] Threemile Cove has appeared in the literature as "cove 3 miles north of Dall Head."

red. The limestone here is less fossiliferous, and the fossils are poorly preserved. The greater amount of deformation of the limestone on Threemile Cove is probably the result of contact metamorphism induced by the intrusive rocks of Dall Head.

The massive limestone is conformably overlain by a great thickness of black slate with intercalated beds of conglomerate, sandstone, and limestone. These beds crop out along the coast of Gravina Island for a distance of about 3 miles north of the limestone area and extend to the high hills of the Dall Ridge north of Dall Head. Similar rocks are exposed on Bostwick and Seal Cove and extend northwestward in a belt from 2 to 3 miles wide as far as Vallenar Bay and North Vallenar Point.

The dominant rock of this series is black clay slate that has a pronounced cleavage. Intercalated with the slate are thin beds of quartzose sandstone, quartzite, conglomerate, and sandstone. The limestone beds are not numerous but are usually fossiliferous. The interbedded limestone layers are 20 to 30 feet in thickness but appear to be lenticular.

The black slate and associated sediments are closely folded, especially on Threemile Cove, where the folds are sharply contorted. The beds on Vallenar Bay are much more regular, and show none of the close folding.

Associated conglomerate, limestone, schistose slate, and phyllite on Revillagigedo Island are correlated with the sedimentary series of Gravina Island on the basis of the similarity of lithology and sequence and the stratigraphic and structural relations. The beds are exposed on George Arm, Carroll Inlet, and Thorne Arm. The lithologic similarity of these rocks to the Triassic rocks of Gravina Island is marked, notwithstanding their more schistose nature, which is due to their proximity to the large masses of intrusive rocks. The conglomerate is very schistose, and the cobbles are mashed and deformed. The limestone is white and crystalline. The slate is in part schistose and might more correctly be termed phyllite and schist. Similar slate, phyllite, and schist occur on the north end of Tongass Narrows.

The base of the Upper Triassic series of Gravina Island is not visible. The lowest part exposed occurs at Threemile and Thompson Coves, where the actual base of the conglomerate is concealed by water. At Vallenar Bay the Triassic rocks overlie Devonian sediments that come to the surface along the axis of an anticline, but the contact is covered by Quaternary deposits. The presence of Devonian pebbles in the conglomerate of Threemile Cove indicates an underlying Devonian rock. On George Arm the supposedly Triassic rocks rest upon rocks that are probably Carboniferous. A marked unconformity at the base of the Upper Triassic rocks is thus evident.

On Gravina and Revillagigedo Islands the Triassic rocks are overlain in places conformably by volcanic beds of Upper Triassic or Jurassic age and in places unconformably by slate and graywacke of Jurassic or Cretaceous age.

Greenstone and slate made up of an interbedded series of altered tuff, flows, and black slate, with some intrusive rocks, occur on Gravina, Duke, Annette, and Revillagigedo Islands, in the Ketchikan district. The greenstone and slate overlie the Upper Triassic rocks with apparent conformity. On the evidence of a few fossils found in the intercalated sediments and on the grounds of structure and analogy with rocks of known age, these rocks are regarded as Upper Triassic or Jurassic.

SCREEN ISLANDS

Thick-bedded limestone and conglomerate in a highly disturbed condition form the Screen Islands, off the west coast of Etolin Island, in Clarence Strait. These beds comprise two limestone formations separated by thick, massive conglomerate; the upper limestone and the conglomerate are probably Upper Triassic, and the lower limestone is Carboniferous. On the northernmost islands there are exposed beds about 900 feet thick, comprising limestone with intercalated beds of conglomerate and sandy limestone about 200 feet thick. The cobbles and pebbles in the conglomerate are predominantly chert and limestone, with some rhyolite porphyry and greenstone. Some of the limestone cobbles carry Carboniferous faunas, indicating an unconformity at the base of the Upper Triassic.

KEKU STRAIT

The sedimentary division of the Upper Triassic is again well shown near the north end of Keku Strait. Where exposed on the flanks of the Kake anticline it consists of calcareous beds which rest unconformably on Paleozoic beds; the basal Triassic beds contain fragments of the Paleozoic rocks. At the north end of the long island several miles south of Kake limestone and conglomerate carrying Upper Triassic fossils overlie unconformably tuff with chert and calcareous layers of Devonian age. Many fragments of the Devonian rocks are found in the Upper Triassic conglomerate. At the southeast end of the anticline the Upper Triassic rests unconformably on the Permian cherty limestone, and fragments of the Permian carrying typical fossils are incorporated in the Upper Triassic conglomerate. At most places the Upper Triassic sedimentary beds overlie the upper division of the Permian. The succession, variation, and thickness of the beds intervening between the Paleozoic formations and the Upper Triassic volcanic rocks differ locally and are confused by faulting and unconformable relations with the underlying rocks. At no place was there found a complete section suitable for measurement.

About 4 miles from the head of Hamilton Bay, Kupreanof Island, on the north side, where the coast line swings to the northwest, is a small elongate island composed of Permian limestone with a narrow belt of Triassic limestone overlying it unconformably at the east end and south side. No sandstone or basal conglomerate occurs between the Triassic and the Permian formations here as it does on the near-by shore of Kupreanof Island. The dip of the Triassic beds is about 20° less than that of the underlying Permian, but the strike seems to be the same. No evidence of faulting was seen, though it may be present. The Triassic limestone weathers a dove-gray; the Permian limestone weathers a pale buff and may also be distinguished by the presence of chert beds and layers.

On the shore of Kupreanof Island just north of the elongate island 4 miles from the head of Hamilton Bay good exposures of the lower portion of the Upper Triassic appear at the tip of the partly eroded Kake anticline. The basal beds are about 100 feet thick and consist of coarse conglomerate with a calcareous matrix. The cobbles in the conglomerate are predominantly limestone with Permian fossils, white chert, and fragments of green tuff and chert of Devonian age, named in the order of abundance. The actual unconformable contact between the conglomerate of the Upper Triassic and the Permian limestone with white chert layers may be seen here. The conglomerate toward the top is interbedded with sandstone and passes upward into calcareous sandstone and sandy limestone about 50 feet thick, above which is about 125 feet of interbedded calcareous sandstone and limestone, succeeded in turn by 100 feet of blue-gray limestone in beds 6 inches to 2 feet thick intercalated with black limestone, much of it shaly, from several inches to a foot thick. The limestone beds are fossiliferous. (See lots 11243, 11241, 11242, 11240 in table, p. 151.) The exact contact between the limestone and the overlying volcanic rocks is covered, but the covered beds can not be more than 25 feet thick at this place. One outcrop between the limestone and the volcanic rocks consists of interlayered dense quartzite and limestone carrying fragmentary imprints of *Pseudomonotis subcircularis?* (see lot 11437), which is characteristic of the volcanic series that overlies the *Halobia* beds of the sedimentary division. The beds of this section have in general a northwest strike and a northeast dip; the dip changes from 30° at the base of the section in the southwestern part to 70° where the volcanic rocks come in.

The west side and lower half of the large island south of Kake are composed of the Triassic formations that constitute the southwest limb of the Kake anticline. The extension of these formations to the northwest may be followed in the extreme outer line of reefs. The southeastern part of the island is composed of Triassic conglomerate and limestone, resting on Permian limestone, which is exposed locally, and overlain by the Upper Triassic volcanic rocks. At the extreme southeast tip of the island conglomerate with a calcareous matrix forms the lowest member, but its base is not exposed. Overlying the conglomerate is about 100 feet of limestone in beds ranging from 6 inches to 2 feet thick, with black slaty limestone partings. Many of these beds are richly fossiliferous. The limestone is in turn overlain by a series of thin-bedded rocks consisting of black quartzitic or cherty layers interbedded with limestone; the hard, resistant layers become more abundant near the top. About three-quarters of a mile north of the extreme southeastern tip of the island the basal conglomerate of the Triassic is cut out by faulting, and the overlying limestone is brought directly against the Permian beds, as indicated by the fault breccia zone. From the southeast end of the island northwestward the beds swing around to an east-west strike, with a southerly dip. The Carboniferous limestone, which is exposed here and there as a fringe beneath the Triassic, shows a similar change of direction. At the southeast end of the narrow neck joining the two parts of the island, on the west side, several hundred feet of interlayered limestone, black calcareous shale, and chert, somewhat crumpled, are overlain by about 125 feet of interbedded conglomerate and sandstone with intercalated black slate. The conglomerate is overlain by the volcanic rocks, but the contact is covered. The conglomerate is probably the equivalent of that found on the islets to the northwest of this island and described with the Upper Triassic volcanic series.

On the eastern peninsula of the northwest end of the same large island south of Kake the lower formation of the Upper Triassic is again exposed. The basal conglomerate of the Upper Triassic here apparently rests directly on the chert and tuff of the Upper (?) Devonian, and the beds have a similar strike and direction of dip, though the conglomerate dips more steeply than the chert. The basal conglomerate is medium grained, with pebbles averaging half an inch to an inch in diameter. The pebbles are almost exclusively chert with a few of green tuff that corresponds to the underlying Devonian beds. Limestone nodules are present in the conglomerate and are highly fossiliferous. (See lot 11237 in table, p. 151.) There are here about 100 feet of thin-bedded limestone, calcareous sandstone, and slate with the intercalated basal conglomerate. These beds are overlain by limestone that is too much disturbed for measurement. Overlying the limestone is a most extraordinary breccia, which is described with the volcanic rocks on page 139. The Triassic beds have a general northwest strike and southwest dip. The nearest underlying Devonian beds exposed dip about 35° SW., the Upper Triassic limestone dips about 70° SW., and the agglomerate is vertical.

On the northwest tip of Kupreanof Island about halfway between Point Macartney and Cape Bendel the basal conglomerate of the Upper Triassic appears as the east limb of the Kake anticline, with a very gentle dip. The pebbles and cobbles, as usual, comprise limestone, chert, and green tuff, one or the other being the more common in different beds. To the east is red shale conglomerate, succeeded by variolitic pillow lava and breccia. The contacts are covered.

About 2½ miles northeast of Cape Bendel the Upper Triassic basal conglomerate reappears as the east limb of a syncline with a vertical dip. There is about 100 feet of conglomerate with several sills (?) of andesite lying between the Permian limestone and the Upper Triassic volcanic rocks.

On the north side of Cornwallis Peninsula, about a mile southeast of Point Cornwallis, the contact between the Triassic beds and the upper division of the Permian is exposed. The beds of Triassic limestone, which are very gently warped and folded, extend along the shore line, with local interruptions, for 2½ miles to the southeast. At the northern contact the gently folded Triassic beds rest on Permian limestone with layers of white chert. The Permian beds strike N. 35° W. and dip 65° NE. The basal beds of the Triassic limestone are conglomeratic, and the cobbles and pebbles are wholly of white chert. At the southern contact the Triassic limestone overlies unconformably a series of volcanic rocks that probably belong to the lower division of the Permian. The contact is covered. The limestone is in beds from 1 foot to several feet thick and is very fine grained. The beds are locally fossiliferous. (See lots 11931 and 11932, p. 151.)

ADMIRALTY ISLAND

On the east side of the east arm of Pybus Bay, Admiralty Island, Permian cherty limestone is overlain by 200 feet of conglomerate of Upper Triassic age, which consists almost exclusively of cobbles and pebbles of limestone and white chert from the underlying formation. The conglomerate is in turn overlain by crumpled beds of interlayered gray limestone and dark-gray to black calcareous slate, and these beds are overlain unconformably by Lower Cretaceous slate.

Edwin Kirk reports the presence of Upper Triassic fossils in interlayered slate and limy layers at the head of Mole Harbor, Seymour Canal.

Triassic formations are found in a narrow strip extending along Seymour Canal southeast from the east headland of Windfall Harbor. The succession of beds is as follows: Conglomeratic limestone, white layered chert, slate, and greenstone, and very highly sheared limestone. The limestone crops out along the coast for 1½ miles; for another 1½ miles along the coast the beds consist predominantly of andesite with intercalated zones of bedded limestone and black chert.

VOLCANIC ROCKS WITH PSEUDOMONOTIS-BEARING BEDS

The volcanic rocks with intercalated sedimentary beds carrying the characteristic fossil *Pseudomonotis* overlie, probably unconformably, the calcareous, wholly sedimentary division of the Triassic rocks.

Along the southwest limb and at the southeast nose of the Kake anticline a conglomerate bed, in part of volcanic origin and 150 to 200 feet or more thick, lies at the base of these volcanic rocks. This bed was not found on Kupreanof Island and may represent only a local development.

The long island south of Kake is contracted near the center to a narrow neck. At the southeast end of this neck, on the west side, above the interlayered limestone, black calcareous shale and chert, there is about 125 feet of interbedded conglomerate and sandstone with intercalated black slate, with the top not exposed. These beds are believed to represent the base of the volcanic series. The conglomerate has a greenish hue on the fresh surface, but weathers with a reddish glazed appearance. It is composed of fragments of chert, in part carrying Permian fossils, andesite, and black slate, with feldspar crystals common in the groundmass. Many of the fragments are angular; those of sedimentary rock are from underlying formations, but the volcanic fragments are similar to the lava of the Upper Triassic horizon. The beds are overlain by andesitic lava with associated thin beds of black slate, calcareous quartzite, and limestone. Fossils from layers between pillow lavas (lot 11246, 88BN) were submitted to T. W. Stanton, who identified them as *Pseudomonotis subcircularis* and *Halobia* sp. (Upper Triassic).

Along the line of strike to the northwest of the northwest tip of the large island south of Kake are two small islands which are formed in part of volcanic breccia and in part of beds partaking of the nature of both a breccia and a conglomerate. The rocks are in a much sintered condition and consequently weather with the characteristic glazed surface. There are about 200 feet of these beds, consisting of very coarse conglomerate at the base and medium conglomerate (average diameter of fragments 2 inches) in the upper part. The top is not exposed. The fragments comprise black slate, andesite, andesite porphyry, chert, green tuff, calcareous quartzite, and limestone. Some of the chert fragments are fossiliferous and are presumably derived from the upper Carboniferous, whereas the green tuff is doubtless from the Upper Devonian. Many of the fragments are sharply angular; others are rounded. One 2-foot boulder of andesite porphyry had a 2-inch chill zone surrounding it. In thin section fragments of andesite show similar chill zones completely surrounding them. Fragments of unmistakable perlite were identified; vesicular and amygdaloidal volcanic rocks are abundant; and feldspar fragments are very common. These constituents suggest that volcanic material and perhaps fragments of underlying sedimentary beds shattered by volcanic explosions fell where normal conglomerates were accumulating. Hence the beds are correlated with the volcanic series.

The volcanic rocks are exposed along the southwest limb of the Kake anticline on the southwest side of the long island south of Kake. The series here comprises pillow lava 5 to 20 feet thick, massive and polygonal jointed flows 10 to 30 feet thick, and sedimentary beds of interlayered black slate, quartzite, and limestone 1 inch to 10 feet, commonly several feet thick. *Pseudomonotis subcircularis* and *Halobia* are common fossils. A very extraordinary type of rock is found on the extreme northwest headland of this island. Here the sedimentary beds are broken to fragments and involved in a glassy andesitic matrix. As a rule each fragment is inclosed in a ball of glass, so that on weathering the appearance is that of a very coarse agglomerate. The average diameter of the fragments is about 9 inches, but fragments 2½ inches in diameter are common, and some blocks are as much as 18 by 300 feet. The upper part is predominantly finer, with fragments ranging from the size of a hickory nut to that of an apple. The breccia beds stand about vertical and measure about 150 feet across the strike. At the south end the contact between the breccia and the sedimentary beds is at an angle to the strike of the sediments.

Fragments of andesite occur in the breccia at the north end. Immediately adjacent to the inclosed fragments there is usually a zone of dense pearl-gray lava, which changes abruptly to a green glass. The pearl-gray zone, when examined under the microscope, is found to be less crystalline than the dominant green groundmass. Phenocrysts of plagioclase occur sparingly, and microlites are very abundant in the groundmass. Calcite veinlets are abundant in both the gray and the green rock.

The volcanic rocks are also exposed within the Cape Bendel syncline, along the north side of Hamilton Bay. The series here consists of amygdular and pillow lavas, in part variolitic, with intercalated sedimentary beds. The interstices between the pillows are filled with limestone, and the pillows show a radial jointing and an outer vesicular crust. A peculiar feature of some of the more massive flows is a pseudobreccia structure in which the fragments have not been displaced from one another more than an inch at the maximum but still maintain their relative positions and are separated by a limestone filling. The intercalated sedimentary beds consist of black calcareous slate and gray quartzite interlayered with limestone in bands measurable in inches. Many of the layers are highly fossiliferous. (See lot 11245, table, p. 151.)

In the northern part of the cove just south of Cape Bendel the basal part of the Upper Triassic appears to consist of interbedded conglomerate and lava to a thickness of a hundred feet or more. Devonian beds of green tuff adjoin them on the west. The cobbles of the conglomerate are limestone, chert, and fragments of green Devonian tuff. Some beds are composed almost wholly of fragments of red shale. Similarly on the east side of the syncline the base of the formation consists of about 100 feet of conglomerate interbedded with lava and sandy fossiliferous limestone. (See lot 11933, table, p. 151.) The beds here overlie the Permian. Overlying these basal beds comes a series of volcanic rocks that consists chiefly of green andesitic lava, predominantly with pillow structure but in part amygdaloidal. Variolitic texture is very common. The total thickness of the lava, including the conglomerate at the base, was estimated as approximately 1,400 feet. About 1¼ miles northeast of Cape Bendel, on the east headland of a cove due south of Pinta Rocks, there occurs intercalated in the lava a zone of about 50 feet of conglomerate which grades upward into sandstone and is overlain by about 225 feet of isoclinally folded thin-bedded limestone. The limestone is in layers about 6 inches thick, with black shaly limestone partings. Many of the layers are highly fossiliferous. (See lot 11934, table, p. 151.) These beds are overlain by more pillow lava.

Turnabout Island, off the northwest end of Kupreanof Island, consists of andesite and andesite porphyry lava and breccia with intercalated tuff and a 50-foot bed of gray sandstone. The flows are in part amygdular and in part show pillow structure. Rarely a chalcedony vein is present. The sandstone lies on the east side of a bight on the south side of the island and contains intercalated layers of calcareous sandstone and conglomerate 1 inch to several inches thick, some of which are richly fossiliferous. (See lot 11405, table, p. 155.) Traces of carbonized plant stems are common.

Shale with Upper Triassic fossils is found on both the large islands of the outer line of islands of the Keku group. On the northwesternmost island the beds consist of black shale with intercalated impure brecciated limestone and nodular layers in possible isoclinal folds with a general dip of about 30° SW. On the east side of the north end of the island the beds are adjoined by eastward-dipping black limestone with buff-weathering sandy layers carrying Permian fossils. These beds are associated with beds of conglomerate. The contact between the Triassic and Permian is covered. The relations may be explained as representing an infolded trough of Triassic beds unconformable to the Permian. Fossils (see lot 11436, table, p. 151) gathered from the black shale on the southwest side of the island were reported by T. W. Stanton as Upper Triassic. At the north end of the southeastern island black shale adjoin limestone beds of white chert. The limestone and chert are probably Permian; the shale contains fossils identified by T. W. Stanton as *Halobia* sp., indicating a Triassic age for the beds. The beds are vertical, and faulting is probably the cause of the relations of the Triassic to the Carboniferous.

The lava is mostly felsitic or basaltic in texture but is locally distinctly porphyritic, with phenocrysts of albite. It ranges from green-gray to very dark gray. In thin section it is found to consist in general of a felt of porphyritic plagioclase laths in a groundmass of very irregular texture. The groundmass may be a clear green or it may consist of a deep-green matrix crowded with microlites of plagioclase. Grains of augite are abundant in some sections and absent in others. Magnetite is commonly present as abundant grains or skeletal plates through the groundmass. The groundmass is in part interstitial to the plagioclase laths, a typical intersertal texture, and in part segregated into knots. Locally the microlitic patches are spherical and weather like variolites 0.2 to 0.3 millimeter in diameter. The green groundmass is of peculiar character. At first glance it resembles some chloritic alteration products, but with crossed nicols, in some sections, it is seen to consist of isotropic or nearly isotropic glass locally crowded with minute microspherulites made up of birefringent fibers. In other sections the birefringent fibers are oriented at right angles to cracks in the glass, and in yet other sections the amygdular parts are found to consist of concentric shells of nearly hemispherical spherulites arranged parallel to the borders with a central core rock of microspherulitic aggregates. The interstitial parts of the groundmass are commonly composed of an aggregate of birefringent microspherulites. There appears to be no difference between the interstitial material and that of the amygdule-like parts. The plagioclase laths also project into the amygdular parts in such a fashion as to suggest that these spherulitic amygdules were an integral part of the rock at the time of consolidation. The green groundmass may constitute as much as 30 or 40 per cent of the rock, and it is believed to represent simply an uncrystallized or spherulitically crystallized part of the lava. Inclusions identical in character with the green groundmass are found also in the feldspar.

It is possible that all of the green groundmass was originally glass and that the spherulitic crystallization is the result of subsequent devitrification. With crossed nicols, all the spherulites show well-defined uniaxial crosses. The green spherules weather to resemble amygdules of chlorite, for which they were mistaken in the field. It may be that the groundmass corresponds, in part at least, to what is commonly called palagonite, an altered basic glass. True amygdules of chlorite are found in some of the andesite east of Cape Bendel.

The porphyritic feldspar was determined by the index of refraction method in four different specimens and in each was found to be albite instead of a more calcic plagioclase, such as might be expected. Albite is reported to characterize certain pillow lavas (spilites) of Great Britain,[77] but its sodic character is ascribed to secondary replacement. There is nothing to suggest that the sodic character of the plagioclase in the Alaskan lavas is other than primary. The plagioclase of the groundmass commonly has a very low extinction angle and may be oligoclase.

In the Juneau district Eakin and Spencer[78] have described as the Gastineau volcanic group a series of beds in which they found Upper Triassic fossils. These volcanic rocks were examined on Taku Arm by the writer, and the basal part found to resemble very closely the volcanic rocks of Hamilton Bay, which are of Upper Triassic age. Some of the flows show a rough polygonal jointing, others exhibit a well-defined though distorted ellipsoidal or pillow structure with interstitial limestone, and still others show the peculiar pseudobreccia structure in which the lava is broken up into angular fragments that show no rotation and are separated from one another only by thin films of limestone. All three features are common to the volcanic rocks of Kupreanof Island. The Gastineau volcanic group is overlain by the Thane volcanic group.

VOLCANIC ROCKS OF KUIU AND HOUND ISLANDS

A volcanic formation lithologically similar to the rocks just described but carrying a different fauna is found on the northeast end of Kuiu Island and on Hound Island, Keku Straits.

Directly south of the southeast end of the Keku group of islets the coast line of Kuiu Island has an east-west direction for 1½ miles. Along this coast are exposed very gently folded beds of limestone

[77] Dewey, Henry, and Flett, J. S., On some British pillow lavas and the rocks associated with them: Geol. Mag., new ser., decade 5, vol. 8, p. 203, 1911.

[78] Eakin, H. M., and Spencer, A. C., Geology and ore deposits of Juneau, Alaska: U. S. Geol. Survey Bull. — [in preparation].

with intercalated conglomerate, conglomeratic limestone, sandstone, and andesite. The limestone beds are locally fossiliferous (lots 4305, 5128, 5123), and are reported by Girty to belong probably to the lower division of the Permian. (See pp. 123, 126.) Just east of the point where the shore line turns southward these beds are overlain by sandstone with conglomeratic layers, followed by interbedded limestone and green andesitic tuff with a few conglomerate layers. The beds have in general a northeast strike and a dip of 20° SE., though at the point they are almost horizontal and cross folded. About three-fifths of a mile south of the point the limestone is fossiliferous. (See lot 11406, table, p. 155.) The limestone beds range from 5 to 50 feet in thickness, and the tuff beds from 10 to 20 feet. The limestone is fine grained and of a brownish hue. These beds pass upward into a predominantly volcanic series, with similar strike and dip, consisting of basaltic and andesitic lavas, breccias, and tuffs with interbedded limestone, which is in part sparsely conglomeratic with andesite pebbles. At the head of Six and a Quarter Fathom Cove, on the southwest side, coarse green agglomerate striking northwest and dipping gently northeast is overlain by about 300 feet of thin-bedded sandstone and shale with a few limestone layers, the shale predominating. These beds are exposed on the west headland of Six and a Quarter Fathom Cove and appear to be in the trough of a syncline. They may belong with the series at Point Hamilton, like the beds of shale exposed in the string of islets immediately to the north.

The entire peninsula between Six and a Quarter Fathom Cove and the cove to the south is composed of interbedded coarse agglomerate and pillow lava. The agglomerate predominates in the western half of the peninsula and the flows with interbedded agglomerate in the eastern half. Here also the pillow lava with interstitial limestone is seen to pass gradationally upward into breccia with a limestone matrix, and the lack of a marked dividing line suggests autoclastic structure. The breccia in general consists of amygdular green-gray andesite of felsitic texture in angular fragments ranging from 1 inch to 9 inches in diameter with many bombs 2 feet in diameter and a few blocks as much as 10 feet in diameter. The average is about 10 inches. The matrix is limestone, which locally may form as much as one-third of the rock but predominantly is merely interstitial to the fragments. At a point on the east side of the peninsula, about due west of Pup Island, there is conspicuous pillow lava with layers of limestone as much as a foot in thickness molded to the surface of the ellipsoids. This limestone is baked to a pinkish-brown hornstone adjacent to the contact with the lava. Some of the limestone pockets are extraordinarily rich in well-preserved fossils. (See lots 11407 and 11962, table, p. 155.)

Hound Island and several islets to the northwest consist of gently folded coarse green andesitic breccia with a limestone matrix. Commonly the fragments run from an inch to a foot in diameter, but finer beds occur sparingly, and rarely a bed of dense buff-weathering limestone or of agglomeratic limestone is intercalated.

AGE AND CORRELATION

By THEODORE CHAPIN

The term "Gravina series" was first applied by Brooks[79] to massive conglomerate overlain by black slate or shale occurring on the south end of Gravina Island. He included in his mapping of this "series" the somewhat similar massive conglomerate and associated black slate and arenaceous sediments of the west coast, Bostwick Inlet, and Blank Inlet and suggested its possible extension to other places. As a result of recent investigations, however, the sedimentary rocks of Gravina Island originally defined as the "Gravina series" are now known to include two sedimentary formations—one of Triassic age and one of Jurassic or Cretaceous age. These two sedimentary formations are associated with volcanic rocks of intermediate stratigraphic position. Brooks first regarded the "Gravina series" as Cretaceous and correlated it with the Queen Charlotte series of Vancouver and Queen Charlotte Islands, but later he stated that its identity with the Vancouver (Triassic) seemed equally probable.[80] His correlations with Triassic and Cretaceous formations, which were made without any fossils, proved substantially correct.

A large number of fossil collections made later have shown the age of the limestone, conglomerate, and black slate of Gravina Island to be Triassic, probably Upper Triassic.

Fossils collected by G. C. Martin and R. M. Overbeck from the massive conglomerate at the exposed base of this series were determined by T. W. Stanton as follows:

8831 (G. C. M. No. 3). Gravina Island, south arm of cove 3 miles north of Dall Head. Large limestone nodule in conglomerate. The whole nodule is a nautiloid with deeply lobed suture, possibly referable to *Cosmonautilus*. On the back is a *Rhynchonella?*. Probably Triassic.

8833 (G. C. M. No. 5). Gravina Island, south arm of cove 3 miles north of Dall Head. Near zone of nodular masses of limestone in conglomerate. This lot appears to be Devonian.

Mr. Martin's opinion, with which the writer agrees, is that the Triassic conglomerate rests unconformably upon Devonian rocks, and the Devonian fossils from Threemile Cove were obtained either

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[79] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, p. 45, 1902.

[80] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 226, 1906.

from boulders in the conglomerate or from unrecognized Devonian rocks occuring in complex structural relations with the Triassic beds. The beds on Threemile and Thompson Coves are faulted and also closely folded and contorted, being thus thrown into complex structural relations. From the wording of the locality description above it would appear quite possible that the fossils were collected from included masses of limestone in the conglomerate. In 1916 A. H. Brooks and the writer collected fossils from narrow bands of limestone interbedded with the conglomerate. J. B. Reeside, jr., reports on these as follows:

9899 (16 ACh 136). Threemile Cove, Gravina Island. Echinoid spine, possibly of *Cidaris*. Age undetermined.

Fossils were first collected from Threemile Cove in 1905 by the Wrights.[81] The exact locality is uncertain, but the matrix of the fossiliferous rocks is described as calcareous schist, which is evidently the siliceous limestone. The fauna was regarded by G. H. Girty as coming from the uppermost part of the Carboniferous or from the Mesozoic. The beds were thus doubtfully referred to the Mesozoic for some years, but recent collections have shown them to be without much doubt Triassic and probably Upper Triassic.

Collections made by Martin and Overbeck from the limestone beds of Threemile Cove occurring beneath the black slate were determined by T. W. Stanton as follows:

8830 (G. C. M. No. 2). Gravina Island, south arm of cove 3 miles north of Dall Head; outcrop of massive limestone near anchorage behind wooded island:

Undetermined corals of Mesozoic type, two or three genera represented.
Ostrea? sp.
Pseudomelania? sp., internal cast.
Arcestes?? sp., fragment; may not even be an ammonite.
Probably Triassic.

8832 (G. C. M. No. 4). Gravina Island, near south foreland on arm of cove 3 miles north of Dall Head, near contact with conglomerate:

Undetermined coral fragment.
Pentacrinus sp., segment of column.
Probably Triassic.

8834 (G. C. M. No. 6). Gravina Island, north arm of cove 3 miles north of Dall Head; massive limestone in reef west of cabin, probably about 100 feet below 8704 (see p. 147):

Corals, probably several genera.
Cassianella sp.
Myophoria?? sp.
Natica sp.
Murchisonia? sp.
Triassic.

[81] Wright, F. E., and C. W., op. cit., p. 52.

8835 (G. C. M. No. 7). Gravina Island 20 or 30 feet below 8834; thin-bedded limestone interbedded with shale:

Corals; several genera represented.
Spiriferina? sp.
Myophoria? sp.
Natica sp.
Turritella? sp.
Pseudomelania? sp.
Trachyceras? sp., small fragment.
Triassic.

The following collections made by the writer in 1915 from the limestone overlying the massive conglomerate were determined by Mr. Stanton:

9531 (15 ACh 111). West coast of Gravina Island, cove 2½ miles north of Dall Head:

Echinoid spines.
Undetermined corals.
Ostrea? sp.
Gryphaea? sp.
Pecten sp.
Natica? sp.
Turritella? sp.
The fossils in this lot are poorly preserved and mostly fragmentary. They are apparently Mesozoic and may be Triassic.

15 (ACh 121). Northeast shore of Thompson Cove, Gravina Island:

Corals, genus undetermined.
Pentacrinus sp.
Echinoid spine.
Ostrea? sp.
Solemya? sp.
Turritella? sp.
Spiriferina? sp.
Probably Triassic.

9534 (15 ACh 122). Northeast shore of Thompson Cove, Gravina Island:

This lot includes undetermined corals, Ostrea?, Turritella?, and undetermined gastropods. Probably Triassic.

9535 (15 ACh 123). North shore of Thompson Cove, Gravina Island:

Pecten? sp.
Gryphaea? sp.
Halobia sp.
Undetermined ammonite.
Triassic.

9536 (15 ACh 129). Fivemile Cove, Gravina Island; limestone apparently overlying massive conglomerate:

Corals, several undetermined genera.
Bryozoa?
Pecten sp.
Purpurina?? sp.
Undetermined slender gastropod.
Probably Triassic.

9537 (15 ACh 130). Fivemile Cove, Gravina Island:

Corals, several genera.
Bryozoa?
Myophoria sp.
Purpurina?? sp.
Turbo? sp.
Triassic.

9538 (15 ACh 132). Fivemile Cove, Gravina Island, immediately north of 9537:

Gryphaea sp.
Probably Triassic.

Two lots of fossils collected by P. S. Smith from the black slate of Threemile Cove (8704) and also from Fivemile Cove (8705) were submitted to Mr. Stanton, who reported as follows:

The only fossil species recognized in these two lots is a *Halobia* which is closely related to if not identical with *H. superba* Mojsisovics, an Upper Triassic species. The rocks from which these collections came are therefore referred to the Triassic.

The writer made the following collections in 1915 from the black slate and interbedded limestone and sandstone beds of Threemile Cove, Thompson Cove, and Dall Ridge. Stanton reports:

15 ACh 112. Threemile Cove, Gravina Island, 300 yards north of 15 ACh 111.

Spiriferina? sp.
Halobia? sp.
Probably Triassic.

9532 (15 ACh 113). Threemile Cove, Gravina Island, 300 yards southeast of north end of cove and about 700 yards north of 15 ACh 112; fossils from black slate and limestone:

The black slate shows fragmentary specimens of *Halobia* cf. *H. superba* Mojsisovics, of Upper Triassic age, while the limestone shows imperfect specimens which seem to be referable to *Aucella* and hence is probably of Upper Jurassic age.

The limestone and black slate from which the fossils regarded as Upper Triassic and Upper Jurassic were obtained are apparently interbedded. This anomalous occurrence may be due to very closely infolding of Jurassic rocks, but it appears more probable that the doubtful Jurassic forms are not correctly identified.

9533 (15 ACh 115). Thompson Cove, Gravina Island; *Halobia* slates in fault block:

Cidaris? sp., imprint of surface.
Halobia cf. H. superba.
Triassic.

15 ACh 124. Dall Ridge, 4 miles north of Dall Head, Gravina Island.

Echinoid spines, etc.
Probably Triassic.

The following collection was identified by J. B. Reeside, jr.:

9900 (16 ACh 137). Threemile Cove, Gravina Island:
- Cerithium? sp., fragment showing part of two whorls.
- Isastraea cf. I. profunda.
- Thamnastraea cf. T. rectilamellosa.
- Spongiomorpha? sp.
- Hydrozoan, undetermined.
- Natica? sp.

These forms are apparently of the Upper Triassic coral fauna referred by J. P. Smith to the Noric.

The conglomeratic sandstone near the crest of Dall Ridge contains Devonian fossils, but as these are fragmentary and occur in pebbles they indicate nothing more than the post-Devonian age of the rocks. Edwin Kirk reports:

15 ACh 126. Dall Ridge, 4 miles north of Dall Head. Fragmental fossils apparently occurring as pebbles in conglomerate. At least one of the fossils is Devonian. It is a coral, probably *Alveolites*.

Black slate and sandstone exposed on the west coast of Bostwick Inlet are correlated on structural grounds and lithologic similarity with the upper part of the Triassic rocks on the west coast of the island. The fossils listed below were collected in 1914 by Martin and Overbeck from the west shore of Bostwick Inlet and identified by T. W. Stanton:

8836 (G. C. M. No. 8). Gravina Island, Bostwick Inlet, west shore near entrance; from angular nodules in a brecciated (?) nodular limestone:
- Terebratula sp.
- Spiriferina? sp.
- Pecten sp.
- Plicatula? sp.
- Cassianella sp.
- Myophoria sp.
- Myophoria or Trigonia sp.
- Nucula sp.
- Astarte? sp.
- Arcestes? sp.

Triassic. This assemblage suggests the fauna of the lower part of the Modin formation in California, which was tentatively assigned to the Jurassic.

Near this same locality P. S. Smith [82] also collected fossils on which G. H. Girty reports as follows:

Three lots from Bostwick Inlet, Gravina Island, contain round crinoid stems (13 AS 170) and a single compressed pelecypod (13 AS 169), suggesting the genus *Posidonomya*. The third lot (13 AS 171) contains a pelecypod fauna interesting and varied but entirely new to me. As these fossils at best show only the shapes and some of them the sculpture, and as pelecypods of similar external appearance may belong to widely different genera, the identifications made here are offered with doubt. Though similar doubt tacitly surrounds

[82] Notes on the geology of Gravina Island, Alaska: Prof. Paper 95, p. 103, 1915.

many pelecypod identifications in faunal lists and elsewhere, I have expressed it in this case by the use of question marks because the age of the whole fauna is involved in such uncertainty. In lot 171 five types are represented more or less abundantly and by specimens more or less good. These are *Glossites?* cf. *G. lingualis*, *Schizodus?* cf. *S. appressus*, *Paracyclas?* cf. *P. ellipticus*, *Crenipecten?* cf. *C. crenulatus*, *Elymella?* cf. *E. nuculoides*. Besides these, however, there are a good many indeterminate forms, some of which suggest the genera *Leda*, *Chonetes??*, *Pseudomonotis??*, *Aviculipecten*, and *Nucula*. The age of the fauna is quite uncertain. You declined for the time being to admit it into the Triassic, and nothing resembling it has thus far been brought in from the Alaskan Carboniferous. The generic and specific resemblances suggested above might indicate a Devonian fauna, but neither has any Devonian fauna related to this been obtained from Alaska. The genus *Chonetes*, if definitely present, would at least limit the geologic age to the upper Paleozoic, but the specimen is so imperfect that even the identification as a brachiopod is doubtful.

Thus the age of this, the best fauna in the collection, must for the present remain undesignated. It would be highly rash to attempt any definite age determination or conclusion for the other lots, containing, as they do, for the most part, only crinoid stems (even that being doubtful in some cases), though they may tentatively be placed in the Paleozoic.

Regarding this report Smith suggests that the doubtfully determined fauna from Bostwick Inlet, which is unknown elsewhere in Alaska, may mark a Lower Triassic horizon, also unknown in Alaska. He states:

As Mr. Girty points out, this fauna is entirely unlike any other from Alaska. It therefore affords little aid in solving the stratigraphic position of the beds on Gravina Island. Certain significant deductions, however, suggest themselves. In general in southeastern Alaska the known Carboniferous rocks are limestones and not lithologically similar to the rocks of Gravina Island. The rocks here discussed are much less dynamically metamorphosed and are less intensely deformed than the known Devonian or Carboniferous rocks of the region. Their relation to the andesitic agglomerates and flows fits in better with an assumed Mesozoic age than with a Paleozoic age. The almost uninterrupted succession of beds from a basal (?) conglomerate to shales containing unquestioned Triassic fossils on the southwestern coast suggests that the doubtfully determined genera from that locality, provisionally assigned to the Carboniferous, justify the suggestion made by Mr. Girty at that time that they may mark a Triassic horizon. No Lower Triassic is known in Alaska. Is it not possible that this fauna from Bostwick Inlet, which is unknown elsewhere in Alaska, fits into this as yet unfilled gap?

Its reference to the Lower Triassic, however, seems improbable, for the fauna is in the upper part of the formation, above the position of the *Halobia*-bearing slate (determined as Upper Triassic) and immediately below the Upper Jurassic or Lower Cretaceous volcanic rocks. Its reference to the Upper Triassic or the Lower or Middle Jurassic would be more in keeping with the observed relations.

The term Vancouver series was first applied by Dawson[83] to the entire mass of volcanic materials and interbedded limestone, flaggy

[83] Dawson, G. M., Canada Geol. Survey Ann. Rept. for 1886, p. 10b, 1887.

argillite, and quartzite that unconformably underlie the Cretaceous rocks of Vancouver Island. At that time, on the evidence of intercalated fossiliferous beds, this series of rocks was regarded as largely Triassic, although the possibility of its including both Jurassic and Carboniferous rocks was recognized. The Vancouver series was later subdivided by Clapp,[84] who has shown that it is in part Jurassic and possibly also in part Carboniferous. The Triassic rocks of Gravina Island are probably the equivalent of parts of the Vancouver series of Vancouver and Queen Charlotte Islands.

Triassic rocks are widespread throughout Alaska and occur at many places in southeastern Alaska. Fossils of Upper Triassic age have been found on Admiralty, Kupreanof, and Screen Islands. Martin[85] states that the abundant corals in some of these Triassic rocks of Gravina Island suggest that they may represent the lower Noric coral fauna of Iliamna Lake. He considers that the Triassic limestones of southeastern Alaska, which in general are characterized by faunas containing *Halobia* cf. *H. superba* Mojsisovics, correspond at least approximately in position to the Chitistone limestone of the Copper River Valley.

The age and correlation of the Triassic formations in the vicinity of Keku Strait and the Screen Islands in Clarence Strait have been discussed by Martin,[86] whose statement is here quoted in its entirety.

The apparent stratigraphic succession and the character of the Triassic faunas on Keku Strait are somewhat different from anything that has been found elsewhere in Alaska. The fossils from the limestone and associated sedimentary rocks that are regarded by Buddington as forming the basal portion of the Triassic rocks of this locality and the fossils from sedimentary beds that he regards as intercalated in the overlying volcanic formation are listed in the following tables. Most of these collections include well-known Upper Triassic species that are characteristic of the Triassic rocks of other Alaskan localities, such as *Pseudomonotis subcircularis* (Gabb) and *Halobia* cf. *H. superba* Mojsisovics, as well as some of the ammonites that are customarily associated with the *Halobia*.

[84] Clapp, C. H., Southern Vancouver Island: Canada Geol. Survey Mem. 13, p. 37, 1912.
[85] Martin, G. C., Triassic rocks of Alaska: Geol. Soc. America Bull. vol. 27, p. 700, 1916.
[86] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 83–89, 1926.

Upper Triassic fossils from north end of Keku Strait

[Identified by T. W. Stanton]

	11931	11932	11933	4822	4821	8842	8845	8846	8841	11934	11237	11238	11239	11240	11241	11242	11243	8843	4823	9543	10196	10197	11408	11436	11245	11246	11437	4820	4819	8844	(16B)
Plant stems?	X																														
Cup corals?	X																														
Corals?							X																								
Rhynchonella		X		X	X					X																					
Terebratula	X						X	X		X																					
Terebratula?		X													X																
Spiriferina borealis?							X																								
Spiriferina										X																					
Spiriferina?					X					X																					
Brachiopods			X																												
Pseudomonotis subcircularis																									X	X		X	X	X	X
Pseudomonotis subcircularis?																								X			X				
Pseudomonotis?										X																					
Halobia cf. H. superba										X	X	X	X	X			X	X	X		X	X									
Halobia															X					X			X	X	X	X					
Ostrea?	X																														
Pecten				X					X	X																					
Lima?																					X										
Modiolus										X																					
Pleuromya?				X																											
Astarte?									X					X			X														
Undetermined pelecypods	X	X	X	X			X																								
Natica							X	X																							
Gastropods	X																														
Mojsvaroceras?														X																	
Tropites																X															
Paratropites											X	X			X		X														
Discotropites sandlingensis?											X		X	X		X	X														
Discotropites												X																			
Juvavites?														X																	
Sagenites?															X																
Ceratites	X																														
Ceratites?																			X												
Clionites?											X																				
Trachyceras cf. T. canadense						X																									
Trachyceras (Protrachyceras)								X																							
Trachyceras?				X					X																						
Placites?												X		X																	
Polycyclus?													X		X																
Arcestes											X						X														
Undetermined ammonite				X			X																								
Atractites								X						X										X							

11931 (No. 910). Kuiu Island about 3 miles southeast of Point Cornwallis, on Keku Strait side; gently folded limestone; A. F. Buddington, 1923.

11932 (No. 961). Kuiu Island, opposite round island about 4 miles southeast of Point Cornwallis; limestone that apparently overlies felsite breccia and tuff; A. F. Buddington, 1923.

11933 (No. 980). Kupreanof Island, about 2 miles northeast of Cape Bendel; brown sandy limestone between the white Permian limestone and the conglomerate; may be either basal part of Upper Triassic or upper part of Permian; A. F. Buddington, 1923.

4822 (7). North side of Hamilton Bay near south end of large island southeast of Kake; from a boulder in limestone conglomerate; W. W. Atwood, 1907.

4821 (6). Same locality as 4822; from another boulder in the limestone conglomerate; W. W. Atwood, 1907.

8842 (16). North shore of Hamilton Bay about 2 miles below head of bay; float; G. C. Martin, 1914.

8845 (19). North shore of Hamilton Bay about 3 miles below head of bay; float; G. C. Martin, 1914.

8846 (20). Same as 8845; G. C. Martin, 1914.

8841 (15). Hamilton Bay, about three-quarters of a mile up the northernmost creek entering the head of the bay; from gray limestone that appears to underlie the white Carboniferous limestone at the falls near the mouth of the creek; R. M. Overbeck, 1914.

11934 (No. 979). One and one-fourth miles northeast of Cape Bendel, Kupreanof Island, on east headland of cove due south of Pinta Rocks; fossils from near top of limestone; A. F. Buddington, 1923.

11237 (39). About 2 miles south of Kake, on northwest point of large island; fossils in limestone nodules in calcareous conglomerate beds intercalated in limestone at top of conglomerate series (basal conglomerates); A. F. Buddington, 1923.

11238 (92). Extreme southeast tip of large island south of Kake; limestone overlying basal (?) conglomerate series; A. F. Buddington, 1923.

11239 (91). Limestone overlying that of 92; many interlayers of slate; A. F. Buddington, 1923.

11240 (62). Seven miles southeast of Kake, Kupreanof Island; limestone overlying conglomerate and sandstone; A. F. Buddington, 1923.

11241 (67). Limestone beds a trifle above those of 11240 and about 350 feet above base of conglomerate series; the underlying buff-weathering Carboniferous (?) limestone with chert layers is exposed beneath the conglomerate; A. F. Buddington, 1923.

11242 (66). Limestone beds at about same horizon as 11241 on islet just south of 11241; nose of anticline pitching southeast; A. F. Buddington, 1923.

11243 (68). Same locality as 11240, about 275 feet above base of conglomerate series, limestone; A. F. Buddington, 1923.

8843 (17). North shore of Hamilton Bay, 2 miles below head of bay; near base of cherty limestone that overlies ellipsoidal lava; G. C. Martin, 1914.

4823 (8). North side of Hamilton Bay near south end of large island southeast of Kake; from beds that seem to overlie the limestone conglomerate that yielded lots 4821 and 4822; W. W. Atwood, 1907.

9543. Islet in Frederick Sound, a quarter of a mile southwest of Kake; Mrs. Theodore Chapin, 1915.

10196. South end of northernmost large island of Keku Islets; G. H. Girty, 1918.

10197. Near middle of north shore of small island southeast of northernmost large island of Keku group; G. H. Girty, 1918.

11408 (211 Bu). Northeast end of large island southeast of northernmost large island of Keku group; black calcareous shale adjacent to limestone with beds of white chert; shale probably same formation as 215 and 205; A. F. Buddington, 1922.

11436 (205 Bu). Southwest side of northernmost large Keku Islet; same formation (?) as 215 but more sheared; A. F. Buddington, 1922.

11245 (56 Bu). North shore of Hamilton Bay about 2 miles below head of bay; from thin-bedded slate, quartzite, and limestone intercalated with pillow lava; these beds overlie the limestone beds of 66 and 67; A. F. Buddington, 1922.

11246 (68). West shore of large island southeast of Kake; from beds similar to 56 intercalated in pillow lava overlying limestone of 91; A. F. Buddington, 1922.

11437 (65 Bu). Kupreanof Island, southwest of Kake; from interbedded quartzite and limestone overlying the limestone of 67; A. F. Buddington, 1922.

4820 (2). North side of Hamilton Bay near south end of large island southeast of Kake; from beds that seem to underlie the limestone conglomerate that yielded lots 4821 and 4822; W. W. Atwood, 1907.

4819 (1). North side of Hamilton Bay near south end of large island southeast of Kake; from the same series of beds that yielded lot 4820, apparently a few feet lower; W. W. Atwood, 1907.

8844 (18). North side of Hamilton Bay, 2 miles below head of bay; 40 or 50 feet above lot 8843; G. C. Martin, 1914.

(16B). Near head of Hamilton Bay; float; E. M. Kindle, 1905.

The fossils of lots 11245 to 16B are indicative of the Upper Noric *Pseudomonotis*-bearing beds that constitute the uppermost known Triassic rocks of other Alaskan regions. The fossils of lots 11934 to 11436, all of which contain *Halobia*, most of which contain *Halobia* cf. *H. superba*, and some of which contain several of the ammonites that are generally associated with *Halobia* cf. *H. superba*, are indicative of the Middle or Upper Karnic *Halobia*-bearing beds that generally underlie the *Pseudomonotis*-bearing beds of other regions.

The fossils of lots 11931 to 8841, in which both *Pseudomonotis* and *Halobia* are absent, call for special consideration. The fossils of lot 11931 include an ammonite which Stanton has identified as *Ceratites*. This ammonite, if correctly identified, is suggestive of the Middle Triassic. Lots 11932 and 11933 contain only a few fossils that are not of any special significance. Lots 4822 to 8841 from boulders in the Upper Triassic conglomerate, from float of unknown origin, and from beds that apparently underlie the Permian rocks at an isolated locality on the creek that enters the head of Hamilton Bay, differ from the faunas at the other localities, not only in the absence of *Pseudomonotis*, of *Halobia*, and of the ammonites that are generally associated with *Halobia*, but in the presence of *Trachyceras* and of abundant brachiopods. The float material of lots 8842, 8845, and 8846 was noted in the field as having come "from beds that were not recognized in the observed outcrops." The fossils at localities 8842 and 8845 include species related to *Spiriferina borealis* Whiteaves and *Trachyceras* (*Dawsonites*) *canadense* Whiteaves, which have not been found elsewhere in Alaska or at any American localities except in the Triassic rocks of Liard River, in the eastern foothills of the Rocky Mountains of British Columbia.

The Triassic rocks of Liard River, according to McConnell,[87] "consist of dark shales, usually rather coarsely laminated, and passing into calcareous shales interstratified with sandstones and shaly and massive limestones." The fossils, which have been described by Whiteaves,[88] include eleven species, among which are *Spiriferina borealis* Whiteaves and *Dawsonites canadense* Whiteaves, which have been doubtfully identified from Hamilton Bay. Mojsisovics[89] has pointed out that some of these fossils are indicative of Karnic age. Three of the Liard River species (*Dawsonites canadense, Nathorstites mcconnelli*, and *Nathorstites lenticularis*), one of which occurs at Hamilton Bay, have been found, according to Böhm,[90] in the Upper Triassic rocks of Bear Island, between Norway and Spitsbergen. The Triassic rocks of Bear Island are generally regarded as of Karnic (possibly Lower Karnic) age, and an assignment of the beds on Liard River to the same position has been made by Frech[91] on the basis of the presence of the above-mentioned species, which are common to the two regions.

The Hamilton Bay fauna may also be tentatively correlated with that from Bear Island and referred to the Karnic, which has not been recognized farther south in North America.

The fauna of the limestone and calcareous sandstone interbedded with the lava and tuff of Kuiu Island is very different from any of the previously known Triassic faunas of America. Concerning this fauna, which is represented in the table given below, T. W. Stanton has furnished the following statement:

"Although this small collection [lot 11407] contains an unusually large number of species of fairly well preserved fossils which are apparently of Mesozoic types, there seems to be nothing in it strictly comparable with any known Mesozoic fauna in Alaska or indeed in America. Several of the species do not show important characters that are necessary for positive generic assignment, and this fact weakens the determination of the age of the fauna. It is reasonably certain, however, that this fauna belongs to the Triassic and probably to the Upper Triassic, as determined by comparison with European Triassic faunas."

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[87] McConnell, R. G., Report on an exploration in the Yukon and Mackenzie Basins, Northwest Territory: Canada Geol. Survey Ann. Rept., new ser., vol. 4, pp. 19D, 49D, 1890.

[88] Whiteaves, J. F., On some fossils from the Triassic rocks of British Columbia: Contr. Canadian Paleontology, vol. 1, pt. 2, No. 3, pp. 127–149, pls. 17, 18, 1889.

[89] Mojsisovics, Edmund von, Beiträge zur Kenntniss der obertriadischen Cephalopoden-Faunen des Himalaya: K. Akad. Wien Denkschr., Band 63, p. 697, 1896.

[90] Böhm, Johannes, Ueber die obertriadische Fauna der Bäreninsel: K. Svenska Vetenskaps-Akad. Handlingar, Band 37, No. 3, pp. 56–58, 61–64, 73–76, 1903.

[91] Frech, Fritz, Die zirkumpacifische Trias: Lethaea geognostica, Teil 2, Das Mesozoicum, Band 1, Trias, pp. 488–491, 508, 1908.

Fossils from Upper Triassic (?) limestone and calcareous sandstone associated with lava and tuff on Keku Strait

[Identified by T. W. Stanton]

	11407	11962	11406	11405
Wood fragments	----	----	×	----
Sponge?	----	----	×	----
Pentacrinus	×	×	----	----
Cidaris? and other echinoids (spines)	×	×	----	----
Heteropora	----	×	----	----
Rhynchonella	×	×	----	----
Rhynchonella (Austriella?)	×	×	----	----
Terebratula	×	×	×	----
Terebratula?	----	----	----	×
Spiriferina	×	×	×	----
Spiriferina?	----	----	×	----
Macrodon	×	×	----	----
Macrodon?	×	×	----	----
Pinna?	----	×	----	----
Gervillia	×	----	----	----
Gervillia?	----	×	----	----
Pteria	----	×	----	----
Pteria?	×	×	×	----
Ostrea? (small plicate form)	----	----	×	----
Gryphaea?	----	----	----	×
Myophoria?	×	×	----	----
Pecten (with strong concentric ribs)	×	×	----	----
Pecten (slender radiating ribs and coarse internal lirae)	×	----	----	----
Pecten	----	----	----	×
Pecten (Propeamusium)	----	×	----	----
Lima (with fine sculpture)	----	×	----	----
Lima (coarse-ribbed form)	----	×	----	----
Lima (rotund form with fine sculpture)	×	----	----	----
Lima (small form with strong ribs)	×	----	----	----
Lima? (another ribbed form)	----	×	----	----
Placunopsis?	×	×	----	----
Mytilus	×	----	----	----
Astarte?	×	----	----	----
Cardita?	×	×	----	----
Gonodon?	×	×	----	----
Protocardia?	×	×	----	----
Undetermined pelecypods	----	----	×	×
Scurria?	×	×	----	----
Pleurotomaria	×	----	----	----
Pleurotomaria?	----	×	----	----
Worthenia? (several species)	×	×	----	----
Euomphalus	×	×	----	----
Euomphalus?	×	----	----	----
Coelocentrus?	×	×	----	----
Trochus	×	×	----	----
Trochus? (a sinistral specimen)	----	×	----	----
Neritopsis	----	×	----	----
Pseudomelania?	----	×	----	----
Anoptychia?	×	----	----	----
Eustylus?	×	----	----	----
Promathilda?	×	----	----	----
Platyceras?	----	×	----	----
Spirocyclina?	×	×	----	----
Undetermined gastropods	----	×	×	----
Arpadites?	×	×	----	----
Ammonite	----	×	----	----

11407 (256 Bu). Kuiu Island, 3 miles a little north of west of Point Camden on west side of 9¾-fathom cove about half way between 9¾ mark and north point; conspicuous pillow lava involved with thick layers of limestone molded to the pillows; one pocket of limestone extraordinarily rich in well-preserved fossils; the limestone for several inches adjacent to pillow is baked to a pinkish-brown hornstone; fossils are all from this pocket; A. F. Buddington, 1922.

11962 (256 Bu). Same locality as 11407 but on different pocket; A. F. Buddington, 1923.

11406 (244 Bu). Kuiu Island, west side of Keku Strait, 7 miles northwest of Pup Island, just north of first creek shown on chart south of point where shore line changes from east-west to north-south; interbedded argillaceous limestone and andesitic tuff, with rare thin conglomerate beds and intercalated sandstone; many layers of the limestone are richly fossiliferous; traces of leaf impressions poorly preserved are present in same layers with shells, and carbonized plant stems are common in the limestone and abundant in the sandstone; A. F. Buddington, 1922.

11405 (145 Bu). Turnabout Island, Frederick Sound, east side of the bight on the south side of the island where the house stands; basalt and basalt porphyry flows and breccia with intercalated tuff and a 50-foot bed of gray sandstone; the sandstone contains intercalated layers of calcareous sandstone and conglomerate 1 inch to several inches thick, some of which are richly fossiliferous; traces of carbonized plant stems also noted in the sandstone; A. F. Buddington, 1922.

An assignment of the volcanic beds containing these fossils to a position beneath *Halobia*-bearing limestone would accord with the occurrence of volcanic rocks immediately beneath the *Halobia*-bearing limestone in other parts of

Alaska, notably in the Chitina Valley and on Cook Inlet. There are difficulties, however, in the assignment of the rocks to this position. The *Halobia*-bearing beds at near-by localities rest unconformably upon Devonian and Permian rocks. If the beds that contain the fauna in question belong under the *Halobia*-bearing beds they are separated from the *Halobia*-bearing beds by an unconformity and consequently are considerably older. The fossils themselves according to an oral statement by T. W. Stanton, are suggestive of a horizon above that of *Halobia* or even that of *Pseudomonotis* rather than of a horizon below that of *Halobia* cf. *H. superba*. The writer believes, therefore, that the volcanic rocks containing this fauna are to be correlated with the lava and tuff which Buddington regards as interbedded with the rocks that contain *Pseudomonotis*, or may even be assigned to some horizon even higher in the Noric or in the Rhaetic. The volcanic beds that overlie the Triassic rocks of Gravina Island, which the writer has referred tentatively to the Lower or Middle Jurassic, may possibly belong at the same horizon.

The upper limestone, on the Screen Islands, Clarence Strait, which crops out only on the southernmost island, yielded the Triassic (?) fossils represented in the following table:[91a]

Fossils from upper limestone on Screen Islands

[a, Identified by T. W. Stanton; b, identified by G. H. Girty]

	8839	8838	(22G)	11075	11076	(2)	(3)	(4)
Corals							b	
Crinoidal fragments			b					b
Archaeocidaris? sp			b					b
Burrows		a						
Dielasma sp			b					
Terebratula?	a							
Cyrtia sp			b					
Spiriferina?				a				
Aviculipecten sp			b					
Pecten?		a						
Pelecypods					a			
Pleurotomaria sp			b					
Murchisonia? sp			b					
Tuberculopleura? sp			b					
Several undetermined forms			b					
Ammonite						b		

8839. Near south end of the southernmost of Screen Islands, 100 or 200 feet below 8838; G. C. Martin, 1914.

8838. South end of the southernmost of Screen Islands; from nearly the highest beds exposed on this island; G. C. Martin, 1914.

(22G). Screen Islands; E. M. Kindle, 1905.

11075. South tip of southernmost of Screen Islands; A. F. Buddington, 1921.

11076. Southwest side of longest of Screen Islands; A. F. Buddington, 1921.

(2). Screen Islands; G. H. Girty, 1918.

(3). Near north end of northernmost of Screen Islands; G. H. Girty, 1918.

(4). Screen Islands; G. H. Girty, 1918.

JURASSIC (?) ROCKS

DISTRIBUTION AND CHARACTER

The rocks herein classified as Jurassic (?) include several distinct formations of uncertain stratigraphic relations. At a few localities slate carrying the fossil *Aucella crassicollis* has been found, and

[91a] Martin, G. C., op. cit., p. 78.

these beds of slate, with the associated graywacke and interbedded thin limestone and conglomerate, have been mapped separately and grouped as probably of Lower Cretaceous age, although they may be Upper Jurassic. Most of the sedimentary beds and volcanic rocks are unfossiliferous; they are considered to be of Jurassic (?) age because of their structural relations and lithologic similarity to formations of known age elsewhere. They may include beds as old as Lower Jurassic and as young as or younger than the *Aucella crassicollis* zone. It may be that beds even as old as Ordovician have been erroneously mapped as belonging to this group, and it is highly probable that some Upper Triassic beds have by error been included. On the other hand, it is possible that the slate with thin-layered graywacke-like sandstone described by Chapin as occurring on Gravina and Annette Islands and included by him in the Upper Triassic may be for the most part of Jurassic age.

The definite stratigraphic sequence of the formations which belong to the Jurassic (?) is unknown.

Considered lithologically, the rocks believed to be Jurassic (?), exclusive of the *Aucella*-bearing beds, are here divided for mapping and discussion into two groups—(1) a predominantly sedimentary facies consisting of graywacke, black slate, and conglomerate; (2) a predominantly volcanic facies consisting of schistose greenstone volcanic rocks, mainly hornblende and rarely augite porphyry breccia, with intercalated tuff and flows, black slate, and graywacke.

SEDIMENTARY DIVISION

JUNEAU DISTRICT

Knopf [92] described and mapped as the "Berners formation" a belt of interbedded slate and graywacke with some greenstone, of supposed Upper Jurassic or Lower Cretaceous age, which occurs along the coast on the east side of Lynn Canal from Comet southeastward, including part of Douglas Island and the north end of Admiralty Island. It is now known that some rocks of Jurassic, Triassic, and probably Paleozoic age were erroneously included in this belt, but it seems probable that most of it is Jurassic or Cretaceous.

Knopf describes the graywacke as

> composed of grains of plagioclase feldspar and quartz together with fragments of other minerals and rocks, embedded in an argillaceous cement. The composition is somewhat variant; at Berners Bay, for example, the graywackes contain considerable augite and hornblende derived from it, so that hand specimens might be mistaken for tuffs or even porphyries. As a rule, however,

[92] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 15–17, pl. 5, 1912.

none of the constituents, except the glassy grains of quartz and the fragments of black slate, are recognizable by the eye. * * * Conglomeratic graywacke was seen at only one locality * * * where it forms a belt several hundred feet wide. * * * North of Berners Bay [the graywackes] contains little or no quartz, but south of the bay quartz becomes more prominent. * * * It will be apparent from the foregoing description that at some localities it may be difficult to distinguish the graywackes from tuffs; this difficulty becomes pronounced near the volcanic areas.

Spencer and Eakin [93] have mapped as the Treadwell slate, a formation composed of dominantly black clay slate with some conglomerate and considerable graywacke which occurs along the east coast of Douglas Island. The Treadwell slate is overlain by the Douglas Island volcanic group and underlain by the Thane volcanic group; it is assigned to the Upper Jurassic (?) by Martin.

SEYMOUR CANAL-FANSHAW-KUPREANOF AREA

A belt of rocks so similar in lithology and structure as to make it seem highly probable that they belong to the same formation extends across Admiralty Island between Point Young and Oliver Inlet and southeastward, appearing locally along the borders of Seymour Canal. Farther southeast it includes the Five Fingers, the western part of the Fanshaw Peninsula, and a part of the north end of Kupreanof Island.

On the north side of Admiralty Island between Point Young and Oliver Inlet are exposed a series of conglomerate, graywacke, and slate. The rocks that form Point Young consist predominantly of highly cleaved and mashed conglomerate with interbedded graywacke and some black slate. The pebbles and cobbles in the conglomerate consist of limestone, green-gray felsite porphyry, and other rocks. The island west of Point Young is of greenstone breccia. The beds east of Point Young for some distance are covered with sand and gravel. For 4 miles west of Oliver Inlet graywacke and slate, with sills of andesite porphyry, containing hornblende phenocrysts, are exposed. These beds are intruded by a small mass of granodiorite just west of the entrance to the inlet. East of the inlet for several miles are exposed intrusive masses of quartz diorite with included strips of graywacke and slate; these in turn are adjoined by the typical greenstone of Douglas Island with intrusive sills and dikes of quartz diorite, which together form the peninsula for 1½ miles west of Point Arden.

Along Seymour Canal the lowest beds are exposed on Windfall Harbor. For a few miles around this harbor the formations are Carboniferous and Triassic. (See pp. 118, 138.) The contact of the older beds with the graywacke-slate formation mapped as Juras-

[93] Spencer, A. C., and Eakin, H. M., manuscript report on the Juneau district.

sic (?) is 3 miles southeast of Windfall Harbor, but this contact is covered. The lowest beds of the Jurassic (?) formation are graywacke with conglomeratic lenses overlain by black slate which passes upward into a thick bed of conglomerate with a black slate matrix. The strike and dip are indeterminate. The predominant component of the conglomerate is a gray-green felsite porphyry with small plagioclase phenocrysts; some limestone cobbles are included, and limestone nodules occur sparingly; rarely granitoid rock is present. The fragments range from 1 to 9 inches in diameter. This conglomerate is adjoined along the coast to the southeast by black slate and graywacke with local beds of fine conglomerate. The beds along the coast for 15 miles northwest of Mole Harbor have a general northwest strike and a dip of 70°–90° W., probably due to a slight overturning toward the east. In the vicinity of Mole Harbor, both to the north and to the south, black slate with sparing nodules and nodular layers of dense blue-gray limestone is cut by many dikes of diorite of the Coast Range type. These slate beds are lithologically identical with those typical of the graywacke-slate series.

North of Windfall Harbor to a point within about 2 miles of the head of the next bay the rocks along the coast consist of schistose chert, greenstone, and slate. Black slate of the graywacke-slate series forms the head of the first bay north of Windfall Harbor, the peninsula to the east, Swan Island, and Tiedeman Island. Rarely a sill of green andesite occurs in it. Interlayered slate and graywacke form the second peninsula north of Swan Island on the west side. The beds here have a northwest strike; the dip is 50° SW. in the southwestern part and changes to vertical toward the northeast. The line of islets on the east side of Seymour Canal about 3 miles from its head consist of interbedded coarse graywacke and fine conglomerate with a vertical dip. The Glass Peninsula consists of greenstone schist containing hornblende or pyroxene phenocrysts, with intercalated slate and graywacke. The rocks along the east side of Seymour Canal consist of interbedded schistose greenstone, black slate, graywacke, and local conglomeratic beds and thus constitute a transition between the interbedded slate and graywacke with occasional greenstone sills found farther west and the predominantly greenstone series that forms most of the Glass Peninsula. The beds in general strike northwest. The dip along the west side of Seymour Canal is in general to the west; farther northeast across the strike it steepens to vertical; and on the east side of Seymour Canal it is vertical or steep eastward. Along the east side of the Glass Peninsula the dip is 35°–65° NE.

Bedded rocks similar to those along Seymour Canal are found on Fanshaw Peninsula, along the coast from a locality about 1½ miles west of Bay Point to the point south of Point Walpole, and along the stream at the head of the north arm of Farragut Bay, also on Whitney Island, Storm Islands, and the Five Fingers. The beds consist of graywacke, slate, and thin-bedded graywacke and slate. Any one of these types of rocks may dominate locally, but graywacke is the more common. Conglomeratic slate beds and rarely a tuffaceous bed occur locally intercalated with the graywacke. The graywacke varies from a very fine-grained rock with a fissile parting to a coarse-grained rock of more massive character. The more massive type is found on the Storm Islands, where the beds of coarse-grained graywacke with intercalated black slate and fine conglomerate are 1 foot to several feet thick. The beds of graywacke contain many lenses of conglomerate; but they are particularly characterized by an abundance of small calcareous pockets from one-fourth of an inch to several inches in diameter, which weather out and leave the rock exceedingly pitted with holes. Much larger lenses of calcareous material or limestone are also common in the graywacke and slate. Beds as much as a foot thick containing abundant fragments of black slate occur intercalated with the graywacke. In thin section the graywacke is found to consist almost wholly of waterworn fragments of plagioclase and of andesite porphyry with feldspar phenocrysts; it might be called a waterworn tuff.

The more fissile facies of the graywacke occur in beds from 1 to 6 feet thick with layers of slate several inches thick. The graywackes are a greenish gray on the fresh surface and a whitish or ash gray on the water-rounded surface. On weathering they break down along the cleavage planes and resemble the slates. In thin section they are seen to consist of quartz, plagioclase (albite-oligoclase), and fragments of other rocks in varying amounts in a very fine-grained groundmass. Locally fragments of black slate are common.

Limestone layers several inches thick are commonly intercalated with the graywacke and slate in the thin-bedded zones. Limestone occurs also as nodules and persistent thin layers in the thick-bedded slates and here and there in beds as much as a foot thick. Calcareous lenses are common in the graywacke.

The slates are thin-cleaving dark-gray to black argillaceous rocks of normal character.

The conglomeratic slates occur in beds that are usually not more than 20 feet thick but at some places are as much as 100 feet, as just north of Point Highland. The fragments are commonly a fraction of an inch to 2 inches in diameter. In the 100-foot bed cobbles 1 foot and boulders 5 feet in diameter are present. The fragments are exclusively a gray-green feldspar porphyry, locally with border outlines resembling those of a breccia. The phenocrysts are albite-oligoclase. The matrix ranges from a slate to a very fine graywacke. The pebbles and cobbles have been very much flattened by pressure, and the groundmass has a slaty cleavage. Just southeast of Point Highland a bed of uniform massive green tuff about 30 feet thick occurs intercalated in conglomeratic slate. In thin section this rock is found to consist mostly of fragments of felsite porphyry with euhedral crystals of plagioclase (albite-oligoclase) and pyroxene in a microfelsitic groundmass.

The north end of Kupreanof Island from a point about 10 miles east of Cape Bendel to a point 4 miles west of Portage Bay is composed of rocks similar to those of the Fanshaw Peninsula and the north end of Admiralty Island. About 10 miles east of Cape Bendel a series of beds comprising graywacke and black slate with intercalated conglomerate comes in overlying, presumably unconformably, Devonian limestone, slate, and green chlorite schist. The contact is covered, but the Devonian beds have a very steep dip, in general to the west, whereas the overlying formation has a moderate dip to the northeast. Overlying the basal beds of the group of rocks mapped as Jurassic (?) is a great thickness of isoclinally folded black slate, which was evidently crumpled as a result of drag folding between the more massive beds below and above. At the headland about 12 miles east of Cape Bendel the slate is overlain by about 1,000 feet of conglomeratic beds with intercalated graywacke and slate. The lower part of these beds consists of thick conglomerate, which passes upward through interbedded conglomerate and graywacke into interbedded conglomeratic slate and black slate, and finally into a series of slate and gray phyllite. The slate-phyllite series is exposed almost continuously for a width of more than 10 miles at right angles to the prevailing strike. The general strike of the cleavage is N. 10°–40° W., and the dip 40° E. So great an apparent thickness is best explained as the result of repeated duplication through isoclinal folding and crumpling. Minor folds with a southeast pitch and a uniform crosscutting cleavage were seen repeatedly within the beds. About 4 miles west of West Point the slate-phyllite series gives way abruptly to several hundred feet of Devonian rocks, which consist of a series of thin-bedded black slates with layers of chert and sills or dikes of intensely altered intrusive rock that weathers pale greenish gray. The contact between the two formations is covered, but the Devonian (?) rocks are intensely crumpled near the contact.

The conglomerates range in texture from a coarse graywacke to beds with cobbles 3 to 9 inches in diameter. Beds with pebbles half an inch to several inches in diameter predominate. The beds have been severely compressed, and the pebbles and cobbles are very much flattened and traversed by many close-set minute faults. The pebbles and cobbles are mostly felsite porphyry, with fragments of slate next in abundance. Quartz, black and white chert, and limestone are less common. A typical cobble of the felsite porphyry, viewed under the microscope, consists of abundant phenocrysts of albite-oligoclase and a few crystals of much altered augite in a cryptocrystalline groundmass. The felsite porphyry is commonly slightly impregnated with pyrite, and its color ranges from pale gray-green to grayish white, depending in part on the denseness of texture.

Thin layers of limestone and layers with limestone nodules occur sparingly throughout the slates and the slate-phyllite series. The gray phyllite is probably a sheared very fine-grained graywacke. Limestone also forms the matrix of a few of the conglomerate beds.

The only traces of organic remains in these beds were found in graywacke from the northeasternmost tip of Whitney Island, Cleveland Passage. These were submitted to Arthur Hollick, who states that they are casts and impressions of what are apparently branching fronds of a fucoid plant resembling "*Chondrites heeri*" Eichwald and that even if the specific identity of these remains could be established it would not possess any special significance, as the stratigraphic position of the species has never been definitely determined.

A significant feature of the rocks of the Seymour Canal-Fanshaw-Kupreanof area, however, is the predominance of similar green-gray felsite or felsite porphyry pebbles in the conglomerates or conglomeratic slates of each locality.

Specimens of pebbles from the conglomerates of Point Young, Seymour Canal, Fanshaw Peninsula, and Kupreanof Island were examined with the microscope. The porphyritic rocks usually have a cryptocrystalline unidentified groundmass, and the dominant phenocrysts are usually a sodic feldspar (albite-oligoclase) but locally augite is equally abundant. A specimen from the conglomerate of Seymour Canal is microcrystalline in texture and is composed predominantly of plagioclase with interstitial quartz. The feldspars are so altered that the presence or absence of orthoclase could not be positively determined. The rocks in general have the appearance of quartz keratophyre or keratophyre. No pebbles or cobbles of porphyry with large phenocrysts of hornblende or pyroxene, such as characterize the greenstone rocks of the Glass Peninsula and Douglas Island, were found in these conglomerates. The conglomerate beds might therefore be older than the greenstones, so far as this evidence is concerned.

Pebbles of a granitoid rock similar to the Upper Jurassic or Lower Cretaceous intrusive rocks are present, but rare, in the conglomerates; this need not mean that the conglomerate beds are younger than the intrusive rocks, for pebbles of similar granitoid rocks are found also in Silurian conglomerates.

The conglomerate-graywacke-slate beds on Seymour Canal lie between the Carboniferous beds (perhaps with some Upper Triassic and younger beds) on the west and the greenstones of the Glass Peninsula on the east. Sills of greenstone occur in the sedimentary series, which grades through transitional interbedded greenstone, slate, and graywacke into the dominantly volcanic series. All the formations are cut by the Upper Jurassic or Lower Cretaceous intrusive rocks. These phenomena, taken in connection with the structural relations, suggest that the sedimentary series overlies the Carboniferous and probably the Upper Triassic series and underlies the greenstones. Such an interpretation is equally applicable to the Kupreanof and Fanshaw areas.

KUPREANOF-MITKOF-ETOLIN ISLANDS AREA

A series of fine-grained foliated, more or less fissile graywacke with black slate partings forms a large part of a northwestward-trending belt through Etolin Island, Mitkof Island, and the Lindenberg Peninsula. These beds are intruded by a great many masses of granitoid rocks and are more broken up and metamorphosed than the beds in the Seymour Canal-Fanshaw-Kupreanof area.

The fissile dark-gray graywacke occurs in beds from 1 to 6 feet thick, with beds 1½ to 2 feet very common. The slate partings range from a fraction of an inch to a foot or more in thickness and average several inches. Persistent layers of fine-grained black impure limestone occur sparingly, and layers of limestone lenses several inches thick are common. Lenticles of limestone an inch in length are common in some beds of graywacke, and weathering results in a pockmarked sufrace. Fragments of black slate flattened along the foliation planes are abundant locally in the graywacke. On the west side of Wrangell Narrows the fissile graywacke weathers with a pseudoporphyritic or tuffaceous aspect. Thin-bedded slate-graywacke zones are intercalated in the prevailingly thicker-bedded rocks. Locally sheets of melaphyre are found in the formation, as in the mountains on the west side of Wrangell Narrows and on the north end of Etolin Island, southeast and southwest of Chichagof Pass. A bed of melaphyre breccia is intercalated in the graywacke on the east side of Blind Slough on the south side of Mitkof Island. Two large blocks of melaphyre breccia are found at the head of Portage Bay, on Kupreanof Island, but it is not certain that they are in place.

The southern peak of the Portage Mountains is composed of a series of beds of fine to medium grained tuff underlain by slate. The tuff is green on the fresh surface and weathers to a gray hue. It consists of angular fragments of melaphyre crowded with phenocrysts of plagioclase and of augite almost wholly altered to hornblende.

The graywackes are usually fine-grained gray rocks with a distinct foliation which results in a more or less thin cleavage. In many beds the cleavage planes are so accentuated by weathering that the graywacke resembles slate or phyllite. In thin section the rock is found to consist typically of altered fragments of plagioclase (andesine to oligoclase) with a variable amount of quartz in a sericitic, argillaceous, or chloritic groundmass. Quartz may be absent or it may form a large percentage of the rock and constitute a quartzitic facies. Particles of andesitic rocks are occasionally present, and slate fragments are common in some beds. Near intrusive masses the graywacke is garnetiferous, and many dots of graphitic matter are arranged along certain of the foliation planes; hornblende is present in the calcareous phases, and a trace of tourmaline or apatite may be disseminated throughout the rocks. Other minerals that may be present are pyrite, magnetite, pyrrhotite, and epidote.

The beds of slate are of the usual black or bluish-black clay slate and locally form the bulk of the formation.

No fossils were obtained in the graywacke-slate beds of this belt. The stratigraphic position must therefore be surmised from structural relations and from a comparison with similar formations of known age in adjacent regions.

These beds of graywacke and slate are similar in lithology to those of the Seymour Canal-Fanshaw-Kupreanof area, but they are much more broken by intrusive granitoid rocks and locally are more metamorphosed. The conglomerates, which form so marked a feature of the northern belt, have not been found within the belt under discussion. The two belts may belong to different formations, though they are grouped together in this report.

CHICHAGOF ISLAND

Overbeck [94] has described fossiliferous slate and graywacke from the head of Slocum Arm on Chichagof Island. Stanton reported the fossils as *Aucella* sp. related to *A. fischeriana* D'Orbigny, with the following comment on age:

> The form of *Aucella* in these two lots appears to be distinct from the forms identified as *A. piochii* Gabb and *A. crassicollis* Keyserling in previous collections from Pybus Bay, Admiralty Island. The present collections are believed to be of Upper Jurassic age. It should be remembered, however, that the distinction between Jurassic and Lower Cretaceous on the basis of *Aucella* alone is not always safe. It is possible that all the *Aucella*-bearing rocks of southeast Alaska may belong in the same series.

[94] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, p. 108, 1919.

FELSITE VOLCANIC ROCKS

The beds at the south end of the Fanshaw Peninsula between Bay Point and Farragut Bay and for several miles north of Bay Point constitute a series of rocks not found elsewhere in the district. They comprise very fissile schists that weather white or rusty brown, intercalated black slate and conglomeratic slate, and schistose green andesite porphyry. The light-colored schists are of volcanic origin and include schistose felsite porphyry flows, breccias, and tuffs. The tuffs are often found in thin beds alternating with slate. A specimen of one of these schists, seen in thin section, is found to consist of plagioclase (albite-oligoclase) in a cryptocrystalline groundmass. The groundmass is much altered; in it secondary pyrite, calcite, and epidote are common, and needles of amphibole are abundant. The characters are those to be expected in a sheared felsite porphyry flow. In the beds of breccia black pyroxene crystals are conspicuous against the light-colored groundmass.

The correlation of these beds is an unsolved problem. The presence of andesite porphyry volcanic rocks, which may be sills, suggests a correlation with the Jurassic (?) greenstone volcanic series which adjoins them on the west. The fine conglomeratic slates resemble very closely those in the sediments of Fanshaw Peninsula to the north and may be of the same age, although they appear to be interbedded with the volcanic rocks. The cobbles in the conglomerates of the Jurassic (?) conglomerate-graywacke-slate series are similar to the felsite volcanic rocks of these beds; this similarity suggests that the volcanic beds are older than the conglomerates.

Knopf [95] states that some quartz porphyry schists are associated with the Jurassic or Cretaceous graywackes and slates in the Berners Bay area. Dolmage [96] describes dacite associated with the Vancouver group of volcanic rocks, which are believed to be Triassic in age.

GREENSTONE VOLCANIC ROCKS

DISTRIBUTION

Greenstone volcanic rocks of Jurassic or Cretaceous age have been mapped by Knopf [97] as occurring in a belt on the mainland on the east side of Lynn Canal north of Point Sherman; on the coast from Berners Bay to Auke Bay; on Douglas Island; and on the east side of Gastineau Channel. Near Juneau part of the greenstone is probably of Upper Triassic age and the remainder is of unknown age; this portion of the belt has been mapped for this report with the schists.

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95 Knopf, Adolph, U. S. Geol. Survey Bull. 446, p. 14, 1911.
96 Dolmage, Victor, Canada Geol. Survey Summary Rept. for 1920, pt. A, p. 14, 1921.
97 Knopf, Adolph, op. cit., pl. 5.

To the southeast the greenstone volcanic rocks form most of the Glass Peninsula, Admiralty Island, and a belt striking across Farragut Bay, on the mainland. They are again exposed as a narrow band intercalated in graywacke on the east side of Blind Slough and as a belt east of Point Alexander, Mitkof Island. They form Vank and Sokolof Islands and a belt on the north end of Etolin Island at Olive Cove and Anita Bay. In the Ketchikan district they form Onslow Island and the west part of the Cleveland Peninsula and extend southeast along Tongass Narrows, Gravina, Annette, and Mary Islands, and the coast north of Cape Fox.

Beds of black clay slate are intercalated with the greenstone at most places, but the amount is variable and in some thick sections they are absent. On the borders of many of the greenstone belts greenstone and slate are interbedded, and locally greenstone sheets are intercalated in the graywacke series.

On favorable weathered surfaces the breccia structure of the greenstone is well exhibited. The fragments may range in size from a fraction of an inch to a foot but are usually a few inches; they have been very much compressed and are elongated parallel to the foliation. In many beds the fragments form most of the rock with only a little groundmass. The most conspicuous feature of the rock is the abundance of black hornblende crystals, which are almost always present and are 0.2 to 0.3 inch in diameter and as much as 0.5 inch in length.

In thin section the rocks all show extensive alteration and parallel orientation of the secondary minerals. The component secondary minerals are amphibole, epidote, chlorite, calcite, quartz, a little magnetite, and often albite.

The least metamorphosed facies consists of phenocrysts of augite in process of alteration to hornblende in a groundmass composed of crowded fibers of uralite and actinolite in a microcrystalline plagioclase aggregate with large grains of epidote. Locally amygdules filled with calcite or chlorite are present. Usually the augite has been completely altered to hornblende and the groundmass consists of epidote, chlorite, sericite, actinolite, uralite, and microcrystalline secondary plagioclase, perhaps with some quartz. Local phases of the rocks, probably metamorphosed tuffs, consist almost wholly of hornblende with a trifle of biotite and muscovite and a few grains of epidote. Others have a little quartz. The rocks have been called augite melaphyres by Knopf.

Knopf [98] reports that in the Eagle River region conglomerates are associated with the breccias and consist essentially of pebbles and well-rounded boulders of volcanic material in a matrix of tuffaceous

[98] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 19, 20, 1912.

or waterworn material. He notes further that between Yankee and Bridget Coves the lavas display a remarkable development of ellipsoidal structure. This is the only reported occurrence of ellipsoidal structure in the Jurassic or Cretaceous volcanic rocks, and for this reason a question arises as to whether these particular lavas do not belong to some other system.

KETCHIKAN DISTRICT

By Theodore Chapin

In the Ketchikan district interbedded altered tuffs, flows, and black slate with some intrusive rocks occur on Gravina, Duke, Annette, and Revillagigedo Islands. The greenstone and slate overlie the Upper Triassic rocks with apparent conformity. On the evidence of a few fossils found in the intercalated sediments and on structural grounds and analogy with rocks of known age these rocks are regarded as Upper Triassic or Jurassic.

On Gravina Island the greenstone and slate occupy three parallel belts—one extending from South Vallenar Point to Seal Cove, another from the east shore of Bostwick Inlet to Vallenar Point, and the third along Tongass Narrows from Old Indian Town to Gravina Point. Northeast of Tongass Narrows similar rocks extend from Radio Station to Herring Bay. On Annette Island the greenstone and slate occupy two belts along the east and west coasts of the island.

The detailed sequence of the volcanic rocks of Gravina Island has not been worked out. In general they may be divided into two parts—a lower series of purely igneous material, mainly coarse pyroclastic rocks and breccia; and an upper series of mixed water-laid tuff and black slate and limestone, with porphyritic basic rocks of similar composition, evidently partly intrusive and partly extrusive. No sharp line separates the two parts, and the writer has not differentiated them on the geologic map. The black slate passes into green fissile tuffs and these into more massive varieties, so that as a rule no sharp line of contact can be drawn between them. By more detailed work the lower purely volcanic material might be separated from the upper mixed sedimentary and igneous material. The limestone bodies are too small to be shown on a map.

The base of the volcanic rocks is evidently the coarse breccia that overlies the Upper Triassic sediments of the west coast of Gravina Island. This breccia occupies the southern part of Dall Ridge and parts of California Ridge. It is a fine-grained green rock with large angular fragments set in a dense matrix of the same composition.

The breccia passes upward into finer-grained tuff, in part at least water-laid material, with which are intercalated black slate and thin

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beds of crystalline limestone. The black slate is typical clay slate that has a well-developed cleavage, with bedding planes discernible in places. The beds of slate are plainly conformable with green tuff.

The black slate and green bedded tuff are best developed along the north shore of Tongass Narrows from Ketchikan to Mountain Point. The black slate is in places considerably metamorphosed and schistose and might more correctly be called phyllite. It is closely interbedded with and grades into fissile green tuff, both of which are interbedded with more massive tuff. The green tuff also is schistose and in places is completely recrystallized. The greater part of the town of Ketchikan stands on rocks of this character, and excavations for street building show both blocky and fissile types. The most schistose types are completely recrystallized and consist of secondary quartz, feldspar, calcite, epidote, and chloritic material. The massive types consist essentially of secondary epidote, hornblende, chlorite, sericite, and calcite, with pyroxene and plagioclase feldspar crystals almost entirely replaced by secondary minerals.

AGE AND CORRELATION

Chapin[99] has discussed the age and correlation of the greenstone and slate in the Ketchikan district as follows:

The age determination of the greenstone and slate rests upon rather slender paleontologic foundation. The collections from Bostwick Inlet were submitted to Mr. Stanton, who reports as follows:

9528 (15 ACh 104). Bostwick Inlet, Gravina Island.

9529 (15 ACh 105). Bostwick Inlet, Gravina Island.

Aucella sp.

Probably Upper Jurassic; possibly Lower Cretaceous.

9530 (15 ACh 106). Bostwick Inlet, Gravina Island.

Pecten? sp.

Not sufficient for determining age but probably from same formation as 9528 and 9529.

These fossils were collected from the west coast of Bostwick Inlet about half a mile south of the localities from which the Triassic and doubtful collections were made. The fossils occur in sedimentary beds apparently interbedded with the volcanic breccias and overlying the Triassic sediments, but the relations are somewhat obscured by the gravel covering.

Some correlations with rocks of known age are suggested. The greenstone and slate series extends more or less continuously along the mainland and adjacent islands of southeastern Alaska. In the Juneau region the recent detailed work of Spencer and Eakin shows a section similar to that exposed along Tongass Narrows and adjacent islands, and Brooks, who has studied both sections, believed that the black slate and greenstones of Ketchikan should be correlated with the andesitic flows and black slates of Juneau, which carry Triassic fossils. The finding of Upper Triassic fossils by Spencer and Eakin[1]

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[99] Chapin, Theodore, The structure and stratigraphy of Gravina and Revillagigedo Islands, Alaska: U. S. Geol. Survey Prof. Paper 120, pp. 96–97, 1919.

[1] U. S. Geol. Survey Thirty-eighth Ann. Rept., p. 90, 1917.

in the slate and greenstone series of Juneau suggests to the writer the possibility that the rocks of Tongass Narrows are of similar age. Smith[2] notes the similarity between the volcanic rocks of Gravina Island and the augite melaphyres of the region north of Juneau, referred by Knopf[3] to the Upper Jurassic or Lower Cretaceous, and it is not at all unlikely that the upper portion of the slate and greenstone series of the Ketchikan district may be the equivalent of the volcanic rocks associated with the "Berners formation." The slate and greenstone of the Ketchikan district may thus be correlated with both the Triassic and Jurassic rocks of the Juneau region.

Martin[4] has given a thorough discussion of the Jurassic system in southeastern Alaska, from which the following quotation is taken:

> Although Jurassic rocks cover considerable areas in southeastern Alaska, the Jurassic sequence is by no means complete, several of the characteristic Jurassic formations and faunas that are so well developed elsewhere in the southern part of Alaska apparently being absent here. The next younger marine sedimentary beds above the Triassic are the supposed Upper Jurassic *Aucella*-bearing beds. The interval between the Upper Triassic and the Upper Jurassic probably includes some volcanic rocks that may be Lower or Middle Jurassic and may be represented by some of the unfossiliferous metamorphic rocks, chiefly slate, graywacke, and greenstone. The age and relations of these metamorphic rocks are in general highly problematic. Some of these rocks have been regarded as the metamorphic equivalent of the Lower Cretaceous *Aucella*-bearing beds, and this interpretation undoubtedly is in part correct. Others have been assigned to the Carboniferous, for which there apparently is strong evidence. Another part of these rocks contains Aucellas of the Jurassic type. Still others, which have been included in the "Berners formation," contain poorly preserved fossil plants which indicate a Jurassic or Lower Cretaceous age, the evidence, though by no means conclusive, favoring an assignment to the Jurassic. The evidence from these plants, and from the supposed Jurassic Aucellas, is the only paleontologic evidence that Jurassic rocks are present in southeastern Alaska.
>
> In assigning the unfossiliferous or poorly fossiliferous rocks of southeastern Alaska to the Jurassic, to the Cretaceous, or to the pre-Jurassic, the writer has used a combination of paleontologic and physical evidence. The Aucellas of the Jurassic type occur in or associated with beds that contain volcanic deposits and do not contain granitic boulders. The Aucellas of the Cretaceous type occur in beds that contain only reworked volcanic material and are interbedded with conglomerate containing granitic boulders. This occurrence is in harmony with the facts known in other parts of Alaska, where volcanic beds are not known in the Cretaceous rocks and where the larger masses of granitic rocks are believed to have been intruded in early Jurassic time. It has been assumed, therefore, that if the beds contain unreworked volcanic material they are probably pre-Cretaceous or post-Cretaceous; if they are intruded by granitic rocks they are probably early Jurassic or pre-Jurassic; and if they contain boulders of granitic rocks they are probably late Jurassic, or, more likely, post-Jurassic. Additional evidence on the age of the rocks may be obtained from the apparent continuity or discontinuity of the succession. For example, it is believed that

[2] Smith, P. S., Notes on the geology of Gravina Island, Alaska: U. S. Geol. Survey Prof. Paper 95, p. 164, 1916.

[3] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 18, 1912.

[4] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 245–247, 1926.

beds which directly overlie the known Triassic rocks, with no evidence or with slight evidence of unconformity, like some of the interbedded sedimentary and volcanic strata of Gravina Island and near Juneau, are probably Jurassic rather than Cretaceous, whereas beds which overlie the Triassic or older rocks with a more evident unconformity and without the intervention of rocks of transitional character, or beds which are separated from the Triassic rocks by a considerable thickness of intervening strata, are more likely to be Cretaceous than Jurassic. All these criteria ought to be used with caution, and little confidence can be placed in one kind of evidence alone; but when several kinds of evidence agree, the age assignments may be made with considerable confidence.

The supposed Lower or Middle (?) Jurassic rocks of southeastern Alaska include breccia, tuff, and lava on Gravina Island, the Thane volcanic group of the Juneau district, and possibly the melaphyre breccia of the Wrangell district. The Jurassic rocks of Gravina Island and the Juneau district are included in the following sections:

Section of Mesozoic rocks on Gravina Island[5]

	Feet
Lower Cretaceous (?): Conglomerate, graywacke, and black slate with *Belemnites*	800±
Unconformity.	
Upper Jurassic: Slate and limestone interbedded with tuffs and containing *Aucella*	1,200±
Lower or Middle Jurassic (?): Breccia, tuff, and lava	
Unconformity (?).	
Upper Triassic: Limestone, slate, and conglomerate	1,600±

Stratigraphic section near Juneau[6]

Upper Jurassic (?):
- Douglas Island volcanic group (melaphyre flows, tuff, and agglomerates).
- Treadwell slate (black clay slate, with some conglomerate and considerable graywacke).
- Concealed (Gastineau Channel).

Lower or Middle Jurassic (?):
- Thane volcanic group—
  - Melaphyre tuff.
  - Limestone.
  - Tuff and slate.

Upper Triassic:
- Gastineau volcanic group:
  - Slate.
  - Andesitic tuff.
  - Calcareous slate with Upper Triassic fossils.
  - Andesitic lava with local lenses of slate.

Triassic or older:
- Perseverance slate (clay slate).

Paleozoic, with perhaps some infolded Triassic:
- Clark Peak schist (schistose rocks derived from slate, sandstone, limestone, and conglomerate).

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[5] Compiled by G. C. Martin from information given by Chapin (U. S. Geol. Survey Prof. Paper 120, pp. 83–100, 1918).

[6] After Eakin, H. M., and Spencer, A. C., Geology and ore deposits of Juneau, Alaska: U. S. Geol. Survey Bull. (in preparation), with age assignments by G. C. Martin.

Buddington seriously questions the validity of certain criteria suggested by Martin as a basis for separating the Jurassic and Cretaceous systems in southeastern Alaska. These criteria are that the presence of granitic boulders in conglomerates indicates a probable post-Jurassic age, and that if the beds are intruded by granitic rocks they are early Jurassic or pre-Jurassic.

Lithologically the nonfossiliferous sedimentary beds mapped as Jurassic (?) resemble the fossiliferous rocks mapped as Lower Cretaceous (?). The former differ from the latter, however, in that they are in part more metamorphosed, and they are definitely cut by masses of the Upper Jurassic or Lower Cretaceous intrusive rocks. The greater metamorphism is, however, directly correlated with proximity to these intrusions, and it is therefore not an argument against a correlation of the two formations. The fossils, if originally present in the Jurassic (?) beds, may have been largely destroyed by the greater metamorphism.

The nonfossiliferous slates of Seymour Canal appear to be structurally the equivalent of the *Aucella*-bearing slates of Pybus Bay. Conglomerate beds of similar character occur intercalated in both formations, and both overlie Upper Triassic beds. A very marked unconformity exists between the similar Jurassic (?) sedimentary formation on the north end of Kupreanof Island and the underlying Devonian formation. The *Aucella*-bearing slates of Point Pybus are not cut by any intrusive rocks, but they are cut by quartz veins, which are restricted to the proximity of the diorite masses of The Brothers Islands and are therefore believed to be genetically connected with those intrusive masses.

Cobbles of diorite, granodiorite, and granitoid rocks occur in the conglomerate beds both along Seymour Canal and at Point Pybus. On Seymour Canal the beds associated with the conglomerates are cut by diorite at Mole Harbor. The presence of these cobbles, which are, it is true, so similar to the Upper Jurassic or Lower Cretaceous intrusive rocks that they can not be distinguished therefrom, nevertheless does not point to a postbatholithic age for the conglomerates. On the contrary, similar rocks are found also as cobbles and boulders in Silurian conglomerates throughout southeastern Alaska.

The conglomerates and associated beds at Point Young, Admiralty Island, were correlated by Wright[7] with the *Aucella*-bearing beds of Lower Cretaceous (?) age on Pybus Bay. This seems to Buddington a reasonable interpretation, although it is questioned by Martin.

No fossils were found with the volcanic rocks in these districts, and an opinion as to their stratigraphic position must be gained from

[7] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 143, 1906.

a comparison with similar rocks of known age in other districts and from their structural position.

On the Glass Peninsula, Admiralty Island, the volcanic rocks appear structurally to overlie the Jurassic (?) sedimentary beds of Seymour Canal. An alternative explanation would be to consider that the volcanic rocks are overturned and that the sediments overlie them and are isoclinally folded in a major syncline. The absence of cobbles of the volcanic rocks in the conglomerates of the sedimentary series and the presence of sills of andesite porphyry in them suggest that the first interpretation is the correct one.

On Etolin Island, north of Rocky Bay, similarly, the volcanic rocks appear to overlie the fossiliferous Lower Cretaceous (?) sediments, which here are *Aucella*-bearing slates.

If the age determination and the interpretation of the structural relationship of the sediments of Rocky Bay are correct, they would indicate that the volcanic rocks are at least as early as Lower Cretaceous. The evidence, however, is too uncertain to warrant assigning these volcanic rocks definitely to the Lower Cretaceous, and they are mapped as Jurassic (?). All the volcanic rocks are definitely older than the Coast Range batholith.

Schofield and Hanson [8] describe as the "Bear River formation" a series of Mesozoic volcanic rocks that occur at the head of Portland Canal on the east side of the Coast Range batholith. Their description follows:

> This group of rocks is almost entirely of volcanic origin, and the name "greenstone" commonly applied to it is suitable in a general way. The lower members are largely fragmental rocks of agglomerate character. Their constituent fragments are angular purple and green masses of andesite in an andesitic matrix. They vary in size from minute particles to pieces a foot or more across. In thin section they show phenocrysts of a plagioclase of intermediate composition, probably an andesine, scattered through a highly altered matrix in which hornblende and plagioclase are the main constituents. The rock is highly altered, and many secondary minerals such as calcite, epidote, and chlorite are present. In some places bands of tuff are interbanded with the agglomerates. * * * The agglomerates are overlain conformably by fine-grained tuffs that form the upper part of the Bear River formation.

The "Bear River formation" is overlain conformably by the Salmon River conglomerates, which in turn pass upward into the conformable Nass argillites or slates with some interbands of sandstone and fine conglomerate. Schofield and Hanson [9] obtained fossils from the conglomerates near the base of the Nass formation which were identified by McLearn, who suggests that they indicate a Jurassic age, although the evidence is not conclusive.

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[8] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, pp. 11–12, 1922.

[9] Schofield, S. J., and Hanson, George, Canada Geol. Survey Summary Rept. for 1920, pt. A, p. 8a, 1921.

From the literature quoted it is evident that a volcanic formation of probable Jurassic age and very similar lithologically to that under discussion is widespread throughout southeastern Alaska and British Columbia.

It may be that the volcanic rocks here included under the term Jurassic (?) comprise more than one formation—that part belong to the Jurassic and underlie the *Aucella*-bearing beds and part to the Lower Cretaceous and overlie the *Aucella*-bearing beds. The evidence at hand is not sufficiently determinative to indicate positively that part of the volcanic rocks are younger than the *Aucella*-bearing beds, but Buddington believes this to be the case.

UPPER JURASSIC OR LOWER CRETACEOUS INTRUSIVE ROCKS

GENERAL CHARACTER

The Upper Jurassic or Lower Cretaceous intrusive rocks are the dominant geologic feature of southeastern Alaska. They are but a part of a great composite batholith and its satellitic intrusions that extend for more than 1,100 miles northwestward into Yukon Territory from Fraser River, in British Columbia. From Vancouver to Skagway, on the mainland, the batholith forms the backbone of the Coast Range and is exposed either at the shore line or not far inland. Outlying dikes, stocks, and batholiths that are believed to be of the same general period of intrusion as the Coast Range batholith and genetically allied to it are found locally on Vancouver Island and the Queen Charlotte Islands and abundantly throughout most of the Alexander Archipelago. The Coast Range batholith is the largest on the North American continent.

It is much wider south of Skeena River, in British Columbia, than north of it, and reaches a maximum width of 110 miles. The part of the main batholith in southeastern Alaska and the adjacent strip of British Columbia is 35 to 60 miles wide, with an average of about 50 miles, and about 350 miles long.

The term "batholith" is applied to intrusive igneous bodies that occupy considerable areas and show no observable evidence of a bottom; the term "stock" is applied to smaller similar bodies. Daly [10] has proposed that "batholith" be confined to bodies more than 40 square miles in area.

The rocks in southeastern Alaska grouped as Upper Jurassic or Lower Cretaceous intrusive rocks include a minor amount of widely varying ultrabasic rocks and a predominant more siliceous, sub-

[10] Daly, R. A., Igneous rocks and their origin, p. 90, New York, McGraw-Hill Book Co., 1914.

alkalic series. The ultrabasic rocks comprise the olivine-rich rocks dunite, wehrlite, and saxonite; the pyroxenites hypersthenite or bronzitite, diallagite, and augitite; and hornblendites. There are all gradations between hornblendite, hornblende diorite, and pyroxenite, and between pyroxenite and dunite.

The normal subalkalic series includes norite; augite gabbro and gabbro-diorite; diorite, monzodiorite, quartz diorite, granodiorite, quartz monzonite, granite, and exceedingly rare monzonite and syenite. Albite and albite-oligoclase varieties of diorite, monzodiorite, quartz diorite, granodiorite, and quartz monzonite are found in small volume associated with the predominant varieties of these rocks which carry a more calcic plagioclase. Pegmatitic facies of the hornblendite, pyroxenite, and norite are found, and pegmatitic and aplitic facies of the other subalkalic rocks.

The Upper Jurassic or Lower Cretaceous intrusive rocks may be discussed with respect to six approximately parallel belts, based upon the mode of occurrence, the environment, and the character and range in variation of the intrusive masses. These belts, beginning on the northeast, are the border zone east of the Coast Range batholith, the Coast Range batholith of the mainland, the Wrangell-Revillagigedo belt, the Prince of Wales-Chichagof belt, the Kuiu-Heceta belt, and the Dall-Baranof belt.

In classifying the rocks Johannsen's system[11] has been used with some modifications which are noted here. An upper limiting ratio of about 10 per cent of potassic feldspar to total feldspar, instead of 5 per cent, is chosen to delimit quartz diorite from granodiorite, and rocks with as much as 10 per cent of quartz are grouped with the diorite. Only rocks with a ratio of 10 per cent or more of potassic feldspar to total feldspar are included in the monzodiorite. The plagioclase is divided according to the following system: Albite ($Ab_{10}An_0$ to Ab_9An_1), oligoclase (Ab_9An_1 to Ab_7An_3), andesine (Ab_7An_3 to Ab_5An_5), labradorite (Ab_5An_5 to Ab_3An_7), bytownite (Ab_3An_7 to Ab_1An_9), anorthite (Ab_1An_9 to Ab_0An_{10}).

In the following tables minerals due to hydrothermal alteration or replacement have been counted as part of the minerals which they are replacing. The estimates of the minerals are based on Rosiwal analyses of thin sections, and the percentages are given by weight. The term potassic feldspar includes microcline, microperthite, and orthoclase.

The table below gives for the major types of rocks their average mineral composition and the range in composition of the specimens of intrusive rock which were studied. Some rocks which

[11] Johannsen, Albert, A quantitative mineralogical classification of igneous rocks, revised: Jour. Geology, vol. 28, Nos. 1–3, pp. 38–60, 158–177, 210–232, 1920.

slightly exceeded the upper limiting ratio of potassic feldspar for a given type were nevertheless treated with this type if they were closely associated with it in minor amount in the field. The table therefore shows ranges differing slightly from those adopted as a standard. The term "granodiorite" is often used in the field for any or all facies of the Coast Range batholith where a more precise designation is not essential. Many geologists use the term "albite syenite" in preference to "albite diorite" and "albite granite" or "sodic granite" in preference to "albite-quartz diorite."

In contrasting the average alkalic content of the rocks of the several belts it is recognized that potassium occurs both in the potassic feldspars and in biotite, and that some rocks of the same gross chemical composition would be classed either as biotitic quartz diorite or as granodiorite relatively free from biotite, the classification depending upon whether the potassium molecule is present as the biotite or the feldspar molecule.

Average and range in composition of major types of the Upper Jurassic or Lower Cretaceous intrusive rocks

	Labradorite	Andesine-labradorite	Andesine	Albite or oligoclase	Potassic feldspars	Pyroxene	Hornblende	Biotite	Magnetite	Quartz	Accessories
Gabbro:											
Average	51					31	10	2	5		
Range	35–65				0–5	0–60	0–50				
Gabbro-diorite:											
Average		46			1	6	42		3	1	
Range		30–75			0–5	0–20	35–65			0–5	
Diorite:											
Average			63		1.5		27	2.5	2–	4	
Range			60–70		0–8		20–30	0–12		0–10	
Monzodiorite:											
Average			56		19		17	2		4	2
Range			50–75		9–30		0–35	0–7		0–10	
Quartz diorite:											
Average			54		4		9.5	12		19.5	1
Range			40–60		0–8		15–23			15–30	
Albite or sodic quartz diorite:											
Average				73	2		1	2		22	
Range				65–75	0–5		0–5	0–10		15–30	
Granodiorite:											
Average			50		12.5		7.5	8.5		20	1.5
Range			38–60		9–28		8–25			15–30	
Oligoclase granodiorite:											
Average				56	12		1	2		29	
Range				49–65	10–15		0–2.5	1.5–4		20–35	
Quartz monzonite:[a]											
Average			[a] 35		33		2	3.5		25	1.5
Range			30–50		25–45		0–10	0–8		20–35	
Oligoclase-quartz monzonite:											
Average				31	37		0	1.5		30	0.5
Granite:											
Average				13	61		1	2		23	
Range				10–15	55–73					12–40	

[a] Plagioclase is oligoclase to andesine, averaging possibly about Ab_7An_3.

BORDER ZONE EAST OF THE COAST RANGE BATHOLITH

The border zone east of the Coast Range batholith lies mainly within British Columbia and is for the most part relatively inaccessible. The country has been but little studied, except very locally, and there is very little exact information as to the character of the intrusive rocks.

The most striking phenomenon in this border zone is the absence of contact metamorphism on a regional scale and the meager evidences of local contact metamorphism produced by the Coast Range batholith. The rocks are closely folded; argillaceous rocks have been changed to slaty types and, locally, andesitic volcanic rocks to greenstone; but there is practically no phyllite and no crystalline schist away from the immediate contact with intrusive bodies.

The number of intrusive stocks or batholiths varies markedly within this eastern border zone. Hanson[12] states that between Skeena and Nass Rivers the eastern border of the batholith is irregular and there are a number of apophyses and outlying stocks of granodiorite but that between Nass River and Portland Canal the border is approximately straight.

Near or adjacent to the eastern border of the batholith in the Hyder district there is a mass of hornblende granodiorite that is close to quartz monzonite in composition. This mass, which the writer has named the Texas batholith, is cut by many dikes of younger quartz monzonite and granodiorite and has been locally very intensely mashed and altered by the thrust from the intruding quartz monzonite magma. The Texas batholith must be markedly older than the quartz monzonite and granodiorite which cut it, and there is a question as to whether it should be interpreted as an older facies of the intrusive rocks of the Coast Range or whether it is so much older as to warrant its exclusion from that group. It is not known whether the quartz diorite mapped by Dolmage to the south, at the head of Hastings Arm and Observatory Inlet, should be grouped with the Texas batholith. This batholith is sparsely porphyritic, with large crystals of microperthite, except locally, where it plunges beneath a cover of sediments and is an even-grained quartz diorite. These features suggest that it is a stock differentiated in place and older than at least the bulk of the intrusive rocks of the Coast Range. It is intrusive, however, into the "Bear River series" and Nass argillite of Jurassic age. Its average composition is 48 per cent andesine, 20 per cent potassic feldspar, 19 per cent quartz, and the rest hornblende, with a little accessory biotite.

In the Hyder district the problem is thus complicated by the fact that there are two batholiths of similar composition but of different age. The Texas batholith of granodiorite with local border facies of quartz diorite underlies much of the country between Salmon River and the north and south branches of Chickamin Glacier. West of Mount Bayard there is a mass of granodiorite that is intru-

[12] Hanson, George, Reconnaissance between Skeena River and Stewart, B. C.: Canada Geol. Survey Summary Rept. for 1923, p. 37a, 1924.

sive into the Texas batholith and is either an outlying stock or an apophysis of the eastern part of the main Coast Range batholith, which in this region is quartz monzonite. The younger facies of the Upper Jurassic or Lower Cretaceous intrusive rocks also exhibits sparse local masses of diorite. North of Long Lake on the Canadian side there is a stock of augite porphyrite or porphyritic gabbro-diorite, which is cut by dikes of quartz diorite and granodiorite belonging to the younger series of intrusive rocks.

Between the head of Portland Canal and the Atlin district the country is relatively unknown. In the Atlin district, according to Cairnes,[13] there are a number of stocks of granodiorite or quartz monzonite. Descriptions of the outlying intrusive masses in the Whitehorse district, Yukon Territory,[14] suggest that albite or oligoclase quartz monzonite predominates. One mass of gabbro-diorite with considerable potassic feldspar is present.

The scanty data suggest that the more common intrusive rocks within this belt range from quartz diorite through granodiorite to quartz monzonite, with local development of more basic facies. They appear to be in general more alkalic and siliceous than the stocks in the Prince of Wales-Chichagof belt, west of the batholith, where the country rocks show a similar degree of metamorphism.

COAST RANGE BATHOLITH

The data at hand are insufficient for an adequate description of even the grosser variations in composition of the Coast Range batholith. Only general statements applicable to local sections can be made.

The rocks of the batholith are often called by the general term " granite " or " granodiorite," as it is difficult or impossible in the field to distinguish their character more precisely. Detailed examination, however, shows that only a relatively very small proportion of the batholith is true granite—that is, a quartzose rock in which two-thirds or more of the total amount of feldspar present is potassic feldspar and in which the plagioclase is a sodic variety.

Of 78 specimens taken at intervals across the batholith along the west side of Portland Canal and along Chickamin and Stikine Rivers, 28 were granodiorite, 26 quartz monzonite, 16 quartz diorite, 2 granite, 2 hornblende-biotite diorite, 2 monzonite, 1 hornblendite, and 1 gabbro. These figures give an approximate idea of the probably relative quantitative distribution of the different types of igneous rock

[13] Cairnes, D. D., Portions of the Atlin district of British Columbia: Canada Geol. Survey Mem. 37, p. 57, 1913.

[14] Cockfield, W. E., and Bell, A. H., Whitehorse district, Yukon: Canada Geol. Survey Mem. 150, pp. 29–32, 1926.

within the southern part of the mainland Coast Range batholith in Alaska and show that granodiorite, quartz monzonite, and quartz diorite are predominant.

Analyses of 19 specimens taken at intervals completely across the batholith along Stikine River and 23 specimens taken at intervals along Portland Canal show the average composition to be that of a granodiorite with 19 to 24 per cent of potassic feldspar, about 22.5 per cent of quartz, 40 to 46 per cent of oligoclase andesine, 6 per cent of hornblende, 5 per cent of biotite, and the rest accessory minerals. These averages are given in the table on page 180 as Nos. 1 and 3. A weighted average of 18 specimens taken along Chickamin River is given as No. 2.

There is variation in composition both lengthwise of the batholith and across it, but in this area the variation lengthwise is much less marked than that crosswise. The variation across the batholith along Stikine and Chickamin Rivers and along Portland Canal is in general from a hornblende-biotite-andesine-quartz diorite on the southwest to a biotite-oligoclase-quartz monzonite on the northeast, with rock whose composition averages that of a granodiorite in the core. This gradation is not continuous, however, but irregular. Along Portland Canal, in the core of the batholith, there are at least two broad belts of quartz monzonite interbanded with broad strips of granodiorite, which in turn is locally interbanded with quartz diorite. On Stikine and Chickamin Rivers no quartz monzonite was noted in the core of the batholith, but quartz diorite bands are found; and on Stikine River there are in places small masses of diorite and of more basic rocks. There is a tendency toward increase of potash feldspar and sodic plagioclase and decrease of ferromagnesian minerials from the southwestern to the northeastern border of the batholith. Hornblende is wholly and biotite almost wholly absent from the quartz monzonite of the eastern part. Wherever reaction and injection gneisses are present the rocks may be extremely variable within very short distances, owing probably in part directly to the nature of the original country rock and in part indirectly to the influence of the original rock in shortening or prolonging the period of crystallization of the magma and thus permitting greater or less differentiation. Inclusions of country rock ranging from large belts to disintegrated shreds are found within the batholith; these are usually restricted to certain belts, where all gradations may be found from schist through injection and reaction gneisses to normal intrusive rock.

The western portion of the batholith throughout southeastern Alaska is known to be composed of quartz diorite for a width of

5 to 15 miles from the contact. The average composition of 20 specimens from this belt is given in the table on page 180 as No. 4.

The core of the batholith consists predominantly of granodiorite, with some associated quartz monzonite and quartz diorite and a few small masses of diorite and more basic rock. The average of 44 specimens from the core of the batholith between Portland Canal and Stikine River is given as No. 5.

The quantitative petrography of the eastern flank of the batholith is practically unknown. For a width of about 12 miles and a length of about 25 miles between Portland Canal and Chickamin River the rock is quartz monzonite. The average of 16 specimens from this belt is given as No. 6. On the Stikine River the rock of the eastern border is an oligoclase quarz monzonite. An average of 5 specimens is given as No. 7. At the head of Hastings Arm and Alice Arm, 40 miles south of Portland Canal, the eastern border of the batholith for a width of 5 to 10 miles from the eastern contact is mapped by Dolmage [15] as quartz diorite.

In the Stikine River section the predominant rock of the west flank of the batholith in a belt 5 to 10 miles wide is quartz diorite (see No. 9), and near the east flank is a belt of oligoclase-quartz monzonite about 10 miles wide (see No. 7). The successive rock belts from west to east contain increasing amounts of alkali feldspars and quartz and decreasing amounts of hornblende, biotite, and calcic feldspars. But although taken as a whole the changes are toward increasing alkalies (both of K_2O and Na_2O) and increasing silicity, the series of sections examined by the writer does not show a uniform gradation from west to east but a very abrupt change from a belt of quartz diorite to one predominantly of granodiorite, then to one practically all quartz monzonite. Quartz diorite occurs locally and diorite rarely (see No. 10) within the predominantly more alkaline core of the batholith.

The writer is indebted to W. B. Jewell for a description of the Chickamin River section. At the mouth of the river, adjoining a band of crystalline schist and injection gneiss, there is a narrow band of quartz diorite. To the northeast is a belt of granodiorite about 14 to 15 miles wide, adjoined in turn to the northeast by a belt of quartz monzonite 10 to 12 miles wide. A belt of granodiorite very low in potassium intervenes between the normal granodiorite and the quartz monzonite. The average of six specimens of the normal granodiorite from the western half of the batholith is given as No. 11.

[15] Dolmage, Victor, Coast and islands of Brtish Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept. for 1922, pt. A, map facing p. 10, 1923.

In the Portland Canal section the southwestern border zone of the batholith, 10 to 12 miles wide, consists of quartz diorite; the core, 45 miles or so wide, of granodiorite and quartz monzonite (see Nos. 12 and 13), with local bands of quartz diorite; and the eastern border zone of quartz monzonite. This section is different from that on Stikine and Chickamin Rivers in that at least two broad bands of quartz monzonite occur within the granodiorite of the core. This quartz monzonite of the core, however, is considerably more basic than that of the eastern border, as shown by Nos. 6 and 13.

Boundary Peak, on Unuk River, is composed of quartz monzonite (see No. 14), indicating that here, too, quartz monzonite forms the eastern border facies of the batholith.

Approximate mineral composition of Coast Range batholith

		Oligoclase or andesine	Potassic feldspars	Quartz	Hornblende	Biotite	Accessories
1	Average of 23 specimens taken at intervals across batholith along west side of Portland Canal	40.5	24	22.7	5.8	.5	2−
2	Weighted average of 18 specimens taken at intervals across batholith along Chickamin River [a]	46	20	22	3.5	7.3	1.2
3	Average of 19 specimens taken at intervals across batholith along Stikine River	46	19	22.5	6	5	1.5
4	Average of 20 specimens from west border	54	2	20	11	12	1+
5	Average of 44 specimens from core between Portland Canal and Stikine River	44	21.6	20	6	7	1.4
6	Average of 16 specimens of quartz monzonite from east border between Portland Canal and Chickamin River	37.3	32.7	24.5	.1	4	1.5
7	Average of 5 specimens of oligoclase quartz monzonite from east border along Stikine River	31	37	30	0	1.5	.5
8	Average of 5 specimens of granodiorite from core, vicinity of Stikine River	50	17	21	5	5	2
9	Average of 5 specimens of quartz diorite from west half along Stikine River	61	2	18.5	11	6.5	1
10	Average of 2 specimens of diorite from core along Stikine River	52	2.5	2	22	20	1.5
11	Average of 6 specimens of granodiorite from west side along Chickamin River [a]	49	20	20	3.5	6.5	1
12	Average of 7 specimens of granodiorite from core along Portland Canal	46.5	15	21.5	9	6	2
13	Average of 6 specimens of quartz monzonite from core along Portland Canal	33	32	22	7	4	2
14	Boundary Peak, Unuk River, east border of batholith	43	37	18	------	1	1

[a] Furnished by W. B. Jewell.

It is interesting to note that the intrusive rocks of the Coast Range, in the Atlin district of British Columbia, far to the northwest, on the eastern border of the batholith, are described by Cairnes [16] as granodiorite or quartz monzonite. An analysis of a specimen described by Cairnes as typical is quoted below. It is on the border line between a granodiorite and a quartz monzonite.

[16] Cairnes, D. D., Portions of the Atlin district, British Columbia: Canada Dept. Mines Mem. 37, pp. 57–59, 1913.

Analysis of granodiorite from the Atlin district, British Columbia

Analysis		Norm	
SiO_2	69.08	Quartz	26.22
Al_2O_3	13.93	Orthoclase	23.35
Fe_2O_3	2.72	Albite	29.87
FeO	1.62	Anorthite	10.56
MgO	.80	Diopside	4.81
CaO	3.38	Magnetite	3.94
Na_2O	3.55	Ilmenite	.46
K_2O	3.99		
H_2O at 110° C	.03		
H_2O above 110° C	1.05		
TiO_2	.23		
P_2O_5	.07		
MnO	Trace.		
	100.45		

In summary, the meager data on the Coast Range batholith suggest that for 150 miles between Portland Canal and Stikine River there is a pronounced variation in the composition across the batholith from southwest to northeast. The southwest border facies of the batholith, in a belt 5 to 15 miles wide, is quartz diorite; the core, 15 to 25 miles wide, has the average composition of a granodiorite and is composed predominantly of granodiorite, quartz monzonite, and quartz diorite; and the eastern border facies, 10 to 15 miles wide, is quartz monzonite. Dolmage,[17] however, in describing about 150 miles of the Coast Range batholith to the south of Portland Canal, writes: "These more acid types [granodiorite and quartz monzonite] show a general tendency to lie toward the central part of the batholith, but there are exceptions to this." The changes from one type of rock to another appear to take place rather abruptly, but no evidence of brecciation of one variant by another was seen, except in the small masses of gabbroic and ultrabasic rocks. Nevertheless, certain features suggest that we may be dealing with a group of very closely related interlocking batholiths.

WRANGELL-REVILLAGIGEDO BELT OF METAMORPHIC ROCKS

The Coast Range batholith is paralleled on the southwest by a belt of injection gneiss, crystalline schist, and phyllite intruded by abundant batholiths, stocks, sheets, and dikes, believed to be outlying masses genetically associated with the main batholith. This belt will be designated here the Wrangell-Revillagigedo belt of metamorphic rocks. It is narrow and loses its individuality at the north but widens and is very well defined toward the south. Near the mouth of Gastineau Channel and west of Thomas Bay this belt has a width of about 13 miles; opposite the mouth of Stikine River, about 25 miles;

[17] Dolmage, Victor, Coast and islands of British Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept. for 1922, p. 16A, 1923.

and at the south end of Revillagigedo Island, about 35 miles. This composite belt of sedimentary and intrusive rocks appears to swing from a northwest strike northwest of the Cleveland Peninsula to a north-south strike south of the peninsula. But this apparent change in strike is due essentially not to a change in the general strike of the formations but to the fact that at the south the intrusive rocks, including both the main batholith and the outlying stocks, have worked over farther to the west.

Within this belt about half the siliceous intrusive rocks are hornblende-biotite-andesine-quartz diorite with only a trace to 2 per cent of potassic feldspar, and half are hornblende-biotite-andesine granodiorite with usually 7 to 12 per cent of potassic feldspar. The average composition of 20 specimens from this belt is given in the table on page 188. The differences between these outlying intrusive rocks and the quartz diorite of the western border of the batholith are slight. The percentage of andesine, biotite, and quartz is practically the same; the potassic feldspar is considerably higher in the intrusive rocks of the Wrangell-Revillagigedo belt, and the hornblende somewhat lower.

There appears to be a regional variation in the potassic feldspar content of the intrusive rocks, most of those between Cleveland Peninsula and Windham Bay being on the border line between quartz diorite and granodiorite and those in the vicinty of the north end of Revillagigedo Island being quartz diorite. The average composition of 13 specimens of granodiorite and quartz diorite between Cleveland Peninsula and Windham Bay is given in the table as No. 2, and that of 7 specimens of quartz diorite from the Cleveland Peninsula and the vicinity of the north end of Revillagigedo Island is given as No. 3. North of Windham Bay quartz diorite is again common.

There are more than a score of small stocks and sheets of hornblendite distributed throughout this belt. The hornblendite is usually cut to pieces on the borders by diorite or granodiorite intrusions. A few masses of dunite, pyroxenite, and peridotite are also present.

Distributed through the entire length of this belt are small stocks, sheets, and dikes of granodiorite and quartz diorite which are relatively very low in ferromagnesian minerals and usually higher in sodium, and all of them show an intense state of alteration of similar character. The plagioclase is usually an oligoclase and if unaltered would range usually from 60 to 70 per cent; the potassic feldspar is microcline or microperthite and ranges from a trace to 12 per cent; the quartz ranges from 20 to 30 per cent. Hornblende is either absent or present only as an accessory mineral. Biotite usually ranges from 4 to 6 per cent. The plagioclase is partly replaced by a latticework of muscovite plates and by irregular grains of epidote and occasional zoisite. The biotite and potassic feldspars are practically fresh and unaltered or unreplaced. Calcite is abundant in some masses and absent in others.

PRINCE OF WALES-CHICHAGOF BELT

West of the Wrangell-Revillagigedo belt and parallel to it is the Prince of Wales-Chichagof belt, in which intrusive masses are common but of different character, and the country rock consists predominantly of slate, limestone, graywacke, greenstone, and dynamically metamorphosed schistose rocks, with locally some crystalline schist and marble. The stage of metamorphism in general is much less advanced than in the Wrangell-Revillagigedo belt, though locally, adjacent to large igneous bodies, it may be intense.

This belt includes Chichagof Island, Admiralty Island except the northeastern part, the west side of Lindenberg Peninsula, the southwestern part of Mitkof Island, the east side of Zarembo Island, all of Etolin Island except the northeast end, and the northern and eastern parts of Prince of Wales Island. It is 40 miles wide at the north, but may not be much more than 5 miles wide on Kupreanof Island; it widens on Etolin Island and is about 25 miles wide through Prince of Wales Island.

The igneous masses consist predominantly of hornblende-andesine diorite and monzodiorite and quartzose variants of these rocks. Hornblende diorite predominates. A few large masses of younger granite are present in the southern part. Granodiorite and quartz diorite occur as variants of the predominant less quartzose masses and here and there as separate stocks. A few masses of ultrabasic rocks are present. Locally, the diorite grades into hornblendite and gabbro as marginal variants. Throughout this belt there are local marginal variants of the albite or albite-oligoclase type of diorite, monzodiorite, granodiorite, and quartz diorite, as well as dikes of albite and albite-oligoclase trachyte. Thus though certain types of intermediate igneous rocks predominate in this belt, extreme differentiates, such gabbro and gabbroic hornblendite on the one hand and albite varieties of diorite, monzodiorite, and quartz diorite on the other, are common. The rocks of this belt thus differ in general from those to the east in that they are predominantly diorite rather than quartz diorite and that differentiates of highly contrasted composition are more abundant.

The average composition of 65 specimens from this belt is given in the table on page 188 as No. 4. The younger granites are not included here. The average is that of a quartzose hornblende diorite with considerable potassic feldspar. As contrasted with the average composition of the rocks in the belt to the east, it shows a very marked decrease in quartz and biotite and a very marked increase in the amount of hornblende almost to the exclusion of biotite; the total content of ferromagnesian minerals is considerably higher, and magnetite and pyroxene are the predominant accessory minerals. About half of the rocks studied were diorite; the rest were equally distributed between monzodiorite, quartzose diorite, quartzose monzodiorite, granodiorite, and quartz diorite.

As in the Wrangell-Revillagigedo belt, there is in a very general way a greater proportion of potassic feldspar in the rocks of a certain portion of the belt that includes the western parts of the Lindenberg Peninsula and Mitkof Island and the southern part of Admiralty Island. The rocks here are predominantly monzodiorite or its quartzose variants, whereas to the north and south within the Prince of Wales belt the predominant rocks are diorite or quartzose variants. The stock at Copper Mountain, Prince of Wales Island, is an exception to this grouping. The average composition of 27 specimens from Prince of Wales and Etolin Islands is given in the table as No. 5. The average of 6 specimens from Kupreanof, Mitkof, and southern Admiralty Islands is given as No. 6. The data from the northern islands are not so extensive as those from the southern part of the belt, but they indicate a much higher content of potassic feldspar and lower content of ferromagnesian minerals.

Wright [18] describes the main intrusive rock of the Kasaan Peninsula as a quartz-bearing diorite with the following characters:

> The quartz is scarcely more than an accessory, generally forming not more than 5 per cent of the mass. Orthoclase appears in about the same amount. Plagioclase, which makes up 50 to 70 per cent of the rock, is basic andesine, ranging chiefly from Ab_3An_2 to Ab_1An_1. The range of the composition of the individual plagioclase crystals is about the same. For this reason zoning is not pronounced. Twinning according to both the albite and the Carlsbad laws is very common in the plagioclase. Hornblende is everywhere present, constituting 10 to 25 per cent of the weight of the rock. It is the common variety; it is pleochroic in various yellow-greens; it is optically negative, showing a large optic axial angle; its maximum extinction angle, measured from the trace of the cleavage, is from 20° to 25°, corresponding to an angle of 15° to 20° on (010); and its indices of refraction are considerably higher than those of other recorded measurements; namely, from 1.665 to 1.680, determined by the immersion method. Some facies of the diorite contain about 15 per cent of yellow-brown or orange-brown biotite. The rock contains small amounts of augite—less than 10 per cent. The minor accessories are apatite, titanite, and magnetite. * * *

[18] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, pp. 74, 75, 1915.

Near some of its margins the diorite becomes basic and passes into gabbro, the hornblende giving place to augite and the plagioclase becoming richer in lime. Specimens from the mines and prospects north of Karta Bay illustrate this transition.

In addition to the predominant diorite and its local gabbroic variants just described, there are large masses and dikes of diorite, quartz diorite, and monzodiorite with albite or albite-oligoclase as the predominant plagioclase in place of andesine. The large masses occur principally as differentiation variants of the dioritic magma. The sodic variants, however, occur principally as dikes of porphyritic texture. The Mount Andrew mass on Kasaan Peninsula appears to be prevalently an albite-oligoclase-hornblende monzodiorite.

A great many batholiths and stocks of Upper Jurassic or Lower Cretaceous intrusive rocks are found on Prince of Wales Island. The types of rock forming the intrusive masses in the vicinity of Copper Mountain and Kasaan Peninsula have been described in detail by Wright and Merwin.[19] The main Copper Mountain and Beaver Mountain batholiths range in composition from granodiorite to monzodiorite, with a very local development of gabbro. Near the contact the masses are locally syenitic or more sodic. The igneous mass exposed along the coast between Skowl Arm and Cholmondeley Sound is in general a quartzose hornblende diorite, as exemplified by the average mineral composition of six specimens, given in the table as No. 7. The mass is heterogeneous and comprises local variants of hornblendite, diorite, and granodiorite. The Kendrick Bay igneous mass is likewise a quartzose hornblende diorite with local marginal variants toward diorite. The average composition of four specimens is given as No. 8. In the more hornblendic and less quartzose diorites there is a relative concentration of apatite and magnetite. The apatite forms more than 1 per cent and magnetite more than 2 per cent of the rock.

At the head of Brownson and Nichols Bays there is a mass of highly siliceous quartz diorite with diorite as a local marginal variant.

Chichagof Island appears to resemble Prince of Wales very closely in its geology. The prevailing country rocks, except on the southwest coast, are the same and are in a similar stage of metamorphism, and the predominant intrusive rocks and range of variants are likewise similar. The chief intrusive rock on Chichagof Island is hornblende-andesine diorite. Of 30 samples collected from various parts of the island, more than half were diorite. The other common types are hornblende-biotite-quartz diorite and granodiorite. Locally

[19] Idem, pp. 33–37, 74–84.

there are developed alkalic siliceous marginal variants and dikes of albite-quartz diorite, oligoclase granodiorite with sparse ferromagnesian minerals, or highly hornblendic gabbro-diorites. These variants, however, are small in volume. Masses of hornblendite, bronzitite, and norite are also found on the main island and the islands off its west coast. The average approximate mineral composition of 30 specimens (18 diorite, 6 quartz diorite, 4 granodiorite, and 2 gabbro-diorite) from Chichagof Island is given in the table on page 188 as No. 9. The plagioclase commonly ranges from 50 to 75 per cent, potassic feldspar from 0 to 10 per cent, quartz from 0 to 30 per cent, hornblende from 0 to 40 per cent, biotite from 0 to 10 per cent, and magnetite from a trace to 4 per cent.

The area from Lynn Canal and Chilkat Inlet west to the Pacific Ocean, with the possible exception of the eastern part, probably lies within the Prince of Wales-Chichagof belt. Wright[20] reports granodiorite and diorite as the predominant types in the Glacier Bay region.

KUIU-HECETA BELT

The Kuiu-Heceta belt includes the western fringe of the north half of Prince of Wales Island, the north end of Dall Island, San Fernando, Heceta, Tuxekan, Kosciusko, and Kuiu Islands, Kupreanof Island with the exception of the Lindenberg Peninsula, and the southwestern part of Admiralty Island. This belt is somewhat elliptical in shape, as it includes the parts of the Prince of Wales-Chichagof belt on the east and of the Dall-Baranof belt on the west in which intrusive rocks are relatively sparse and the degree of metamorphism is correspondingly slight. The stage of metamorphism of the pre-Tertiary rocks in this belt is less than in any other area in southeastern Alaska. Many of the oldest beds contain great numbers of comparatively well preserved fossils.

Near the head of Washington Harbor, Kuiu Island, and at the north end of the west side of Kupreanof Island there are masses of augite gabbro. The stock on Marble Island, Davidson Inlet, has not been studied.

DALL-BARANOF BELT

The Dall-Baranof belt includes Dall, Forrester, Suemez, Baker, Lulu, Noyes, Warren, Coronation, and Baranof Islands. Within this belt stocks and batholiths are more numerous than in the adjoining Kuiu-Heceta belt, and the composition of the more common

[20] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

intrusive rocks appears to differ from that of the prevailing types in the Prince of Wales-Chichagof belt. But here again our knowledge of the composition and relations of the intrusive masses is scanty, and any inferences drawn need further substantiation.

The average composition of 21 specimens (13 quartz diorite, 4 granodiorite, 3 diorite, and 1 gabbro-diorite) exclusive of ultrabasic types, collected at different points within the belt, is given as No. 10. The rocks, on the average, are much more siliceous and carry less of ferromagnesian minerals than the average of the Prince of Wales-Chichagof belt and are slightly more feldspathic and carry less of ferromagnesian minerals than the average of the Wrangell-Revillagigedo belt.

On Baranof Island highly mashed hornblende diorite and hornblende gabbro occur on Bear Lake and Silver Bay; serpentine on the north side of Red Bluff Bay; and amphibolite with associated nickeliferous pyrrhotite on Snipe Bay. On Dall Island augite diorite and gabbro occur near Squaw Mountain.

There is a wide variation in the types of intrusive rocks, but quartz diorite and to a less extent granodiorite are predominant. The quartz diorite varies from a leucocratic type, which contains less than 5 per cent of ferromagnesian minerals (mostly biotite), 60 to 65 per cent of plagioclase (oligoclase or oligoclase-andesine), and 30 to 35 per cent of quartz to quartzose hornblende-andesine diorite. Leucocratic oligoclase granodiorite also occurs.

On Dall and Suemez Islands moderately to coarsely crystalline schists are restricted to the immediate vicinity of the intrusive masses.

But few data on the rocks of Baranof Island are available. Of seven specimens from the larger masses, all except one were quartz diorite; the exception is an oligoclase granodiorite of leucocratic character. The rocks are peculiar (see table on p. 188, No. 11) in their low percentage (8.5) of ferromagnesian minerals.

The intrusive mass on Baker Island is a leucocratic quartz diorite composed of about 30 per cent of quartz, 65 per cent of plagioclase (oligoclase or oligoclase-andesine), and 5 per cent or less of biotite and accessory minerals. Warren Island is composed of hornblende or biotite granodiorite with about 10 per cent or so of potassic feldspar, 50 per cent of andesine, and 22 per cent of quartz. A small intrusive mass on Indiada Island, in Santa Cruz Harbor, Suemez Island, is a quartzose feldspathic hornblende diorite. A specimen from the south side of Lulu Island is a very highly feldspathic (90 per cent andesine) hornblende diorite.

Approximate average mineral composition of the Upper Jurassic or Lower Cretaceous intrusive rocks in the Alexander Archipelago

	Locality	Andesine	Potassic feldspar	Quartz	Hornblende	Biotite	Pyroxene	Magnetite	Accessories
	WRANGELL-REVILLAGIGEDO BELT								
1	Average of 20 specimens distributed throughout the belt	54	6.5	19	8	11.5	------	----	1
2	Average of 13 specimens taken between Cleveland Peninsula and Windham Bay	51.5	9	19	8	11.5	------	----	1
3	Average of 7 specimens from vicinity of northern part of Revillagigedo Island	60	1.5	19	9	10.5	------	----	----
	PRINCE OF WALES-CHICHAGOF BELT								
4	Average of 65 specimens from Prince of Wales-Chichagof Belt	57.5	5	9.5	20.5	3.5	1.5	2	.5
5	Average of 27 specimens from Prince of Wales and Etolin Islands	55	6	9	20	4	3.5	2	.5
6	Average of 6 specimens from Kupreanof, Mitkof, and southern Admiralty Islands	63	16	5	11	3	------	----	2
7	Average of 6 specimens, Skowl Arm to Cholmondeley Sound, Prince of Wales Island	58.5	4	9	25	1	------	2	.5
8	Average of 4 specimens from Kendrick Bay, Prince of Wales Island	67	0	9	20	1	------	2	1
9	Average of 30 specimens from Chichagof Island	58.5	3	11	21	4	------	2	.5
	DALL-BARANOF BELT								
10	Average of 21 specimens distributed throughout the belt	62	5.5	20	6.5	3.5	.5	----	2
11	Average of 7 specimens from Baranof Island	62	5	23.5	3.5	5	------	----	1

ROCK TYPES

ULTRABASIC GROUP

GENERAL FEATURES

The ultrabasic and gabbroic rocks in southeastern Alaska are relatively sparse compared with the great volume of more siliceous and alkalic siliceous intrusions, but they are, nevertheless, widely distributed throughout the Alexander Archipelago and near the western border of the mainland batholith. Taken together, they form a very considerable volume, and there is no doubt that there are a great many masses which have not been reported. They are important economically because of the local association of ilmenitic magnetite with the diallagite or hornblende-augite varieties and of pentlandite and chalcopyrite-bearing pyrrhotite with certain of the norite, amphibolite, bronzitite, and troctolite varieties.

The ultrabasic group includes such types as dunite, pyroxenite, hornblendite, peridotite, troctolite, saxonite, wehrlite, and probably many others. More than a score of stocks and sills of ultrabasic rock have been found along the coast line of a northwest-southeast belt about 200 miles in length and 50 miles in width, paralleling a straight line drawn between Ketchikan and Juneau. These masses range in size from sheets 100 feet thick, intruded parallel to the cleavage of the inclosing schist, to stocks 2 or 3 miles in diameter.

Ultrabasic rocks have been noted by the writer as follows: Hornblendite on the north side of the entrance to Taku Harbor; hornblendite and hornblende-pyroxenite with ilmenitic magnetite ore bodies on the north end of the Snettisham Peninsula at Snettisham; saxonite on the north side of Tracy Arm, about 7 miles east of the first elbow, and pyroxene hornblendite on the south side, about southeast of the saxonite; dunite near the head of the east arm of Fords Terror, on the south side; hornblendite with many widely divergent pegmatitic variants on the Midway Islands; hornblendite at Point Lookout and south of Point League; hornblendite and pyroxenite on the north side of Windham Bay, about 3 miles east of Point Windham; hornblendite at the mouth of Shuck River, on the west side; hornblendite on the south side of Port Houghton, at the west side of the entrance to Walter Island Arm; hornblendite at the east side of the entrance to Portage Bay; hornblendite, dunite, wehrlite, and pyroxenite in the vicinity of Kane Peak, Kupreanof Island; hornblendite southeast of Frederick Point, Mitkof Island, and on the Sukoi Islets; hornblendite with disseminated sulphides at Circle Bay, on the south side of Woronkofski Island; hornblendite in patches along Zimovia Straits; dunite and pyroxenite on the Blashke Islands; pyroxenite with titaniferous magnetite on the east side of Union Bay, Cleveland Peninsula; and a dike of troctolite near Funter Bay, Admiralty Island.

In the Ketchikan district the occurrences of ultrabasic rocks are reported by Chapin [21] as follows: Pyroxenite with titaniferous magnetite on the east side of Union Bay, Cleveland Peninsula; peridotite in the mountains on the west side of Helm Bay; pyroxenite at the Salt Chuck mine, at the head of Kasaan Bay, Prince of Wales Island; peridotite and pyroxenite on the Percy Islands, Duke Island, Cat Island, Annette Island near Metlakatla, and the south end of Sukkwan Island.

Northwest of Juneau, according to Knopf, hornblendite occurs near Herbert Glacier, in the Eagle River area,[22] and about 2 miles north of the mouth of Johnson Creek, in the Berners Bay area,[23] and highly hornblendic gabbro, hornblendic pyroxenite, and augitic hornblendite, locally associated with considerable titaniferous magnetite, occur on Chilkoot Inlet and the adjacent mountains near Haines,[24]

[21] Chapin, Theodore, unpublished report on the Ketchikan district.

[22] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 25, 1912.

[23] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 25–26, 1911.

[24] Knopf, Adolph, The occurrences of iron ore near Haines: U. S. Geol. Survey Bull. 442, pp. 144–145, 1909.

The Wrights[25] report hornblendite, pyroxenite, and basic gabbro as different facies of a gneissoid body on the west side of Dixon Harbor.

On Chichagof Island Knopf[26] noted a mass of hornblendite at the head of Port Althorp; Overbeck[27] noted hornblendite on Lisianski Strait near Miner Island and gabbro (norite) near Nickel and on Lisianski Strait north of Canoe Pass; the writer[28] has noted norite, bronzitite, and hornblende gabbro at Bohemia Basin, Yakobi Island, and hornblendite at the Apex-El Nido property, on Lisianski Inlet.

On Baranof Island the only masses of ultrabasic rock so far reported are amphibolite on Snipe Bay and serpentine on Red Bluff Bay.

A specimen collected from Mount Cook, in the St. Elias Range, by I. C. Russell, is reported by Williams[29] to be troctolite.

DUNITE

The true dunite consists almost wholly of olivine with an accessory opaque spinellid mineral, possibly pleonaste or magnetite. The dunite rocks weather typically with a pale reddish to yellowish hue and have the appearance of a very uniform fine grain. On fresh surface they range from olive-gray to yellowish gray. Locally, partial alteration to serpentine or talc has occurred, and on Tracy Arm the olivine contains abundant needles of secondary tremolite. A mass of serpentine occurs on the north side of Red Bluff Bay, Baranof Island. Gradations between dunite and pyroxenite are found, both hypersthene and augite occurring in association with the olivine.

A stock of differentiated ultrabasic rocks forms the core of the Blashke Islands, in Clarence Strait. This stock deserves a more detailed examination, as it is easy of access, is well exposed, and exemplifies a striking case of magmatic differentiation within this type of rock. A cursory examination seems to indicate that the essential features are a core of dunite about a mile in diameter with an encircling ring of pyroxenite and an outer border of hornblende gabbro-diorite. The two rings of pyroxenite and hornblende gabbro-diorite are together roughly about three-eighths of a mile wide,

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25 Wright, F. E. and C. W., A geologic reconnaissance of Glacier and Lituya Bays (unpublished report).

26 Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, p. 15, 1912.

27 Overbeck, R. M., Geology of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 109–112.

28 Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 101–102, 118, 1925.

29 Williams, G. H., Notes on some eruptive rocks from Alaska: Nat. Geog. Mag., vol. 4, p. 68, 1892.

though accompanied by outlying masses of diorite in the adjacent sediments. No evidence of one rock intruding another was noted, but the gradations must be abrupt. The dunite is relatively less resistant to weathering and erosion than the gabbro-diorite and pyroxenite. As a result a most striking and peculiar phenomenon has arisen. A basin has been worn out of the dunite and is occupied by a salt lake. The rim rock of the basin is the pyroxenite and gabbro-diorite, through which there are three gorgelike entrances to the basin. The tide rushes in and out through these narrows with great velocity, and they constitute three "salt chucks" or "skookum chucks."

Around this salt lake the fresh dunite is dark yellowish olive-green, fine grained, and close jointed with a fissile and platy structure. Many of the joint surfaces are coated with a thin film of magnesite or dolomite. In thin section a specimen from the east side of the salt lake is found to consist exclusively of olivine in a state of partial alteration to serpentine, with about 3 per cent of idiomorphic opaque pleonaste octahedra.

The pyroxenite is a dark-green granular rock. In thin section a specimen from the north side of the stock is found to consist predominantly of monoclinic pyroxene with about 17 per cent of hornblende, 12 per cent of olivine, and a little hypersthene. The hornblende is mostly secondary after the pyroxene.

The gabbro-diorite is a medium-grained dark rock of mottled appearance, composed predominantly of black hornblende with associated white plagioclase. A specimen from the northeast corner of the salt lake was found on microscopic examination to consist of 61 per cent of hornblende, 30 per cent of plagioclase (andesine-labradorite), 6 per cent of pyroxene, and 3 per cent of titaniferous magnetite.

The intrusive mass lies within a belt of Silurian greenstone. A storm prevented the writer from examining the southeastern part of the islands, but the geology of the northwestern part suggests that the mass is encircled by a ring of the graywacke-slate formation which stratigraphically underlies the greenstone. Hence it is concluded that the magma was forced upward as a plug, doming the overlying rocks and shoving the beds to one side. Dikes of diorite are common in the surrounding rocks. The sedimentary beds have been baked to dense, hard rocks and the hornblende andesitic greenstones altered to epidote-hornblende rocks as a result of the intrusion.

At the head of Fords Terror, on the mainland, Juneau district, on the south side of the east arm at the bend where the coast turns north, there is a mass of dunite with associated highly hornblendic gabbro. These ferromagnesian rocks are intruded and brecciated by quartz diorite and granitic pegmatite veins. The dunite consists almost wholly of olivine and secondary talc with accessory hypersthene and secondary magnetite. The talc is in part in well-crystallized plates and in part in fibrous aggregates. Veinlets of fibrous tremolite traverse the dunite.

On Kupreanof Island the range of hills south and southwest of Cape Strait is composed of igneous rocks. Kane Peak itself and the mountains to the west appear to be of monzodioritic character, but on the southeast flank of Kane Peak there is a very conspicuous bare reddish-brown area visible from Frederick Sound. This color is due to the oxidation and weathering of ultrabasic rocks comprising pyroxenite and dunite and intermediate gradations between these two types. A core of pyroxenite is encircled along the south and east sides by a border of dunite and wehrlite. Rocks of this character also appear within the outer borders of the pyroxenite in vertical dikes or dikelike forms. The pyroxenite forms a bare nubbin with very steep cliff faces and is marked by bouldery spheroidal weathering. A long vein which weathers bright red and another which weathers brown occur in the pyroxenite; this coloring is probably due to sparse disseminated sulphides. The pyroxenite consists of a granular aggregate of pale-green diallage. On the north side of the pyroxenite core, along the shores of Frederick Sound for 1¼ miles southeast of Cape Strait, hornblendite appears to be the predominant rock. A specimen of the subalkalic rock from Kane Peak near the pyroxenite mass along its western border is a hornblende-pyroxene monzodiorite, a very peculiar variant of the normal monzodiorites. It has probably resulted from partial reaction of normal intrusive monzodiorite with pyroxenite. A specimen of dunite just southeast of Cape Strait is a very dark rock which on fresh surfaces shows a mottling of black and dull greenish-yellow. In thin section it is found to consist of granular olivine altered to serpentine clouded with black opaque magnetite dust. A trifle of talc is also present. A specimen of wehrlite from Kane Peak, near the pyroxenite mass on its south side, consists of about 78 per cent of olivine, 20 per cent of monoclinic pyroxene, and 2 per cent of magnetite. The rock is fresh and wholly unaltered.

SAXONITE

On the north side of Tracy Arm, about 7 miles east of the first elbow, is a small point about 3½ miles west of another conspicuous elbow. In the inner bend on the east side of the point is an exposure of ultrabasic rock that has weathered yellowish to reddish brown. The fresh color is yellowish gray to olive gray. About 500 yards is exposed, though included beds of gneiss or intrusive sills of quartz diorite occur. The rock is fissile and is traversed locally by closely spaced veinlets of white fibrous tremolite from a quarter of an inch to 6 inches wide. Films of serpentine coat the joint planes. Microscopic examination of a specimen shows it to be a variety of peridotite called saxonite, consisting of about two-thirds olivine, one-third orthorhombic pyroxene, and a small percentage of magnetite. The hypersthene contains rounded inclusions of the olivine. The magnetite occurs in part as disseminated grains and in part as dust and dots throughout the olivine and pyroxene. The rock is practically unaltered, except for abundant tremolite needles in the olivine. Some specimens show flakes of talc visible in the hand specimen.

PYROXENITE

The pyroxenites include varieties made up of a monoclinic pyroxene composed almost wholly of the diopside molecule or of a monoclinic pyroxene composed of diallage with a percentage of an aluminous and ferric iron molecule and locally in association with the norite of the orthorhombic pyroxene bronzite. The diopside and diallage pyroxenites are light to dark green granular rocks. The bronzitites are of a prevailing bronze color.

The diopside pyroxenites are associated with the dunite and other olivine-rich rocks; the diallagites are associated with hornblendite and gabbro. So far as studied in this region, magnetite with a little associated ilmenite occurs in marked magmatic concentrations and segregations entirely with the diallagites and hornblende-augite rocks, the latter usually associated with hornblendite. Apatite tends to be markedly concentrated in many of the hornblendites and hornblende-augite rocks, and pyrrhotite with a little associated pentlandite and chalcopyrite is concentrated in the norite, hypersthenite, hornblendite, troctolite, and gabbroic rocks.

A large mass of pyroxenite of the diallagite variety crops out along the east side of Union Bay, on the Cleveland Peninsula, from the saltery north to the head of the cove on the east side of Union Point. The pyroxenite is a medium-grained granular dark-greenish rock, locally with a gneissic structure as the result of flowage, Coarse pegmatite veins are present, some of which are gabbroic to highly feldspathic. Dikes of intrusive diorite cut the pyroxenite. In thin section the pyroxenite is seen to consist almost wholly of pyroxene with a variable amount of ilmenitic magnetite. A trifle of the magnetite occurs as minute inclusions in the pyroxene, but most of it is present as large grains with the borders molded against the pyroxene and with projecting points or threads interstitial to the pyroxene. Some pyroxenite boulders, presumably from this mass, carry as much as 30 per cent of magnetite. The pyroxene has indices of refraction considerably higher than those of diopside and probably consists in part of the augite and hedenbergite molecules. A trace of green spinel is associated with the magnetite.

The ultrabasic rocks north of Karta Bay in which the palladium-copper ores of the Salt Chuck mine occur have been described by Wright [30] and by Mertie.[31] Mertie describes the country rock as

> in general a pyroxenite, with gabbroic and gabbro-pegmatitic phases. * * * The chief rock-forming mineral is augite, and the subordinate constituents are biotite, iron oxides, plagioclase, apatite, and titanite, though not all of these are invariably present in any one specimen.

Merwin describes one facies of this mass as consisting of about 55 per cent of augite, 25 per cent of biotite, and 10 to 15 per cent of magnetite, and states that the biotite is much later than both the augite and magnetite, and the magnetite in part later than the pyroxene.

At Cobb's prospect, on Karta Bay the rock consists of about 8 per cent of biotite, 15 per cent of magnetite, 10 per cent of plagioclase, and 67 per cent of augite. The biotite and plagioclase are interstitial to the pyroxene but nearly contemporaneous with the last of the pyroxene.

HORNBLENDITE

The hornblendite masses are readily recognizable by their rich black color on the fresh surface. Locally they weather with a rusty reddish-brown hue as a result of disseminated sulphide particles.

The most marked and characteristic feature of the hornblendite masses is their wide and abrupt variation in texture and the local abundance of pegmatitic facies which may vary widely in composition. Usually the hornblendite ranges from a coarse, massive, even-grained rock with individual grains a centimeter or so in diameter to a rock in which the hornblende crystals are conspicuously columnar with a length of several millimeters and a diameter of a millimeter. In the finer-grained rock a gnessic structure is usually present as a result of the rough parallel orientation due to flowage. Locally the mass may be composed of hornblende in crystals averaging 6 inches in length and 2 or 3 inches across.

In a few places, hornblendite masses have developed as marginal facies to monzodiorite, quartz diorite, granodiorite, or diorite.

The hornblende is variable in composition, as is indcated by the variation in the indices of refraction, which are the same as those of the hornblende in the diorites—α from 1.650 to 1.680 and γ from 1.672 to 1.700. Hornblendites are common members of the Upper Jurassic or Lower Cretaceous intrusive rocks west of the main batholith.

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[30] Wright, C. W., U. S. Geol. Survey Prof. Paper 87, p. 75, 1915.

[31] Mertie, J. B., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, p. 122, 1921.

A chemical analysis of hornblende from hornblendite on Knight Inlet is given in a report by Bancroft. The analysis of hornblende from hornblendite on Vancouver Island has been calculated by Clapp from an analysis of the rock. These analyses are given in the table below, together with the composition obtained by averaging the two. This average probably closely approximates the composition of the hornblende of the hornblendites under discussion.

Chemical composition of hornblende in hornblendite

	1	2	3		1	2	3
SiO_2	41.0	42.8	42.0	MgO	13.2	14.9	14.0
Al_2O_3	14.6	14.6	14.6	K_2O	.4	1.1	.8
Fe_2O_3	4.1	3.3	3.7	Na_2O	2.7	1.9	2.3
FeO	10.5	7.3	8.9	H_2O		.5	
TiO_2	2.7	1.1	1.9	P_2O_5		.8	
CaO	11.6	11.4	11.5				

1. Analysis of hornblende from hornblendite about 2 miles beyond the Aknuati Valley on the north shore of Knight Inlet, B. C. Analyst, W. B. Campbell. Bancroft, J. A., Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B. C.: Canada Geol. Survey Mem. 23, p. 87, 1913.
2. Analysis (calculated) of hornblende from hornblendite northwest of Prospect Lake, southeast end of Vancouver Island. Clapp, C. H., Geology of the Victoria and Saanich map areas, Vancouver Island, B. C.: Canada Geol. Survey Mem. 36, p. 70, 1913.
3. Average of Nos. 1 and 2.

Biotite, plagioclase, magnetite, pyrite, pyrrhotite, apatite, and titanite are the common accessory minerals. Biotite usually occurs as hexagonal plates disseminated throughout the rock. It is common as large plates in some of the pegmatitic variants. In feldspathic varieties of the hornblendites or the highly hornblendic gabbros the plagioclase is an andesine ($Ab_{65}An_{35}$); but in the coarse pegmatitic facies the feldspar appears to be exclusively an almost pure albite. Pyrite and pyrrhotite are variable in amount and give rise on weathering to a rusty-brown outcrop. Magnetite shows, in part, a tendency to concentrate with the pyroxenitic facies of the hornblendite. Apatite is uniformly more abundant than in any other type of the Upper Jurassic or Lower Cretaceous intrusive rocks. Titanite is locally very abundant in some of the pegmatitic facies. Epidote occurs locally in some of the pegmatitic facies as a primary mineral. Epidote, quartz, and calcite occur as secondary minerals.

Each of the minerals albite, orthoclase, and magnetite locally occurs in the form of veins in the hornblendic rocks. Plagioclase is usually present, and with an increase in this mineral the hornblendite becomes feldspathic and grades toward highly hornblendic gabbro.

A coarse-grained granular aggregate, with crystals of hornblende that average about 0.5 millimeter in diameter and are as much as 2 centimeters in length, forms the headlands of Southwest Cove, Etolin Island, and crops out along the coast for several miles to the north. It consists almost entirely of hornblende with a little interstitial feldspar and aggregates of quartz, epidote, and calcite. The hornblende contains many corroded remnants of pyroxene and a few of brown biotite.

Another specimen from the west headland at the south entrance to Zimovia Straits consists almost exclusively of hornblende with a little biotite and abundant interstitial microscopic accessory apatite and crystals of magnetite. The hornblende crystals are about a millimeter in diameter and several millimeters in length.

Another facies of the hornblendite is found on the Lindenberg Peninsula, Kupreanof Island, about 4 miles northwest of Duncan Peaks. The hornblendite here occurs as narrow lenses or sheets near the border of a monzodiorite stock. The main mass of hornblendite is composed almost wholly of columnar hornblende showing euhedral basal sections with disseminated hexagonal crystals of biotite. Near the contact with the normal diorite the hornblendite contains abundant phenocrysts of plagioclase which have been completely altered to an aggregate of epidote and zoisite with a groundmass of hornblende. In the border zones lenses of normal diorite occur in the hornblendite, suggesting that the hornblendite is intrusive into the diorite. It appears, however, to grade transitionally into the diorite through a gradual increase in the number of plagioclase phenocrysts.

A gabbroic hornblendite consisting of about 80 per cent of hornblende, 18 per cent of plagioclase, and 2 per cent of quartz, magnetite, and biotite occurs at the mouth of Fords Terror, on the mainland in the Juneau district. It is shattered and cut to pieces by dikes of quartz diorite. At the foot of Brown Glacier a highly hornblendic rock, possibly of gabbroic origin, forms a shatter breccia with intrusive quartz diorite.

A marginal development of hornblendite from quartz diorite on the northwest side of Herbert Glacier, in the Eagle River area, has been described by Knopf.[32]

A hornblendite that occurs about 2 miles north of the mouth of Johnson Creek, in the Berners Bay area, has been described by Knopf[33] as follows:

> The hornblendite is a heavy black rock composed mainly of hornblende. Abrupt variations in texture and composition are of general occurrence and give the rock a wide range in appearance. The hornblende in places forms prisms up to 2 inches in length and is characterized by its brilliant cleavage faces and metallic luster on cross-fractured surfaces. Locally feldspar, in part converted to epidote, occupies the triangular interstices between the hornblende prisms.

About 7 miles east of the first elbow of Tracy Arm, on the south side, there is a small mass of pyroxene hornblendite, shattered and

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[32] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 25, 1912.

[33] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 25–26, 1911.

reticulated by granitic pegmatite veins. The rock consists of many black hornblende crystals about half an inch in diameter in a medium-grained granular groundmass. In this section the rock is found to consist of about 50 per cent of brown hornblende, 5 per cent of labradorite, 1 per cent each of quartz and magnetite, and the remainder of pyroxene, including both monoclinic pyroxene and hypersthene, the former about twice as abundant as the latter. The large hornblende crystals have abundant corroded inclusions of both pyroxenes.

The northern portion of the Snettisham Peninsula, on the mainland, is composed of a mass of diorite and hornblendite about 2¾ miles in width as exposed along the coast at the entrance of Port Snettisham. The eastern 1½ miles of this mass is hornblendite with associated variants. The most marked characteristic of this hornblendite mass, as of all the other masses of hornblendite in southeastern Alaska, is the abrupt and extreme variation in its texture. The predominant rock, however, is a black medium-grained variety composed almost wholly of hornblende, with accessory magnetite, apatite, and plagioclase. Coarse-grained pegmatitic variants occur within the mass and may consist of long columnar hornblende, of hornblende and biotite, or hornblende and pyroxene, of pyroxene and magnetite, or of magnetite. Occasionally chlorite, in large well-crystallized plates, is intergrown with the other minerals. Rarely an epidote veinlet cuts the pegmatitic veins. The hornblendite is intruded by dikes of diorite and of aplite. Narrow vein dikes of white albite occur sparingly, and rarely one composed almost wholly of pink orthoclase is found.

About 100 yards east of the first point opposite the post office at Snettisham there is a 6-foot vein of practically solid ilmenitic magnetite. The country rock is a medium-grained hornblende pyroxenite, consisting of about 56 per cent of pyroxene, 26 per cent of brown hornblende, 14 per cent of magnetite (with ilmenite), and 4 per cent of apatite.

A magnetite amphibolite from Snipe Bay, Baranof Island, has previously been described by the writer.[34] This amphibolite is associated with nickeliferous pyrrhotite. Only one specimen was examined in detail, and this consisted of 49 per cent of brown hornblende, 39 per cent of ilmenitic magnetite, 7 per cent of plagioclase, 2 per cent of chlorite, 2 per cent of pyrrhotite, and 1 per cent of apatite.

Magnetite-bearing hornblende-pyroxene rocks and coarsely crystalline gabbro and diorite on Chilkoot Inlet from a point 4 miles south

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[34] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 106–107, 1925.

of Haines to a point 2 miles north of Haines have been described by Knopf,[35] as follows:

The rock mass exposed along the shore north of Haines is a remarkable occurrence geologically. Specimens collected from the finest-textured portions show a rock composed of coarsely crystalline aggregate of feldspar, hornblende, and pyroxene, throughout which are scattered some visible grains of magnetite. The dark minerals (hornblende and pyroxene) make up half the bulk of the rock. When examined microscopically the rock is found to consist of an allotriomorphic granular assemblage of plagioclase feldspar (bytownite), hornblende, and augite. Magnetite and apatite are present as accessory constituents in unusually large amounts. From this normal type of rock, which would be termed a gabbro, abrupt variations in texture and mineral composition are encountered. In places the cliffs for hundreds of feet are composed solidly of formless hornblende individuals 6 inches long by 3 inches broad. Commonly this hornblende rock contains more or less grayish-green augite admixed with it and is ramified by coarse white feldspathic dikelets or blotched by masses of gabbro. In places it even forms a breccia cemented by such material. Locally the hornblendite contains numerous lumps and particles of magnetite. * * * Near Fort Seward, which is situated just west of Haines, the rock exposed consists of a coarsely granular aggregate of pyroxene, hornblende, and black mica (biotite).

Knopf has described an amphibolite from the vicinity of the Crystal mine at Port Snettisham, and gives a chemical analysis. He suggests that the rock is the result of alteration of a porphyritic basalt, but the writer believes it to be an altered hornblendite. Knopf's description [36] follows:

In thin section the rock proves to be composed largely of amphibolite, zoisite, and epidote, with subordinate albite, which is largely associated with the epidote minerals. The amphibole comprises two varieties, a brown-green strongly pleochroic variety, and a light-green feebly pleochroic variety. Other constituents are ilmenite, titanite, chlorite, and muscovite. The chemical analysis of a specimen of this rock obtained near the entrance to the upper tunnel of the mine is as follows:

Analysis of amphibolite from Port Snettisham

[J. G. Fairchild, analyst]

SiO_2	46.87	H_2O+	2.23
Al_2O_3	15.14	TiO_2	2.20
Fe_2O_3	3.87	CO_2	None.
FeO	8.41	P_2O_5	.15
MgO	6.10	S	None.
CaO	11.27	MnO	.17
Na_2O	3.02		
K_2O	.30		99.73

Norm: Albite, 26.2; anorthite, 28.1; orthoclase, 1.7; magnetite, 5.7; ilmenite, 4.2; diopside, 24; olivine, 8.0; hypersthene, 2.1.

[35] Knopf, Adolph, The occurrence of iron ore near Haines: U. S. Geol. Survey Bull. 442, pp. 144–146, 1910.

[36] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 39–40, 1912.

GABBRO

The gabbroic rocks include hypersthene gabbro or norite, augite gabbro, augite-biotite gabbro, and hornblende gabbro. The distinction between gabbro and diorite is in this report based upon the composition of the feldspar—rocks with labradorite or more calcic feldspar are grouped with the gabbros. The gabbros are relatively sparse. Their association locally with the ultrabasic group of rocks has already been referred to. Small masses, in part isolated, are also found.

The only noritic masses so far reported are on Chichagof Island and the adjoining islands to the west. Only two masses have been studied, and these only in a reconnaissance fashion.

At Bohemia Basin, Yakobi Island, about 2¼ miles southwest of Miner Island, there is an elliptical mass of gabbroic rock about 1⅖ miles wide and 2 miles long. The rock is of very diversified character and comprises such facies as hornblende gabbro, norite, bronzitite, and amphibolite. As observed at the head of the basin, the country rock is a greenstone schist and the outer border of the intrusive mass is a light-colored quartz diorite about 500 feet wide. The following table shows the composition of the diorite, gabbro, norite, and bronzitite.

Composition of igneous rocks from intrusive mass at Bohemia Basin, Yakobi Island [a]

	1	2	3	4	5	6
Plagioclase	55 (Ab_3An_2)	52 (Ab_3An_2)	50 (Ab_2An_3)	34 (Ab_1An_3)	12 ($Ab_{35}An_{65}$)	Trace.
Olivine						10
Bronzite				60	84	82
Diopside						6.5
Hornblende	16	39	47	5		
Biotite	10					
Quartz	18	8	2			
Sulphides					4	1.5
Accessory minerals	1	1	1	1		

[a] Secondary minerals have been considered as part of the minerals which they are replacing.

1. Quartz diorite 100 feet from outer border of intrusive mass.
2. Quartzose diorite 500 feet from outer border of intrusive mass and adjacent to norite.
3. Hornblende gabbro from northern outer margin of norite mass.
4. Norite, fine-grained facies.
5. Feldspathic bronzitite.
6. Olivine bronzitite.

The bronzite is a bronze-colored pyroxene on the border line between hypersthene and enstatite and was determined as a variety with about 86 per cent of the enstatite molecule $MgSiO_3$ and 14 per cent of $FeSiO_3$.

Locally the ultrabasic facies are extensively altered. Masses of sulphides occur in lenslike form or as disseminations. The sulphides comprise pyrrhotite, pentlandite, and chalcopyrite; the pyrrhotite predominates. The disseminated sulphide blebs are primary late magmatic minerals and an integral part of the rock.

The basic rocks associated with nickeliferous pyrrhotite near Nickel, on the west coast of Chichagof Island have been briefly described by Overbeck.[37] The rock that makes up most of the intrusive body is reported to be diorite, and the most basic facies—hornblende gabbro and norite—are found close to the outcrops of the ore bodies. A facies with disseminated sulphides is reported as consisting chiefly of hornblende, pyroxene, and feldspar, together with a little biotite and disseminated sulphides that consist predominantly of pyrrhotite with associated pentlandite and chalcopyrite. Kerr[38] has described a pyroxene gabbro which is also associated with the ore deposits; the pyroxene is described as diopside with a little hedenbergite molecule in solid solution.

On the property of the Admiralty-Alaska Co., on Funter Bay, Admiralty Island, at an altitude of 1,650 to 1,700 feet, there is a dike of troctolite in schist. The fresh troctolite consists of 55 per cent of labradorite, 39 per cent of olivine, 4 per cent of pyroxene, and 2 per cent of magnetite. The texture is diabasic. Locally sulphides are disseminated throughout the rock. These sulphides consist predominantly of pyrrhotite with a little associated pentlandite and chalcopyrite. In places the rock is extensively modified by hydrothermal alterations.

Knopf[39] reports hornblende gabbro at the head of Tenakee Inlet, Chichagof Island, and gabbro along Nakwasina Passage and Katlian Bay, Baranof Island.

Gabbro was noted by Chapin on the eastern shore of Duke Island, in the Ketchikan district. Highly hornblendic gabbro was noted by Wright[40] in the Copper Mountain area, and augite gabbro on the Kasaan Peninsula north of Karta Bay, Prince of Wales Island. The peak of Thunder Mountain, north of Sakie Bay, Dall Island, is made up of gabbro, which occurs as a local marginal facies to a diorite stock.

The gabbros may be fresh and massive, altered and massive, or very intensely mashed, depending upon local conditions.

The approximate mineral composition of a few representative types of the gabbroic group of rocks is given in the table below. The gabbros show no unusual features. A trace of orthoclase is present

[37] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 129–133, 1919.

[38] Kerr, P. F., A magmatic sulphide ore from Chichagof Island, Alaska: Econ. Geology, vol. 19, pp. 371–372, 1924.

[39] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, p. 15, 1912.

[40] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, pp. 36, 75, 1915.

in many of them, and in a few microscopic veinlets of orthoclase cross the grains. A noteworthy feature is the concentration of magnetite.

Mineral composition of gabbroic types of rock from southeastern Alaska

	Labradorite	Pyroxene	Hornblende	Magnetite	Orthoclase	Accessory minerals	Biotite
East side of Hooniah Sound, Chichagof Island	59	[a] 30	2	8	1		
South side of Nakwasina Passage, Baranof Island	64	[b] 35		1			
Mountain (altitude 3,035 feet) at north end of Kupreanof Island	38	44	6	12			
Near head of Washington Harbor, Kuiu Island	57	41		.5	1.5		
Bohemia Basin, Yakobi Island, pocket marginal to norite	50		47			3	
South side of Portage Bay, Prince of Wales Island	20	10	70				
Hornblende-augite gabbro, Kasaan Peninsula, Prince of Wales Island	45	30	15	10			
Biotite-augite gabbro, Kasaan Peninsula	42	35		8			15

[a] Pyroxene partly altered to hornblende.
[b] Pyroxene partly altered to serpentine.

GABBRO-DIORITE

The dioritic rocks, including gabbro-diorite, diorite, monzodiorite, and quartzose variants of these, are almost wholly restricted to the area between Lynn Canal and the Pacific Ocean and the islands of the Alexander Archipelago, where they are further localized in certain belts. They form the predominant type of rock within the Prince of Wales-Chichagof belt and the area west of Glacier Bay. In addition, stocks are found here and there in the northern part of the Juneau belt adjacent to the main batholith, rarely within the mainland batholith itself, and on the islands west of Prince of Wales Island.

Commonly the most basic variant of the intrusive rocks of the Coast Range after the ultrabasic group of rocks and their associated variants, is gabbro-diorite. Rock of this type forms separate stocks and occurs also as marginal variants of the predominant more alkalic or siliceous and less ferromagnesian types. It is relatively sparse, however, and forms only a very small percentage of the total mass of intrusive rock. The gabbro-diorite locally grades into very highly hornblendic variants.

The approximate mineral composition of several representative types is given in the table below. The feldspar is usually near Ab_1An_1, an andesine-labradorite. Hornblende is commonly the predominant ferromagnesian mineral and forms 35 to 65 per cent of the rock. Pyroxene may be present as an accessory mineral and in some rocks may be the predominant ferromagnesian mineral. Quartz and orthoclase may be present as accessory minerals. Magnetite is always present and in certain rocks shows a marked concentration, reaching 10 per cent or more. Biotite may be present but is usually restricted to the more typical hornblende-andesine diorite and the more siliceous and alkalic types.

Mineral composition of typical gabbro-diorite from southeastern Alaska

	Andesine-labradorite	Hornblende	Biotite	Potassic feldspar	Quartz	Pyroxene	Accessory minerals	Magnetite
Three-quarters of a mile southwest of Hetta Mountain, Prince of Wales Island	15	70	------	5	------	10	------	------
South side of Portage Bay, Prince of Wales Island	50	47	------	------	------	------	3	------
Blashke Islands, Kashevarof Passage	30	60	------	------	------	5	------	5
21 miles west of Tenakee, Chichagof Island	50	36	------	------	------	------	------	13
4 miles northwest of Hadley, Kasaan Peninsula	55	35	------	------	5	------	5	------
14 miles below international boundary, Stikine River	77	3	------	------	1	18	------	1

A belt of augite diorite (gabbro-diorite) on the mainland near Eagle River, in the Juneau district has been described by Knopf.[41] It forms a mass about 5 miles long and from a tenth to a quarter of a mile wide, of sill-like form. The rock is described as consisting of plagioclase partly converted to epidote, augite in abundance, biotite, sporadic hornblende, and orthoclase filling the triangular interstices between the plagioclase feldspars.

Knopf[42] has described as the Jualin diorite a stock of gabbro-diorite in the Berners Bay region of the Juneau district. The stock is about 5½ miles long, in a direction parallel to the general trend of the structure of the country, and has a maximum width of 1½ miles. The rock consists essentially of labradorite near Ab_1An_1, hornblende, and biotite. Orthoclase and interstitial quartz are present in subordinate amounts, and locally the rock grades into granodiorite. Magnetite, titanite, and apatite are accessories. Hornblende is the most prevalent dark mineral; biotite exceeds it in prominence locally but in other places is absent.

DIORITE

The diorite differs from the gabbro-diorite essentially in having a slightly more sodic plagioclase (andesine), and a smaller percentage of hornblende. The diorite and monzodiorite very commonly show a local marginal development of hornblendite. With an increase in quartz the monzodiorite grades locally into granodio-

[41] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 29, 1912.

[42] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 24–25, 1911.

rite, and the diorite into quartz diorite. In many of the dioritic masses the plagioclase shows considerable alteration.

The predominant mineral in the diorite is an andesine feldspar. This usually forms 60 to 70 per cent of the rock but ranges from 50 to 90 per cent. Hornblende usually forms 20 to 30 per cent and ranges from 6 to 45 per cent. Biotite is practically absent in half the specimens of diorite examined and in the other half ranges from 1 to 12 per cent. Quartz ranges from 1 to 10 per cent. Potassic feldspar, including orthoclase and microperthite, ranges from 1 to 8 per cent but is usually present only as a trace. Magnetite is usually present to the extent of 1 to 2 per cent but in a few places forms as much as 5 per cent of the rock. Titanite is usually present as an accessory mineral and may constitute 1 per cent or so of the rock. Apatite is practically always present and locally forms as much as 2 per cent of the rock. Zircon is a common accessory in minor amounts.

The approximate mineral composition of representative types of diorite is given below.

Approximate mineral composition of types of diorite in southeastern Alaska

	Andesine	Hornblende	Biotite	Potassic feldspar	Quartz	Magnetite	Accessory minerals
Average of 12 specimens from Prince of Wales Island	62	26.5	3	2	4	1.5	1
Average of 16 specimens from Chichagof Island	63	28	2	1	4	2−	(a)
East side of Port Althorp, Chichagof Island	48	45	------	------	6	1	------
Zimovia Straits, Wrangell district	24	64	7	------	3	------	2
Bald Mountain, Tenakee Inlet, Chichagof Island	64.5	30	------	------	------	5	.5
Point south of entrance to Ingraham Bay, Prince of Wales Island	66	26	------	1	4	2.5	.5
Kasaan Peninsula, Prince of Wales Island	68	19	1	------	7	------	1
4 miles east of head of Tenakee Inlet, Chichagof Island	71	28	------	------	------	1	------
Burnett Inlet, Etolin Island	75	22	1	------	------	------	2
Anita Bay, Etolin Island	73	6	11	6	4	------	------
Grindall Point, Prince of Wales Island	63	20	------	7	7	2	1
North side of Mitchell Bay, Admiralty Island	83	15	------	1	------	1	------
South side of Lulu Island	90	7	------	------	1	------	2
1½ miles above Hudson Bay Flat, Stikine River	62	21	13	------	3	------	1
1½ miles above Flood Glacier, Stikine River	42	25	26	5.5	1	------	.5

a Present.

A chemical analysis of a representative specimen of diorite from the east side of Burnett Inlet, Etolin Island, is given below. The plagioclase of this rock is an andesine-labradorite, and the ferromagnesian mineral is almost exclusively hornblende. Only about 1 per cent of biotite is present. The hornblende is slightly altered to uralite, and the plagioclase slightly sericitized. A little microperthite is present.

Analysis of diorite from Burnett Inlet, Etolin Island

[J. G. Fairchild, analyst]

Analysis		Norm	
SiO_2	50.24	Albite	28.5
Al_2O_3	17.86	Anorthite	28.8
Fe_2O_3	2.00	Orthoclase	8.3
FeO	6.56	Nephelite	.8
MgO	5.47	Diopside	14.0
CaO	10.59	Olivine	12.5
Na_2O	3.51	Magnetite	2.8
K_2O	1.40	Ilmenite	2.4
H_2O-	.03	Apatite	1.9
H_2O+	1.39		
TiO_2	1.32		100.0
P_2O_5	.24		
	100.61		

Quartzose diorite intermediate between normal diorite and quartz diorite is common in the Prince of Wales-Chichagof belt. The approximate mineral composition of nine specimens from this belt is given below in column 1.

A more feldspathic type is shown in column 2. These rocks have closer affinities with the diorite than with the quartz diorite. They have slightly less hornblende and more quartz than the normal diorite but are markedly distinguished from the quartz diorite by their small content of biotite.

Approximate mineral composition of quartzose diorite from southeastern Alaska

	1	2		1	2
Andesine	63	70	Biotite	1	1
Hornblende	23	15	Potassic feldspar	1	1
Quartz	10	11	Accessory minerals	2	2

1. Average of 9 specimens from Prince of Wales-Chichagof belt.
2. Average of 2 specimens from Dall-Baranof belt.

MONZODIORITE

Monzodiorite occurs both as separate stocks, particularly on Mitkof Island and the Lindenberg Peninsula, Kupreanof Island, and as marginal variants of diorite or granodiorite stocks. Locally the monzodiorite has marginal hornblendite variants or grades into granodiorite or, rarely, into monzonite.

The predominant mineral of the monzodiorite is normally an andesine plagioclase, which forms 50 to 75 per cent of the rock. Potassic feldspar forms 9 to 30 per cent. In most places the potassic feldspar is microperthite, in small part microcline without perthitic intergrowths; and in the Copper Mountain region, Prince of Wales Island, according to Wright, the potassic feldspar is orthoclase. Hornblende ranges from several per cent to 35 per cent, but usually is around 20 per cent. Biotite ranges from a trace to 7 per cent. Quartz is commonly present as an accessory mineral and ranges from 1 to 10 per cent. Magnetite, apatite, titanite, and zircon are other common accessory minerals. In the monzodiorite mass on the east side of Portage Bay, Kupreanof Island, epidote is present to the amount of several per cent and seems to be a primary magmatic mineral; it occurs as fresh grains and euhedral rods and is locally corroded on the edges by the feldspar. In many of the monzodiorite stocks the plagioclase is intensely altered to epidote, zoisite, and muscovite.

The average approximate mineral composition of hornblende-andesine monzodiorite from the Prince of Wales-Chichagof belt is given below.

Average mineral composition of seven specimens of hornblende-andesine monzodiorite from the Prince of Wales-Chichagof belt

Andesine	56
Potassic feldspar	19
Hornblende	17
Biotite	2
Quartz	4
Accessory minerals	2
	100

An analysis by George Steiger of quartzose monzodiorite from the Jumbo Basin, Prince of Wales Island, is given by Wright.[43]

Analysis of quartzose monzodiorite from Jumbo Basin

Analysis		Norm	
SiO_2	59.44	Quartz	8.94
Al_2O_3	17.40	Orthoclase	18.35
Fe_2O_3	3.30	Albite	35.63
FeO	2.77	Anorthite	19.46
MgO	1.81	Diopside	8.68
CaO	6.51	Hypersthene	1.93
Na_2O	4.22	Magnetite	4.87
K_2O	3.12	Ilmenite	1.37
H_2O-	.06	Apatite	.67
H_2O+	.56	(Water)	.62
TiO_2	.66		100.52
ZrO_2	None.		
CO_2	None.		
P_2O_5	.28		
S	.02		
MnO	.17		
BaO	.07		
SrO	.05		
	100.44		

Albite and albite-oligoclase monzodiorites occur locally in small masses on Prince of Wales Island. Such rocks form a marginal variant to the Copper Mountain stock and are found also at the

[43] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 106, 1915.

Mamie mine, on Kasaan Peninsula. These sodic variants carry much less ferromagnesian mineral, consisting of only a small percentage of hornblende. The orthoclase is interstitial to the plagioclase and locally contains apatite crystals. Accessory magnetite and titanite are usually present. They locally grade into albite diorite. A typical specimen obtained near the Mamie mine consists of 71 per cent of albite, 23 per cent of orthoclase, 5 per cent of hornblende, and 1 per cent of apatite and magnetite. Another from a dike near the head of Hole in the Wall is described by Merwin as consisting predominantly of albite, with 15 to 20 per cent of orthoclase, 10 per cent of biotite, and accessory apatite, titanite, and magnetite.

SYENITE

Syenite is exceedingly rare, both in the islands of the Alexander Archipelago and in the mainland batholith. Only three specimens were found by the writer in the whole district covered by him. A specimen collected 2 miles south of McLean Arm, Prince of Wales Island, is a syenite composed almost wholly of microperthite with a little interstitial meshwork of oligoclase and accessory interstitial quartz. The approximate mineral composition of a specimen from the Copper Mountain region, Prince of Wales Island, and of two specimens from the mainland batholith is given below.

Approximate mineral composition of syenite from southeastern Alaska

	1	2	3		1	2	3
Microperthite	75	67	74	Hornblende	------	6	------
Plagioclase	5	20	10	Biotite	------	1	4.5
Quartz	10	5	1	Zircon, magnetite, apatite	------	1	.5
Pyroxene	8	------	------				

1. Near contact of main granitic mass, 1,000 feet east of Jumbo No. 4 mine, Copper Mountain region, Prince of Wales Island. Described by H. E. Merwin in Wright, C. W., U. S. Geol. Survey Prof. Paper 87, p. 36, 1915.
2. River Point, Portland Canal, Hyder district.
3. North center, Chickamin Bay, Behm Canal.

Merwin [44] has described the syenites from the Copper Mountain district, on Prince of Wales Island, as follows:

> The syenites are medium-grained light-gray to pale-pink rocks composed essentially of orthoclase and plagioclase (oligoclase variety) in different proportions, with hornblende as the principal dark mineral and pyroxene, magnetite, apatite, and titanite as accessories. * * * The syenite forms a part of the batholithic masses occurring near its margin. It is also found in outlying dikes and in tongues branching from the main intrusive masses.

The Wrights [45] report that no syenite was discovered in the Glacier Bay region.

[44] Merwin, H. E., in Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 36, 1915.

[45] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

QUARTZ DIORITE

Quartz diorite forms the western border of the mainland batholith, and perhaps a part of the extreme eastern border. It also occurs locally within the Coast Range batholith. It is one of the predominant igneous rocks of the Wrangell-Revillagigedo belt adjacent to the batholith on the west and is the predominant intrusive rock of the Dall-Baranof belt. Elsewhere in the Alexander Archipelago it is common but is exceeded in prominence by less quartzose, more typically dioritic rocks. It also occurs as local marginal developments on the borders of masses of dioritic or granodioritic rocks.

In the Coast Range batholith of the mainland the quartz diorite commonly grades into granodiorite toward the core. Locally on the outer borders small masses of hornblendite are developed as marginal variants of it. In the Wrangell-Revillagigedo belt it grades into granodiorite, low in potassium, the dividing line between the two being taken at 8 per cent potassic feldspar.

A mass of quartz diorite forms a marginal border to a mass of norite at the Bohemia Basin, on Yakobi Island, near Chichagof Island.

The quartz diorite is mottled in black and white with a generally predominant light-gray to white color. In the hand specimens a well-defined gneissoid structure is usually evident. The hornblende occurs in black prismatic crystals without terminal faces, and the biotite in hexagonal flakes and chunky crystals. The hornblende and biotite may occur separate and oriented, or segregated in small patches or in short, indistinct narrow linear lenticles. Locally titanite crystals are common, though they are of erratic distribution. The rock is essentially of even grain with here and there a slight, inconspicuous tendency toward a porphyritic texture. The plagioclase of first crystallization may appear in euhedral tabular crystals of very slightly larger diameter, many of which weather more easily in the center.

The average grain of the mainland batholith is between 1 and 2 millimeters, with local facies averaging 3 millimeters. Some of the slightly porphyritic plagioclase crystals may have a longer diameter of more than 0.5 centimeter; and some of the larger hornblende prisms are 1 centimeter in length. In many of the specimens examined by the writer some of the larger plagioclase crystals show a slight to conspicuous zoning. In the outlying stocks zoning of most of the plagioclase is common.

The hornblende of the granodiorite in the Wrangell-Revillagigedo belt, which is near quartz diorite in composition, must have a considerable variation in composition, as the indices of refraction range from 1.660 to 1.680 for α and 1.681 to 1.700 for γ.

The approximate mineral composition of representative types of quartz diorite from the mainland batholith is given in the table on page 212. Andesine is the predominant mineral and ranges usually from 40 to 60 per cent. Hornblende and biotite together commonly form 15 to 23 per cent, but in a few specimens reach 35 per cent and very rarely are as low as 6 per cent. Usually, where the amount of hornblende and biotite together is between 19 and 27 per cent, hornblende predominates slightly over biotite; if the combined percentage of both constituents is 18 per cent or less biotite usually predominates over hornblende, but there are exceptions to both generalizations. Quartz commonly forms about 20 per cent but ranges from 15 to 30 per cent. Potassic feldspar is absent in about half the specimens and where present may form as much as 7 per cent. The accessory minerals include titanite, magnetite, apatite, and zircon. Titanite is variable in distribution but is usually present and may form more than 1 per cent of the rock. Apatite and magnetite may likewise locally form more than 1 per cent. A few of the quartz grains inclose abundant needles that may be rutile.

The average composition of five specimens in which hornblende exceeds biotite is given in the table on page 212 as No. 3. These rocks have a slightly higher ferromagnesian content than those shown by No. 2, in which the hornblende and biotite are about equal. No. 4 shows the average composition of eight specimens in which biotite exceeds hornblende. The ferromagnesian content of such rocks is on the average somewhat lower, 15 per cent as compared with 19 per cent, than that of the rocks in which hornblende and biotite are approximately equal and considerably lower, 15 per cent as compared with 22 per cent, than that of the rocks in which hornblende greatly exceeds biotite. The biotite granodiorite is also slightly more quartzose.

The abnormally high content of hornblende and biotite in a few of the specimens, Nos. 5 and 6, may be due in part to assimilation or reaction with inclusions of sediment and schist.

The average composition of the siliceous intrusive rocks in the Wrangell-Revillagigedo belt adjacent to the mainland batholith on the west is given as No. 7. It shows only slight difference from the average composition of the rocks of the western border of the main batholith. There is a slight increase in the percentage of potassic feldspar and an apparent decrease in hornblende, but this apparent decrease might not be substantiated if more extensive data were available. The quartz diorite of this belt grades into granodiorite in the stocks in the vicinity of Wrangell and Mitkof Islands, and this raises the average of the potassic feldspar content. The intrusive rocks of this belt are otherwise similar to the western portion of the main batholith.

The average composition of five specimens from the Wrangell-Revillagigedo belt in which biotite and hornblende are approximately equal is given as No. 8. In No. 9 is given the average of three specimens in which biotite considerably exceeds hornblende. Rocks of this type have a trifle less ferromagnesian minerals than those in which hornblende and biotite are approximately equal. The average of six specimens of biotite-quartz diorite, which forms small stocks and masses in the vicinity of Revillagigedo Island, shows a marked decrease in the total amount of ferromagnesian minerals and a preponderance of biotite almost to the exclusion of hornblende. There is a correlative increase in the amount of quartz in similar quartz diorite from the Coast Range batholith. The smaller amount of potassic feldspar in these rocks, as compared with those that contain more hornblende, is due to the fact that these were collected from a part of the Wrangell-Revillagigedo belt in which the potassic content is low, whereas most of the hornblende rocks came from the high-alkali part of the belt.

A very detailed, careful petrographic study of the composition of certain of the Upper Jurassic or Lower Cretaceous intrusive rocks in the Ketchikan and Wrangell districts has been made by the Wrights.[46] They do not state whether the specimens selected for study came from the mainland or the islands, or from both. The average composition obtained by them is that characteristic of the western border of the batholith and of the intrusive rocks in the Wrangell-Revillagigedo belt. Their results are quoted herewith:

> Although the composition of the Coast Range granodiorites varies considerably from point to point, it is desirable to ascertain the approximate average composition of the entire mass. To this end seven typical specimens were selected from different parts of the range. These specimens were chosen with special regard to their abundance and general distribution throughout the area, abnormal and rare types being disregarded altogether. Each of these specimens was studied in detail under the microscope, and a careful estimate of the relative quantity of each mineral in the rock was made from the thin sections by the Rosiwal method. Although the values thus obtained are necessarily only first approximations, they represent roughly the general mineral content of the Coast Range granodiorite.
>
> The following average mineral composition was thus obtained:

Average mineral composition of the Coast Range intrusive

Quartz	19.4	Pyrite	.1
Orthoclase	6.6	Titanite	1.3
Andesine ($Ab_{56}An_{44}$)	47.4	Epidote	3.5
Hornblende	7.6	Chlorite	.1
Biotite	11.6	Calcite	.1
Apatite	.6	Kaolin and muscovite	.8
Magnetite	.9		100.0

[46] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 63–65, 1908.

The average specific gravity, 2.77, was determined by weighing the hand specimens in air and then in water.

From these data the average chemical composition was calculated by assuming for the hornblende and biotite the compositions of like minerals from a similar rock from Butte, Mont.

Average chemical composition and norm of the Coast Range intrusive

Constituent	Per cent	Molecular ratio	Norm			
SiO_2	61.0	1.017	Q	16.14		84.26
TiO_2	1.0	.013	Or	13.32	68.12	
Al_2O_3	17.5	.171	Ab	27.78		
Fe_2O_3	1.6	.010	An	27.02		
FeO	2.7	.038	Di	4.81	10.56	15.52
MnO	.1	.001	Hy	5.75		
MgO	2.4	.060	Mt	2.32	4.29	
CaO	6.9	.123	Il	1.97		
Na_2O	3.3	.053	Ap	.67		
K_2O	2.3	.024				
H_2O	.9	.050				99.78
P_2O_5	.3	.002				
	100.0					

This chemical and mineral composition places the rock in the family of the quartz diorites, of the type tonalite according to the usual classification. In the new quantitative classification of Cross, Iddings, Pirsson, and Washington the rock is dosalic, dosalane, quardofelic, alkalicalcic, and dosodic, and belongs in Class II, order 4 (austrare), rang 3 (tonalase), and subrang 4 (tonalose). In short, it is tonalose of the ordinary type.

The amount of titanite is unusual and is characteristic of many of the Coast Range intrusives. The highly lustrous, well-shaped crystals of this mineral glisten in the sunlight and attract the attention of the most casual observer. The hornblende occurs usually in dark prismatic crystals, noticeable for the excellent prismatic cleavage and the lack of terminal faces. Many biotite flakes are hexagonal and deep brown in transmitted light. A few apatite crystals are visible to the unaided eye, but this mineral occurs generally in fine hexagonal crystals of microscopic dimensions. Pale-green veinlets of secondary epidote, which follow fracture planes in the granodiorite, are not rare.

These even-grained rocks usually have the normal, sharply defined, granitoid texture. However, gradations to holocrystalline porphyritic phases, due to the superior development of the feldspars, occur. Gneissic structure is common near the western margin of the Coast Range belt. In some places the development of gneissic structure in the granite has been so far advanced and the recrystallization of the neighboring invaded sediments to gneiss has been so thorough that it is difficult to define the precise limits of the original intrusive granite.

A chemical analysis of a composite sample of 14 specimens collected by Buddington from the western part of the Coast Range batholith and from outlying masses is given below:

Chemical analysis of composite sample of quartz diorite

[J. G. Fairchild, analyst]

Analysis		Norm	
SiO_2	59.55	Quartz	10.59
Al_2O_3	16.18	Orthoclase	15.57
Fe_2O_3	1.94	Albite	28.82
FeO	5.61	Anorthite	20.85
MgO	2.86	Diopside	4.39
CaO	6.26	Hypersthene	13.62
Na_2O	3.40	Titanite	2.37
K_2O	2.62	Apatite	.79
H_2O-	.04	Magnetite	2.79
H_2O+	.82		
TiO_2	.96		99.79
P_2O_5	.26		
	100.50		

Only four specimens of quartz diorite from the Prince of Wales-Chichagof belt were studied. These are given in the table on page 212 as No. 12. They differ from the Coast Range type in that hornblende is the predominant ferromagnesian mineral, even where the combined percentage is less than 15 per cent. They are essentially more quartzose and less ferromagnesian mineral variants of dioritic masses, and the data are not sufficiently extensive to warrant detailed discussion.

Four specimens of quartz diorite from Chichagof Island are similar to those of the Coast Range batholith. Their average composition is given as No. 13. Hornblende usually exceeds biotite in these rocks except where their combined percentage is 18 or less. The rocks are slightly more basic and less quartzose than the normal Coast Range type. Magnetite averages 1 per cent or more in these rocks and seems to be slightly more abundant on the average than in any of the other belts in which quartz diorite occurs.

The average approximate mineral composition of seven specimens of quartz diorite from Baranof Island is given as No. 14. Quartz diorite appears to be the predominant type of intrusive rock on this island. It is more quartzose and has a far smaller percentage of ferromagnesian minerals than the normal Coast Range type of quartz diorite. Biotite commonly predominates over hornblende, but there are exceptions. The ferromagnesian minerals together form 6 to 14 per cent, andesine 57 to 75 per cent, quartz usually 20 to 30 per cent, and potassic feldspar from a trace to 8 per cent. The accessory minerals include magnetite, apatite, titanite, and zircon, but they are usually small in amount.

The average composition of three specimens of biotite-quartz diorite from Baranof Island is given as No. 15. The total ferromagnesian content is lower than the average, quartz is higher, and biotite preponderates almost to the exclusion of hornblende. The percentage of accessory minerals is low.

Approximate mineral composition of quartz diorite in southeastern Alaska

		Andesine	Hornblende	Biotite	Quartz	Potassic feldspar	Accessory minerals
	COAST RANGE BATHOLITH						
1	Average of 21 specimens from west border of Coast Range batholith	54	11	12	20	2	1+
2	Average of 4 specimens; hornblende and biotite approximately equal	59	10.5	8.5	19	1	2
3	Average of 5 specimens; hornblende in excess of biotite	54.5	15	7	19	3	1.5
4	Average of 8 specimens; biotite in excess of hornblende	59	3	12	23	2	1
5	Average of 2 highly ferromagnesian specimens; hornblende in excess of biotite	44.5	22	14	18	------	1.5
6	Average of 3 highly ferromagnesian specimens; biotite in excess of hornblende	43.5	12	22	19	2	1.5
	WRANGELL-REVILLAGIGEDO BELT						
7	Average of 20 specimens	54	8	11.5	19	6.5	1
8	Average of 5 specimens; biotite and hornblende approximately equal	54.5	9	10.5	19	6	1
9	Average of 3 specimens; biotite in excess of hornblende	56.5	6	12.5	18	6	1
10	Average of 6 specimens; biotite greatly in excess of hornblende	63	1.5	10	24	1	.5
11	Average of 2 highly ferromagnesian specimens	39	17	19	17	7	1
	PRINCE OF WALES-CHICHAGOF BELT						
12	Average of 4 specimens, Prince of Wales Island	65	7	3	22	2	1
13	Average of 4 specimens, Chichagof Island	56	13.5	11	16.5	1	2
	DALL-BARANOF BELT						
14	Average of 7 specimens, Baranof Island	62	3.5	5	23.5	5	1
15	Average of 3 specimens, Baranof Island; biotite in excess of hornblende	26	1	6	29	1	.5

A study of the mineral relations of the diorite to the quartz diorite as given in the table on page 213 shows that up to a certain limit an increase of quartz in the diorite, though it may be accompanied by a decrease in the amount of ferromagnesian minerals, particularly hornblende, is not normally accompanied by a change of hornblende to biotite; but on the other hand, in the change from quartzose diorite to quartz diorite there is normally a corresponding change of part of the hornblende to biotite. A study of the mineral relations within the quartz diorite also shows that the amount of hornblende or hornblende and biotite combined may vary markedly though the amount of quartz remains constant. The data are inadequate for determining positively whether or not a decrease in the quantity of ferromagnesian minerals within the andesine-quartz diorite is accompanied by a slightly increased sodic content of the plagioclase.

Average mineral composition of diorite and quartz diorite of southeastern Alaska

	Andesine	Hornblende	Biotite	Potassic feldspar	Quartz	Accessory minerals
28 specimens of diorite from Prince of Wales-Chichagof belt	62.5	27	2.5	1.5	4	2.5
11 specimens of quartzose diorite from Prince of Wales-Chichagof belt	63	23	1	1	10	2
21 specimens of quartz diorite from west border of Coast Range batholith	54	11	12	2	20	1+
20 specimens of quartz diorite from Wrangell-Revillagigedo belt	54	8	11.5	6.5	19	1
7 specimens of quartz diorite from Baranof Island	62	3.5	5	5	23.5	1
7 specimens of quartz diorite of Coast Range batholith near Vancouver, British Columbia[a]	64.5	9.6	1.5	------	21.7	3−

[a] Averaged from data given by Burwash, E. M. J., The geology of Vancouver and vicinity, Univ. Chicago Press, 1918.

Albite and oligoclase quartz diorites, so far as known, form a very minor portion of the Upper Jurassic or Lower Cretaceous intrusive rocks and are restricted to very small stocks, to dikes, or to local marginal variants of larger dioritic stocks. The mineral composition of several specimens of rock of this type is given in the table below. The albite-quartz diorite locally varies toward albite diorite, as in No. 7, and toward albite granodiorite, as in Nos. 3 and 6. Accessory minerals include magnetite, titanite, apatite, and zircon, but they are usually sparse.

Analyses of sodic quartz diorite from Alexander Archipelago

		Oligoclase	Albite	Potassic feldspar	Quartz	Hornblende	Biotite
1	Average of 3 specimens of sodic quartz diorite, Dall and Baker Islands	63	------	1	32	0.5	2.5
2	Double Island, Clarence Strait	------	73	2	25	------	------
3	Point Agassiz, Frederick Sound	------	71	5	24	------	------
4	About 4 miles south of Hadley, Prince of Wales Island[a]	------	70	------	20	------	10
5	Dike north of Karta Bay, Prince of Wales Island[a]	------	68–73	------	25–30	------	------
6	South side of Kasaan Peninsula, Prince of Wales Island	------	74	5	15	5	------
7	1½ miles southeast of Boggs landing, Kasaan Peninsula, Prince of Wales Island[a]	------	[b] 90	------	10	------	------

[a] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 86, 1915.
[b] Contains 15 per cent dissolved orthoclase molecule.

The stock on Baker Island appears to be composed of a quartz diorite very low in ferromagnesian minerals, with biotite predominating almost to the exclusion of hornblende, and with the plagioclase varying from albite-oligoclase to andesine.

Albite-quartz diorite from Lisianski Strait near Miner Island and from the Porcupine Islands, off the west coast of Chichagof Island, has been described by Overbeck.[47] Albite to albite-oligoclase quartz

[47] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 109–110, 1919.

diorite also forms the country rock at the border of a stock of diorite about 4½ miles north of the head of Pinta Bay, Chichagof Island.

GRANODIORITE

Granodiorite is one of the major types of rock forming the core of the Coast Range batholith in the region under consideration, and it is found also as outlying stocks and local variants of other types of rock throughout the Alexander Archipelago and on the mainland to the northwest. The Texas batholith, a small batholith of granodiorite older than the bulk of the Coast Range intrusions, forms an area in the Salmon River district on the east side of the Coast Range batholith.

In the Wrangell and Petersburg districts stocks and sheets of granodiorite on the border line of quartz diorite in composition are found throughout a belt about 20 miles wide paralleling the main batholith of the Coast Range. This belt includes a wide strip of the mainland and the adjoining islands, comprising the eastern half of the Lindenberg Peninsula and Mitkof Island, the group of islands at the mouth of Stikine River, and Wrangell Island. Other outlying masses are found on Prince of Wales, Forrester, Dall, and Warren Islands, in the Ketchikan district, and on Chichagof Island.

The Wrights[48] have described granodiorite as forming stocks on the west side of Queen Inlet about 3 miles from the entrance point, north of Morse Glacier and at the head of Muir Inlet, Glacier Bay, at the head of the east arm of Excursion Inlet, at the south entrance to Chilkoot Inlet, and in Lituya Bay.

The granodiorite as seen in the field closely resembles the quartz diorite, and in many places the two rocks grade imperceptibly into one another. However, much of the granodiorite is of a slightly more pinkish hue, owing to the higher percentage of potassic feldspar; this is particularly true within the Coast Range batholith, where the potassic feldspar is a prominent component.

The predominant type of rock is a hornblende-biotite granodiorite, though locally biotite alone or hornblende alone may constitute practically the whole amount of ferromagnesian mineral. In places within the core of the Coast Range batholith and the intrusive masses of the Alexander Archipelago there are more siliceous alkalic variants, such as oligoclase granodiorite with very low ferromagnesian content. In the Alexander Archipelago such masses usually form small stocks, local marginal variants, or dikes.

Very rarely an augitic variant of the andesine granodiorite is found. The predominant granodiorite is prevailingly a medium-grained light-colored rock, mottled with black ferromagnesian minerals, with locally a tendency toward an inconspicuous porphyritic or

[48] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

inequigranular texture, and usually a gneissoid structure. With the naked eye the rock is seen to consist of plagioclase, potassic feldspar, quartz, biotite, hornblende, and scattered crystals of titanite. The feldspar grains are usually about 3 to 5 millimeters in length, but the average grain diameter is about 1 to 2 millimeters. Near the bordering schist, or near inclusions of schist, the rock may contain a little disseminated pyrite or pyrrhotite and more rarely minute garnets. Locally, also, as a result of reaction with inclusions of hornblende gneiss, the rock carries a higher percentage of hornblende than normally.

When examined in thin section, the texture is seen to be hypidiomorphic granular, with local traces of granulation of the feldspars and cataclastic structure. Where a porphyritic texture is developed the phenocrysts are usually andesine feldspar, but microcline phenocrysts as much as 2 inches in length are common in a granodiorite mass which forms the mountains about 4½ miles northeast of Spray Island, Thomas Bay, and microperthite locally occurs in part as phenocrysts.

The plagioclase feldspar crystals are prevailingly subhedral, with a length several times greater than the width. They commonly show a conspicuous zonal structure, particularly in the border facies of the quartz diorite masses. The plagioclase ranges from $Ab_{55}An_{45}$ to $Ab_{80}An_{20}$. In the low-potash feldspar facies the plagioclase averages about andesine (Ab_6An_4), and in the high-potash feldspar facies it probably averages about oligoclase-andesine. The hornblende has a prismatic development without terminal faces and is associated with biotite and accessory minerals. The biotite occurs in chunky crystals with frayed ends and is deeply pleochroic from light yellowish-brown to deep chestnut-brown. The potassic feldspars include microperthite, microcline, and locally orthoclase.

Near contacts with schist inclusions and usually in the outlying masses on the islands the rock is slightly altered. In such places the plagioclase is flecked with sericite or muscovite fibers and zoisite or epidote rods and grains; and the hornblende may be partly replaced by epidote. The unaltered portions of the minerals are fresh and clear. Epidote and zoisite usually form several per cent of the rock. The Horn Cliffs stock and several masses in Hobart Bay show an unusually high degree of alteration; the plagioclase is almost entirely replaced by well-crystallized plates of muscovite and grains of epidote with a little zoisite, but the microperthite is entirely unaffected.

The approximate average mineral composition of specimens of granodiorite from the core of the Coast Range batholith is given in the table on page 217 at Nos. 1 to 4. Plagioclase is the predominant mineral and ranges from 38 to 60 per cent but usually runs between 38 and 46 per cent. Quartz ranges from 15 to 30 per cent but is usually near 20 per cent. Potassic feldspar ranges from 10 to 28 per cent but is predominantly between 13 and 20 per cent. Hornblende and biotite together range from 8 to 25 per cent, but are predominantly between 10 and 18 per cent; when the combined percentage of the ferromagnesian minerals is greater than 13 per cent hornblende usually exceeds or equals biotite, and when the combined percentage is 12 or less biotite usually exceeds hornblende, but exceptions are common. Hornblende predominantly ranges from 0 to 14 per cent, and biotite from 0 to 15 per cent. The plagioclase usually ranges in composition from oligoclase to andesine, and the average for a given rock may be an oligoclase-andesine.

The accessory minerals are the same as those of the quartz diorite—magnetite, apatite, titanite, and zircon. Magnetite is usually the most abundant accessory mineral and may form as much as 2 per cent of the rock. Titanite is usually present, but is variable in concentration; it may form 1 per cent or more of the rock. Apatite is always present and locally may form 1 per cent or more. Zircon is usually very minor in amount.

A chemical analysis of a composite sample of six specimens of granodiorite from the core of the Coast Range batholith in the Hyder district is given below.

Chemical analysis of composite sample of granodiorite from the Coast Range batholith

[J. G. Fairchild, analyst]

Analysis		Norm	
SiO_2	64.87	Quartz	16.98
Al_2O_3	16.26	Orthoclase	19.46
Fe_2O_3	1.51	Albite	32.49
FeO	2.89	Anorthite	17.24
MgO	1.72	Diopside	2.17
CaO	4.72	Hypersthene	7.36
Na_2O	3.82	Titanite	1.78
K_2O	3.30	Apatite	.45
H_2O-	.00	Magnetite	2.09
H_2O+	.28		
TiO_2	.70		100.02
P_2O_5	.19		
	100.26		

In the Hyder district, just west of the international boundary, along Boundary Glacier, there is a mass of granodiorite which constitutes a contact facies of the quartz monzonite that here forms the eastern portion of the Coast Range batholith. It is not certain whether this granodiorite is an apophysis or a stock. Its approximate average composition is given in the table on page 217 as No. 5. It differs from the granodiorite of the core of the batholith in having less ferromagnesian mineral and a little more plagioclase.

The average composition of specimens of granodiorite from the Wrangell-Revillagigedo belt of outlying stocks and batholiths adjacent to the main batholith is given in the table below as Nos. 6 to 8. In comparison with the more abundant granodiorite of the Coast Range batholith, these outlying stocks are considerably more basic and less alkalic. The combined percentage of hornblende and biotite is considerably higher and that of potassic feldspars considerably lower. In average composition the plagioclase is an andesine. Andesine ranges from 40 to 60 per cent, quartz from 15 to 25 per cent, combined ferromagnesian minerals from 13 to 30 per cent, and potassic feldspars from 7 to 10 per cent. The accessory minerals are similar to those in the granodiorite of the Coast Range batholith. Where the combined percentage of ferromagnesian minerals is 18 per cent or more, biotite is usually only slightly in excess of hornblende, if at all; where the combined percentage is less than 18, biotite commonly greatly exceeds hornblende; but there are numerous exceptions to both generalizations. Hornblende ranges from 0 to 15 per cent, and biotite from 11 to 18 per cent.

The approximate average mineral composition of nine specimens of granodiorite from the Alexander Archipelago west of the Wrangell-Revillagigedo belt is given in the table as No. 9. The average shows that the rocks are relatively low in ferromagnesian minerals and high in andesine. The data are too meager to warrant further discussion, as the average might be considerably affected by more samples.

Approximate mineral composition of granodiorite in southeastern Alaska

		Andesine	Hornblende	Biotite	Quartz	Potassic feldspar	Accessory minerals
	COAST RANGE BATHOLITH						
1	Average of 15 specimens	[a]46	8.5	7.5	21.5	15	2
2	Average of 5 specimens, hornblende in excess of biotite	45.5	12	2	19	20	1.5
3	Average of 4 specimens, hornblende and biotite approximately equal	40	10	9	21.5	17.5	2
4	Average of 6 specimens, biotite in excess over hornblende	46	2	10	24	17	1
5	Average of 5 specimens of granodiorite stock on east side of Coast Range batholith, in the Hyder District	48	4	6	19.5	17	2.5
	WRANGELL-REVILLAGIGEDO BELT						
6	Average of 10 specimens	50.5	7	13	18	10	1.5
7	Average of 5 specimens, biotite slightly in excess of hornblende	49	10	13	16.5	10	1.5
8	Average of 4 specimens, biotite in great excess over hornblende	54	2	13	20	10	1
	ALEXANDER ARCHIPELAGO, WEST OF WRANGELL-REVILLAGIGEDO BELT						
9	Average of 9 specimens	56	7	5	19	12	1

[a] Oligoclase-andesine.

Locally an augitic variant of the usual hornblende-biotite-andesine granodiorite is found. One rock of this type has been described by Merwin [49] from samples collected north of Green Mountain, Prince of Wales Island, and another occurs in a sill in injection gneiss north of Duck Island, Bradfield Canal. Their composition is given in the table below.

Approximate mineral composition of augite granodiorite

	1	2		1	2
Andesine	47	40	Hornblende	8	10
Quartz	11	10	Augite	9	10
Potassic feldspars	24	25	Accessory minerals	1	5

1. Sill in injection gneiss, north of Duck Island, Bradfield Canal.
2. North of Green Mountain, Prince of Wales Island. H. E. Merwin, in Wright, C. W., U. S. Geol. Survey Prof. Paper 87, pp. 35–36, 1915.

Oligoclase granodiorite is found throughout the Alexander Archipelago as very small stocks, as dikes, or as local variants of the andesine granodiorite. Usually in the stocks or dikes it is intensely altered and replaced by muscovite and epidote. It grades into oligoclase and albite-quartz diorites and into andesine granodiorite. The combined percentage of hornblende and biotite is low, and accessory minerals are relatively sparse. A study was made of specimens of oligoclase granodiorite from four widely separated localities on Chichagof Island, Dall Island, Revillagigedo Island, and Portland Canal. The average composition of two specimens from Tenakee, Chichagof Island, is given in the table on page 219 as No. 1. These rocks are characterized by a very high content of quartz and very low content of ferromagnesian minerals, and accessory minerals are sparse. The rock that forms the small islets at the entrance of Port Bazan, Dall Island, is of almost the same composition.

On the west side of Portland Canal, about halfway between Hidden Inlet and Edward Passage, there is a mass of light-colored oligoclase granodiorite which brecciated and injected a block of schist. The composition of this rock is given in the table as No. 2. The oligoclase is Ab_4An_1, and the potassic feldspar is microperthite. The accessories include apatite, zircon, titanite, and magnetite. This rock from the core of the Coast Range batholith is similar to those from the Alexander Archipelago just described. A specimen from Revillagigedo Island is given as No. 3.

[49] Merwin, H. E., in Wright, C. W., Geology of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 35, 1915.

Approximate mineral composition of oligoclase granodiorite from southeastern Alaska

		Oligoclase	Potassic feldspar	Quartz	Hornblende	Biotite	Accessory minerals
1	Average of 2 specimens from Tenakee, Chichagof Island	53	10	33	2	1.5	------
2	West side of Portland Canal, halfway between Hidden Inlet and Edward Passage	49	15	34	------	1.5	0.5
3	9 miles from head of Carroll Inlet, Revillagigedo Island	65	11	20	------	4	------

The Texas batholith, a small batholith of granodiorite, occupies an area in the Salmon River district at the head of Portland Canal on the east side of the Coast Range batholith. This mass of granodiorite is intruded into graywacke, slate, tuff, and breccia of probable Jurassic age, and is itself intruded by apophyses and dikes genetically connected with the quartz monzonite and granodiorite of the Coast Range batholith. It is therefore older than the bulk of the intrusive material of the Coast Range batholith but still belongs to the series of Jurassic or Cretaceous intrusions. It is grayer and more gneissoid than the younger granodiorite and quartz monzonite, and near its contact with those rocks is mashed and crushed for a width of a mile or more as a result of the pressure exerted by their intrusion. The granodiorite of the Texas batholith is well exposed along Texas Creek and its tributaries. The average composition of this granodiorite is given in the table below as No. 1. The ferromagnesian minerals are so altered in most of the rock that a distinction between hornblende and biotite can not be made. In the few sections in which this can be done hornblende predominates and biotite forms from 2 to 5 per cent of the rock. Titanite and magnetite locally may form as much as 1 per cent each, and apatite is usually present as an accessory mineral.

The granodiorite of the Texas batholith locally develops a less alkalic facies at or near the contact with the country rock, as at the head of the West Fork of Texas Creek. The average composition of this type is given in the table as No. 2. A still more basic facies is developed locally within a few feet of the contact, such as the monzodiorite whose composition is given as No. 3.

Approximate mineral composition of granodiorite of the Texas batholith

		Andesine	Hornblende	Biotite	Quartz	Potassic feldspar	Accessory minerals
1	Average of 22 representative specimens	48	12.5		19	20	0.5
2	Quartz diorite facies near western end at head of West Fork, Texas Creek	60	14.5		20	5	.5
3	Monzodiorite a few feet below contact with roof of graywacke	66	17.4	1.6	4	11	------

QUARTZ MONZONITE

Quartz monzonite is one of the three major types of rock forming the Coast Range batholith. Between Stikine River and Portland Canal it constitutes a belt 10 to 15 miles wide, and on Portland Canal it forms wide belts within the core of the batholith. It is very rare in the intrusive rock of the Alexander Archipelago but has been found as local variants of the other prominent types there.

The average composition of 16 specimens from the northeastern belt of the Coast Range batholith is given in the table on page 221 as No. 1. Immediately adjacent to the contact the quartz monzonite is locally less alkalic or siliceous and may carry more ferromagnesian minerals, as shown by No. 2.

The quartz monzonite of the central part of the core (see No. 3) is in general highest in hornblende and biotite (10.52 per cent), and hornblende is greater in amount than biotite. In the quartz monzonite of the eastern part of the core, on Portland Canal (see No. 4), the total amount of hornblende and biotite (8 per cent) is smaller than in the central core, and biotite (5 per cent) exceeds hornblende (3 per cent). Along the eastern flank of the batholith (see No. 1) the total amount of ferromagnesian minerals is still less (4 per cent), hornblende is practically absent and quartz is high.

In the border belt also the quartz monzonite varies considerably, as is indicated in Nos. 5, 6, and 7. The combined percentage of ferromagnesian minerals is much lower in the quartz monzonite than in the granodiorite and the content of potassic feldspar is, of course, much higher.

Along Portland Canal the potassic feldspar of the quartz monzonite is microperthite (hypoperthite), and only locally does it show microcline structure; it never shows more than a slight amount of the plagioclase phase, and in some rocks none. The gridiron structure of microcline is, however, usually present in the potassic feldspar of the quartz monzonite of the eastern belt.

The plagioclase of the quartz monzonite along Portland Canal appears to average about oligoclase-andesine; along Stikine and Chickamin Rivers it averages oligoclase. The plagioclase is markedly zoned in the belt between Portland Canal and Chickamin River but zoning is inconspicuous on Stikine River. Myrmekite is only rarely present in more than slight amounts.

The biotite occurs as chunky crystals and is in many places intergrown with thin chlorite leaves as a result of partial alteration, or locally it is wholly altered to chlorite.

The accessory minerals are more abundant in the quartz monzonites high in ferromagnesian minerals than in the more siliceous and alkalic facies. Magnetite forms on the average about half of the accessory minerals, and titanite, apatite, and zircon the other half. Zircon is relatively rare. Magnetite appears to be more common than in the quartz diorite. One specimen of quartz monzonite contained 2 per cent of titanite and a small percentage of magnetite and apatite with accessory zircon.

The quartz monzonite on Devilfish Bay, Kosciusko Island, is a marginal variant of a large stock of dioritic character whose predominant composition is unknown. This facies is unusually quartzose and contains about 5 per cent of magnetite and 1 per cent of titanite. It contains both microperthite and microcline, the latter in interstitial relations. Apatite, magnetite, and titanite are present as accessory minerals. The plagioclase is a very sodic andesine.

Approximate average mineral composition of quartz monzonite from southeastern Alaska

		Oligoclase-andesine	Potassic feldspar	Quartz	Hornblende	Biotite	Magnetite	Titanite	Apatite
1	16 specimens from east border facies of batholith between Portland Canal and Stikine River	37.3	32.7	24.5	0.1	4	0.6	0.5	0.25
2	2 specimens of chilled contact part of quartz monzonite on northeastern border	45	30	14	4	6	------	1.0	------
3	9 specimens from core of Coast Range batholith	37	30.5	20	6.5	4	------	2.0	------
4	6 specimens from eastern part of core of batholith, Portland Canal	38	32	20	3	5	------	2.0	------
5	4 specimens from northwest of Hyder	39	30.5	23.75	------	5	.75	.9	.20
6	4 specimens from valley of Greenpoint Glacier	36	34	26.5	------	2.5	------	1.0	------
7	5 specimens from east part of batholith, along Stikine River	31	37	30	------	1.5	------	.5	------
8	Dike rock cutting schist on east side of Hetta Lake, Prince of Wales Island [a]	50	30	15	(b)	(b)	(b)	(b)	------

[a] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 36, 1915.

[b] 5 per cent of accessory minerals, including hornblende, biotite, diopside, magnetite, and titanite.

A chemical analysis of a composite sample of six specimens of quartz monzonite from the Hyder district is given below:

Chemical analysis of composite sample of quartz monzonite from eastern part of Coast Range batholith, Hyder district

[J. G. Fairchild, analyst]

Analysis		Norm	
SiO_2	70.86	Quartz	24.72
Al_2O_3	14.96	Orthoclase	27.24
Fe_2O_3	1.06	Albite	33.01
FeO	1.43	Anorthite	9.73
MgO	.41	Hypersthene	2.72
CaO	2.23	Titanite	.79
Na_2O	3.90	Apatite	.35
K_2O	4.60	Magnetite	1.52
H_2O-	.00		
H_2O+	.40		100.08
TiO_2	.34		
P_2O_5	.11		
	100.30		

GRANITE

Granite occurs as stocks throughout the Alexander Archipelago and to the northwest, but it forms only a minor element in the intrusive complex. In all places so far described it bears an intrusive relation to the Wrangell-Revillagigedo belt of metamorphic rocks. It appears to be very rarely present within the Coast Range batholith.

In the Ketchikan district Chapin has mapped and described large masses of granite occupying the central part of Annette Island and a part of the south end of Prince of Wales Island. Small bodies of granite are found on Gravina Island and about a mile north of Hadley, on the Kasaan Peninsula, Prince of Wales Island.

Large masses of granitic rock occur in the Wrangell district, but it is not positively known whether they should be grouped with the Upper Jurassic or Lower Cretaceous intrusive rocks of the Coast Range or with the Tertiary intrusive rocks. They comprise granite, granite porphyry, and rhyolite porphyry and occur in a belt that extends from the northwest end of Zarembo Island southeast across the central part of Etolin Island to Ernest Sound. Small stocks of granite are found on the northwest side of Etolin Island at the second point north of Steamboat Bay and at Quiet Harbor. Near Round Point, Zarembo Island, there are small masses of granite porphyry and rhyolite porphyry intrusive into slate. The rhyolite porphyry is exceptionally miarolitic, and the volume of the druses as measured on the polished surface of a hand specimen is about 4.5 per cent. The druses range from a fraction of a centimeter to a centimeter in diameter. These druses are lined with terminated quartz crystals projecting into the cavity and are associated or flecked with many small plates of crystalline hematite (specularite). The druses are further partly or completely filled with a microcrystalline aggregate of kaolinite, usually with calcite in the center.

The stock which cuts the diorite on Etolin Island ranges from a medium-grained granite on the southeast to a granite porphyry on the northwest. The porphyry has a very prominent miarolitic structure. The druses average about 0.5 centimeter in diameter and are lined with terminated quartz crystals and well-bounded crystals of microperthite projecting into the cavities. There are also many masses of granite porphyry forming the islands in Ernest Sound. Many of these are miarolitic; and hexagonal biotite crystals are common in the druses in addition to the quartz and feldspar.

These granitic masses differ from the intrusive rocks of the Coast Range in their more massive character and miarolitic structure and in certain features of texture characteristic of volcanic rocks. They are similar to the known Tertiary granite near Point St. John, Zarembo Island. It is possible that they are either of Tertiary age or a very late phase of the Upper Jurassic or Lower Cretaceous intrusions of the Coast Range.

A sill of granite is intrusive into black slate on the southwest side of Endicott Arm, in the Juneau district, and rarely a granitic facies develops in the main Coast Range batholith, as near Tombstone Bay, Portland Canal.

A stock of granite 3 miles wide, intrusive into diorite gneiss, on the east side of the North Arm of the West Bay of Dundas Bay, on the mainland north of Cross Sound, has been described by the Wrights.[50]

The predominant mineral in the granite is a potassic feldspar which may be orthoclase, microperthite, or microcline. Microperthite is most common in the stocks of the Ketchikan and Wrangell districts. It forms 55 to 73 per cent. The plagioclase ranges from 10 to 15 per cent and is albite or albite-oligoclase. Quartz ranges from 12 to 40 per cent. The accessory minerals are usually sparse; they include magnetite, apatite, and zircon. Hornblende or biotite is usually present, but their total amount forms only a small percentage. The granites are usually of a distinctly pinker or redder hue than the dioritic and quartz dioritic types of rock.

PEGMATITE AND APLITE

Pegmatite is a facies of the Upper Jurassic or Lower Cretaceous intrusive rocks which occurs predominantly as dikes or sheets near the borders of the stocks or batholiths, either in the igneous rock itself or in the adjoining schist and country rock. It is usually considerably coarser grained than the main mass of the igneous rock. Aplite has a similar relation and mode of occurrence but is finer grained than the igneous rock with which it is associated.

In the central part of the mainland batholith, in the igneous rock itself at a distance from included slabs or blocks of schist, pegmatite and aplite are rare; but along the western margin, in the Ketchikan and Wrangell districts and the southern part of the Juneau district, they are abundant, and the adjacent schist as far north as Juneau is usually intimately penetrated by them parallel to the schistosity, so as to constitute injection gneiss over belts several miles in width.

North of Juneau, in the Eagle River and Berners Bay region, the development of aplitic and pegmatitic differentiates and the resulting injection gneisses is not so extensive as in the southern part. Near

[50] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

and in large inclusions of schist, even in the central part of the batholith, pegmatite dikes and veins are common. Where the pegmatite and aplite are not abundantly developed aplite is usually the more common; it may be found as dikes far away from the nearest igneous intrusion and widely distributed.

In the sedimentary rocks of the Hyder district around the borders and in the roof of the Texas batholith dikes of aplite and less commonly pegmatite occur within several hundred feet of the contact.

Wright, in describing the mode of occurrence of pegmatite and aplite in the neighborhood of stocks in the Copper Mountain area, Prince of Wales Island, says that they form in places a network of small dikes and stringers within a zone of fractured schist, though they are more prominent as separate dikes traversing the granitic intrusive masses. In general, pegmatite and aplite dikes are present in the borders of intrusive stocks and the adjacent metamorphic rocks in the Alexander Archipelago, but they are not plentiful.

Wright calls particular attention to the relative absence of pegmatite and aplite dikes in the intrusive rocks in the vicinity of Glacier Bay. Pegmatite is relatively more rare than aplite.

The pegmatite dikes along and near the west flank of the Coast Range batholith typically consist predominantly of albite ($Ab_{95}An_5$) to oligoclase-andesine ($Ab_{65}An_{35}$) plagioclase with quartz. Microcline or microperthite is usually present in small amounts.

The dikes are usually light colored and coarse grained, and only the common accessory minerals are present. Crystals of muscovite or of biotite are common in the pegmatite dikes along Bradfield Canal and at the head of Knygs Lake, on the mainland, and on Fools Inlet, Wrangell Island. In a typical pegmatite dike about a mile east of Bergs Basin the dominant feldspar is oligoclase-andesine (Ab_3An_1) accompanied by a little orthoclase, accessory muscovite, and about 30 per cent quartz. Most of the feldspar is untwinned, but its identification as a plagioclase may be made by its index of refraction.

Near the head of Knygs Lake on the west side there are albite pegmatite veins with abundant small miarolitic cavities in which platy hexagonal barrel-shaped crystals of prehnite about 0.75 centimeter in diameter are found. Some of the pegmatite veins here carry considerable pink orthoclase and grains of black magnetite. Others are remarkable for a graphic intergrowth of garnet and quartz interstitial to the albite feldspar.

The pegmatites of the core and the eastern part of the Coast Range batholith have not been seriously investigated. The few observations available suggest that these pegmatites, like the igneous rocks with which they are associated, are higher in potassic feldspars and are of a quartz monzonitic or granitic composition.

Aplite occurs in part as discrete dikes but for the most part as narrow veins intimately penetrating the belt of injection gneiss adjacent to the Coast Range batholith on the mainland or adjacent to some of the outlying stocks. In the discrete dikes quartz constitutes as much as 30 per cent of the rock, but in the injected veinlets whose borders fade into the adjoining schist layers quartz is present only as an accessory. In both modes of occurrence, however, the feldspars are similar. The decrease of quartz in the veinlets of the injection gneisses must be the result of reaction with the original minerals of the schist.

In composition, the aplite shows a wide range of variation similar to that of the granular igneous rocks. Such varieties as oligoclase-quartz diorite aplite, oligoclasite, quartz monzonite aplite, granite aplite, syenite aplite, and granodiorite aplite are found. The highly sodic aplites are usually found in conjunction with the more sodic granitoid rocks, such as quartz diorite and granodiorites low in potassium, and the more potassic aplites are found predominantly with granodiorite and quartz monzonite.

Near the southwestern border of the Coast Range batholith aplite dikes are common. Soda-lime feldspar is the predominant mineral in most of these aplites, and they are characteristically oligoclase-leuco-quartz diorite aplite or granodiorite aplite; or in the injection gneisses, oligoclasite (probably as a result of reaction with the sediments).

A typical specimen of aplite from sharply defined dikes in the quartz diorite south of Thomas Bay is a fine-grained white rock with a trace of porphyritic texture. (See table on p. 227, No. 1.) The aplitic material in the body of the schists of Thomas Bay is almost entirely plagioclase feldspar, ranging from oligoclase-andesine (Ab_7An_3) to andesine (Ab_6A_4) with locally a little quartz. At Thunder Point, Le Conte Bay, a sheet of aplite intrusive into hornblende schist consists almost wholly of plagioclase (Ab_7An_3) with a small percentage of quartz and shredded corroded remnants of hornblende torn from the adjoining schist. The aplitic injection gneisses of the Groundhog Basin consist almost exclusively of oligoclase-andesine ($Ab_{72}An_{28}$) with accessory hornblende, biotite, garnet, pyroxene, or epidote that have been torn from the adjoining schist and corroded or formed by reaction. Quartz is present as an accessory mineral only. Muscovite is common in many of the aplite dikes.

Typical examples of oligoclase-quartz diorite and oligoclase granodiorite aplite from the western border zone of the Coast Range batholith are given in the table as Nos. 1 to 4.

Aplite of the potassic type also occurs both as discrete dikes and as veinlets in injection gneiss of the western border zone of the batholith. Typical examples of discrete dikes are found southeast of Groundhog Basin. The rock is white and fine grained (average diameter about 0.2 millimeter); microperthite and microcline constitute the predominant feldspar and are accompanied by a little plagioclase and about 30 per cent of quartz. In the injection gneiss along Bradfield Canal, some of the aplite veinlets are composed almost exclusively of microcline and microperthite, and others of oligoclase-andesine and quartz with a trifle of orthoclase or microcline. Both types may appear in the same layers of gneiss, and in such occurrences the microcline-microperthite variety seems to be the older. Both the sodic and the potassic aplites have only a little quartz in the injection gneiss but are normally quartzose in the discrete dikes.

Analyses of typical examples of oligoclase-quartz monzonite aplite from the core and the eastern part of the Coast Range batholith are given in the table as Nos. 5, 6, and 7; of two examples of granite aplite from the eastern part of the batholith as Nos. 8 and 9; and of two examples of potassic aplite, associated with an outlying stock on Prince of Wales Island as Nos. 10 and 11.

An unusual type of granite aplite dike on the Kasaan Peninsula has been described by Wright.[51] Its composition is given as No. 12. The unusual feature is the occurrence of calcite as a primary mineral. Merwin writes that

> Two periods of crystallization can be made out. In the first period quartz, orthoclase, and a little calcite formed an even-grained mass penetrated by spider-like stringers of the mother liquor. In the second the mother liquor solidified in a partly granular, partly poikilitic mass. Orthoclase and calcite are much more abundant in the later crystallization, and the calcite is coarser grained and anhedral.

The data available on rocks within the Coast Range batholith suggest that in the aplites associated with a particular type of igneous rock the plagioclase is more sodic than that of the genetically associated rock and the percentage of potassic feldspar is higher in the aplite than in its parent rock.

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[51] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 81, 1915.

Mineral composition of typical aplite

		Plagioclase	Quartz	Potassic feldspar	Calcite	Accessory minerals
1	Oligoclase granodiorite aplite from Thomas Bay, Wrangell district	62 (Ab_6An_1	25	12	----------	-------------
2	Oligoclase-quartz diorite aplite, Port Houghton	52	36	6	----------	6 (Muscovite)
3	Oligoclase granodiorite aplite, Hobart Bay, Juneau district	45	30	22	----------	-------------
4	Oligoclase granodiorite aplite, head of Bradfield Canal, Wrangell district	57 (Ab_7An_3)	28	15	----------	-------------
5	Oligoclase-quartz monzonite aplite, 1 mile below Dirt Glacier, Stikine River	31	27	41	----------	1
6	Oligoclase-quartz monzonite aplite, head of Thumb Creek, Hyder district	28	36	35	----------	1
7	Quartz monzonite aplite, Chickamin River, 1½ miles above South Fork [a]	26	47	21	----------	6
8	Granite aplite, north side of Texas Glacier, Hyder district	14.6	34	51	----------	.4
9	Goat Mountain, near head of Chickamin River, Hyder district [a]	16	39	45	----------	-------------
10	Adamellite aplite, near Jumbo mine, Prince of Wales Island [b]	45 (Ab_4An_1 to Ab_2An_1)	8	45	----------	2
11	Alaskite aplite, Kasaan Peninsula, Prince of Wales Island [b]	10–15 (Albite)	30–55	40–50	----------	-------------
12	Calcite alaskite aplite, Kasaan Peninsula, Prince of Wales Island [b]	-------------	30	60	9	-------------

[a] Collected and described by W. B. Jewell (personal communication).
[b] Described by Merwin, H. E., in Wright, C. W., U. S. Geol. Survey Prof. Paper 87, pp. 40, 81, 1915.

The Wrights[52] state that in practically all the aplites and pegmatites in the Glacier Bay region a little orthoclase or microcline is present. Oligoclase and quartz are the predominant minerals. Hornblende, biotite, magnetite, titanite, and apatite may occur as accessory minerals.

Knopf,[53] in describing the Sitka mining district, writes:

> Pegmatite and aplite dikes accompany the quartz diorites. * * * The aplite dikes are of greater importance and are widely distributed, though nowhere present in large numbers * * * and consist essentially of andesine (Ab_2An_1) with minor amounts of biotite or hornblende. Pyrite, calcite, muscovite, and chlorite appear as secondary minerals.

In the ultrabasic rocks pegmatitic facies are restricted almost wholly to the hornblendites, but in these they are common. Predominantly they are very coarse and consist of hornblende and albite with accessory plates of biotite; some contain abundant crystals of titanite or apatite or both. Locally the veins are highly feldspathic or consist wholly of albite. In a mass of hornblendite on Mitkof Island pegmatitic facies with large plates of biotite several inches in diameter are common.

The Midway Islands, in Stephens Passage, are formed of hornblendite with abundant pegmatitic facies, consisting of very coarse columnar black hornblende; hornblende with biotite; hornblende and

[52] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).
[53] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, p. 16, 1912.

albite; hornblende with pyroxene and magnetite; hornblende and albite with abundant pyrite, apatite, and titanite; albite and epidote, or albite alone. The albite in the last-mentioned facies occurs as discrete veinlets.

One such pegmatitic facies of hornblendite consists of columnar crystals of hornblende as much as 6 inches in length and half an inch in diameter, with interstitial white albite. The basal sections of the hornblende crystals are euhedral and approximately equidimensional. The albite is almost exclusively molded against the crystal faces of the hornblende, but locally small veinlets and threads of albite break across the hornblende and slightly replace it. A little epidote and titanite are associated with the albite. The epidote is of contemporaneous crystallization and in part occurs interstitial to the hornblende and molded against its crystal facies.

Another facies is a very coarse pyroxene-hornblende rock with black hornblende predominant in crystals averaging 2 inches in length. A considerable percentage of magnetite is associated with the pyroxene. Traces of titanite, albite, and epidote occur interstitial to the hornblende and pyroxene and molded against their crystal faces. Here and there a magnetite or pyrite crystal with idiomorphic outlines occurs in the albite.

Another variety is composed of about three-fourths epidote of a pale greenish-amber color and one-fourth albite, in a granular aggregate with accessory titanite. The epidote shows crystal faces against the albite, and the albite occurs interstitial to the epidote and locally sends off thin veinlets across it.

Still another facies is predominantly a medium-grained granular aggregate of black hornblende with very abundant apatite and pyrite and idiomorphic crystals of titanite a quarter of an inch in diameter. In the weathered rock the titanite can be picked out as perfect crystals. In an albite-rich facies of this rock pyrite forms a triangular area between large albite plates, is molded against the albite, and is probably of late pegmatitic origin. A small vug with crystals of epidote occurs in the pyrite. Epidote also coats cleavage surfaces of the albite and locally replaces the albite along the border of the albite and pyrite. Apatite crystals are abundant as inclusions in the hornblende.

Pegmatitic veins consisting of hornblende and albite with hornblende predominating, of albite, of albite and biotite, of microperthite and pyroxene, and of calcite and albite occur in the ultrabasic rocks of Kane Peak, Kupreanof Island.

In the hornblendite pegmatites the accessory minerals are the first to crystallize but finish late. The order of crystallization among the accessories is apatite, magnetite, titanite. Hornblende is the first of the major minerals to form but is soon joined by albite, with a little epidote. The crystallization of the albite overlaps that of the hornblende and epidote. Locally a little pyrite succeeds the albite. This completes the distinctly pegmatitic stage. Epidote of a later generation locally replaces the hornblende and albite.

MALCHITE DIKES

In the Hyder district dikes of malchite are common in the country rock to the east and north of the eastern border of the quartz monzonite of the Coast Range batholith. They also cut granodiorite porphyry dikes, which are offshoots of the quartz monzonite or are genetically connected with it.

The malchite is a green-gray or dark-gray rock of fine grain or sparsely porphyritic felsitic texture. When examined microscopically it is seen to consist typically of small phenocrysts of plagioclase and locally of plagioclase and hornblende in a groundmass composed of a mat of plagioclase laths with subordinate green hornblende rods and a little interstitial quartz and potassic feldspar. Abundant minute crystals of magnetite are distributed throughout the groundmass, and apatite occurs here and there. The variety of the plagioclase is difficult to determine, but it appears to range from an albite-oligoclase to andesine. These dikes appear to be in part late facies of the Coast Range batholithic intrusions in this area, grading toward lamprophyres, and in part simply quickly chilled, less differentiated facies of the magma.

LAMPROPHYRE DIKES

Dikes of lamprophyre, dark green-gray to gray-black rocks of fine grain, are found at many places cutting batholithic intrusive masses and the surrounding country rock. They are locally very abundant within the Coast Range batholith. On Tracy Arm they are particularly well shown. They occur here in the quartz diorite throughout the length of the arm, but are especially abundant in certain belts—at one place 13 dikes were counted within 100 feet. They range in width from 1 foot to 10 feet. On the bare walls of the fiord they may be seen to form ribbon-like bands extending upward from sea level several thousand feet to the tops of the mountains. They are also well shown in certain belts along Portland Canal.

Spessartite, garganite, kersantite, minette, and vogesite are types of lamprophyre which have been found in this district. The predominant type is allied to spessartite; the ferromagnesian mineral is predominantly brown hornblende, and the feldspar is almost wholly the oligoclase or andesine variety of plagioclase. Lamprophyre composed of these minerals will here be classed as spessartite. Augite is present locally, and there the rock varies toward the garganite type. Brown hornblende usually forms 10 to 50 per cent of the spessartite of southeastern Alaska, but may be as high as 75 per cent or even more. Plagioclase is usually the predominant mineral. Potassic feldspar is only rarely present.

The spessartite usually consists of long prismatic rodlike crystals of brown hornblende with or without a few augite crystals, in a groundmass formed by a felt of oligoclase or andesine laths with or without associated rods of brown hornblende. Magnetite is usually present as disseminated abundant small crystals, and apatite in long, slender rods. Titanite is found occasionally. There is commonly a trace of interstitial quartz. Secondary minerals are always present and may be very prominent; they comprise calcite, chlorite, and epidote. Calcite is usually abundant in the groundmass, and much of it shows replacement relations to the other minerals, but in part it is interstitial to the plagioclases and molded against them. It must belong to a late magmatic stage and phase of alteration.

On the Commonwealth claims, about 14 miles below Hyder, on Portland Canal, a tunnel has been driven along an augite minette dike that occurs in quartz monzonite in the eastern part of the Coast Range batholith. The dike rock consists of augite and dark-brown biotite phenocrysts in a groundmass of orthoclase with accessory apatite and ilmenite. The biotite is locally altered to chlorite and secondary magnetite. The orthoclase is flecked with sericite and is partly replaced by chlorite and calcite. Augite in rods forms about two-fifths of the rock, biotite about one-fourth, and orthoclase with secondary and accessory minerals the remainder.

West of the Coast Range batholith the presence of younger Tertiary basic dikes and of older basic porphyritic dikes complicates the study of the lamprophyre and lamprophyrelike dikes, which may be genetically associated with the Upper Jurassic or Lower Cretaceous intrusive rocks. The types described include vogesite—a highly augitic variety—and spessartite, with rarely a minettelike type. Diabase dikes are locally common and in places cut the ore deposits, but many of them give no evidence as to whether they belong to the Tertiary intrusive rocks or to the Upper Jurassic or Lower Cretaceous.

A dike of hornblende minette on the inland shore of Gastineau Channel about 2 miles southeast of Juneau has been described by Spencer.[54] This rock is said to consist mainly of biotite and basaltic hornblende, with some feldspar, a small amount of augite, and accessory magnetite and titanite. Mertie reports a sodic augite minette from the west side of Lynn Canal which consists of biotite and augite, with accessory iron oxide and apatite and interstitial albite.

[54] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 19, 1906.

Lamprophyric dikes in the Eagle River region, where they are of widespread occurrence, have been described by Knopf.[55] A common variety is said to consist of phenocrysts of augite in an altered isotropic groundmass containing smaller crystals of augite and some brown hornblende. Another variety of basaltic appearance that is not so common is described as consisting of hornblende, augite, and biotite in a groundmass of brown hornblende with sporadic augite and interstitial labradorite, also accessory magnetite and apatite. Still another type consists of pyroxene, olivine, biotite, and hornblende in a matrix of analcite (?), zeolite, and probably orthoclase. Knopf[56] also describes lamprophyre dikes in the Berners Bay region, where one variety consists of augite phenocrysts in a groundmass of augite and a little biotite, brown hornblende, and interstitial labradorite, and another variety consists of hornblende phenocrysts in a much altered groundmass of plagioclase.

In the Sitka district Emerson[57] noted a spessartite dike at Hot Springs, near Sitka; F. E. Wright has determined others from the same locality to be vogesite.

A spessartite dike on the west side of Baker Island, about 1½ miles north of Veta Bay, in the Ketchikan district, consists of brown hornblende with some interstitial plagioclase and abundant minute crystals of magnetite. The hornblende occurs both as phenocrysts and in the groundmass. Sparse augite phenocrysts are also present. Merwin[58] has described a spessartite type of lamprophyre from the Copper Mountain region. It is reported to consist of 35 per cent of green hornblende, part of which occurs as phenocrysts, plagioclase (andesine to acidic labradorite), 10 per cent of magnetite, and accessory minerals.

STRUCTURE OF THE INTRUSIVE ROCKS

In the mainland batholith the rocks are prevailingly gneissoid. The banded character is most accentuated near the borders of the batholith or near inclusions within the batholith. Local schistose zones are found along intensely sheared narrow bands. In the central parts of the batholith masses of considerable extent show only an indistinct gneissic structure.

Where evidences of shearing and mashing are absent or practically so, as is usually the case, the two most distinctive gneissoid character-

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[55] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 31–32, 1912.

[56] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 18–19, 1911.

[57] Emerson, B. K., Alaska, vol. 4, p. 18, Harriman Alaska Expedition, 1904.

[58] Merwin, H. E., in Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 42, 1915.

istics are (1) the parallel dimensional orientation of the inequidimensional mineral grains, such as the more or less lath-shaped or tabular feldspars, the prismatic hornblendes, and the lenses or leaves of quartz; and (2) the relative indistinct segregation of the light and dark minerals in flat en échelon lenses or in small patches. It is noteworthy that most of the abundant biotite crystals are chunky in form and that many of them are oriented with the c axis parallel to the foliation, which is contrary to the usual orientation in secondary or recrystallized gneiss.

The gneissic structure is for the most part interpreted as having arisen during the period of crystallization of the magma and before its completion, and the rock is therefore a primary gneiss. Flowage currents, nonuniform stresses, the pressure of the shouldering effect of the intruding magma upon the walls of the batholith, and locally a gneissic structure inherited from reaction with slabs of schist have all contributed to produce the structure which we now find.

The writer examined 20 specimens of gneissoid quartz diorite from the west side of the mainland batholith between Portland Canal and Taku Inlet and found not a trace of crushed or granulated minerals in any of them. Most of the quartz shows strain shadows, and some of the biotite crystals may show distortion and slip planes, but these comprise the only evidences seen of the effects of stress upon the rocks subsequent to their consolidation.

The structure of the rocks near Behm Canal has been described by Westgate[59] as follows:

> Structural variations in the granitoid rocks are marked and have an important bearing on origin. The rocks are dominantly gneissoid. Even in the most massive types well in toward the heart of the batholith it is difficult to find ledges without some parallel structure, either a faint banding and orientation of the dark minerals or drawn-out streaks of darker rock (Schlieren). And even in these more massive parts frequent transitions take place to a conspicuously banded rock, the bands of which are commonly bent, sometimes intricately folded. These folded gneissoid granitoid rocks are not the result of mountain-making forces acting after the solidification of the rocks. * * * They result from the flow of yet unsolidified magma. * * * Sederholm[60] has likened the banding of the gneiss to twisted lines of sawdust seen on a flowing stream.
>
> The gneissic character * * * is accentuated because * * * the intrusion is not simple but took place by successive advances of somewhat different magmas. Injection of later magma along planes already determined in the earlier magma—probably not then fully consolidated—would emphasize the banded character of the resultant complex.

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59 Westgate, L. G., The geology and mineral resources of the area east of Behm Canal (unpublished manuscript).

60 Sederholm, J. J., Über ptygmatische Faltungen: Neues Jahrb., Beilage-Band 36, pp. 491–512, 1913.

It is certain, however, that the mainland batholith has been subjected to very considerable stresses subsequent to its complete consolidation. Yielding has taken place through extensive mashing along local belts or zones, which may be of considerable width and great length (75 miles or more), or through intensive shearing along narrow zones, or through slipping along many planes of various orientation throughout a zone. In most of the specimens examined in thin section the quartz shows strain shadows or locally and less commonly is irregularly broken into ribbons or has a sutured or denticulate texture typical of recrystallization. In specimens from the shear zones the quartz is mashed and the feldspar grains are extensively comminuted on their borders.

A belt of highly mashed rock 15 miles or so wide is crossed by Stikine River from the head of Little Canyon to and below Flood Glacier. The varieties of rock included within this belt are diorite, quartz diorite, granodiorite, quartz monzonite, and granite.

In 15 specimens chosen by the writer at intervals along the west side of Portland Canal 4 show very pronounced cataclastic structure, 7 show neither crush phenomena nor strain shadows in quartz, and 4 show only strain shadows in quartz. The writer found no evident relation between the type of rock and the degree of crushing or between the degree of crushing and proximity to the border of the batholith. In the shear zones the quartz is completely granulated, as is also a very considerable part of the peripheral zone of the feldspar.

Knopf [61] has described a rock in which cataclastic effects, resulting from stress acting upon the completely consolidated igneous rock with its primary gneissoid structure, predominate and accentuate the original gneissic character:

> The gneissic structure of the quartz diorite, like the foliation of the adjoining schists, trends northwest and southeast and dips steeply to the northeast at about 70°. It is in part a primary structure assumed by the magma during solidification but is mainly a result of dynamic metamorphism, the most obvious effect of which has been the reduction of the large feldspar crystals to augen. In a few places the feldspars were sufficiently crushed and drawn out to form narrow white bands. The foliation of the gneiss is most pronounced near the contact, where it is in places so strongly developed as to form a black diorite schist carrying porphyritic eyes of feldspar; toward the northeast the gneissic structure gradually and progressively gives way to the massive granular texture characteristic of the normal granitic rocks.

The structure of the stocks and batholiths of the Alexander Archipelago is variable and depends upon several factors. The margins of the masses show locally a gneissoid structure. The granodiorite is usually gneissoid, whereas the diorite and gabbro are more commonly

[61] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 23–24, 1912.

predominantly massive. In the Glacier Bay region, also, the Wrights[62] noted that, with the exception of a few bodies of diorite gneiss, the diorites are fairly fresh, massive rocks. Knopf[63] has described the Jualin diorite stock in the Berners Bay area and an augite diorite stock in the Eagle River area[64] as generally massive. In describing the geology of the Sitka district Knopf[65] writes: "The intrusive rocks are commonly fresh and unaltered and are little affected by schistose or gneissic structure. The marginal portions of some of the intrusive masses, however, show gneissic foliation."

The outlying intrusive masses, like the mainland batholith, also exhibit local shear zones in which the minerals are crushed and mashed. On the west coast of Chichagof Island, according to Overbeck,[66] most of the area mapped is not far from the contact between the intrusive igneous rocks and other rocks, and consequently the rocks of the intrusive body are greatly sheared. Though this is a common phenomenon it is far from being uniformly true.

At some places west of the Coast Range batholith extensive belts, including intrusive igneous stocks, dikes, and sills constitute a local shear zone or zone of close folding; the larger masses of igneous rocks may show considerable mashing, and the thin sills may be closely folded together with the schists.

In a belt adjacent to Stephens Passage, from Port Houghton north to Point Astley on the mainland, outlying stocks of igneous rocks have been considerably crushed and recrystallized and altered. The inclosing rocks are likewise intensely sheared and plicated. The extension of this belt of shearing is apparently indicated by the mashed character of the intrusive masses on Grand Island and near Point Arden, Admiralty Island. The pegmatites are mashed as well as the main bodies of intrusive rock. The Tertiary basaltic dikes, however, are unaffected.

The Wrights[67] describe the quartz diorite on the west side of Sullivan Island and granodiorite at the south entrance to Chilkat Inlet as much crushed and suggest that this crushing is the result of movement along a great shearing plane, in the course of which the west shore of Lynn Canal rose relatively to the east shore.

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[62] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

[63] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 466, pp. 13–14, 1911.

[64] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 29–30, 1912.

[65] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, p. 15, 1912.

[66] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, p. 109, 1919.

[67] Wright, F. E. and C. W., The geology of Glacier and Lituya Bays (unpublished manuscript).

These zones evidently mark an area of unusually intense shearing of an age subsequent to that of the Upper Jurassic or Lower Cretaceous intrusions.

The ultrabasic rocks are in general massive, and though some facies may show a gneissic structure they are usually without any evidences of crushing; locally, however, they are severely sheared and mashed. The diorites are almost uniformly massive, and only rarely are mashed. The hornblendites are generally massive in the coarser facies but may be slightly gneissoid in the medium-grained facies. The gabbroic hornblendites usually show a well-developed gneissic structure due to flowage.

The granites are uniformly massive.

The structure of the pegmatite and aplite dikes is variable, some being gneissoid and mashed and others massive. In thin section some show crushing of the feldspars, undulatory extinction in the quartz and feldspars, and recrystallized quartz; others show a massive texture of primary crystallization without any evidence of crushing or gneissic character.

Knopf[68] found the same relations in the Eagle River region. He writes: "A period of dynamic deformation set in during the pegmatitic stage, for some of the pegmatite and aplite dikes are sheared like the gneiss, but others have escaped the general dynamic metamorphism."

ORIGIN OF VARIATIONS IN INTRUSIVE ROCKS

The various types here described as Upper Jurassic or Lower Cretaceous intrusive rock all appear to cut the Jurassic or Cretaceous formations and to be unconformable beneath the Eocene. They must, therefore, have been intruded after the formation of the Jurassic or Cretaceous beds which they cut and before the Eocene epoch. The possible length of time for their intrusion is thus restricted to a relatively short period geologically, though this period may have been very long in terms of years. Because these rocks belong to the same general period of intrusion and because their composition and character are such as to suggest genetic relations, they are commonly believed to have been derived through very complicated interaction of processes and differentiation from an original common magma.

We do not yet know the processes entering into magmatic differentiation sufficiently well to solve the problems of origin of a suite of simple rock types of the same magmatic period, even when we have adequate data as to the rock types and their interrelations, and as the data on the types and interrelations of the Upper Jurassic or

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[68] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 14, 1912.

Lower Cretaceous intrusive rocks in southeastern Alaska are wholly inadequate, we are therefore not in a position to speak with any definiteness as to their origin. It is desirable, however, to bring out certain interrelations which may have a bearing upon any theory of magmatic differentiation proposed to explain the origin of these various types and associations of rocks. Two major problems arise in this connection; one concerns the amount and character of differentiation in place; the other the number, importance, and relations of successive intrusions.

The types of the Upper Jurassic or Lower Cretaceous intrusive rocks of southeastern Alaska are essentially similar qualitatively and quantitatively to those characteristic of the intrusive rocks belonging to the same period far to the northwest and to the southeast. The genetic problems involved are therefore essentially the same; hence the data accumulated and the inferences drawn by workers elsewhere within the Coast Range and the adjoining islands are pertinent to the consideration of the origin of the intrusive rocks in this area.

DIFFERENTIATION IN PLACE

Significant data covering variations within a single mass of the Upper Jurassic or Lower Cretaceous intrusive rocks have been established by workers in other areas.

Burwash [69] writes of the southern part of the mainland batholith:

> Quartz diorite is easily the dominant type for the area under consideration. The more quartzose phases occur at a distance from Paleozoic contacts, and the more basic as the contacts are approached. This marginal differentiation generally takes the form of a decrease in quartz and an increase in hornblende. * * * In some cases, as in the vicinity of The Lions, the hornblende becomes so predominant that the rock over small areas might be properly described as hornblendite. This type of differentiation occurs in contact with the basic eruptives and limestones of the Texadan series, and where it occurs at a distance from roof pendants it probably indicates that the roof originally existed in close proximity to the remaining differentiation rocks.

Bancroft [70] in discussing the geology of the intrusives of the Coast Range in the vicinity of the Strait of Georgia and Queen Charlotte Sound, B. C., writes:

> In general, the sequence of intrusions has been marked by an increasing acidity of the magma with a corresponding decrease in the specific gravity. The hornblendites and some of the larger bodies of dark basic rocks are the oldest, while the light-colored quartz diorites, granodiorites, and granites are the youngest. As a rule, differentiation has likewise taken place in the individual batholiths in such a manner as to form a peripheral zone of rela-

[69] Burwash, E. M. J., The geology of Vancouver and vicinity, p. 50, Univ. Chicago Press, 1918.

[70] Bancroft, J. A., Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B. C.: Canada Geol. Survey Mem. 23, p. 103, 1913.

tively basic rocks such as dark diorites and gabbros, which shade gradually into an interior of more siliceous and homogeneous character. For example, near Kwalate Point in Knight Inlet the hornblendites, which seem to be an ultrabasic marginal modification of the oldest batholiths within this area, pass gradually into a dark diorite.

Wright[71] and Merwin have described in detail certain of the intrusive rocks on the south end of Prince of Wales Island. In the vicinity of Hetta Inlet the main batholiths of Copper Mountain and Beaver Mountain range in composition from granodiorite to monzonite. Near the contacts the rocks are locally syenitic. Gabbro (in part hornblendite) and quartz diorite are local variants. On the Kasaan Peninsula the main intrusive rock is diorite, with accessory quartz. Local variants include gabbro, monzonite, albite, diorite, and a little granite (sodic and potassic-sodic). Marginal variants of the diorite include gabbro, which is found north of Karta Bay, and monzonite, which occurs at the contact at the Mamie mine.

Knopf[72] describes marginal phenomena of the Coast Range batholith in the Eagle River region as follows:

> Various modifications of the quartz diorite gneiss are found along the contacts with the main schist belt and with the outlying bands of schist. The most common change, as already alluded to, is the passage from the coarse-textured, imperfectly oriented gneiss of gray color to a dark, closely foliated, fine-grained gneiss. Locally, as on the northwest side of Herbert Glacier, the hornblende becomes segregated so as to form a coarse hornblendite in which the interstices between the hornblende prisms are filled with biotite and pyrrhotite.

The evidence in southeastern Alaska and in regions immediately to the south where the relations have been studied is positive in indicating that quartz diorite is in many places a marginal border variant to more alkalic types such as granodiorite. It forms a border zone on the west flank of the Coast Range batholith from Portland Canal to Stikine River for a distance of 150 miles, whereas granodiorite types predominate farther in toward the core.

The average composition of four contact phases and eight subcontact phases of the Coast Range batholith in the vicinity of Vancouver, B. C., is given in the table below. The contact phases are hornblende diorite with an andesine-labradorite plagioclase, and the subcontact variants are hornblende-quartz diorite with an intermediate andesine plagioclase.

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[71] Wright, C. W., Geology and ore deposits of the Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, pp. 33–41, 73–83, 1915.

[72] Knopf, Adolph, The Eagle River region: U. S. Geol. Survey Bull. 502, p. 25, 1912.

Average volumetric composition of contact and subcontact phases of the Coast Range batholith in the vicinity of Vancouver, British Columbia [a]

	1	2		1	2
Andesine	64.45	65.38	Magnetite	0.95	0.98
	($Ab_{59}An_{41}$)	$Ab_{52}An_{48}$)	Apatite	.13	.09
Quartz	21.66	4.33	Titanite	.08	----------
Hornblende	9.58	26.55	Accessory minerals	1.66	.21
Biotite	1.49	2.46			

[a] Based on data given by Burwash, E. M. J., The geology of Vancouver and vicinity, p. 47, Univ. Chicago Press, 1918.

1. Average composition of eight specimens of quartz diorite; subcontact phases of Coast Range batholith.
2. Average composition of four specimens of diorite; contact phases of Coast Range batholith.

The average quartz diorite of the Coast Range batholith in the vicinity of Vancouver appears to have a considerably greater percentage of andesine than the quartz diorite in southeastern Alaska and only half the amount of ferromagnesian minerals; and, in keeping with this, hornblende is by far preponderant over biotite in the southern type. The quartz diorite of the Coast Range batholith in southeastern Alaska does not show a contact variant to diorite, as in the vicinity of Vancouver. These differences may be explicable by the hypothesis that in the vicinity of Vancouver the adjacent country rock was not so thoroughly and highly heated as in southeastern Alaska, and that consequently more rapid chilling with the subsequent difference in relations resulted.

Clapp [73] in discussing the Saanich granodiorite on Vancouver Island writes:

> Near its contacts, especially with the Sutton limestones, the granodiorite becomes in places more dioritic and passes into quartz and quartz-bearing diorites, and also into feldspar-rich, quartz-poor rocks, which are best considered as quartz-bearing feldspathic diorites, although some of them are monzonitic in character. The quartz diorites differ from the normal granodiorites in their lack or small amount of potash feldspar.

The origin of the quartz diorite masses which occur within the Coast Range batholith is an unsolved problem. The evidence is insufficient to determine whether they are older and are intruded by the more alkalic types surrounding them, or whether they represent chilled contact variants against deeply penetrating portions of the roof of the batholith, or against earlier intruded magmas.

In the Hyder district the eastern part of the main batholith is quartz monzonite. (See table, p. 180, No. 6.) An apophysis or large outlying stock in the vicinity of Boundary Glacier is a granodiorite (see table, p. 217, No. 5), with a tendency toward a porphyritic texture and a finer-grained groundmass. Large dikes in this same area and of the same age are granodiorite porphyry and quartz diorite por-

[73] Clapp, C. H., Sooke and Duncan map areas, Vancouver Island: Canada Geol. Survey Mem. 96, p. 192, 1917.

phyry with a felsitic groundmass, whereas narrow dikes that are almost wholly felsitic in texture are quartzose diorite. The relation of degree of differentiation to size of mass and slowness of crystallization is well shown by this sequence.

The Texas batholith, in the Hyder district, which is predominantly granodiorite, passes locally at or near the contact with the country rock into a quartz diorite facies or even, immediately adjacent to the contact, into a monzodiorite.

Among the mediosilicic rocks there is a tendency for differentiation within a single intrusive mass to produce locally a more basic variant on the periphery and a more alkalic-siliceous variant in the core. Some of the ultra-basic group of rocks show the reverse phenomena. The dunite stock on the Blashke Islands, in Kashevarof Passage, appears to consist of a core of dunite with a narrow peripheral zone of pyroxenite, which changes abruptly through gabbrodiorite to diorite on the outer borders.

In Bohemia Basin, Yakobi Island, the mass of norite with bronzitite segregations appears to be surrounded by diorite, which toward one part of the border, at least, grades into quartz diorite. Dikes of diorite, however, appear in the norite.

At Kane Peak, on the north end of Mitkof Island, pyroxenite appears to form the core of a stock and to be partly surrounded by a shell of dunite on its southern edge and hornblendite on its northern edge. The relations here have not been thoroughly studied.

SUCCESSIVE INTRUSIONS

Except in the Texas batholith the writer has not seen in the areas in which he has worked brecciation phenomena or other unequivocal evidences of intrusive relations between such varieties as diorite, monzodiorite, quartz diorite, granodiorite, or quartz monzonite. In a rapid reconnaissance survey, however, such evidence might easily be overlooked. There is, however, abundant and positive evidence that members of the diorite-monzonite group of rocks locally intrude and brecciate members of the ultrabasic group and gabbro, though abrupt apparent transitions, such as have been previously described, also occur. The hornblendite masses in particular are in general severely brecciated on the borders by intrusive diorite or quartz diorite.

There is also abundant and positive evidence that the highly potassic granite batholiths and stocks in the islands of the Alexander Archipelago intrude and brecciate older diorite, monzodiorite, and quartz diorite.

On the east side of the Coast Range batholith, in the Hyder district, the small Texas batholith probably intrudes Jurassic beds but is itself intruded by granodiorite of the main Coast Range batholith

The Wrights[74] make the following very interesting statement concerning the problem of intrusion, with particular respect to the mainland batholith:

The variations across the range [Coast Range batholith] are apparently not so gradual as those along its trend. The Coast Range massif consists of many interlocking batholiths, or batholiths within batholiths, intruded at successive epochs but during the same general period of irruption. In the southern part of Alaska, especially in the Unuk River, Stikine River, and Portland Canal sections, the contacts between the different batholiths are less sharp than in the northern Skagway cross section. The geologic evidence indicates that the granite in the southern section was intruded into more deeply buried rocks than that in the northern region, and this fact may account for the difference in contacts. * * * In this portion of the Alaskan Coast Range rapid gradations from one type to another occur and indicate in many ways intrusion within intrusion besides variation due to differentiation and assimilation. Naturally it is not probable that intrusion was or could be accomplished over such a wide area at one time and by one huge magma. For the gradual relief of strains and stresses due to the transfer of so much material and also for the action of a viscous magma the lapse of considerable time must be assumed.

Dolmage[75] writes as follows concerning the eastern side of the Portland Canal sections:

Quartz diorite and granodiorite form over 90 per cent of the total exposed bulk of the batholith. These two rocks are very similar in appearance and the one often merges into the other, making it difficult to map the two types separately. However, the granodiorite, granite, and quartz monzonite have sharp intrusive contacts with the gabbro.

Knopf[76] describes the northern part of the batholith as follows:

At Skagway and at the upper end of Taku Inlet it is found that the batholith is of composite origin and that more salic rocks were intruded subsequently to the quartz diorite.

Knopf[77] says further:

The Jualin diorite is undoubtedly of younger age than the quartz diorite gneiss and has escaped the widespread crushing to which the older rock has been subjected.

The general geologic history of southeastern Alaska suggests that the irruption of the quartz diorite and the Jualin diorite took place during one broad epoch of intrusion, which so far as known extended through the greater part of the Jurassic period. At Berners Bay powerful deformational forces have been operative between successive intrusions.

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[74] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 61–62, 1908.

[75] Dolmage, Victor, Coast and islands of British Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept. for 1922, pt. A, p. 15, 1923.

[76] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 24, 1912.

[77] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 13–14, 1911.

Concrete evidence of intrusion of one type of intrusive into another appears to be more abundant on the islands west of the Coast Range batholith than within the central part of the batholith.

Clapp[78] discusses the relations among the intrusive rocks at the south end of Vancouver Island as follows:

Intrusive into the pre-Upper Jurassic rocks described above are batholiths and stocks of plutonic rocks and smaller masses of injected rocks. All the plutonic or batholithic rocks were irrupted during the same general period of batholithic intrusion, but nevertheless they may be subdivided into three principal types, irrupted in a definite sequence. These types are, in the order of their irruption; Wark gabbro-diorite gneiss, Colquitz quartz diorite gneiss, and Saanich granodiorite. * * * The Wark [gabbro-diorite] and Colquitz [quartz diorite] gneisses form virtually a single batholith, but the Colquitz gneiss is clearly intrusive into the Wark gneiss. * * * The Saanich granodiorite * * * is clearly intrusive into the Wark gneiss, and is quite certainly younger than the Colquitz gneiss. * * * It seems clear that the batholithic rocks were irrupted during two main periods, which have been called the Wark and Saanich periods. During the first period the Wark and Colquitz gneisses were irrupted independently. Thus the Wark period is divided into two subperiods, the second subperiod being characterized by the irruption of a more acid or salic magma than that first irrupted. A similar division into two subperiods is made of the Saanich irruptive period. The first subperiod, during which the basic or mafic rock, the Beale diorite, was irrupted, is possibly represented in the Duncan map area only by some of the contact phases of the Saanich granodiorite, such as the quartz gabbro.

Again Clapp[79] states:

Perhaps preceding, but chiefly during and closely following, the deformation [Jura-Cretaceous], batholiths and stocks of granitic rocks, and sills, dikes, and irregular masses of porphyrites were intruded into older surface-formed volcanic and sedimentary rocks of the Vancouver group. * * * Those granitic rocks irrupted during the deformation were foliated and pulled out into bands, the Wark and Colquitz gneisses, while the younger granitic rocks, the Saanich granodiorite, irrupted after a greater part of the deformation had ceased, are still largely unfoliated. The earlier injected porphyrites, the Tyee and Sicker, were injected into the Sicker series and were folded and sheared. The later porphyrites were injected into the Saanich granodiorite to form dikes, and their injection apparently closed the irruptive cycle begun long before by the eruption of the volcanic rocks.

Wright,[80] in discussing the intrusive rocks of Kasaan Peninsula, Prince of Wales Island, writes:

The granitic intrusives include diorite, gabbro, syenite, and a little granite. These intrusives differ considerably in mineral composition and probably represent several periods of igneous invasion during one general epoch, though some of the differences can undoubtedly be attributed to segregation of minerals within the igneous magma while it was becoming solidified.

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[78] Clapp, C. H., Sooke and Duncan map areas, Vancouver Island: Canada Geol. Survey Mem. 96, pp. 172, 195, 197, 202, 1917.

[79] Idem, pp. 360–361.

[80] Wright, C. W., op. cit. (Prof. Paper 87), p. 74.

At the contacts of these granitic batholiths with the country rock there are masses of slightly altered and locally sheared diorite surrounded by unaltered diorite. At some places these masses show sharp contacts, though at others the two kinds of rock merge gradually into each other, suggesting a peripheral solidification of the igneous batholith, a fracturing of its outer part, and subsequent injection of molten rock into the interstices.

Bancroft [81] discusses the phenomena of intrusion as follows:

The vast majority of these intrusive bodies may thus safely be assumed as of Jurassic age, probably being injected during the latter part of that geological period. It would seem that at that time this area was resting upon a deep-seated magma which, by its intrusion in one locality and then in another, relieved the accumulating stresses. A number of batholiths of more basic magmas were the first to invade the region. They may be looked upon as the introduction to the chapter of igneous activity which followed. Although within a given locality periods of quiescence seem to have alternated with periods of renewed advance on the part of the magma, such periods of quiescence in one locality may have corresponded to periods of activity in another. The upward progress of some of the individual batholiths seems to have been of this periodic character. A single batholith must have advanced to a certain level and remained stationary for a sufficient length of time to permit the accumulation of more basic magma at its margins and solidification through crystallization to a certain depth. Then followed a renewed demand for relief of stress in this locality, the still molten and more acid magma of the interior ruptured the more basic and solidified peripheral portions of the batholith and proceeded upward once more. For example, it seems difficult otherwise to explain how in some localities the granite batholith which comprises the majority of the islands in Queen Charlotte Sound merges gradually with its basic marginal modifications, and in other places the granite is in sharp contact with the same basic rocks.

SUMMARY OF RELATIONS OF VARIANTS

FIELD RELATIONS

From the foregoing descriptions and interpretations, and from the data presented elsewhere in this report, the following conclusions may be stated.

West of the Coast Range batholith, more particularly on the islands off the coast from Vancouver to Icy Strait and Cross Sound, there is a group of ultrabasic intrusive rocks which, though relatively minor in amount when compared to the immensely greater mass of intrusives of more siliceous-alkalic character, yet are numerous and, taken together, form a not inconsiderable volume. These include hornblendite, pyroxenite, dunite, peridotite, and intermediate variants; they are older than the group of more siliceous-alkalic types.

Hornblendite occurs also as a local marginal variant to more alkaline and siliceous rocks such as diorite, monzodiorite, quartz diorite, and granodiorite. Hornblendite of this origin and relation may be

[81] Bancroft, J. A., Geology of the coast and islands between the Strait of Georgia and Queen Carlotte Sound, B. C.: Canada Geol. Survey Mem. 23, p. 104, 1913.

of slightly different age from the separate discrete intrusive masses of hornblendite, though it too may locally be intruded by the rock which forms the more siliceous-alkalic core.

Diorite and gabbro-diorite occur both as discrete stocks and batholiths, and also to a minor extent as marginal variants of quartz diorite and granodiorite. Locally gabbro-diorite and augite gabbro form marginal variants to diorite. The gabbro-diorite and gabbro are locally intruded by diorite, quartz diorite, and more siliceous-alkalic types. Locally they form marginal zones to ultrabasic stocks.

Granodiorite in stocks and small batholiths may show marginal variants to quartz diorite, gabbro-diorite, diorite, monzodiorite, and very rarely to syenite. A decrease in potassic feldspar and quartz locally on the margins is a common feature of the granodioritic stocks and small batholiths. Clapp reports that quartz diorite and more basic rocks are cut by the granodiorite. Quartz monzonite in the eastern part of the batholith locally shows border apophyses or stocks of granodiorite and outlying dikes as basic as quartzose diorite.

Granite (potassic) is the youngest of the major members of the plutonic complex, and is uniformly found with intrusive relations toward the older members.

It is noteworthy that west of the Sierra Nevada batholith in California there is a similar older group of ultrabasic intrusive rocks and a younger group of more alkalic-siliceous intrusive rocks, including quartz diorite, granodiorite, quartz monzonite, and granite.

Accompanying each of the prevalent rock types, such as diorite, monzodiorite, quartz diorite, and granodiorite of andesine variety in the Alexander Archipelago, there is a relatively very small volume of more sodic (albite or oligoclase) leucocratic variants, such as oligoclase or albite diorite and oligoclase or albite quartz diorite, with a relatively smaller amount of accessory minerals, such as magnetite, apatite, and titanite. These usually occur locally in small volume as marginal variants or perhaps more commonly as satellitic dikes, sheets, apophyses, and small stocks.

A pegmatitic facies may be associated with each of the major rock types except dunite and peridotite. The plagioclase of the pegmatite is usually more sodic than the rock with which it is associated. Aplite dikes are associated with each of the rock types from diorite to granite, and in these, too, the plagioclase is usually of a more sodic variety than that of the rock with which it is associated. Veins of albite or of albite and calcite and orthoclase in sparse amounts accompany the ultrabasic rocks. In general it seems probable that the aplite associated with a particular type of igneous rock contains a more sodic plagioclase and a higher percentage of potassic feldspar and quartz than the rock with which it is genetically associated.

Lamprophyre dikes are the youngest members of the intrusive series, but it is not known whether or not they vary in relation to the rock with which they are associated.

ORDER OF CRYSTALLIZATION

A theory of differentiation which is very prominent at the present time is based upon the principle of fractional crystallization. Stated in the broadest terms, it is based upon the facts that magmas crystallize not at any one temperature but throughout a temperature interval, and that the average composition of the crystals separated at any one time is different from that of the liquid with which they are in equilibrium at the given temperature; and it involves the conceptions that if through the action of gravity these crystals sink or rise through the liquid or if the liquid is removed from the crystals through a process of deformation or filter pressing at a stage when the crystals have separated to a sufficient extent to form a crystal meshwork, then we would have an original common magma differentiated into two or more portions in which the crystal aggregates are of different composition from the liquid residuum or from the expressed liquid, as the case may be, and each submagma will form a different type of rock. Modifications of this simple type of differentiation are introduced by alternating periods of deformation and quiescence, by the effects of the relatively volatile substances termed mineralizers, by marginal chilling with differentiation proceeding in the core, and by other factors. The influence of fractional crystallization has been especially developed and stressed by Bowen.[82]

As the major unit in such a theory of differentiation is the crystal, it is necessary to know the order of crystallization in order to study its relation and effect on the order of differentiation. The period of crystallization of the different minerals varies essentially with the composition of the magma in which crystallization is proceeding.

In the normal hornblende diorites plagioclase is the first of the major minerals to begin to separate. The hornblende is in part contemporaneous with the plagioclase and in part interstitial to the plagioclase. Euhedral crystals are common. Quartz and potassic feldspars occur only in an interstitial position.

In the monzodiorites plagioclase is in general the first mineral to separate. The potassic feldspar either begins very soon after the plagioclase and is intergrown with the plagioclase, or it begins at a much later stage and is interstitial, depending upon the percentage of potassic feldspar present. Microcline is more common in the interstitial groundmass, and microperthite is most common at the early

[82] Bowen, N. L., The evolution of the igneous rocks, Princeton Univ. Press, 1928.

stage of separation. Hornblende separates after the plagioclase and may crystallize together with the potassic feldspar or cease before the feldspar begins, according to its composition. Myrmekitic intergrowths of plagioclase and quartz locally replace the potassic feldspars along their borders. Quartz is restricted to interstices and is uniformly the last mineral to finish crystallization.

In the quartz diorites the order of crystallization is similar to that of the granodiorites. Plagioclase is the first mineral to crystallize and at a later stage is accompanied by hornblende, biotite, and quartz. The potassic feldspars, myrmekite if present, and quartz form the last stages in the crystallization of the magma. The accessory minerals are for the most part concentrated and associated with the ferromagnesian minerals, but in part they occur as inclusions in the other minerals.

In the quartz diorites and the granodiorites of both the Coast Range batholith and the adjoining Wrangell-Revillagigedo belt hornblende and biotite are usually approximately equal in amount if the combined percentage is 18 or thereabouts; whereas if the total amount of both is greater than about 18 per cent, hornblende usually exceeds biotite, and if less than 18 per cent, biotite usually exceeds hornblende. Where biotite predominates over hornblende there is a correlative increase in quartz, as if the biotite and quartz were formed by the breakdown and modification of hornblende.

A similar relation between hornblende and biotite is found in the quartz monzonites. Here, however, the average total ferromagnesian content of all variants is lower, and the combined percentage around which hornblende and biotite are approximately equal in amount is much smaller.

In the quartz diorites of Baranof Island the total ferromagnesian content is low; and in them also where the combined percentage of hornblende and biotite is lower than the average for the region, biotite preponderates over hornblende and is accompanied by an increase of quartz.

The quartz diorites differ from the diorites in an increase from 4 per cent of quartz to 19 or 20 per cent, and in a considerable decrease in total content of ferromagnesian minerals, plagioclase, and magnetite. The ratio of biotite to hornblende increases markedly in the average type of quartz diorite from that of the diorites. Indeed, a part of the increased percentage of quartz in the quartz diorites may have originated from the breakdown and modification of the hornblende molecule.

In the albite-leucoquartz diorites the plagioclase is the first major component to crystallize, and in the porphyritic facies it forms the phenocrysts. In the alaskitic granites microperthite appears to be the first mineral among the major components to separate, though the evidence is not certain, and in the porphyritic facies it forms the phenocrysts. At a later stage the ferromagnesian minerals, plagioclase, and quartz accompany the microperthite.

In the granodiorites the plagioclase feldspars are, in general, the first of the major mineral components to separate, and in the porphyritic facies, with only two exceptions noted, they were found to form the phenocrysts. At a later stage of precipitation they are accompanied by the ferromagnesian minerals and by the potassic feldspars and quartz. Quartz forms in part an interstitial groundmass to the other minerals. Myrmekite, a vermicular intergrowth of quartz and andesine, is characteristically present, locally replacing the potassic feldspars on their borders; it seems to have preceded at least a portion of the quartz. In the granodiorite porphyry from the mountains near the head of Cascade Creek on Thomas Bay and in an augite granodiorite sill on Bradfield Canal microperthite forms large phenocrysts; these are the only rocks noted in which the potassic feldspar might be interpreted as having crystallized at the earliest stage. In the crystallization of the potassic feldspars microcline or orthoclase is more common in the later stages and microperthite in the earlier stages; locally microperthite forms the core of the crystal and microcline the outer zone. Here and there hornblende is full of rounded inclusions of quartz, and more rarely plagioclase contains similar inclusions of quartz.

In the quartz monzonites along Portland Canal minute euhedral and rounded quartz crystals occur within and on the borders of the feldspars. The ferromagnesian minerals occur in slight part as minute idiomorphic inclusions within the feldspars but are mainly contemporaneous with the feldspars. Most of the feldspar, quartz, and ferromagnesian minerals are essentially contemporaneous. In part the microperthite forms large crystals which have a porphyritic aspect, but they usually contain inclusions of the other minerals and, though they may have started early, they must have grown with relative rapidity throughout a considerable period of time. Quartz may finish crystallization a trifle later. Microcline is later than microperthite.

The accessory minerals occur to a slight extent as minute inclusions in any or all of the other minerals; but there is a tendency for them to occur within the outer borders of the ferromagnesian minerals, especially in the biotite or between the boundaries of the other minerals. The zircons in particular tend to be restricted to minute rods in the biotite. Some large titanite crystals seem definitely to be contemporaneous with the major minerals, and such crystals may inclose minute euhedral crystals of apatite and magnetite. The magnetite grains are frequently found in groups of idiomorphic crystals, many of them with associated apatite. Euhedral crystals of magnetite and apatite are often found clustered around the borders of titanite crystals.

In the quartz monzonite on Stikine River the first minerals to begin to crystallize were the accessories magnetite, apatite, and titanite. These occur also in quartz of late crystallization and are therefore in part contemporaneous with the other minerals. Quartz occurs as idiomorphic crystals in the plagioclase or as large grains, in part interstitial and molded on the feldspars and in part showing crystal faces against microperthite; it appears to have begun early and finished last. The biotite is sparse and appears for the most part to be in the quartz, but locally it occurs as included crystals in the feldspars. The plagioclase is hypidiomorphic and occurs in part as included crystals in the microperthite. The biotite is almost entirely altered to chlorite. The crystallization of the microperthite and plagioclase was for the most part contemporaneous, though plagioclase may have started first.

In the granites at many places microperthite bears a porphyritic relation to the other minerals, and plagioclase occurs in the groundmass or interstitial to the microperthite. This might suggest that the microperthite started crystallization before the plagioclase were it not for the fact that many of the large microperthite crystals contain included small crystals of plagioclase. In the granite, as in the quartz monzonite, the crystallization of the microperthite and plagioclase must for the most part have been contemporaneous, though plagioclase may have started first.

It is exceedingly difficult to tell the exact period of crystallization of the accessory minerals, such as magnetite, apatite, zircon, and titanite. In general they occur as minute inclusions in the other minerals, particularly in the ferromagnesian minerals, or mainly as small grains of early crystallization; but in part, where they are present in unusual abundance, they occur within or on the borders of the ferromagnesian minerals or interstitial to the major minerals. The interstitial mode of occurrence is particularly noticeable in some of the pyroxenite and hornblendite where magnetite or apatite, respectively, is in considerable abundance. In general, apatite is associated with the magnetite crystals and may occur as inclusions in them. Both apatite and magnetite may occur as euhedral crystals inclosed in titanite.

In hornblende diorite that contains 2 per cent of magnetite and 1 per cent of apatite practically all the magnetite and apatite occur as inclusions in the hornblende crystals. The hornblende in these rocks began to crystallize after the plagioclase and is in part interstitial to it. In slight part magnetite occurs interstitial to the other minerals or as included crystals in interstitial quartz.

In the ultrabasic rocks the predominant accessory mineral is magnetite. Where this is small in amount (less than 1 or 2 per cent) it occurs as minute euhedral crystals in the other minerals. Where it is more than a few per cent, as in the diallagites and hornblendites only 1 per cent or so occurs within the other minerals and the remainder belongs to a later stage of crystallization. In the augitite from Union Bay the magnetite (20 per cent) forms irregular-shaped blebs interstitial to the pyroxene with offshooting threadlike streamers between the borders of the pyroxene grains. In a hornblende-magnetite augitite from Snettisham practically all of the magnetite and apatite form a mesh interstitial to the pyroxene and hornblende. The apatite is in part inclosed as euhedral crystals in the magnetite. In a hornblendite from Kupreanof Island practically all the magnetite (3 per cent) and apatite (4 per cent) are in euhedral crystals situated between and intersecting the borders of the grains of hornblende; they belong to a late stage of crystallization. The same is true of the hornblendite from Etolin Island. In the hornblendite from Snipe Bay, Baranof Island, the apatite is in perfect crystals in the interstitial labradorite.

RATE OF COOLING AND MINERALIZERS

In a consideration of the theory of differentiation through the separation of crystals from the solution in which they are growing and of the action of mineralizers, the rate of cooling, or the length of time during which the magma consists of both solid and liquid phases, is a most important factor affecting the degree and character of differentiation. Other factors being the same, the slower the rate of cooling the longer will the usual magma consist of crystalline and liquid phases and the greater will be the opportunity for differentiation. Rapid cooling will tend to check differentiation and will result in a rock closely similar in composition to the original magma, except for the loss of most of the more volatile constituents. A relatively high content of mineralizers reduces the viscosity and tends to facilitate crystallization and produce a coarse texture; it may also have an influence in determining the particular assemblage of minerals which crystallize from the magma. The mineralizers may also act as agents to transfer more soluble or volatile constituents and thereby themselves directly cause differentiation.

ULTRABASIC ROCKS

The data on the field relations of the dunites, peridotites, and pyroxenites are inadequate for a discussion of their origin.

The hornblendites present certain features which must be taken into consideration in explaining their origin. There is no doubt that in part they bear intrusive relations to the sediments, for they are repeatedly found as sills, and southeast of Petersburg, on Mitkof Island, intrusive masses of hornblendite have produced contact metamorphism in the adjoining slates, with the formation of such minerals as andalusite.

The most pronounced feature of the hornblendite masses is their wide and abrupt variation in texture and the local abundance of pegmatitic variants which may differ widely in composition. Some bands of hornblendite are composed of crystals averaging 6 inches long and 3 inches broad. The most common mineral of the pegmatite facies, in addition to the hornblende, is albite; biotite is locally common, and in many places titanite and apatite are abundant. Albite may occur as separate veinlets. Locally ilmenitic magnetite veins are present. In thin section many of the hornblendite masses are found to be unusually rich in apatite, containing as much as 4 per cent. All these features suggest that a very potent factor in the origin of these rocks has been a relatively high percentage of volatile constituents, especially water, in the magma.

Some, at least, of the hornblendites, especially the feldspathic types, are of such a composition that if calculated in terms of anhydrous minerals they may be shown to be equivalent to an olivine gabbro. For example, an analysis of the amphibolite from Port Snettisham, recalculated in terms of normative minerals, gives andesine-labradorite 54.3 per cent, orthoclase 1.7 per cent, ilmenitic magnetite 9.9 per cent, diopside 24 per cent, hypersthene 2.1 per cent, and olivine 8 per cent. A hornblendite northwest of Prospect Lake, Vancouver Island, is reported by Clapp[83] to consist of hornblende 85.2 per cent, augite 8 per cent, magnetite 5.5 per cent, and apatite 1.3 per cent. The chemical analysis recalculated in terms of the norm gives 31.8 per cent of labradorite-bytownite, 5 per cent of orthoclase, 19.64 per cent of diopside, 22.02 per cent of olivine, 9.28 per cent of magnetite, 3.04 per cent of ilmenite, 2.79 per cent of apatite, and 3.41 per cent of nephelite. The relatively high percentage of apatite shown here is in accord with the composition of many of the hornblendites in southeastern Alaska.

These results indicate that the hornblendites may have resulted from the crystallization of a magma of a composition which would usually have produced an olivine gabbro but which in the presence of a relatively high content of volatile materials, particularly water, formed hornblendite.

The hornblendites are as a rule severely brecciated and intruded by the more alkalic-siliceous types, such as diorite and quartz diorite, and are therefore older. For that reason it is permissible to consider

[83] Clapp, C. H., Geology of the Victoria and Saanich map areas, Vancouver Island, B. C.: Canada Geol. Survey Mem. 36, p. 70, 1913.

them as belonging to the same sequence as the younger intrusive rocks of the Coast Range and as representing an early intruded magma very rich in volatile constituents and relatively undifferentiated because of quick crystallization, due to the relatively small size of the masses and to the fact that the country rock must have been relatively cooler than it was later, when large volumes of magma reached the same level and gave out great quantities of heat.

The hornblendite masses in part appear to be the result of differentiation in place from the predominant alkalic-siliceous group of rocks and bear a definite relation to marginal or contact phenomena connected with included blocks of country rock. This is in accordance with the idea that the hornblendites represent relatively quickly crystallized undifferentiated portions of the magma which have a high percentage of volatile constituents. Why there should be this local concentration of volatile constituents is an unsolved problem.

GABBRO, DIORITE, AND ALKALIC-SILICEOUS ROCKS

If the order of differentiation corresponds to the order of crystallization, gabbro, gabbro-diorite, diorite, quartz diorite, granodiorite, quartz monzonite, and granite should appear in the order named.

The most basic type of intrusive rock in southeastern Alaska, exclusive of the dunite, pyroxenite, and related types, is gabbro or its equivalent, hornblendite. The gabbro is restricted to sills, small stocks, or very local marginal developments of moderate-sized stocks, and should represent approximately the relatively little differentiated, quickly cooled original magma. Almost all of the gabbro and gabbro-diorite is found on the islands of the Alexander Archipelago.

The extreme alkalic-siliceous differentiate among the major rocks is a potassic granite, which is usually intrusive into the other major types of rock and is therefore the youngest. This determination of relative age accords with the order suggested by the succession of crystallization.

Very slow cooling in the deep core of the batholith—still deeper than that exposed by the present erosion level—may have permitted maximum differentiation and the formation of a granitic solution which under stresses was intruded locally into the less differentiated, more quickly cooled stocks and batholiths of the Alexander Archipelago, which are smaller and were intruded in a belt of cooler country rock than the Coast Range batholith. Thus the effects of relative rate of cooling may afford a partial explanation of the fact that the rocks of the Prince of Wales-Chichagof belt are predominantly diorites of various types (gabbro-diorite, diorite, monzodiorite, and quartzose variants), with associated low potassic granodiorite and quartz diorite (the average composition of 65 specimens is that of a quartzose hornblende diorite containing 8 to 11 per cent of quartz), whereas the rocks of the Coast Range batholith are predominantly the more alkalic-siliceous types, such as granodiorite and quartz monzonite with peripheral quartz diorite (the average composition of 37 specimens is that of a granodiorite with about 20 per cent of potassic feldspar and 20 per cent quartz).

Within a given stock or batholith differentiation may have been checked at different stages in different portions as a result of different rates of cooling and local conditions. Normally, if there is a variation within a given stock due to different rates of cooling, the more quickly cooled portion will be on the borders, and a more basic type of rock, representing an early stage of differentiation, will be formed there. Many examples of local and peripheral basic borders in stocks and batholiths of the Alexander Archipelago have already been referred to.

The belt of quartz diorite on the western flank of the Coast Range batholith likewise bears a position and relation to the more alkalic-feldspathic rocks (granodiorite and quartz monzonite) of the core, explicable as a marginal, relatively more quickly cooled variant. There is a question, however, whether the relations observed here are due to differentiation in place or to successive intrusions, of more advanced differentiated magma toward the northeast; the latter seems more probable.

The quartz diorites with relatively low ferromagnesian content, which seem to predominate on Baranof Island, are not readily explained, and further data are needed.

The leucocratic sodic types of rock, such as albite diorite and albite monzodiorite, albite, and oligoclase quartz diorite, oligoclase granodiorite, oligoclase monzonite, and the pegmatites and aplites which are associated in minor amount with each of the similar but respectively more basic andesine types, apparently have not originated through the same complex processes of differentiation that gave rise to the submagmas constituting major types of rocks but are due to local causes and processes acting upon the individual submagma. The sodic variants do not lie within the same sequence of differentiation as the more calcic major types. Their composition is that of late-stage differentiates from the local submagmas. Many of them occur as apophyses and outlying dikes, and this mode of occurrence is compatible with what might be expected of a late differentiate of small volume. It is probable that the mineralizers have played an active part in the origin of these facies.

It is certain that some of the intrusive rocks—the quartz diorite and granodiorite of the Wrangell-Revillagigedo belt in particular—have had their composition locally very considerably modified by reaction with incorporated fragments of schist and sediment. This is true also of portions of the core of the Coast Range batholith immediately adjacent to included or shredded blocks of schist. The resultant variations in composition are in part due directly to the differences in composition of the assimilated rock and in part indirectly to the same differences because of their effect in prolonging or shortening the period of crystallization of the magma and thus permitting varying degrees of differentiation.

AGE

The age of the Mesozoic intrusive rocks has not been definitely determined. To the northeast, on the east side of the batholith in the Whitehorse district, Yukon Territory, the intrusive rocks are reported by Cockfield [84] to cut rocks of Middle Jurassic age and therefore to be probably of Upper Jurassic age or later. Hanson [85] reports that on the east side of the batholith, in British Columbia, between Skeena River and Stewart, the Coast Range batholith intrudes the Hazelton group (Jurassic) but does not intrude the Skeena (Lower Cretaceous) series. He says: "It is therefore probably mainly of Upper Jurassic age, but parts of the batholith may be of later age." Dolmage,[86] in describing the Tatla-Bella Coola area, writes: "In Taseko Lake district what appears to be the main Coast Range batholith cuts a thick series of coarse fragmental volcanic rocks in which the writer found plant remains, determined by E. W. Berry to be of Cretaceous age. * * * This evidence proves that this part at least of the batholith is younger than the lowest Cretaceous, and the evidence found in Tatlayoko Lake, Taseko Lake, and Bridge River districts strongly suggests that much of the eastern part of the batholith is of postbasal Lower Cretaceous." Cairnes [87] suggests that at the southeastern part of the batholith, on the eastern border, there are intrusions of two ages. Masses of intrusive rocks that cut probable Jurassic beds are reported by him to be overlain unconformably by beds of Lower Cretaceous age, and the Lower Cretaceous beds are in turn cut by intrusions of pre-Tertiary age. On Vancouver Island the Mesozoic intrusive rocks are known definitely to be older than Upper Cretaceous.

In southeastern Alaska all the intrusive rocks classed as Mesozoic are definitely known to be older than the Eocene. On Chichagof

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[84] Cockfield, W. E., and Bell, A. H., Whitehorse district, Yukon: Canada Geol. Survey Mem. 150, pp. 32–33, 1926.

[85] Hanson, George, Reconnaissance between Skeena River and Stewart, B. C.: Canada Geol. Survey Summary Rept. for 1923, pt. A, p. 37, 1924.

[86] Dolmage, Victor, Tatla-Bella Coola area, Coast district, B. C.: Canada Geol. Survey Summary Rept. for 1925, pt. A, p. 161, 1926.

[87] Cairnes, C. E., Coquihalla area, B. C.: Canada Geol. Survey Mem. 139, pp. 71–77, 89–105, 1924.

Island intrusions of the Coast Range type are proved by Overbeck [88] to cut fossiliferous beds of Upper Jurassic age. The writer is convinced that on Admiralty Island intrusions of the Coast Range type cut beds which, where not metamorphosed, carry the fossil *Aucella crassicollis* and which are therefore probably of lower Cretaceous age. At the head of Portland Canal there is positive evidence of two epochs of intrusion; the older batholith cut beds of the Hazelton series (Jurassic) and is in turn intruded by the quartz monzonite of the Coast Range batholith.

It is evident that for the most part the youngest beds with which the Mesozoic intrusive rocks are found in contact are of Middle or Upper Jurassic age; at a number of localities intrusive rocks of the Coast Range type cut Lower Cretaceous formations; there were at least two epochs of intrusion; and the Mesozoic intrusive rocks are all older than the Upper Cretaceous. So far as southeastern Alaska is concerned, the writer is aware of no evidence to disprove the assumption that all the Mesozoic intrusive rocks may be of Lower Cretaceous age, but the data given for adjacent territory suggest that they may be in part of Upper Jurassic and in part of Lower Cretaceous age.

The writer would emphasize the fact that in southeastern Alaska there are thick conglomerate beds that have been found throughout a length of 175 miles which are of known Silurian age but which contain pebbles, cobbles, and boulders similar in every way to the Mesozoic intrusive rocks. Similar pebbles are also found in beds intercalated with slates carrying the fossil *Aucella crassicollis*, and the writer believes that this formation, too, is cut by the Mesozoic intrusions. It is therefore essential that the occurrence in conglomerates of fragments resembling the Mesozoic intrusive rocks should be used only with the greatest caution as a criterion to indicate the age of the conglomerate bed with respect to the Mesozoic intrusions.

LOWER CRETACEOUS(?) ROCKS

DISTRIBUTION AND CHARACTER

Fossiliferous beds definitely recognized as of Upper Jurassic or Lower Cretaceous age are known at only five localities in southeastern Alaska—the vicinity of Point Pybus and other places on the south side of Admiralty Island; the north end of the peninsula between Hamilton Bay and Keku Strait, in the northern part of Kupreanof Island; the south end of the northwest half of Etolin Island in the vicinity of Rocky Bay; Blank Inlet, Gravina Island; and Slocum Arm, Chichagof Island. The beds comprise black slate or shale and

[88] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 91–112, 1919.

graywacke with intercalated beds of conglomerate and calcareous sandstone and thin layers of impure limestone. The beds of Slocum Arm, Chichagof Island, may possibly be somewhat older than those of the other localities. As explained on pages 156–157, the fossiliferous rocks of Jurassic or Cretaceous age have on the map been separated from the nonfossiliferous Jurassic or Cretaceous rocks and have been tentatively designated Lower Cretaceous (?).

GRAVINA ISLAND

By THEODORE CHAPIN

A formation consisting essentially of interbedded conglomerate, graywacke, and black slate exposed along a wedge-shaped strip extending from Blank Inlet to the northeast coast of Gravina Island is determined on fossil evidence to be Upper Jurassic or Lower Cretaceous. Similar rocks just northwest of Ward Cove, Revillagigedo Island, and on Annette Island are correlated with this formation.

The conglomerate is composed of rather small pebbles with a few boulders as much as a foot in diameter. The matrix is essentially a graywacke but contains a considerable amount of fragments of igneous rock. The pebbles and cobbles are mostly igneous and resemble the volcanic rocks of Gravina Island. Pebbles of dioritic rocks that resemble the plutonic rocks of the Coast Range also occur. No members of this formation are known to be of igneous origin, although both matrix and cobbles of some of the conglomerates contain so great an amount of igneous material that they resemble agglomerates.

The conglomerate passes by increase in fineness and decrease of igneous material into typical-looking graywacke containing angular fragments of slate and decomposed particles of dioritic rocks, hornblende, pyroxene, and epidote.

The slates are very fissile black clay slates and are closely interbedded with the graywacke members. The slates have a marked cleavage.

The stratigraphic sequence of the conglomerate, slate, and graywacke was not determined, as the beds are very closely folded and overturned in places. The conglomerate does not appear to be the basal member but occurs at intervals throughout the formation, interbedded with the slate and graywacke.

The conglomerate, graywacke, and slate are the products of normal deposition in a shallow sea. The changes in character of the deposits indicate corresponding constant changes of conditions during their deposition. The materials of the rocks were apparently derived in part from the volcanic rocks of Gravina Island, near by, and in part from the surrounding regions.

These Upper Jurassic or Lower Cretaceous beds overlie the volcanic rocks of Gravina Island, which are regarded as Triassic or Jurassic, but in most places the relations are rather obscure. On the northeast shore of Bostwick Inlet, near the entrance, the slate and graywacke overlie the eroded surface of the volcanic rocks with marked unconformity. On the northeast shore of Gravina Island conglomerate and graywacke overlie the volcanic rocks without apparent angular unconformity. The conglomerate and graywacke of Ward Cove are noticeably unconformable upon the black phyllite that has been correlated with the Upper Triassic rocks.

The conglomerate, slate, and graywacke beds of Gravina Island occupy the trough of a closely folded overturned syncline in which are involved also the older Mesozoic rocks, which actually overlie them along the eastern flank of the syncline. The slate has a distinct cleavage and the graywacke and conglomerate are sheared in places but are not schistose. There appears to be about 800 feet of these sediments.

ROCKY BAY, ETOLIN ISLAND

The rocks that occur in the vicinity of Rocky Bay, on the south side of the northwest part of Etolin Island, comprise in part a series of beds characterized by the prevalence of graywacke and in part a closely folded black slate formation. Structurally the graywacke series appears to overlie the slate.

The slate formation consists essentially of a very cleavable black argillaceous slate with thin layers and partings of graywacke. Intercalated thin layers of rusty-weathering impure limestone are common, and nodules of limestone and nodules and thin bands of blue-black chert are conspicuous in many of the beds. Rarely a thin layer of fine-grained conglomerate is present. The pebbles of the conglomerate consist of felsite and felsite porphyry, andesite, chert, limestone, slate, and graywacke. A thin section from a leaf of graywacke in the slate examined under the microscope is found to consist of angular fragments of plagioclase (oligoclase-andesine), fine-grained rock fragments that are possibly chert, and a trace of quartz, in an argillaceous, very finely sericitic groundmass. Plagioclase fragments are found also in the limestone layers in the slate.

The graywacke series comprises massive-looking graywacke beds as much as 10 feet thick, interbedded with slate, and thin-bedded graywacke and slate. The graywackes are greenish-gray or gray and medium to coarse grained. They consist, in general, principally of fragments of plagioclase (labradorite), with intermingled grains of melaphyre and augite. Some layers consist principally of fresh fragments of green augite with a minor amount of fragments of plagioclase and melaphyre. Occasionally it is difficult to say whether the rock is detrital or a true volcanic tuff. The groundmass is argillaceous, and in places a little calcite is present. Quartz is sparse or absent. The feldspars are usually considerably altered to sericite. Many of them show zonal growth; some are partly bounded by crystallographic outlines; some are angular; and others have rounded corners. Accessory minerals are hornblende, rounded grains of epidote, apatite, pyrite, and magnetite. Locally thin bands of red slate are intercalated with the graywacke, but usually the slate layers are black.

In the vicinity of Marsh Island waterworn volcanic breccias are interbedded with black slate and graywacke. Nodules of limestone occur in the slate, and dikes of pyroxene and plagioclase porphyry are common. The waterworn fragments composing the breccia beds consist predominantly of light gray-green keratophyre and amygdaloidal plagioclase and pyroxene porphyries in an argillite groundmass. These beds are very similar to those of doubtful age found on the Fanshaw Peninsula. Structurally overlying these beds is a series of volcanic rocks, which consists predominantly of plagioclase and pyroxene porphyry breccias with interbedded thin flows of similar rock. Both red and green beds are present. These breccias, in part, have the appearance of flow breccias.

The interbedded waterworn volcanic breccia and slate are structurally underlain by beds of slate and graywacke that carry *Aucella*. It thus appears that the volcanic beds overlie the *Aucella*-bearing beds and are as young as Lower Cretaceous. The possibility that the beds are overturned and that the *Aucella*-bearing beds are unconformable on Triassic and Jurassic and structurally overlie the volcanic beds must, however, be borne in mind in view of the close folding and complex structure of the district. This possibility, however, does not seem probable to the writer.

POINT HAMILTON AND VICINITY

A series of Lower Cretaceous or Upper Jurassic sedimentary beds is exposed on the peninsula at the north end of Kupreanof Island, between Hamilton Bay and Keku Straits. East of Point Hamilton these beds are intruded by a mass of Tertiary gabbro; south of Point Hamilton they are overlain unconformably by Eocene sandstone containing typical Kenai plant fossils. They comprise about 1,000 feet of thin-bedded gray shale and sandstone 1 inch to several inches thick, with intercalated beds or nodular layers of fine-grained limestone from 6 inches to a foot thick. The beds have a general northwest strike and dip 10°–20° S. At Point Hamilton a slightly calcareous sandstone crops out in a bed 1 foot thick, and it is present also in the abundant weathered blocks scattered over the tidal flats. This sandstone is moderately fossiliferous, but the shells are mostly in fragments and poorly preserved. (See lot 11404, p. 260.) Rarely a thin bed of tuff is intercalated, and traces of carbonized plant remains are found. The beds are the least metamorphosed of all the Jurassic or Cretaceous formations in this region.

Beds of similar type, predominantly shale, are found again in the line of islets lying south of Hound Island and halfway between it and Kuiu Island. A sill of basalt forms the backbone of this string of islets.

Again on the west headland of the cove, about 3 miles southwest of Hound Island, somewhat more than 300 feet of thin-bedded sandstone and shale with a few limestone layers is exposed. Beds of sandstone as much as 2 feet thick occur in the basal part. These beds apparently overlie Upper Triassic volcanic rocks, but the contact is covered and the beds are nonfossiliferous.

PYBUS BAY

The Cretaceous (?) beds in Pybus Bay have been briefly described by Wright.[89] Some additional data are given here. The main body of Pybus Bay is eroded out of the *Aucella*-bearing slates, which lie in a synclinal relation to the older formations. The south end of the peninsula between Gambier Bay and Pybus Bay appears to be formed by the southeastward-plunging nose of a broad anticline, though this suggestion needs further confirmation.

The succession of formations is best shown on the east arm of Pybus Bay. In the upper half of the bay the beds consist predominantly of cherty layers several inches to 9 inches thick, with associated slate, calcareous material, and tuff. The chert is blue-green, green, gray, and black, with intercalated layers of brilliant red to reddish-brown jasper. The beds are closely folded and very much broken and faulted. The strike is more or less parallel to the bay and the dip is vertical. These beds may be of Devonian age. Overlying them comes the upper Permian white limestone with intercalated layers of white chert and abundant silicified fossils. On the east side of the bay the Permian beds form a line of islets, and toward the south they are overlain by 200 feet of Upper Triassic conglomerate. This consists almost exclusively of cobbles and pebbles of limestone and white chert that resemble the Permian formations, with an interstitial groundmass of limestone. The conglomerate is in turn overlain by crumpled beds of interlayered gray limestone and dark-gray to black calcareous slate of the Upper

[89] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 144, 1906.

Triassic. These are overlain by the *Aucella*-bearing beds, which consist of dark-gray slate with sparse small black cherty nodules and lenses of limestone from 1 foot to several feet in diameter and 6 inches or so thick. The contact between the formations is covered but only for a narrow width. The Triassic and Permian formations are approximately vertical; the *Aucella*-bearing beds dip about 50° SW. These slates pass upward into beds in which thin graywacke-like sandstone is interbedded with the slate in certain zones. The beds are closely folded, and zones with *Aucella* are common.

Point Pybus is composed of conglomerate, and the channel between it and the first small islet to the south is cut along the axis of an asymmetrical anticline in the conglomerate. At Point Pybus the conglomerate beds dip 30°–35° N. and on the islet about 80° S. The conglomerate must be several hundred feet thick, as about 300 feet appears to be exposed. The beds are predominantly of the pebble type, but cobble beds also occur. In most of the beds the pebbles and cobbles are almost exclusively of chert, but in some beds a green-gray felsite predominates. Limestone, granodiorite, rhyolite, and andesite pebbles occur sparsely. Small nodular lenses of limestone occur in the conglomerate. North of Point Pybus the conglomerate passes upward through sandstone into dark-gray slate interbedded with sandstone. The beds of slate are almost isoclinally folded within an asymmetrical syncline which strikes approximately east, and the conglomerates come to the surface again on the conspicuous headland about 2¾ miles northeast of Point Pybus. Several of the conglomerate beds are richly fossiliferous with *Aucella*. The next headland to the northeast, about 1½ miles southwest of False Point Pybus, is composed of Permian white limestone with white cherty layers and abundant silicified fossils. These beds are vertical. South of the headland thin-bedded sandstone and slate are crumpled and broken as in a fault zone.

At Point Pybus and in the islands to the south the beds are cut by shear zones along which quartz veins have been formed. Quartz veins do not occur to the north or west, and their presence here is attributed to a genetic connection with the diorite mass of The Brothers Islands.

AGE AND CORRELATION

Martin [90] makes the following statements concerning the Lower Cretaceous (?) formations in southeastern Alaska:

> The rocks in southeastern Alaska that are believed by the writer to be of Cretaceous age include the *Aucella*-bearing sandstone, shale, and conglomerate of Pybus Bay and other localities in the southern part of Admiralty Island;

[90] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, p. 375, 1926.

shale and calcareous sandstone at Hamilton Bay on Kupreanof Island; slate and graywacke on the west coast of Etolin Island; the conglomerate, slate, and graywacke of Blank Inlet, on Gravina Island; and possibly some graywacke, slate, and conglomerate on Prince of Wales Island. These rocks are distinguished from the somewhat similar slaty rocks that have been described as Jurassic by containing the Cretaceous rather than the Jurassic type of *Aucella* (on Admiralty and Etolin Islands), by containing no volcanic beds, by containing conglomerate with pebbles of granite that are believed to have been derived from the supposed Jurassic granitic intrusive rocks, and by having in some localities, as on Pybus Bay, a notably lesser degree of metamorphism than the Jurassic slate and a distribution and attitude that is not controlled by the well-marked northwesterly structural, intrusive, and outcrop lines which show in most of the older rocks. The writer believes that these rocks are of Lower Cretaceous age and that they were laid down unconformably upon the Upper Jurassic and older beds after those rocks were folded and metamorphosed and after the intrusive rocks of the Coast Range had been partly unroofed. No Upper Cretaceous rocks have been recognized in southeastern Alaska.

As previously stated, Buddington is of the opinion that the Cretaceous (?) formations referred to are not necessarily younger than the Coast Range batholith but may be older. Though cobbles of granodiorite and diorite similar to the rocks of the Coast Range batholith occur in the Lower Cretaceous (?) conglomerates, cobbles of similar rock occur also in Silurian conglomerates. This feature, therefore, has no value as a criterion of age. Furthermore, quartz veins believed to be genetically allied with the intrusive rocks of the Coast Range cut the *Aucella*-bearing beds, and slate and conglomerate lithologically similar to and geographically allied to the *Aucella*-bearing beds are actually intruded by masses of diorite.

The age determination of the conglomerate, slate, and graywacke of Gravina Island rests on fossils collected by Chapin. Only one form was identified. Mr. Stanton reports:

9527 (ACh 99). Blank Inlet, 1½ miles north of Blank Point, Gravina Island.
Belemnites sp.
Jurassic or Lower Cretaceous.

Fossils were collected on Etolin Island by G. C. Martin in 1914 from the black clay slate near the cabins on Johnson Cove, a small harbor on the west side of the island, just east of the north end of the Screen Islands. They were determined by T. W. Stanton as distorted specimens of *Aucella crassicollis* Keyserling?, signifying a probable Lower Cretaceous age if the specific identification is correct.

Fossils were also collected by the writer from the same belt of rocks on the island off the mouth of Johnson Cove. The rocks here are slate with a few thin beds of graywacke, calcareous rock, and fine conglomerate. Chert nodules are common in the slate. The fossils are abundant but distorted, and it is difficult to obtain good specimens because of the close-set fracture cleavage which crosses the bedding. They were identified by Mr. Stanton as *Aucella crassicollis* Keyserling? and *Belemnites* sp., imprint. Aucellas in a poor state of preservation were found also in black clay slate at the head of Rocky Bay, Etolin Island.

At the northwest end of Kupreanof Island, at Point Hamilton, a slightly calcareous sandstone bed 1 foot thick occurs intercalated in the shales, and weathered slabs are abundant over the tidal flats. These slabs are fossiliferous, but the shells are mostly fragments and poorly preserved. A collection from this place was submitted to T. W. Stanton, who identified the fauna and gave the age as Upper Jurassic or Lower Cretaceous.

11404. Point Hamilton, Kupreanof Island.
- Worm trails or burrows.
- Rhynchonella? sp. Fragment.
- Aucella sp.
- Pteria? sp.

The determination of the age of the beds at Point Pybus is based on collections of *Aucella* made by C. W. Wright and described by T. W. Stanton[91] as follows:

> The specimens of *Aucella* from Pybus Bay, Admiralty Island, are apparently referable to species that in California and adjacent States are characteristic of the Lower Cretaceous, *Aucella piochii* occurring in a lower zone than *Aucella crassicollis*. The Alaskan specimens probably also come from the Lower Cretaceous, although strict correlation is rendered somewhat hazardous by the fact that the genus *Aucella* with similar specific forms ranges down into the Upper Jurassic.

TERTIARY ROCKS

The only fossils found in Tertiary rocks of the Alexander Archipelago are of Eocene age. In Lituya Bay on the mainland rocks with Pliocene fossils are found.

The Wrights[92] report a belt of probably Tertiary lavas ranging from acidic andesite to basalt on the south side of Pleasant Island, in Icy Strait, and on the southwest shore of Excursion Inlet.

EOCENE ROCKS

DISTRIBUTION AND CHARACTER

The Eocene rocks of southeastern Alaska are now for the most part restricted to separate areas within a belt about 200 miles long and 20 miles or less in width that extends southeast from the southwest end of Admiralty Island, roughly parallel to Keku and Clarence

[91] Stanton, T. W., cited by Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 144, 1906.

[92] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

Straits. Within this belt they were once doubtless more continuous; the remnants now exposed are those which have not yet been removed by erosion. They are found in Kootznahoo Inlet and form most of the southwest end of Admiralty Island, the northeast side of Kuiu Island, the west side of Kupreanof Island, and the west half of Zarembo Island. Residual patches are found on certain of the Castle Islands, Duncan Canal; at the southeast end of Onslow Island; at the east headland of Union Bay, Cleveland Peninsula; near Dall Head, Gravina Island; in Coal Bay, Prince of Wales Island; and on Long and Daisy Islands, Kasaan Bay.

A small area of Tertiary volcanic rocks outside the main belt forms the southwestern part of Suemez Island in the Ketchikan district. These rocks may be younger than those on Admiralty, Kupreanof, and Kuiu Islands.

The Eocene beds are considered on the basis of their lithologic character and associations, in three groups. The group of beds believed to be the lowest, which are found in Port Camden, Kuiu Island, and in Hamilton Bay, Kupreanof Island, comprise 1,350 feet or more of sandstone with intercalated conglomerate. The second group consists predominantly of rhyolitic volcanic rocks and conglomerate of lava cobbles, or both, with some associated basaltic and andesitic volcanic rocks; these are believed to represent a horizon higher than the sandstone series, for in Port Camden they definitely overlie sandstone. The third group comprises dominantly basaltic and andesitic lavas, with some rhyolitic flows and minor amounts of intercalated breccia and conglomerate of lava cobbles; these overlie the rocks of the other two groups and at several localities there is the suggestion of a slight unconformity. It is possible that future work will show that the upper group is not Eocene.

The most complete section of the Eocene rocks is found in Port Camden, Kuiu Island. For about 6 miles south of the west headland at the entrance to Port Camden the mountains along the shore are composed of sandstone, conglomerate, and rhyolitic volcanic rocks, with sills of basalt; the strike is northeast and the dip 8°–10° SE. The point at the north headland is formed by a mass of basalt with very coarse polygonal jointing, which is intrusive into sandstone; each of the five points along the coast to the south is similarly formed from a sill of basalt.

The thickness of the formations from their base in the cove west of the headland at the entrance of Port Camden to the point west of Cam Island, as given below, has been estimated on the basis of an average dip of 8°, with allowance made for sills of basalt. Southwest of Cam Island there is great variation in the strike and dip, with the attendant probability of duplication of beds, and basaltic volcanic rocks and conglomerate are present in relations suggestive of the possibility of a slight unconformity. The rhyolitic breccia and tuff, the conglomerate of lava cobbles, and the basalt flows southwest of Cam Island are therefore not included in the estimate.

Section of Eocene rocks at Port Camden, Kuiu Island

	Feet
Conglomerates of lava cobbles with interbedded tuff and breccia, predominantly rhyolitic	1,000+
Rhyolite breccia and tuff	500±
Sandstones with intercalated conglomerate near top	1,200±
Basal conglomerate with intercalated sandstone	150±
Unconformity.	
Upper Triassic andesitic volcanic rocks.	

BASAL CONGLOMERATE AND SANDSTONE

The contact between the Tertiary and Upper Triassic volcanic rocks on Kuiu Island in the cove west of Point Camden is covered. The pebbles and cobbles of the lowest exposed beds of the Tertiary, however, consist predominantly of andesite with some rhyolite; the andesite cobbles are such as might have come from the underlying Triassic volcanic rocks.

At the head of Port Camden, on the east side, there is a narrow belt of sandstone and normal conglomerate, which strikes southeast into Threemile Arm. The beds dip 20°–30° NE. and are overlain by conglomerate of lava cobbles with associated felsite flows and breccias. The base of the sandstone series is not exposed. The pebbles in the interbedded conglomerate are predominantly quartz, granite, and phyllite. The beds are similar to those at the mouth of the arm and may represent the same formation exposed here either by faulting or by flexing.

The main sandstone belt of Port Camden strikes northeast and is found on Kupreanof Island south of Point Hamilton and on the south side of Hamilton Bay. The beds are predominantly coarse white feldspathic sandstone with abundant small fragments of black slate and other rocks. They weather a light-brownish hue. Intercalated beds of dark-gray shale and shaly sandstone and of conglomerate are present. The former are usually fossiliferous. The pebbles in the conglomerate are of rocks common to neighboring pre-Tertiary formation; they usually include quartz, slate, phyllite, quartz diorite, and granite.

On the west side of Port Camden the conglomerate includes pebbles of chert and locally red jasper in addition. The chert and jasper are

SILICIFIED STUMP AND TRUNK OF TREE OF EOCENE AGE, KUIU ISLAND, 4 MILES EAST-SOUTHEAST OF POINT CAMDEN probably derived from the Carboniferous formations that are exposed on the north. Locally thin seams of coal are found in the sandstone. A noteworthy feature of the sandstone series is the practically complete absence of volcanic rocks either as flows or as fragments.

On the Cleveland Peninsula, in the Ketchikan district, normal coarse conglomerate crops out for a short distance along the shore just south of Union Point. On the north the conglomerate overlies beds of slate and sandstone and consists almost wholly of fragments of slate and phyllite, some of which are 4 feet in length, with sparse boulders of quartz diorite as much as 5 feet in diameter; intercalated in the conglomerate are light-colored sandstone and pale-brownish shaly sandstone with a few veinlets of bitumen filling cross fractures. On the south the conglomerate is dark-colored to black and consists predominantly of angular to rounded slate cobbles, with abundant boulders of pyroxenite and some of quartz diorite; as the hills southeast of Union Point are formed by a boss of similar pyroxenite with intruded dikes of quartz diorite, the source of all the materials in the conglomerate is near at hand. This deposit bears every resemblance to a coarse delta or alluvial-fan deposit built up by torrential streams flowing down mountain slopes lying to the east. The fact that there are no fragments of volcanic rocks in the 1,000 feet or more of basal conglomerate suggests the possibility that these beds belong to the same horizon as the sandstone and conglomerate of Port Camden.

At Coal Bay, on the north coast of Skowl Peninsula, Prince of Wales Island, there is a small area of sandstone carrying thin beds of coal. The sandstone beds occupy a small local basin and unconformably overlie Devonian greenstone and sediments. The beds are flat-lying and apparently are not more than 100 feet thick.

On Admiralty Island, Wright [93] found a series of conglomerate, sandstone, and shale, with a few coal beds, which occupies an area of about 36 square miles at Kootznahoo Inlet.

CONGLOMERATE OF LAVA COBBLES AND RHYOLITIC FLOWS, BRECCIA, AND TUFF

The rhyolite breccia and tuff of Port Camden are white and medium to coarse, with fragments one-fourth of an inch to an inch in diameter. It is possible that some flow material may be present here also. Overlying these rhyolite beds is a conglomerate of lava cobbles that is markedly different from the normal conglomerate of the sandstone series. It is characteristically coarse; most of the

[93] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, pp. 144–147, 1906.

cobbles are 6 to 12 inches in diameter and well rounded. In the lower part of the formation the cobbles are predominantly felsite and felsite porphyry, but the conglomerates of the upper part contain basalt cobbles and are associated with basalt and andesite flows. Intercalated with the conglomerate are uniform fine-grained white tuff or tuffaceous sandstone. Many of the bedding planes of these fine-grained rocks are covered with the carbonized remains of plants, mostly sprays of *Sequoia*. The conglomerate formation is also noteworthy for the common occurrence of silicified wood. Locally, abundant silicified stumps still in place and silicified trunks lying where they fell (pl. 21) indicate the site of a buried forest. About 3½ miles south of the west headland of Port Camden, on the low beach on the north side of the conspicuous point, six stumps were counted in place in a tract 50 yards square. The remnants of another such forest are exposed on the west side of Keku Straits, about 4 miles southeast of Point Camden, on the south side of the cove.

A series of conglomerate beds composed of lava cobbles and associated with rhyolite and andesite volcanic rocks is exposed on the east side of Port Camden near the head. This belt strikes southeast and is exposed again near the head and along the west side of Threemile Arm. It comprises flows of white, gray, and, locally, red rhyolite and andesite interbedded with corresponding breccia and conglomerate. All the conglomerate beds are coarse, and some are very coarse; one such bed is composed of lava boulders 3 to 5 feet in diameter in a conglomeratic groundmass. The white rhyolite and rhyolite breccia usually contain disseminated pyrite and weather a rusty brown. The andesite is a dense green-gray rock and commonly shows a rough indistinct polygonal jointing with a platy structure at right angles to the columns. Much of the red and white rhyolite likewise shows a platy fissility. White rhyolite is exposed at the head of Seclusion Harbor and is adjoined on both the east and the west by basalt, which appears to overlie it.

A coarse conglomerate of lava cobbles and boulders, some of which are as much as 2 feet in diameter, is exposed in the vicinity of Point Nesbitt, Zarembo Island. The cobbles are predominantly felsite and felsite porphyry; basalt and basalt porphyry are secondary. Beds of basaltic breccia and basalt flows are associated with the conglomerate. The beds strike northeast and dip about 30° NW. The total thickness is doubtless more than 1,000 feet.

In the Wrangell district, on both the north and the south sides of Zarembo Island, in Kah Sheets Bay, Kupreanof Island, and in the cove just east of the east headland of Steamer Bay, Etolin Island, rhyolitic volcanic rocks, accompanied by conglomerate composed of cobbles of rhyolitic lava, overlie Devonian beds unconformably at the eastern boundary of the Tertiary formations.

The coast line for 3 miles south of the southwest headland of Seclusion Harbor, Conclusion Island, the islands and reefs north of Conclusion Island, and the islands at the entrance to Keku Straits are composed of a series of gray to black felsitic or finely porphyritic lava or vitrophyre, which commonly weather along the coastal cliff to a bright reddish or orange hue. A little breccia is interbedded with the lava, and on Conclusion Island there are many beds of coarse conglomerate with lava pebbles, cobbles, and boulders as much as 4 feet in diameter of the same material as the flows. Many of the lava flows show a well-developed columnar jointing and a platy parting at right angles to the columns. Locally the upper parts of the flows are amygdaloidal, with chalcedony, quartz, and calcite fillings. One flow near the northwest end of Conclusion Island shows a flow breccia at the base, which passes upward into columnar-jointed felsite. The basal part consists of great boulderlike or pillowlike masses with radial jointing, set in a matrix made up chiefly of angular fragments that evidently resulted from the disaggregation of similar masses. Some of the pillows have an outer surface of obsidian.

The vitrophyres of Conclusion Island, south of Seclusion Harbor, and the west side of Threemile Arm, in general strike northwest and dip northeast, whereas those of the other islands strike northeast and dip southeast.

Rhyolitic lava and breccia are exposed on Kupreanof Island opposite Conclusion Island, in Totem Bay, in Little Totem Bay, about 3 miles west of Totem Bay, and at the eastern contact in Kah Sheets Bay. A little more than 6 miles east of Point Barrie green and purple felsites are exposed. The beaches here are of waterworn pebbles of varicolored tuff, breccia, felsite, and porphyry, many of which are very beautiful. The shores of Little Totem and Totem Bays are composed of green, white, red, and gray rhyolite. Many of the rocks show marked fluxion banding, others are porous, and others spherulitic; some are very much altered. Quartz and feldspar phenocrysts are common in some phases of these flows and feldspar in others. Shingle Island is composed of a fissile platy rhyolite with abundant vesicles lined with crystals of chalcedony and quartz. Very beautiful flow structure exemplified in swirling green and white bands is found in flows of rhyolite associated with basalt on the Level Islands. Much of the rhyolite lava there is minutely spherulitic. The rhyolite at the head of Totem Bay is so platy that it might easily at a superficial glance be mistaken for shale or slate. West of the rhyolitic lava on the west side of Totem Bay is basaltic lava overlying tuff and breccia, with intercalated beds of sandstone and conglomerate. One bed of tuff is greenish and contains fragments of black, green, and red glass or obsidian.

At several localities rhyolite flows overlie older formations unconformably and are generally believed to be of Tertiary age. In the Ketchikan district, near the south tip of Gravina Island, a rhyolite flow overlies granite and greenstone, and at Long Island, Kasaan Bay, platy rhyolite overlies Middle Devonian limestone.

BASALTIC AND ANDESITIC LAVA FLOWS AND ASSOCIATED ROCKS

Basaltic and andesitic volcanic rocks, mostly flows, occupy large areas at the southwest end of Admiralty Island, a belt 15 to 18 miles wide on Kupreanof and Kuiu Islands paralleling Keku Straits, and an area at the west side of Zarembo Island. Small patches are found on certain of the Castle Islands, Duncan Canal, and on the group of islets southeast of Onslow Island, in the Ketchikan district. These lavas and pyroclastic beds have a maximum thickness of 2,500 feet. The greater part appear to be the result of fissure eruptions that filled existing valleys and even submerged the tops of mountains. On Port Camden they overlie the sedimentary formations carrying Kenai (upper Eocene) fossils.

In the vicinity of Point Mitchell, Kupreanof Island, the lava is olivine basalt; it is light gray and has a fissile, platy structure parallel to the surface of the flows. For 6 miles east of Point Barrie the lavas are predominantly basalt porphyry with labradorite phenocrysts. Local layers are highly amygdaloidal.

The rocks along Keku Straits from the mouth to the head are basalt with some associated green platy andesite. The basalts are in part red and felsitic to finely uniform in grain, in part dark-weathering porphyry; the former variety shows a very pronounced close-set vertical jointing. Rarely globules of brown glass are uniformly distributed throughout the rock. Here and there the phenocrysts are pyroxene. Well-developed polygonal jointing in basalt is very beautifully shown on one of the Castle Islands, in Duncan Canal, on the Level Islands, Sumner Strait, and at Arena Cove, Suemez Island. Some of the flows consist of a gray-black basalt porphyry at the center with an oxidized red highly amygdaloidal or vesicular upper surface.

Locally the andesitic lavas are altered, with the development of secondary minerals, such as zeolitized glass, calcite, epidote, chlorite, serpentine, sericite, and magnetite, and the introduction of pyrite.

The amygdules consist for the most part of chalcedony or calcite, or both, but many of the vesicles are only lined or partly filled with drusy quartz; chlorite is locally a common filling, and in one area heulandite is abundant; a zeolite supposed to be stilbite is reported by Wright.

At Murder Cove, on the south side of Admiralty Island, coal beds are interstratified with the basaltic tuff, breccia, and lava.

ORIGIN

The Tertiary formations accumulated in a great depressed trough or structural valley between mountain ranges with differences in altitude probably equal to those of the present time; also, to some extent, in erosional valleys leading into the major valley. Mountains 2,000 feet in height appear to have been buried under the Tertiary lavas. The beds of coarse conglomerate are of the nature of alluvial fans spread at the mouths of rivers with very steep gradients, where they debouched upon the more level floor of the valley. The sandstone deposits were probably formed by the interlacing of alluvial fans that spread out toward the center of the trough and valley and formed a gentle piedmont slope such as is found to-day at the foot of the Sierra Nevada and the Coast Ranges in San Joaquin Valley, California.

The andesitic and basaltic lavas were probably erupted mostly from fissures, though in part from local volcanoes. The dominance of fissure eruptions is suggested by the abundance of dikes and sills in the adjacent country rock.

There are no known marine deposits associated with the Eocene beds in southeastern Alaska.

AGE

The age of the sedimentary formations has been determined as Tertiary by Knowlton and Hollick, from fossils collected at several localities.

The original collection made by F. E. and C. W. Wright was determined by Knowlton and referred to as probably of Kenai age (upper Eocene). Hollick assigns their later collection to the "Arctic Miocene," which is the equivalent of the Eocene. The lists are given in the accompanying table.

Eocene flora of southeastern Alaska

[a, Identified by Arthur Hollick; b, identified by F. H. Knowlton]

	7565 (55)	A	7581 (258)	7582 (291)	7580 (271)	B	7518
Pteris sitkensis	a						
Taxodium occidentale	a						
Taxodium tinajorum	a						
Taxodium dubium	a		b	a		a	
Taxodium distichum miocenum		b			b		
Taxites olriki	a				b		
Sequoia langsdorfii	a	b			b	a	b
Sequoia couttsiae ?	a						
Sequoia nordenskioldi ?		b					
Dioon praespinulosum n. sp. (ined.)	a						
Flabellaria gronlandica	a						
Populus		b					
Populus balsamoides	a						
Populus glandulifera	a						
Dryophyllum stanleyanum	a						
Castanea castaneaefolia	a					a	
Oreodaphne	a						
Magnolia inglefieldi	a						
Vitis olriki	a						
Alnus		b					
Alnus carpinoides				a			
Corylus macquarri				a	b	a	
Osmunda doroschkiana						a	
Planera ungeri						a	
Juglna snigella		b			b		
Ulmus		b					
Quercus		b					
Laurus		b					
Castalia		b					
Lastraea stiriaca				b			

7565(55). Dark gray, almost black, friable shale, associated with coal seam intercalated in coarse white sandstone and conglomerate. South side of Hamilton Bay, Kupreanof Island.

A. Collection made by F. E. and C. W. Wright, probably from the same locality as 7565.

7581(258). White rhyolitic tuff with silicified tree stumps and fragments of trunks and branches. Tuff underlies coarse volcanic comglomerate. North side of point about 3 miles southwest of Point Camden, Kuiu Island.

7582(291). White sandstone layers intercalated in very coarse conglomerate of volcanic cobbles between basalt flows.

7580(271). White rhyolitic tuff and breccia. Port Camden, Kuiu Island, 3 miles southwest of Cam Island.

B. Collection made by F. E. and C. W. Wright 3 miles south of entrance to Port Camden. Fine-grained gray argillaceous sandstone interstratified with conglomerate composed of lava cobbles.

7518. Just south of fourth brook south of McNamara Point, Zarembo Island.

Although the lower part of the Tertiary formations is thus of Eocene age, it is by no means certain that the upper part may not belong to a later epoch of the Tertiary. Locally the basaltic and andesitic lavas of the highest formation appear to bear unconformable relations to the sedimentary beds; but this is not sufficiently pronounced, especially in view of the disturbances which accompany volcanism, to warrant their definite assignment to a later epoch.

PLIOCENE (?) DEPOSITS

LITUYA BAY

The Tertiary deposits of Lituya Bay are described by the Wrights [94] as follows:

The strata along the shore line between Lituya Bay and Icy Point consist of conglomerate, sandstone, and shale, and constitute the low, nonincised foreland fringe, which is characteristic of this part of the coast and extends northwest to Yakutat Bay and beyond. The strata strike parallel with the shore and dip at low angles seaward; they are coastal shelf deposits that have derived their materials from the adjacent mountains. The formation is well exposed on Cenotaph Island in Lituya Bay. On the north end of this island the sandstone and conglomerate beds are more highly tilted than usual, and dips as steep as 55° S. 60° W. have been observed; on the south end of the island the dip is considerably less and averages about 20°. * * * The sandstone and conglomerate of Cenotaph Island consist of subangular fragments to rounded pebbles of different sizes, the largest 6 inches or more in diameter, of granodiorite, amphibolite gneiss, greenstone, slate, and vein quartz, intermixed and distributed in the manner characteristic of coastal shelf deposits. Most of the rocks have a greenish tinge, as a result, no doubt, of the relatively large amount of greenstone material present. In Lituya Bay the field relations indicate that the Tertiary deposits probably rest directly on the greenstone.

These beds occur only in low-lying basins adjacent to the shore. The materials were deposited by the streams from the mountains in the background, in part as a piedmont assemblage of the interlacing fans extending to the ocean, and they were worked over by wave action, deposited in bands, and finally loosely consolidated. The character of the material, especially the coarse conglomerate, indicates that at the time of deposition of these beds the mountains rose rather abruptly from sea level, as at present. It is significant that these deposits and also the sand beaches end with the recession inland of the high peaks capable of supplying much material for such deposits.

Similar relations exist with respect to the Eocene beds on Admiralty and Kupreanof Islands to the southeast and furnish an argument against the hypothesis that the Coast Ranges underwent peneplanation during Tertiary (Miocene) time.

On the north end of Cenotaph Island a volcanic agglomerate consisting of lava intermixed with considerable sandstone was discovered. The field relations indicate that the eruption was submarine and probably took place while the deposition of the sediments was still in progress. The lava is basaltic and deep red and contains visible plagioclase and pyroxene. The fragments of sandstone in the agglomerate are dark brown and apparently less fresh. This lava is the youngest volcanic rock that has been observed in the Glacier Bay region.

On the east side of Cenotaph Island fossils were found in several of the sandstone beds. They were referred to W. H. Dall for examination. His report is given below:

"The fossils from Cenotaph Island, Lituya Bay, Alaska, are marine mollusks, etc., contained in much-crushed blackish shale and sandstone; they have a strong similarity to those collected by I. C. Russell in the foothills or mountains

[94] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

near Mount St. Elias, and like them have a rather northern facies. Russell's specimens, however, were much better preserved. The present fossils are mostly so crushed that any exact comparison with the analogous species of the recent fauna is impracticable. It can only be said that they resemble certain recent forms and, in part, may be identical. The age of the fauna is either Pliocene or Pleistocene, probably the former. There are no characteristic Miocene species. The list is as follows: *Arca* sp., *Cardium* near *C. groenlandicum*, *Cardium* near *C. islandicum*, *Cardium* near *C. corbis*, *Panomya* n. sp., *Uya* near *U. arenaria*, *Leda* sp., *Yoldia* near *Y. montereyensis*, *Nucula* sp., *Acila* sp., *Macoma* near *M. sabulosa*, *Macoma* near *M. balthica*, cast of large pholad burrow like that of *Parapholas californica*, *Diplodonta* sp. near *D. aleutica*, *Pandora* near *P. grandis*, *Saxicava* sp., *Hinnites?* sp., *Purpura* sp. near *P. crispata*, *Chrysodomus?* sp., *Lunatia* sp., worm tube, *Echinarachnius* sp., an impression apparently fucoid, other fragments of vegetable matter."

Fragments of wood gathered from the same locality were examined by F. H. Knowlton, who reports as follows:

"This material consists of a considerable quantity of minute fragments of wood, some of which, possibly all, is evidently coniferous; but beyond this it is impossible to go. Thin sections of this wood could be cut, but it is doubtful if they would show much of value, as it would doubtless prove to be new."

These fossils were not taken from the base of the formation, and it is possible that several Tertiary horizons are represented here as they are farther west in the Yakataga section[95] and in the marine Tertiary of Controller Bay.[96] It is significant that the Pliocene rocks of the Mount St. Elias region, as described by Russell[97] and Maddren, are intensely folded; in the Lituya Bay area they are little disturbed.

At several points on Cenotaph Island coal seams were observed interbedded in the sandstone and shale, but at no point are the beds of sufficient size to be commercially valuable.

The total thickness of the exposed Tertiary deposits can not be estimated with any degree of exactness from the data at hand. No time was available in the field for careful stratigraphic work. The best estimate which can at present be made is possibly several thousand feet.

SUEMEZ ISLAND

At the south end of Suemez Island the broad, flat valley that extends from Arena Cove northeast to Port Refugio is occupied by an area of Tertiary volcanic rock. These include rhyolite, obsidian flows, andesite, and basalt. In Arena Cove the east side and Lontano Point are composed of andesitic lava with intercalated red shale of Devonian (?) age. The peninsula a little west of the middle of the cove consists of platy andesitic lava of Tertiary age. The coast line north of Cape Felix is composed of Devonian (?) volcanic rocks, but the high mountains back of Cape Felix appear to be formed by the Tertiary volcanic flows. Just east of Cape Felix there is a small cove. The headland in front of this cove is formed by a great dike

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95 Maddren, A. G., Mineral deposits of the Yakataga district: U. S. Geol. Survey Bull. 592, pp. 126–132, 1913.

96 Martin, G. C., The Controller Bay region, Alaska: U. S. Geol. Survey Bull. 335, 1908.

97 Russell, I. C., Second expedition to Mount St. Elias, in 1891: U. S. Geol. Survey Thirteenth Ann. Rept., pt 2, pp. 1–91, 1893.

of basalt with conspicuous columner jointing, and the shore of the cove is a flow of rhyolite. A part of the rhyolite flow is obsidian, consisting of layers of greenish-black glass and a considerable mass of yellow glass with black glass nodules. A little south of the head of Port Refugio basaltic lava appears in small outcrops along the streams. It is reported that coal seams have been found within this formation.

This formation resembles lithologically the Tertiary volcanic rocks of Kupreanof, Kuiu, and Admiralty Islands and also in part the Tertiary volcanic rocks of Graham Island, to the south in British Columbia. Its geographic location allies it with later volcanic rocks that are assigned by MacKenzie[98] to the early or middle Pliocene.

INTRUSIVE ROCKS

DISTRIBUTION

The Tertiary intrusive masses are of very minor extent compared with the older (Upper Jurassic or Lower Cretaceous) intrusive masses. Nevertheless they are locally conspicuous. A belt 12 to 15 miles wide parallel to and surrounding the borders of the present Tertiary formations is characteristically riven by sills and dikes of basalt and andesite and locally to a minor extent by rhyolite. A belt in which there are several intrusive masses of Tertiary diabase and gabbro passes through Eva Island, the peninsula on Kupreanof Island, between Hamilton Bay and Keku Strait, Pup Island, Point Camden, and the head of Threemile Arm, Kuiu Island. At the north end of Keku Strait there is a sill or laccolith of dacite porphyry.

DIKES

The dikes and sheets are most common in the phyllite, slate, and graywacke, and are sparse or absent in the granite. In the phyllite and slate they are predominantly parallel to the foliation, but in the graywacke they are most common as dikes. The dikes are usually most abundant near the present outcrops of the Tertiary formations. Within the Tertiary formations themselves dikes and sills of basalt and andesite are common, especially in the sandstone and conglomerate series of Port Camden and in the rhyolitic volcanic rocks and lava conglomerates throughout the areas of their distribution. The Level Islands, Sumner Strait, are composed of basaltic, andesitic, and rhyolitic lava of Tertiary age, which is locally intensively intruded by basaltic and andesitic dikes 3 to 10 feet wide and spaced, on the average, not more than 50 feet apart. On the west side of Zarembo Island also dikes are very abundant in the Tertiary lavas.

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[98] MacKenzie, J. D., Geology of Graham Island, B. C.: Canada Geol. Survey Mem. 88 pp. 76–82, 1916.

Near the mouth of Saginaw Bay, Kuiu Island, and on the Keku group of islands dikes of basalt are sparse, but near the head of Saginaw Bay they are abundant. There is a similar concentration of dikes near the head of Bay of Pillars. On the southeast side of Kuiu Island dikes are common between Port Beauclerc and the outcrop of the Tertiary lavas. There are several basalt dikes at the head of Port Beauclerc and a few on Edwards Island, but none were noted on the south arm of the bay. Several great dikes of basalt 50 to 75 feet wide strike through the second island south of Point Amelius and appear again in the bay 3 miles southwest. None were seen along Affleck Canal.

The part of Prince of Wales Island northwest of a line running from the south end of the Barrier Islands to the west headland of Red Bay is cut by a very great number of basalt dikes striking north-northeast. The northeast side of Prince of Wales Island, including the east headland of Red Bay and the east half of Thorne and Stevenson Islands, is crossed by a very great number of basalt dikes striking northwest. Between these two areas dikes are present but not abundant.

On the north coast of Kupreanof Island sills of basalt are abundant in the upper half of Portage Bay and there are a few dikes of felsite, but none were noticed on Frederick Sound east of Boulder Point. Sills of basalt are very abundant in the bay opposite the Castle Islands, Duncan Canal.

On the north side of Zarembo Island basalt and andesite sills and dikes are very abundant in the slate for 5 or 6 miles east of the border of the Tertiary formations, but they are sparse in the quartz diorite mass. On the southeast side of Zarembo Island, where the Tertiary formations adjoin the Devonian (?) slate, great masses of rhyolite porphyry are exposed, and the slate east to and including Round Point is cut by many dikes of rhyolite porphyry.

Sheets of intrusive basalt are common in the Lower Cretaceous (?) slate of Etolin Island. On the southeast side of Canoe Passage, at the lower end, the phyllite for a mile and a half is intruded by a great many sheets of rhyolite and basalt. The basalt cuts the rhyolite. The slate forming the east headland of Windy Bay, in particular, is very closely intruded by sills of basalt. The number of basalt sheets and dikes increases notably toward the present area of Tertiary lava on Eagle Island. On Deer Island and along Seward Passage basalt dikes are rare.

On the mainland basic dikes are locally very abundant in the granitic rocks, but they are probably genetically connected with the Coast Range batholith and are not of Tertiary age. Dikes similar to the typical Tertiary basalt are very rare on the mainland. At

Point Coke, at the entrance to Holkham Bay, however, there is a typical dike of Tertiary basalt 200 feet wide. This dike is fractured and has many gash veinlets of albite and calcite, locally with sparse galena and ilmenite.

Rock from a typical basalt dike in Tertiary sandstone on the west side of Zarembo Island was studied in thin section with the microscope. It has a diabasic texture and consists essentially of labradorite laths with intersertal reddish pyroxene and greenish glass with a microspherulitic crystallization. Magnetite is abundant in disseminated crystals, plates of ilmenite are common, and apatite is sparse.

A sheet of basalt on the west border of the Tertiary formations on Kuiu Island, west of the north end of Conclusion Island, has a typical diabasic texture. It consists of a felt of labradorite laths (Ab_2An_3) with intersertal colorless pyroxene and interstitial radiate fibrous crystallized glass. The glass is brownish and gives a black cross with crossed nicols. Abundant accessory grains of disseminated magnetite are present.

A sample of andesite taken from a dike in the slate at Baht Harbor, Zarembo Island, as seen in thin section, is found to consist of a felt of andesine laths with considerable interstitial decomposed greenish glass. There is a trace of interstitial quartz and abundant plates of ilmenite. This rock is a very common type.

DIABASE

Pup Island, Eva Island, and Point Camden, at the north end of Kuiu Island, are formed of diabase intrusive into Tertiary sedimentary beds.

DACITE PORPHYRY

At the north end of Keku Strait there is a mass of dacite porphyry extending north-northeast. This is believed to be a thick sill or laccolith which thins out to the west. It is intruded between the sandstone and the volcanic conglomerate of the Tertiary. The rock is light green-gray to ash-colored and shows lath-shaped phenocrysts of feldspar and a few of pyroxene. On the big island at the south side of the mass the rock is drusy and the cavities are lined with crystals of quartz and riebeckite. The rock is characterized throughout by a platy fissility, mostly in the vertical plane, but locally parallel to the plane of intrusion. Rarely, flat blocks of sandstone and conglomerate are included within the dacite, and it is cut by dikes of basalt.

In thin section the rock is found to be composed of euhedral crystals of plagioclase and pyroxene in a groundmass of interstitial brown glass and a micrographic intergrowth of quartz and feldspar. The plagioclase ranges from andesine to albite-oligoclase. Small partly resorbed crystals occur locally.

OLIVINE GABBRO

On Kupreanof Island, between Hamilton Bay and Keku Strait, there is a small mass and several sills of olivine gabbro intruded into the Tertiary sediments that form the peninsula just south of Point Hamilton. The gabbro mass is oval, with a longer diameter of somewhat more than a mile. The beds on the east, west, and north dip gently beneath it, and it is overlain by beds that dip gently south-southeast. It appears to form a small basin-like mass with the lower beds on three sides depressed beneath it. Directly east of Point Hamilton, on the east side of Hamilton Bay, there is a diabase sill, intrusive into Devonian sediments, which is probably of Tertiary age.

The gabbro is very heterogeneous in texture. Coarser-grained gabbroic veins rich in feldspar are common. They grade imperceptibly into the normal type of rock. In thin section the rock is found to range from diabasic to ophitic texture. It consists of labradorite, monoclinic pyroxene, and olivine, with accessory magnetite. The olivine is in places partly altered to dark-green serpentine and the pyroxene to chloritic aggregates, and locally there are bundles of actinolite needles. In specimens from the chilled contact facies there is some interstitial dark-brown glass. Much of the magnetite is in skeletal crystals.

ANALCITE GABBRO

About 3 miles northeast of Point Camden a very irregular peninsula makes out from Kupreanof Island. The outer part of this peninsula is composed of a gabbro sill intrusive into Tertiary sandstone. The rock is highly pyroxenic and consists of labradorite (Ab_1An_2) and monoclinic pyroxene with analcite and secondary thomsonite and accessory magnetite and apatite. The rock texture is ophitic. The analcite occurs as grains and as interstitial fillings between the other minerals and may form 10 per cent or more of the rock. It appears to belong to a late stage in the primary crystallization of the magma. Much of the analcite is partly replaced by thomsonite, which usually works into it from the borders and may completely replace it. Veinlets of massive microfibrous pectolite with considerable associated analcite also occur in the gabbro. The identity of the analcite was checked by a chemical analysis made for the writer by Prof. A. H. Phillips, of Princeton University.

On Kuiu Island, at the head of Threemile Arm on the southwest side, there is exposed a mass of gabbro which may form the group of high mountains that lie between Port Camden, Seclusion Harbor, and Threemile Arm. This gabbro mass lies along the belt of Tertiary intrusive gabbro bodies that passes through Point Camden, Pup Island, Point Hamilton, and Eva Island and may be of the same age. If so, its intrusion probably accounts for the uplift of the lower Tertiary beds at this point and the absence of the basal sandstone and conglomerate. The rock consists of labradorite and of pyroxene that is considerably altered to green hornblende and chlorite.

GRANITE PORPHYRY

At the north end of Zarembo Island south of Point St. John there is a mass of granite porphyry exposed along the shore. This granite porphyry is associated with Tertiary volcanic rocks and is probably of the same age. It consists of feldspar in a groundmass of micrographic intergrowth of quartz and feldspar. The feldspar is much altered but appears to be microperthite. Small druses filled with kaolinite and chlorite are present.

QUATERNARY ROCKS

GLACIAL DEPOSITS

Glacial deposits are usually inconsiderable in this region, except where directly connected with modern glaciers. The general submergence of the glacier fronts at the time of recession, the steep fiord walls of the valleys of the mainland and in part of the islands, and the rapid rate of erosion, due to heavy rainfall and steep slopes, account in part for the general lack of glacial deposits on land.

The most conspicuous evidence of glacial deposits is found in the boulder beaches, or accumulations of partly reworked boulders and gravel, which occur locally along the coast. Knopf[90] reports that in the Eagle River region a mantle of tough glacial till covers much of the bedrock and extends up to an altitude of 2,500 feet.

At Thomas Bay Point Vandeput and the bar that forms a convex barrier almost across the mouth of the bay are parts of a terminal moraine composed predominantly of granitic cobbles and boulders; the terrace at Wood Point is studded with glacial boulders of the terminal moraine; and along the south shore of the bay lateral morainal material is found. At the head of Port Houghton the "salt chuck" is separated from the main arm by a terminal moraine through which a narrow channel has been cut. Both at Thomas Bay and at Port Houghton the moraines appear to have been reworked and leveled by marine planation and then uplifted.

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[90] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 32, 1912.

Boulder clay is found at the head of Portage Bay, Kupreanof Island.

Convincing evidence of at least two advances of the ice with a recessional stage are found in Glacier Bay; in the vicinity of Mendenhall Glacier, in the Eagle River region; and in the Porcupine district, northeast of Haines. In Glacier Bay an extensive forest grew above glaciated bedrock and was covered by thick deposits of gravel belonging to an interglacial stage; it is now being uncovered by the retreat of the glaciers and the erosion of modern streams.[1] In the Porcupine River district interglacial gravel and glacial deposits are found in interglacial canyons. Knopf [2] reports a buried forest in the outwash plain in front of Mendenhall Glacier.

Eakin [3] has described the interglacial canyons with interglacial stream gravel in the valleys of Glacier and Porcupine Creeks, tributary to the Klehini River, as follows:

> In places in the Porcupine Valley at the side of the present canyon there are so-called bench deposits, which consist of stream gravels overlain by glacial detritus. It is evident that these deposits occupy sections of a canyon, older than the present but of similar origin, which was in some places followed and in others missed by the course of the stream when the last intrenchment began. Two distinct ice advances are thus indicated, each of which was followed by intrenchment of the hanging-valley streams. * * * In the Glacier Creek Valley also there is evidence of two distinct advances, with a period of stream erosion intervening. An extremely deep and narrow bedrock gorge filled with glacial detritus has been traced for some distance along the lower part of the valley beneath the modern gravels. A base level of erosion much lower than the present is indicated the same as in the lower Porcupine Valley.

MARINE DEPOSITS AND TERRACES

Benches and terraces of fossiliferous marine gravel, sand, and clay are found locally at altitudes up to 600 feet throughout southeastern Alaska.

In the Hyder district marine interlaminated clay and sand occur up to altitudes of 450 feet near Elevenmile on Salmon River at the head of Portland Canal and are reported by Hanson [4] at similar altitudes on Bear River.

In the Ketchikan district Chapin found fossiliferous gravel and blue clay on Gravina Island, about half a mile northwest of the cabin at the head of Dall Bay, at an altitude of about 80 feet. The

[1] Cooper, W. S., The recent ecological history of Glacier Bay: Ecology, vol. 4, pp. 93–128, 223–246, 355–365, 1923.

[2] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 12, 1912.

[3] Eakin, H. M., The Porcupine gold placer district, Alaska: U. S. Geol. Survey Bull. 699, p. 20, 1919.

[4] Hanson, George, Reconnaissance between Kitsult River and Skeena River, S. C.: Canada Geol. Survey Summary Rept. for 1922, pt. A, p. 44, 1923.

outcrop is covered on all sides by vegetation. The exposed base contains about 2 feet of glacial till and blue clay and is overlain by stratified beds of glacial gravel 5 or 6 feet thick. Fossils occur in both the blue clay and the stratified gravel. A collection was submitted by Chapin to W. H. Dall, who reports the following species:

Cylichnella n. sp.
Bela violacea.
Colus sp., fragment.
Cardium (Cerastoderma) ciliatum.
Axinopsis viridis.
Macoma calcarea.
Saxicava arctica.
Mya intermedia.
Balanus sp., fragment.

The assembly naturally indicates the colder climate associated with the period of glaciation.

Buddington is indebted to Mr. Harper Reed, of Wrangell, for directing him to a fossil locality in British Columbia on Goat Creek, a small tributary of Stikine River from the west about 40 miles above its mouth and about 5 miles above the international boundary. The fossiliferous beds are about half a mile up the creek at an altitude estimated as 175 to 200 feet above sea level. The beds crop out in the steep bank of the brook and consist of clay with fossil shells overlain by coarse gravel. The shells are so leached as to crumble in the fingers. A collection was submitted to W. H. Dall, who reported the following species:

Cardium ciliatum.
Pecten islandicus.
Macoma balthica.
Mytilus edulis.
Leda minuta.
Chrysodomus liratus.
Barnacle, fragments.

Mr. Dall also made the following comments:

> In 1899 on Douglas Island I traced elevated beaches with Quaternary shells along a ditch for the town of Douglas water pipe to an altitude of 200 feet. Other fossils from the same source were collected by Spencer in 1903. There is no doubt that there was an elevation of some 200 feet in the coast region of southeastern Alaska during Quaternary or later time. The Goat Creek fossils are probably of about the same age as those of Douglas Island but were deposited in silt at the end of a glacier, whereas the Douglas Island fossils are in ordinary beach gravel.

Shells of similar character and age were found in September, 1922, by Buddington in the moraine of Great Glacier on the west bank of Stikine River above the mouth of Iskoot River. The fossils were lying on the surface, where they had been washed out of clay at the top of the moraine just in front of the ice. Clay with marine shells is reported to have been struck in digging the foundations for the old cable office at Wrangell.

Uplifted gravel deposits of marine origin are found at several localities. Along the east side of Frederick Sound there is a gravel terrace from the point about 3 miles north of Point Agassiz south to and including Brown Cove. This terrace may be continuous across to Patterson River and may represent uplifted former delta deposits. Just north of Point Agassiz the coastal edge of the terrace is about 20 feet above low-tide level. At the mouth of Patterson River, Thomas Bay, there are terraces of sand and gravel at least 40 feet above the river level.

Dall has reported beach deposits on Douglas Island at an altitude of 200 feet, and Spencer reports sea shells and old beach deposits in the vicinity of Juneau at altitudes of 600 feet or more above the present sea level.

Knopf[5] reports fossiliferous marine gravel on Lemon Creek, Eagle River, and at an altitude of 100 feet on the summit of the divide through which the Amalga tramway passes after leaving the flats of Eagle River.

A remnant of an ancient uplifted delta of Stikine River forms the point at the south entrance to Le Conte Bay, extending out to Camp Island; this terrace consists of clay beds at the base and fine sand at the top. Its altitude at one point measured 60 feet above sea level. Remnants of uplifted deltas of sand and gravel are common at the mouths of many of the streams, such as Powers Creek, on Endicott Arm; Patterson River, in Thomas Bay; and Harding Creek, in Bradfield Canal.

BASALT AND TUFF

Basaltic lava of Quaternary age occupies small areas at many places along the mainland and on Revillagigedo Island. On the mainland the lavas are reported by Wright[6]

> to have been extruded near the granite contact and, following Canon Creek and Blue River valleys to the Unuk River, spread over its valley floor and forced its waters to the south wall, where now they pass by way of the three narrow canyons indicated on the map. The volcanic ash from these eruptions can still be seen as black patches on the glaciers of the mountain peaks 8 to 10 miles distant.

Westgate[7] writes of the volcanic rocks along Behm Canal as follows:

> Lava, chiefly basalt, and associated tuff are found at several points along the shore of Behm Canal north of Smeaton Bay. The largest area, 3 miles long, is at Point Trollop, at the entrance of Smeaton Bay. Two small areas are found on the west side of Behm Canal and another at the south end of the Punchbowl, a small bay on the south side of Rudyerd Bay. On the east shore

[5] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 32–33, 1912.

[6] Wright, F. E., The Unuk River mining region of British Columbia: Canada Geol. Survey Summary Rept. for 1905, pp. 50–51, 1906.

[7] Westgate, L. G., Geology and mineral resources of the area east of Behm Canal (unpublished manuscript).

there is a small mass at Edith Point and another 2 miles north. These may have been once continuous with the basalt of some of the adjacent small islands, including New Eddystone Rock.

These lavas and tuffs are essentially flat-lying, still in their original position. They were extruded after the region had reached essentially its present surface development and are confined to the lowlands. Their flat upper surface is a constructional surface; on Point Trollop it is hardly over 100 feet above the level of the sea. New Eddystone Rock, 234 feet high, is a pillarlike remnant cut by the waves from a flow which may not have arisen originally to a much greater height.

The rocks are dark to black and weather a characteristic red-brown. At Point Trollop two flows are found, each vesicular in its upper part. The base of the lower one is below water level. The rock is very fine grained, gray-black, and massive, and under a hand lens shows a few tabular phenocrysts as much as 5 millimeters in length. The microscope shows unoriented labradorite microlites 0.2 millimeter in length, small grains of augite, crystals of hornblende, and grains of magnetite in a fine-grained plagioclase groundmass. Pyroxene is much more abundant than the hornblende.

At the north end of Winstanley Island another type is found, light gray, fine grained, and containing scattered phenocrysts of feldspar as much as 3 millimeters in length. The thin section shows phenocrysts of feldspar and green augite in a groundmass of plagioclase laths, irregular grains of augite and hornblende, magnetite, and brown iron oxide. The rock is rather an augite andesite than a typical basalt.

The lava flows which came into Behm Canal originally had greater extent than they show to-day. The present distribution seems to be the result of a considerable amount of stream erosion, which must have taken place when the land stood higher in reference to sea level than it does to-day. Since the present position of land and sea was reached wave erosion has been going on. New Eddystone Rock is a pillar left standing above a wave-cut platform, a remnant of an originally much larger mass. Several reefs of lava near Edith Point have been formed by the complete truncation of small islands. Study has not been sufficiently detailed to determine what part of the erosion of the basalt was preglacial, what part postglacial, and recent.

Quaternary lava and tuff make up the volcanic cone of Mount Edgecombe, on Kruzof Island, in the Sitka district. The volcanic rocks comprise mainly basic andesite and basalt and are briefly described by Knopf.[8]

DELTA AND CURRENT DEPOSITS

All the indented arms of the sea are being gradually filled, particularly at their heads, by material brought in by rivers. These delta deposits constitute practically the only large level land areas in the region, except for some low-lying flat islands and through valleys on some of the islands.

[8] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, pp. 14–15, 1912.

Many of the deltas at the heads of the fiords on the mainland are being built forward into deep water with very steep fronts. On the islands of the archipelago most of the arms of the sea were originally shallower, and the ice withdrew earlier; consequently, silting up of the bays and coves has proceeded longer and has reached a more advanced stage. Very wide tidal flats are common, as along the west side and head of Duncan Canal, Portage Bay, and Hamilton Bay, Kupreanof Island; Blind Slough, Mitkof Island; Red Bay, Prince of Wales Island; and Port Camden, Saginaw, and Security Bays, Kuiu Island.

The largest of the deltas is that of Stikine River, which at low tide completely blocks the connection between Frederick Sound and the passages on the south. Stikine River is of large volume and is fed by many glacial streams that carry great quantities of suspended material. Sediment brought down by the river is deposited not only on the immediate delta, which is being built forward, but along the shores of Frederick Sound as far as Thomas Bay and in Sumner and Zimovia Straits and Eastern Passage. Uplifted marine sediments with Recent fossils are found along Stikine River in front of Great Glacier at an altitude of about 200 feet. When these beds were deposited the land must have stood about 200 feet lower and the delta of the Stikine River could not have been built as far as this point. A long fiord must therefore have extended to or beyond this point. To judge from such fiords as Bradfield Canal, Taku Inlet, and others, the probable minimum average depth was 500 feet. Depths of 500 feet occur within 3 miles of the front of the present face of the delta. The width of the arm is from 1½ to 2 miles. It thus seems evident that since the retreat of the glaciers from this region Stikine River has built forward a delta which, at a minimum estimate, must have a length of at least 46 miles, an average depth of at least 500 feet, and a width of 1½ to 2 miles.

This advance of the delta results in continued deposition of material upstream. According to the International Boundary Survey chart, the bed of the river is now at an altitude of about 250 feet above sea level at a point about 85 miles upstream from the edge of the delta at mean lower low water. The tributary streams, such as Iskut and Katete Rivers and Andrews Creek, are necessarily also depositing material in their valleys.

A conspicuous feature of many of the small inlets in or near the mainland is the steep boulder-paved shore line. The boulders were especially noted along Fools Inlet, Kupreanof Island, and Walter Island Arm, Port Houghton. They are residuary from the partial erosion of a veneer of glacial drift, and their arrangement appears to be the result of aggregation accompanying erosion and of ice shove due to the expansive force of freezing water in the protected arms.

Sand and gravel beaches of large volume and extent are not abundant. Much of the north coast of Kupreanof and Prince of Wales Islands consists of sand and gravel. The gravel beaches are perhaps most conspicuous along the coast lines eroded in the Tertiary volcanic rocks, as on the Level Islands, the southwest side of Zarembo Island, and the south side of Kupreanof Island. On the west side of Port Camden the platy, jointed rhyolite and rhyolitic tuff have given rise to many shingle beaches composed of flat, platy fragments.

RELATIONS BETWEEN FORMATIONS

WALES GROUP (ORDOVICIAN, SILURIAN, AND DEVONIAN)

The oldest fossiliferous rocks in southeastern Alaska are the Ordovician beds. The Wales group of metamorphic rocks may include formations as old as the Ordovician or may even be largely pre-Ordovician. It is overlain unconformably at some places by beds of Middle Devonian age; it is overlain at other places by beds of lower and upper Silurian age, but whether conformably or unconformably is not known. The Wales rocks are relatively much more deformed and metamorphosed than the known Silurian formations, but it is possible that this difference may be due to excessive metamorphism resulting from the intrusion of large masses of igneous rock that are only slightly exposed at the present surface. The beds of the Wales group have not been observed in contact with rocks of known Ordovician age, and the relations between them are not known.

The graywacke and slate formations of the Ordovician and lower Silurian are isoclinally folded with nearly vertical axes wherever found, irrespective of the possible effects of the intrusion of igneous masses. The upper Silurian beds, on the other hand, show metamorphism and folding that are locally in part connected with the intrusion of igneous masses but are in general not so pronounced as in the underlying graywacke and slate. There are two possible explanations for this: The Ordovician and lower Silurian beds may have been folded before the deposition of the upper Silurian, or the more intense folding of the older beds has resulted from folding of the incompetent graywacke and slate beneath arches of the thick, massive Silurian limestone, which acted as a competent bed. There is no doubt that the difference in competency has been an important factor in producing the difference in folding between the two groups of rocks, but whether it is the only factor is questionable.

At some places the upper Silurian limestone of Dall Island overlies upper Silurian volcanic rocks and conglomerate, whereas at others it directly overlies lower Silurian slate and graywacke; and in some localities upper Silurian volcanic rocks and conglomerate directly overlie the Ordovician graywacke and slate. These relations suggest a marked unconformity, but there can be no certainty of this until more detailed work has been done and the possibility of faulting and changes in lithology along the strike have been excluded.

On the east side of Tonowek Bay a conglomerate series with intercalated limestone of probably Silurian but possibly Devonian age overlies a series of graywacke. The conglomerate series strikes almost due north and dips west; the beds dip gently where they overlie the graywacke. The beds of graywacke in the vicinity of the passages to El Capitan Passage have a general north-northwest strike, are indurated, and are closely folded almost vertically. There is thus apparently a marked angular unconformity between the conglomerate and the graywacke.

At the north headland of Sarkar Cove, Prince of Wales Island, conglomerate of Silurian age with a northeast strike and a southeast dip overlies beds of graywacke that have a northeast strike and northwest dip. No fragments of graywacke could, however, be found in the conglomerate.

In a cove west of Catalina Island, San Christoval Channel, apparently unconformable relations between Middle Devonian (?) conglomerate and underlying graywacke are well shown. Conglomerate that strikes east and dips 20° N. overlies graywacke that strikes N. 75° E. and is nearly vertical. The contact is not exposed, but the conglomerate and the graywacke crop out not more than 10 feet apart. The conglomerate is composed predominantly of graywacke cobbles, though some chert, limestone, green-gray porphyry, and diorite are also present.

Chapin has studied the relations between the Silurian and Devonian formations in the southern half of Prince of Wales Island and on Dall Island. He finds that the Middle Devonian formations overlie the lower and upper Silurian beds unconformably. Thus the lower Silurian beds at Klakas Inlet, Prince of Wales Island, are surrounded by volcanic breccia regarded as the basal member of the Middle Devonian rocks, and the breccia appears to overlie unconformably the graptolite slates. On Kassa Inlet the lower Silurian beds are exposed in several small areas by the erosion of the Devonian breccia which unconformably overlies them. Similarly, on Dall Island the Devonian igneous rocks overlie unconformably the upper Silurian limestone and lower Silurian slate of Breezy Bay and View Cove. (See fig. 1.)

In the vicinity of San Alberto Bay, Buddington finds that there is some evidence of unconformable relations between the thick limestone member of the upper part of the Middle Devonian section and the older formations. At the north end of San Alberto Bay the limestone is adjoined by coarse conglomerate which overlies Silurian formations. On Fern Point, San Fernando Island, the same limestone member overlies graywacke of Silurian age or older, and on Ham Island, in Karheen Passage, the limestone is adjoined by sandstone of upper Silurian age. The Devonian volcanic and graywacke formations are thus missing from beneath the limestone in these three localities. As the contacts are covered, however, no positive statement can be made that the relations are unconformable.

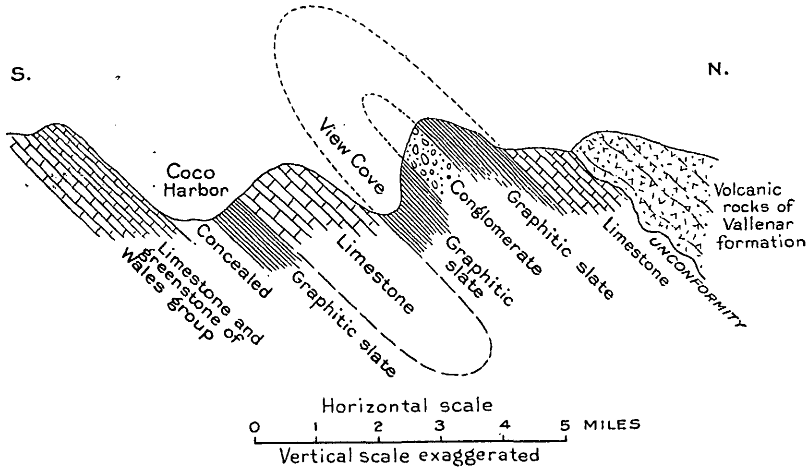

FIGURE 1.—Diagrammatic structure section through the east coast of Dall Island, showing Silurian and adjacent rocks

MIDDLE AND UPPER DEVONIAN

By THEODORE CHAPIN

The western part of the Coronados Islands, a small group at the mouth of Port St. Nicholas, Prince of Wales Island, is composed of fossiliferous limestone of Middle Devonian age. The eastern part of the islands consists of conglomerate, limestone, tuff, and amygdaloidal basalt, regarded as Upper Devonian, which stratigraphically overlie the massive Middle Devonian limestone with apparent unconformity. The relations are not clear, however, for the beds are closely folded and in places overturned. On a number of small islands in Trocadero Bay basalt and tuff with associated conglomerate similar to the Upper Devonian of Port Refugio, Suemez Island, overlie unconformably tuff and breccia regarded as Middle Devonian.

DEVONIAN AND CARBONIFEROUS

In the Ketchikan district Chapin reports that the limestone division of the Permian overlies the Upper Devonian unconformably. In the Keku Islands, of the Petersburg district, Buddington finds that the lower division of the Permian appears to bear unconformable relations to formations as old as Silurian. The southern islands of this group consist of upper Silurian limestone, the adjacent shores and island of Permian limestone, and there is not sufficient distance intervening between these two formations to allow for the presence of the Devonian and Mississippian formations. This might be accounted for by faulting were it not for the fact that on one of the central islands conglomerate beds of the lower division of the Permian directly underlie the upper division of the Permian and carry fossiliferous cobbles of the upper Silurian limestone.

Rocks bearing Permian fossils are described by Chapin as occurring on the small peninsula at the east end of Suemez Island, where they appear to overlie the Upper Devonian and the basalt and interbedded limestone and chert of Point Bocas and the Mississippian black chert and limestone of Ridge Island. The contact is concealed, but the relation is probably unconformable, as the Mississippian and Pennsylvanian beds are apparently absent.

PALEOZOIC AND UPPER TRIASSIC

The Wrights [9] believe that the pre-Upper Triassic formations were folded in a series of northeastward-trending folds at the close of the Paleozoic era. They write:

By a consideration of the entire coastal province of southeastern Alaska, several important features which throw light on the dynamic history of the region are brought out. * * * Prior to the development of the main northwest-trending structural lines, which at present dominate this coastal province and are most pronounced adjacent to the wide areas of intrusive rocks, the prevalent structure was made up of northeasterly-trending folds. These folds still form a minor system prominent in Chichagof, Admiralty, and Prince of Wales Islands. The later and more intense folding of the beds on a broader scale, which forms the major system and trends northwesterly, has in general obliterated this minor system. But the evidence of the two systems is clearly presented on the north shore of Chichagof Island, where the minor system of small folds is the dominant structure at those places which are distant from the northwest-trending intrusive belts and which are not greatly disturbed and metamorphosed. Nearer the intrusive belts the larger system gradually prevails, and the minor folds as a whole are combined in the broader anticlines and synclines of the major northwest-trending folds. Complex minor folding and fracturing is thus produced in the beds. The fact that beds of

[9] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 39, 1906.

upper Carboniferous age have this northeasterly folding indicates that this was the dominant bedrock structure at the close of the Paleozoic era.

The only area in which any evidence for such folds was seen by Buddington is off the west coast of Prince of Wales Island in the vicinity of the Gulf of Esquibel and Bucareli and San Alberto Bays. If the Wrights are correct in their interpretation, the unconformity between the Upper Triassic formations and the Paleozoic indicates a time of pronounced orogeny corresponding to the Appalachian revolution of the eastern part of North America. More data, however, are needed for consideration of this problem.

The Upper Triassic formations bear unmistakably unconformable relations to the Paleozoic, as the basal conglomerates at many localities carry abundant fossiliferous limestone cobbles of Devonian and Permian age. At most places the Upper Triassic beds overlie the upper division of the Permian; but locally, as on Vallenar Bay, Gravina Island, and on the island south of Kake, Kupreanof Island, they directly overlie Devonian formations. On Clover Bay, Prince of Wales Island, they are infolded with Devonian formations.

UNCONFORMITY WITHIN THE UPPER TRIASSIC

An unconformity occurs within the Upper Triassic rocks. On Kupreanof Island and the islands southeast of Kake Upper Triassic sediments overlie the upper limestone division of the Permian and are overlain in apparent conformity by volcanic rocks of Upper Triassic age. Locally, there is a thick bed of coarse conglomerate of the Upper Triassic volcanic rocks. On the northeast side of Kuiu Island, however, the Upper Triassic volcanic rocks overlie the lower division of the Permian, without any apparent angular unconformity. The volcanic rocks on Kuiu Island also carry a different fauna from those on Kupreanof Island. Unconformities are indicated, therefore, within this series of beds.

JURASSIC(?), LOWER CRETACEOUS(?), AND OLDER FORMATIONS

The rocks mapped as Jurassic(?) or Cretaceous are believed to overlie the Paleozoic and Triassic formations unconformably.

On Kupreanof Island about 10 miles east of Cape Bendel a series of beds comprising graywacke and black slate with intercalated conglomerate overlies, presumably unconformably, Devonian limestone, slate, and green chloritic schist. The contact is covered, but the Devonian beds have a very steep dip, in general to the west, whereas the overlying Jurassic or Cretaceous rocks have a moderate dip to the northeast. On Seymour Canal beds of the same graywacke-slate formation overlie Upper Triassic beds, but the formations here are very much disturbed and the relations are uncertain. No fossils have been found in the younger formation, and its assignment to the Jurassic or Cretaceous is based on its lithology and structural relations.

The beds that carry Upper Jurassic or Lower Cretaceous fossils have been mapped as Lower Cretaceous(?); at the localities where they have been studied they overlie Upper Triassic formations.

Chapin reports that on Gravina and Revillagigedo Islands the Triassic rocks are in places overlain conformably by volcanic beds of Upper Triassic or Jurassic age and in places unconformably by slate and graywacke of Jurassic or Cretaceous age. On the northeast shore of Bostwick Inlet, near the entrance, he finds that conglomerate and graywacke overlie, with marked unconformity, the eroded surface of the volcanic rocks, and that on Ward Cove they overlie with noticeable unconformity black phyllite which is correlated with the Upper Triassic.

On Pybus Bay, Admiralty Island, black fossiliferous slate with intercalated conglomerate and interlayered graywacke of Upper Jurassic or Lower Cretaceous age, carrying *Aucella crassicollis* and *Aucella piochii*, overlies limestone and calcareous slate of the Upper Triassic. Similarly, on Etolin Island slate carrying *Aucella crassicollis* overlies Upper Triassic limestone and conglomerate, though here a considerable intervening zone is covered by water. In a cove on Keku Strait, on the northeast side of Kuiu Island, sandstone believed to be of Upper Jurassic or Lower Cretaceous age overlies Upper Triassic volcanic rocks.

The Lower Cretaceous or Upper Jurassic beds thus overlie unconformably the Upper Triassic formations, but no marked angular unconformity between them has been proved. A pronounced angular unconformity is known to exist at the north end of Kupreanof Island between the Jurassic or Cretaceous beds and the underlying Devonian formations.

On Fanshaw Peninsula, on the Glass Peninsula of Admiralty Island, and on Etolin Island the graywacke, slate, and conglomerate formation appears to be overlain conformably by greenstone.

The Jurassic or Cretaceous slate and graywacke appear to be much less metamorphosed than the older Mesozoic formations, but this is certainly in part due to their character. In all the formations the argillaceous beds are most resistant to recrystallization, and their abundance in this series gives the Jurassic or Cretaceous formations a misleading appearance of minor metamorphism. The pebbles and cobbles of the intercalated conglomerate beds are very markedly flattened as a result of very strong pressure. In the Keku synclinorium the Jurassic or Cretaceous beds are very little metamorphosed, but this is true also of the underlying Upper Triassic formations in the troughs of the synclines.

UPPER JURASSIC OR LOWER CRETACEOUS INTRUSIVE ROCKS AND MESOZOIC OROGENY

The invasion of the vast volume of Upper Jurassic or Lower Cretaceous intrusive material and the orogenic folding which gave to the pre-Tertiary formations their dominant northwest trend came after the formation of the beds described as Upper Jurassic or Lower Cretaceous and probably in part at least after the formation of the *Aucella*-bearing beds assigned to the Lower Cretaceous(?). Folding, with the consequent development of cleavage, no doubt took place before the arrival of the intrusive magmas at the horizons where the rocks are now exposed. The folding was accentuated by the side thrust of the magma during the process of its emplacement; locally it was accompanied by recrystallization adjacent to the batholiths and stocks, with the production of the metamorphic complex, and by shearing and mashing at greater distances from the intrusive masses.

Many of the older axes of folding have been swung around into the general northwest trend by the orogenic forces that acted at this time along northeast-southwest lines. In some areas, however, northwest folds are superimposed upon previous northeast and north-northeast folds, and in other areas upon north-south axes of folding. Faulting and brecciation have thus resulted, and the relations are much confused.

The relations of the Coast Range batholith to the country rock have been described. In contrast to the regional metamorphism produced by the great batholith, the smaller outlying stocks and batholiths have produced only zones or pockets of contact metamorphism. Their intrusion has, however, resulted in marked disturbance of the beds, with faulting and displacement. On Blashke Island an ultrabasic stock has domed up graywacke within an area of younger limestone. East of Shakan, Prince of Wales Island, where old sills and dikes occur in marble, the effects of the thrusting force exerted by the magma against its walls are very evident; the marble has flowed under the pressure exerted by the magma, sills parallel to the border of the intrusive mass have been squeezed into lenses, and dikes at an angle to the border are severely crumpled back on themselves.

The Copper Mountain region, on Prince of Wales Island, has been mapped in detail by Wright,[10] who says:

> The structure of the intruded rock beds apparently had little influence on or control of the intrusion of the main masses, for the intrusion evidently determined the present position of the bedded rocks. The larger dimensions of most of the smaller granitic masses, however, lie in the bedding planes of the stratified

[10] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 39, 1915.

rocks. * * * The intruded schistose beds are usually bent to conform with the contact of the intrusive masses, though in places they are much crinkled and squeezed or even brecciated.

There has also been some "reactive" replacement of inclusions broken away from the country rock.

TERTIARY AND OLDER FORMATIONS

The Eocene formations rest with pronounced unconformity upon the Mesozoic intrusive rocks and all older formations. Many beds are folded, tilted, and faulted, but the dip is seldom greater than 30° and is usually less than 15°. The sedimentary beds are consolidated but not metamorphosed. Between them and the older formations there is a marked angular unconformity.

The general character of the structure has been appropriately described by Wright,[11] who says: "The rocks of this formation have no definite strike or dip, but are characterized by frequent and great deviations in the attitude of their stratification, though the amount of flexuring and faulting is moderate." The strike is more or less parallel to the borders of the larger areas, a northeast strike being perhaps most prevalent.

If the interpretation of the structure of the Eocene rocks is correct, the forces that effected their folding were exerted almost at right angles to those that acted upon the Mesozoic formations in pre-Tertiary time. MacKenzie [12] has drawn a similar conclusion with respect to the Tertiary formations of Graham Island, British Columbia; he writes:

A third period of folding affected the island after the Masset formation had consolidated. The date of eruption of the Masset rocks has been placed in the Pliocene, so that this folding probably took place in the late Pliocene.

The direction of the stresses causing this folding has not been thoroughly worked out, but many of the folds seen run more nearly east and west than those in the pre-Tertiary rocks, and these stresses may well have acted in a southwest or southerly direction.

Beds of known Pliocene age are not found in connection with the Eocene rocks in the Alexander Archipelago or adjacent mainland, and their relations are therefore not known. The possible Pliocene beds on Suemez Island overlie Devonian formations with marked angular unconformity and are practically flat-lying.

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[11] Wright, C. W., Reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 144, 1906.

[12] MacKenzie, J. D., Geology of Graham Island, British Columbia: Canada Geol. Survey Mem. 88, p. 111, 1916.

QUATERNARY

The Quaternary deposits, exclusive of the glacial drift, consist of small local marine bench and terrace deposits of interstratified gravel, sand, and clay that bear unconformable relations to all the older formations.

The basaltic lava and tuff of the Mount Edgecombe volcano, Kruzof Island, according to Knopf, are post-Pleistocene. The lava and tuff of Canon Creek and Blue River, tributaries to Unuk River, on the mainland, are reported by Wright to be post-Pleistocene and are the most recent volcanic rocks in the region.

SUMMARY

There appear to have been several disturbances between the Middle Ordovician and Middle Devonian time whose cumulative effect is a pronounced unconformable relation between the Middle Devonian and the older formations. Whether any one of these disturbances was of marked intensity, and if so, at what time it occurred, are unsolved problems. There is some inconclusive evidence to suggest that there was disturbance of considerable intensity between the lower and the upper Silurian. A period of marked disturbance, perhaps one of major orogeny, occurred between the Permian and the Upper Triassic. It is certain that a period of pronounced orogenesis took place between the Lower Cretaceous (?) and the Eocene. The pre-Eocene revolution was accompanied by the continuing intrusion over a considerable period of time of vast bodies of magma, which tended to obliterate and modify the results and evidences of previous disturbances. At some time after the Eocene, possibly in the Pliocene, the Eocene beds were gently folded or warped and faulted. Far to the northwest, in the St. Elias Range, Pleistocene beds have been closely folded and faulted with an intensity characteristic of orogenic deformation.

STRUCTURE

GENERAL FEATURES

Only the broader features of the structural geology of southeastern Alaska are known. Two outstanding major features are the great Coast Range batholith of the mainland, with its innumerable shreds and many large included slabs and narrow bands or belts of metamorphosed sedimentary and volcanic rocks, and the Prince of Wales-Kuiu anticlinorium, a great anticlinal axis which parallels the batholith and extends through Prince of Wales Island, Kuiu Island, the northeastern part of Chichagof Island, and Glacier Bay. Between this anticlinorium and the mainland batholith lies the great Juneau synclinorium, which toward the southeast is split into two branches by the Duncan anticlinorium; the southwestern branch is called in this report the Keku-Gravina synclinorium. The major synclinorium constitutes a northwest extension of the Pacific coast downfold which involves the great valley of California, the Puget Sound Basin, the Strait of Georgia, and Hecate Strait. All these structural elements strike northwest.

A subsidiary cross axis of warping, which strikes east-northeast, parallels Frederick Sound, where it separates Admiralty Island from Kupreanof and Kuiu Islands, and as it affects Eocene rocks it must be of Tertiary age. Another east-northeast axis, not so clearly defined, includes the east side of Noyes Island, Lulu and San Fernando Islands, and the north side of Klawak Salt Lake. Ordovician formations are exposed along this belt with younger formations on each flank and infolded along northwest axes. There are insufficient data to determine the origin or significance of this structural element. The Wrights [13] report that in the Glacier Bay region the prevalent structural trends are northwest, but that locally secondary structural features and minor folds have been produced by movements accompanying the batholithic intrusions. The axes of the secondary folds superimposed on the large folds trend usually in a northeast or east direction.

On the east side of the Coast Range batholith Jurassic formations are exposed in the Hyder district and Paleozoic and Mesozoic rocks on Stikine River. Adjacent to the mainland batholith on the west, from Berners Bay southeast to Dixon Entrance, is the Wrangell-Revillagigedo belt of metamorphic rocks, which consists of formations of both Paleozoic and Mesozoic age, metamorphosed to phyllite, crystalline schist, and injection gneiss with abundant associated intrusive masses. In the trough of the synclinorium the Upper Jurassic or Lower Cretaceous formations are exposed. Tertiary formations overlie the Mesozoic unconformably and occupy a considerable part of the Keku-Gravina synclinorium. The formations exposed along the Prince of Wales-Kuiu anticlinorium are almost exclusively Paleozoic. On the west flank of the anticlinorium, along the west coast of Chichagof Island and Baranof Island, in the Sitka district, there is a belt of Mesozoic formations.

The relations of the various structural elements to each other and the general character of the folding are shown in the series of cross sections in Plate 22. The sections are necessarily somewhat generalized owing to our lack of knowledge of details.

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[13] Wright, F. E. and C. W., Geology of Glacier and Lituya Bays (unpublished manuscript).

Isoclinal folds slightly or very markedly overturned toward the southwest predominate within a belt 15 to 30 miles wide adjacent to the west side of the Coast Range batholith. (See pl. 20, *B*.) Near the batholith the schist and gneiss predominantly dip 60°–90° NE.; in the outer part of the Wrangell-Revillagigedo belt of metamorphic rocks, or locally within the adjoining Jurassic (?) beds of the Juneau synclinorium the predominant dip is much lower, 30°–50° NE. being most common. On the east side of Prince of Wales Island in the vicinity of Moira Sound and at the northeast end of Prince of Wales Island isoclinal folds overturned toward the northeast are prominent.

Faulting on a small scale is prevalent throughout the sedimentary formations in southeastern Alaska. The geology has not been worked out sufficiently to afford satisfactory information as to the extent and character of large-scale faulting, but there is no doubt that it is much more prevalent than might be indicated by the few examples mentioned.

Lynn Canal and Chatham Strait were eroded along a fault zone. In the Juneau district the Silverbow fault, which has an approximately east-west strike and a downthrow on the north, has been mapped by Spencer and Eakin.[14] The beds as exposed at the surface show a horizontal displacement of about 1,600 feet. This fault is later than the Upper Jurassic or Lower Cretaceous intrusive rocks.

A highly mashed overthrust fault zone is indicated by the cataclastic texture of the rocks in a belt on the mainland adjacent to Stephens Passage from Port Houghton north to Point Astley and to the northwest in the vicinity of Point Arden and Grand Island. There are also many zones of intense shearing within the Coast Range batholith itself.

A noteworthy fault plane with a strike of about N. 38° W. occurs along the southwest side of Mount Calder, between the limestone and graywacke, and through the east side of Middle and Divide Islands, off the northwest end of Prince of Wales Island. Brecciation and crumpling and folding of the beds at the northeast end of this fault zone are intense.

Along Bocas de Finas, on the west side of Prince of Wales Island, there is a fault zone with a general N. 60° W. strike. The conglomerate, graywacke, and slate beds here are crumpled, brecciated, offset, slickensided, and generally shattered. Northwest of Point Desconocida the shattering is intense, and every specimen of rock shows narrow veinlets along the fractures. The graywacke-slate beds show many minute thrust faults, suggesting that the major fault may be of the thrust type.

[14] Spencer, A. C., and Eakin, H. M., manuscript report on the Juneau district.

Other fault zones were noted along the east side of the lower half of Orr Island, the east side of San Christoval Channel, and the south side of Zarembo Island.

JURASSIC (?) ROCKS OF THE HYDER DISTRICT

The structure of the Jurassic (?) formations on the east side of the Coast Range batholith north of Hyder has been described by Schofield and Hanson.[15] The formations are folded with a northwesterly strike, and one fold shows slight overturning toward the west.

Discordant features which are considered to be post-Jurassic but older than the main bulk of the intrusive rocks of the Coast Range batholith are found in the vicinity of Salmon River, the West Fork of Texas Creek, and Texas Glacier, in the Hyder district. These are the Texas batholith of granodiorite and the Jurassic (?) slate and graywacke into which it is intruded. The trend of the gneissic structure of the Texas batholith averages about N. 70° E., and the strike of the sedimentary beds averages about N. 80° E. The sedimentary formations are closely compressed and isoclinally folded; south of the ridge between Texas Glacier and West Fork the dip is steep to the south, and north of this ridge it is generally steep to the north. The beds of the "Bear River series" along the international boundary in the Salmon River district, however, have the usual northwest strike. The approximately east-west discordant structure extends for a length of about 13 miles and a width of 10 miles.

COAST RANGE BATHOLITH AND WRANGELL-REVILLAGIGEDO BELT OF METAMORPHIC ROCKS

The Coast Range batholith and the Wrangell-Revillagigedo belt of metamorphic rocks can best be treated together, as one is genetically related to the other.

Along the entire western border of the batholith in southeastern Alaska the strike of the metamorphic rocks is northwest, parallel to the general direction of the belt, and the dip is steep northeast or vertical. In the vicinity of Behm Canal, according to Westgate, the dip averages about 50° NE.; in the latitude of Wrangell it is 70°–90° NE. and flattens out toward the southwest; in the latitude of Hobart Bay the formations are in approximately isoclinal appressed folds with dips of 70° NW. to 75° NE. for a width of about 12 miles adjacent to the batholith, but toward the southwest they flatten out to 45° or so. In the Juneau district, as reported by Spencer, the dip is about 60° NE. in the vicinity of the Sheep Creek mines and somewhat less between Juneau Mountain and Mendenhall River. In the

[15] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, pp. 33–34, 1922.

Eagle River district, according to Knopf, the dip is usually 40°–60° NE., and in the Berners Bay district it averages 70° NE., though locally it is steep to the southwest.

In this region folds can be worked out only rarely except on a minor scale in the thin-bedded graywacke and slate, where it is evident that the axes of the folds are themselves acutely folded and in places pitch almost vertically. As a result of this marked folding of the axes and of a common asymmetric relation of the limbs of the folds, adjacent strata in the graywacke, slate, and phyllite show at many places a marked discordance in strike and dip.

The schist and gneiss in the Ketchikan district are believed by Chapin to constitute the overturned limb of the Gravina Island part of the Keku-Gravina synclinorium. Similarly, the schist and phyllite in the Juneau district are considered by Spencer and Eakin to be the overturned east limb of the Juneau synclinorium. The minor structure of this limb shows overturned folds. A photograph of an overturned fold in graywacke and phyllite east of Frederick Sound is shown in Plate 20, *B*.

There seems to be a tendency for a generally steeper dip close to the batholith and a much more gentle dip away from it.

Throughout the Ketchikan and Wrangell districts and as far north as Thomas Bay the western border of the Coast Range batholith is in general parallel to the strike of the adjacent formations, though locally it shows crosscutting relations. Between Thomas Bay and Endicott Arm for a distance of 40 miles or so the border of the batholith changes from its prevailing northwest strike to a strike more nearly north, and swinging away from the formation strike it cuts across the formations at an angle of 15° to 40°. Northwest of Endicott Arm the border of the batholith swings again to the northwest at a slightly greater angle than the formations, and thus edges back across successive formations, terminating them on the north. The batholith thus appears to work across the east limb and trough of the Juneau synclinorium until it abuts against the Carboniferous formations of the west limb of the synclinorium on Chilkat River.

The intensity of metamorphism increases from west to east as the batholith is approached. The Wrights[16] comment on the metamorphism produced by the batholith as follows:

> By comparing the metamorphic effects of the intrusive granite along its western and eastern flanks in the latitude of the Ketchikan district decided differences are apparent. On the coastal side the metamorphism is usually of the deep-seated type; gneisses and schists predominate and are cut by innumerable pegmatite dikes ramifying from the granite. * * * Along the eastern border of the batholith, on the other hand, the metamorphism is of the contact

[16] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 67, 1908.

type, argillites and slates predominate and are often indurated and heavily impregnated with sulphides. * * * The geologic interpretation of these data indicates clearly that the rocks east of the massifs were less deeply buried at the time of intrusion than those of the coastal side.

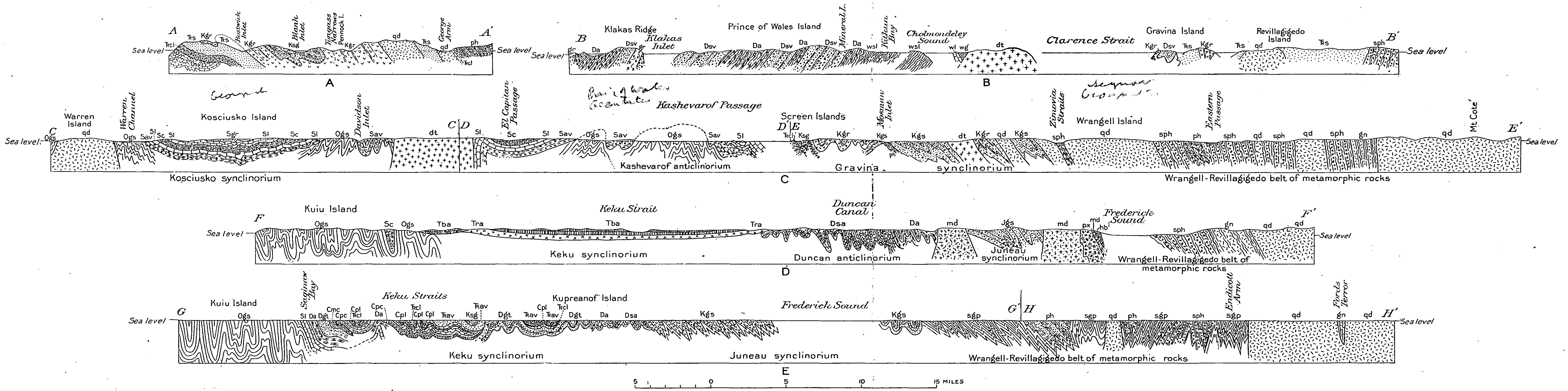
Schofield [17] comments upon the ideas of the Wrights and proposes the following explanation:

Another explanation—the one favored by the author—for the varying intensity of metamorphism of the two flanks may be given. It is well known that the roof of a batholith is always intensely metamorphosed by the ascending hot solutions from the underlying molten magma. On the other hand, the deeper and more vertical contacts do not show contact metamorphism to the same degree, not only as regards intensity but also as regards areal extent.[18] If the batholith and the intruded rocks are exposed in a plane normal to the vertical axial plane of the batholith, the plane would consist of a core of granite surrounded by a contact zone of approximately the same width. On the other hand, if the batholith and the intruded rocks are cut obliquely, the roof rocks will be preserved higher up on the low side, whereas on the high side the highly metamorphosed roof rocks will be entirely removed and the contact will be undulating and fairly even. The contact-metamorphic zone will be very narrow on the high side and very wide and irregular on the low side. In addition, the low side will be marked by many roof pendants of all sizes, whereas the high side will be almost free from them. Examination shows that the two sides of the Coast Range batholith correspond to the above distribution, as can be seen by the following table:

Eastern flank	Western flank
1. Smooth-flowing contact.	1. Very irregular contact.
2. Few roof pendants.	2. Many roof pendants.
3. Very narrow metamorphic zone.	3. Wide metamorphic zone.
4. Slates, sandstones, and tuffs characteristic.	4. Schists and gneisses characteristic.
5. Moderate-temperature conditions.	5. High-temperature conditions.
6. Gold-silver and silver-lead deposits of medium temperature and pressure.	6. Copper deposits of high temperature and pressure.
7. Intruded rocks of roof type, gneisses, and schists reach the same elevation as the unaltered rocks along the steeply pitching contact.	

These facts show that erosion on the western side of the Coast Range batholith has not entirely removed the roof rocks and that the contact between the batholith and these rocks is almost flat. This conclusion is supported by the presence of a large number of roof pendants and the very irregular contact between the granite and the intruded rocks. On the eastern flank, however, erosion has exposed a deeper portion of the batholith, the roof being entirely removed, so that the margin of the batholith plunges very steeply beneath the intruded rocks. Also the contact is smoothly undulating and the roof pendants are absent.

[17] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, British Columbia: Canada Geol. Survey Mem. 132, pp. 65–66, 1922.
[18] Schofield, S. J., Canada Geol. Survey Mem. 76, p. 83, 1915.



STRUCTURE SECTIONS IN SOUTHEASTERN ALASKA

Sections A and B by Theodore Chapin

This points either to greater uplift on the eastern side of the batholith or to a depression on the western flank. The depression seems to be the more probable, since the western coast of British Columbia and southeastern Alaska has all the aspects of a depressed coast that protected the western flank from deep erosion.

It follows that, in the wide metamorphic zone on the western flank, ore deposits of high temperature and pressure would be characteristic, but on the eastern flank a few ore deposits of high temperature and pressure might occur along the immediate contact of the granite. Owing, however, to the very low conductivity of rocks, the zone for these deposits would be very narrow and would rapidly give way to ore deposits characterized by minerals of medium temperature and pressure. The deposits of the latter variety on the western flank are covered by the waters of the Pacific Ocean.

Schofield's correlation of the degree of metamorphism with the character of the contact of the batholith seems well supported by the phenomena in the Wrangell-Revillagigedo belt. But the data used to support his suggestion that the eastern contact is the more deeply eroded are of very doubtful validity. Furthermore, the data at hand do not support his statement that the eastern contact is smoothly undulating, with a few roof pendants; on the contrary, there are numerous large blocks of sedimentary and volcanic rock within the eastern part of the batholith between the head of Portland Canal and Stikine River.

The Coast Range batholith shows an asymmetric character of differentiation, with the more highly differentiated variant—quartz monzonite—in the eastern part. This fact might be used to support Schofield's suggesion that the eastern part is the more deeply eroded if the whole batholith were the result of a single intrusion and if all the variations were the results of differentiation in place. But it is very doubtful if this is the case. The character of the contacts of the batholith appears to vary from place to place independently of the depth of erosion.

Schofield gives copper deposits as characteristic of the west flank of the batholith in British Columbia. The main copper deposits in southeastern Alaska are predominantly associated with outlying dioritic stocks in the Prince of Wales-Chichagof belt and not with the west flank of the Coast Range batholith. In the Juneau district auriferous quartz veins are associated with the west flank of the batholith.

As indicated in the discussion of the Wrangell-Revillagigedo belt of metamorphic rocks in this report, the conditions along the contact of the batholith in southeastern Alaska are very far from uniform, and there is as much difference between the northern and the southern parts along the western contact as there is between the eastern and western contacts in the latitude of the Ketchikan and Wrangell districts. The general upper surface of the west side of the batholith

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appears to have a gentle slope in the Ketchikan and Wrangell districts but a relatively steep slope in the Juneau and Skagway districts.

South of Frederick Sound, in the Wrangell-Revillagigedo belt, the main surface of the batholith must lie at no great depth, as indicated by the abundant intrusions of quartz diorite, which probably represent cupolas or more elevated protrusions of the magma. Associated and genetically correlated with these bodies is a belt of injection gneiss, crystalline schist, and phyllite 20 to 35 miles wide.

North of Frederick Sound the western border of the batholith probably plunges with increasing steepness, as indicated by the marked decrease in the number of intrusive bodies and the appearance as far south as Port Snettisham of masses of diorite close in to the batholith—assuming that the diorite is to be interpreted as a relatively early differentiation product due to quick cooling.

North of Thomas Bay the aplitic injection gneiss thins to a narrow strip immediately adjacent to the batholith, and the belt of crystalline schist and phyllite similarly narrows toward the northwest until in the vicinity of Berners Bay it, too, forms but a border too thin to map, immediately adjacent to the batholith. The decreasing extent of metamorphism may thus be correlated with the increasing depth of the batholith due to an increasingly steeply plunging contact.

The differences in degree and extent of intrusion, injection, and recrystallization along the western contact may thus be accounted for, but there remains the problem of the greater degree of folding in the vicinity of the western border of the batholith. There is a most pronounced increase in the degree of crumpling, plication, foliation, and isoclinal folding as the border of the batholith is approched from the west, suggesting that the batholith has exerted a tremendous thrust. The manner in which the batholith has peeled off great slabs of schist constitutes further evidence. On the other hand, in the vicinity of the adjacent outlying stocks sintering and compacting of the phyllite and slate as the contact is approached indicate that the cleavage and foliation are in part younger than the intrusion.

The data are inadequate for a solution of the problem. But if we assume that the intrusion of the batholith took place within the same general period as the Jurassic or Cretaceous folding, then it is probable that at least two factors were involved—an increased local intensity in the dynamic metamorphism above the location of the rising magma and a thrust exerted by the magma itself during its emplacement at horizons equivalent to those now exposed. Under the same stress and with other conditions the same rocks will be much more highly deformed under higher temperature. Thus it might be that though stresses of essentially similar orders of magnitude affected beds both far to the east and far to the west of the present highly folded zones, the beds to the east and west, relatively much cooler, yielded by close folding and development of cleavage, whereas those in the intensely folded zone, at a higher temperature due to the rising magma with its advance wave of escaping highly heated vapors, yielded far more extensively. A preliminary foliated or cleaved character had thus already been induced before the arrival of the magma, which accentuated the dynamic effects by its own thrusting pressure and aided recrystallization by heat, vapors, and solutions.

Another important factor appears to have been the structural relations which the invaded formations bore to the magma. For example, where they were in steeply dipping attitudes above the rising magma conditions for penetration by magmatic solutions and vapors were favorable and metamorphism was correspondingly facilitated; such seems to have been the condition in the belt adjacent to the southern part of the batholith in southeastern Alaska. Where the contact plunges steeply the transfer of solutions and vapors was markedly obstructed by the relatively much greater impermeability across the foliation surfaces and that portion highly metamorphosed above and adjacent to the batholith must lie below the present topographic surface, deeper down on its flank.

The gneissic structure of the batholith suggests that the magma moved upward along planes dipping steeply to the northeast and that the maximum effect of its thrust was directed against the adjoining formations on the southwest. The country rock was probably irregularly domed up to a considerable extent by the invading magma, was fractured, faulted, and stoped to some extent, and was thrust aside to a very considerable degree. There is abundant evidence in residual structures and in the composition of the resulting rocks that, locally, narrow belts of sediment were wholly incorporated in the magma through a process of reactive replacement, but this was probably not the major factor in the process of emplacement of the batholith.

A series of lamprophyre dikes cut the Coast Range batholith and the country rocks. Those in the Eagle River and Berners Bay regions are reported by Knopf to strike in general parallel to the stratification. Within the Coast Range batholith they strike predominantly across the grain of the batholith, with trends of N. 10°–45° E., although to a minor extent they are approximately parallel to the gneissic structure or locally have a different trend. East of the Coast Range batholith, in the Salmon River district, many of them strike northwest. In the vicinity of the Strait of Georgia and

Queen Charlotte Sound in British Columbia, according to Bancroft,[19] the dikes are somewhat irregular in their strike, "but the greater number of them assume a direction which is parallel or transverse to the trend of the Coast Ranges, thus corresponding to the regional system of joints."

In the Salmon River district and the adjoining territory to the east in British Columbia the predominant trend of the intrusive dikes genetically connected with the Coast Range batholith is northwest.

JUNEAU SYNCLINORIUM

The Juneau synclinorium extends southeastward through Juneau, the outer part of the Fanshaw Peninsula, and perhaps through Mitkof and Etolin Islands to a junction with the Keku-Gravina synclinorium. It includes a belt of rocks of Mesozoic age lying to the west of the belt of crystalline schist and gneiss along the east side of Lynn Canal from Comet southeast; Portland, Shelter, and Douglas Islands; the east side of Gastineau Channel; Glass Peninsula; the east side of Admiralty Island and the islands in Seymour Canal; probably a part of the slate and phyllite belts on the mainland along the east side of Stephens Passage; Sail Island and The Five Fingers; most of the Fanshaw Peninsula; and the north end of Kupreanof Island. It is possible that the Lindenberg Peninsula, Mitkof, and Vank Islands, and the north end of Etolin Island belong to the same belt. At the northwest the belt is cut out by the edging over of the western border of the Coast Range batholith.

The beds comprise predominantly graywacke, slate, some conglomerate, and various types of greenstone. The slate and thin-bedded zones are isoclinally folded and overturned. (See pl. 20, *B*.)

The synclinorial structure is well exhibited in the latitude of Port Snettisham and Windfall Harbor, Admiralty Island. Formations with Carboniferous fossils are found on the west limb of the major syncline on Windfall Harbor and on the east limb in the Taku Harbor-Snettisham Peninsula belt. The Carboniferous beds of Windfall Harbor are adjoined on the southeast for about 1½ miles along Seymour Canal by interbedded limestone and slate of Upper Triassic appearance; these beds are intensely plicated, folded, and faulted; at one locality isoclinal folds with a steep southwestward dip were observed. Southeast of these limy sediments are greenstone and then black slate and graywacke with intercalated conglomerate. The sedimentary beds are mapped as Jurassic(?). The Jurassic(?) slate and graywacke form the islands in Seymour Canal, and greenstone

[19] Bancroft, J. A., Geology of the coast and islands between the Strait of Georgia and Queen Charlotte Sound, B. C.; Canada Geol. Survey Mem. 23, p. 116, 1913.

and slate the Glass Peninsula. Beds with Upper Triassic fossils are found at the head of Mole Harbor. A steep westward dip seems to prevail throughout the beds in Seymour Canal. This westward dip changes through vertical to a steep eastward dip on the east side of the canal and to 65° NE. or less on the east side of the Glass Peninsula. The Carboniferous beds on the east limb along the Snettisham Peninsula dip usually 70°–80° NE. The structure here may thus be of the nature of a synclinal fan fold. To the northwest, near the head of Hawk Inlet, there are beds of schist which dip predominantly 40°–90° E. and structurally should form the west limb of the synclinorium.

East of the Carboniferous beds of the Taku Harbor-Snettisham Peninsula belt there is a belt of slate which passes northwest through the south arm of Port Snettisham, through Prospect Cove, and east of Juneau. Near Juneau Upper Triassic fossils have been found in the slate, and on Port Snettisham there are intercalated beds of very highly mashed conglomeratic black slate that resembles the Jurassic(?) conglomerate of Seymour Canal. This belt is therefore probably an infolded syncline of Mesozoic beds. The dip ranges from 75° NW. to steep northeast, and the Carboniferous beds of the Taku Harbor-Snettisham belt are exposed on an anticlinal fold.

To the southeast near Windham Bay there are apparently three major anticlines and two major synclines in the schistose greenstone, phyllite, and slate. The phyllite and slate exposed on Hobart Bay and in Sumdum Cove in the major synclines may be, in part at least, of Mesozoic age. This belt, including phyllite, slate, and greenstone west of the head of Windham Bay, may therefore belong within the great Juneau synclinorium.

The general strike of both the cleavage and the bedding in the Jurassic(?) slate and graywacke on the north end of Kupreanof Island and north of Cape Fanshaw on the mainland is N. 10°–45° W. The general strike of both the bedding and the cleavage in the same system of beds between Cape Fanshaw and Bay Point, on the other hand, is about N. 70°–90° E. In each of these areas the general trend of the cleavage is more constant than that of the bedding. The wide and uniform change of direction in the strike of the bedding in the belt between Cape Fanshaw and Bay Point is accompanied by a similar change in the strike of the cleavage. Local variations in the direction of dip of the cleavage suggest drag folding.

DUNCAN ANTICLINORIUM

The Duncan anticlinorium strikes southeast from the northwest end of Kupreanof Island east of Cape Bendel along Duncan Canal and across the central part of Zarembo Island. Devonian formations are exposed in the core and form a belt that separates the Mesozoic beds of the Juneau synclinorium from the Mesozoic and Tertiary formations of the Keku-Gravina synclinorium. Very gently dipping volcanic rocks, presumably Tertiary, are exposed on one of the Castle Islands, Duncan Canal.

Along the core of the anticlinorium the beds are folded into several anticlines and synclines. Duncan Canal is eroded along the crest of a closely folded anticline. A synclinal axis lies along a line from the Castle Islands through Deception Point Cove, Woewodski Island; pillow lava and andesitic tuff and breccia are exposed in the trough. West of this the beds are thrown into a series of open folds. In the bay west of the Castle Islands a wide belt of slate is exposed; it has a uniform cleavage with a dip of 40°–60° E. or NE., which remains constant irrespective of the direction of the strike and dip in the beds affected by minor folds.

At the northwest end of Kupreanof Island the beds are closely folded and greatly disturbed; a thick bed of coralline limestone has been mashed and rendered very highly schistose, and the relations of the rocks are not well shown. At the southeast end of Zarembo Island the beds are much broken by faulting.

KEKU-GRAVINA SYNCLINORIUM

The Keku-Gravina synclinorium is one of the major features in the geology of southeastern Alaska. It includes the southwest end of Admiralty Island and extends 350 miles southeast from Kootznahoo Inlet, Admiralty Island, through the territory adjacent to Keku Strait, Clarence Strait, and Gravina Island to Cape Fox, at the entrance to Portland Canal, and has a width of 5 to 20 miles.

The predominant formations within the synclinorium at the southeast end are of Mesozoic age, with rare isolated remnants of overlying Tertiary beds; but in the northwest part the Tertiary formations predominate.

GRAVINA SYNCLINORIUM

By Theodore Chapin

The synclinorium in the latitude of Gravina Island, here called the Gravina synclinorium, has been described in detail in an earlier report.[20] The structure section is shown in Plate 22, section *A–B*. The beds present a dominant northwest strike and, except locally, dip northeast, giving the appearance of a simple monoclinal structure over a wide area. The section is believed to represent truncated closely compressed folds overturned toward the southwest. The

[20] Chapin, Theodore, The structure and stratigraphy of Gravina and Revillagigedo Islands, Alaska: U. S. Geol. Survey Prof. Paper 120, pp. 86–87, 1918.

overturned position of these beds is shown by the relation of the Mesozoic and Paleozoic beds; the younger beds dip beneath the older ones on the east side of the trough.

The following description is quoted from the previous report:

On the southwest coast of Gravina Island Triassic conglomerate, limestone, and black slate are overlain by volcanic rocks and intercalated sediments of Triassic or Jurassic age, which, in turn, are overlain by the slate and graywacke of Blank Inlet, determined to be Jurassic or Cretaceous. Succeeding the Jurassic or Cretaceous sediments are volcanic rocks, with black slates and tuffs. Here the section is interrupted by a boss of granite, beyond which are black slates and phyllites, limestone, and schistose conglomerate. Beyond the conglomerate occur crystalline schists and massive semicrystalline limestone bearing fossils regarded as certainly Paleozoic and probably Carboniferous. This anomalous position of the Paleozoic and Mesozoic rocks is probably due to an overturned position of one limb of the syncline.

From the slate and graywacke area of Blank Inlet the general sequence of rocks is the same toward the northeast as it is toward the southwest, and it is believed that the similar rocks are in fact the same beds exposed on two limbs of an overturned fold, the trough of which is exposed on Blank Inlet. The volcanic rocks on each side of the Blank Inlet area of slate and graywacke are similar and may be correlated, as there is little reason to doubt their identity. The slates and phyllites of Revillagigedo Island are much more schistose than the black slates and sandstones of Gravina Island, with which they are correlated, but this is evidently due to the contact metamorphism caused by the adjoining intrusive granite. The other sediments of Revillagigedo Island are also more metamorphosed than their supposed equivalents on Gravina Island. The limestone is crystalline and the conglomerate is schistose, but these differences in metamorphism are also easily accounted for, not alone by the small body of granite shown in the sketch but also by the immense batholith of the Coast Range.

Along this eastern limb of the syncline is a greatly disturbed belt which apparently continues the entire length of southeastern Alaska along the border of the intrusives of the Coast Range. In this disturbed belt the folding is much more close and the beds are more tightly compressed and, if correctly interpreted, are in part overturned. The structural form is not a simple syncline and might more correctly be termed a "synclinorium," for one prominent anticline and a number of minor folds occur.

On the west coast of Vallenar Bay about a mile east of South Vallenar Point is the crest of a very sharply folded anticline, which has involved the calcareous shale and argillite. This is believed to be the lowest of the Devonian beds, and the limestone and conglomerate to the west are believed to be stratigraphically higher in the section and to occupy the overturned limb of a steeply pitching anticline overturned toward the west. The contact with the Mesozoic beds at the head of Vallenar Bay is covered by gravel. This anticline, along which the Devonian beds are brought to the surface on Vallenar Bay, is presumably the same fold which extends along Dall Ridge to Seal Cove and forms a minor fold in the broad synclinorium involving all the rocks between the west coast of Gravina Island and George Arm.

The topographic features of the broad depression that connects Vallenar Bay and Bostwick Inlet and divides Gravina Island into two distinct parts were regarded by Brooks as indicative of faulting. The movement, however, does not appear to have involved the Devonian beds.

Middle Devonian rocks correlated with those on Gravina Island crop out on Hotspur Island, a small island about 3 miles long that lies between Duke and Annette Islands. The beds of Hotspur Island all strike northwest and have a dominant dip to the northeast. The Devonian beds form a narrow belt of fossiliferous gray limestone and calcareous shale carrying a coral fauna in which *Favosites* is especially abundant. To the north and south of the limestone are interbedded limestone, black slate, and tuff of probable Triassic age, which unconformably overlie the Devonian limestone. The structure of the island appears to be that of a closely folded anticline, in part overturned toward the southwest. The crest of the anticline is occupied by the Middle Devonian limestone, and the limbs are composed of slate and limestone of probable Triassic age.

ROCKY BAY AREA, ETOLIN ISLAND

The Lower Cretaceous (?) slate of the Rocky Bay area, on the west end of Etolin Island, shows apparently anomalous cleavage relations. On Clarence Strait and Stanhope Island the strike of the cleavage averages about N. 15° E. and is uniformly more easterly than the prevailing strike of the bedding. The dip of the cleavage is in most places nearly vertical. In Rocky Bay the strike of the cleavage swings more to the east, and finally, on the east side of the bay, it becomes northwest. The cleavage appears like a close-set fracture cleavage. The conditions are similar to those in the Jurassic (?) slate between Bay Point and Cape Fanshaw, on the Fanshaw Peninsula, but are somewhat more complicated. The explanation of the peculiar conditions is not apparent to the writer.

KEKU SYNCLINORIUM

Between Etolin Island and the north end of Keku Strait the Mesozoic formations are buried beneath the Tertiary. At the north end of Keku Strait there are two major synclines, in the troughs of which Lower Cretaceous (?) beds are exposed, and an anticlinal axis, on which Devonian beds are exposed. Carboniferous formations occupy the Cornwallis Peninsula and the Keku group of islets, except for a narrow belt of infolded or infaulted Upper Triassic beds and an anticlinal ridge of Silurian limestone. Between the Tertiary rocks of Point Camden and the Carboniferous formations of the Cornwallis Peninsula is a series of Upper Triassic volcanic rocks with

Lower Cretaceous (?) shale and minor associated sandstone occupying the trough of a synclinal basin between Kuiu Island and Hound Island, most of which is covered by water. Extending through Hound Island and several islands to the northwest is an anticlinal axis on which Upper Triassic lava is exposed. Lower Cretaceous (?) beds are again exposed in the trough of a syncline at Point Hamilton. The Lower Cretaceous (?) beds in these synclines are the least metamorphosed of all in southeastern Alaska.

The axis of a well-defined anticline passes northwest through the village of Kake on Kupreanof Island. Devonian beds are exposed on the core and Upper Triassic formations on the flanks. The fold pitches 20°–25° SE. and is carried beneath the waters of Hamilton Bay. The channel between the line of islands and reefs and Kupreanof Island is eroded along the core. The anticline is asymmetric, with a gentle dip on the northeast limb and a vertical dip on the southwest limb. The Devonian beds on the core show many minor folds and crumples, and there is considerable faulting.

Adjoining the Kake anticline on the east is the Cape Bendel syncline, in which Upper Triassic formations are exposed. The syncline is asymmetric, with a gentle southwest limb and a vertical northeast limb. It includes several minor anticlinal axes. Permian limestone is brought to the surface on one of these axes and forms the conspicuous mountain north of Kake. Carboniferous and Devonian beds form the east flank of the syncline.

FREDERICK SOUND AXIS OF CROSS FOLDING

Jurassic (?) beds are exposed at intervals along the south side of Admiralty Island and form a considerable part of the coast line. These beds have not been carefully studied, but they appear to have been folded along two axes—the usual north-northwest axis and another about parallel to Frederick Sound—that is, east-west. The axis of cross folding is reflected in the east-west strike of the beds between Cape Fanshaw and Bay Point.

Tertiary formations cover the west half of Zarembo and Kupreanof Islands, the eastern part of Kuiu, and the southwest part of Admiralty Island. The Tertiary formations at the northwest end of Kupreanof Island and those at the southwest end of Admiralty Island appear to lie on opposite flanks of a broadly folded anticline whose axis strikes northeast. On Port Camden the beds dip 8°–10° SE. and on Hamilton Bay about 15° SE. Wright[21] states that on the southwest end of Admiralty Island the Tertiary lava beds are not folded, but show a general dip of 5°–10° NW. Frederick Sound

[21] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 146, 1906.

would thus appear to be eroded approximately along the core of the dome in the Tertiary formations. On the south side of Kupreanof Island and in the vicinity of the southern part of Keku Strait there is a lack of uniformity in the strike and dip. In the vicinity of Point Nesbitt, Zarembo Island, there is a series of lava conglomerate with associated volcanic rocks with a northeast strike and a dip of 30° NW.

If the interpretation of the structure of the Tertiary formations is correct, then the forces that effected their folding were oriented almost at right angles to those that effected the folding of the Mesozoic formations in pre-Tertiary time.

PRINCE OF WALES-KUIU ANTICLINORIUM

GENERAL FEATURES

The Prince of Wales-Kuiu anticlinorium is one of the major features of the geology of southeastern Alaska. It comprises all of Prince of Wales Island, the entire archipelago off the west coast of Prince of Wales Island, including Dall, Suemez, Baker, Noyes, and Coronation Islands, and all of Kuiu Island except the northeastern part. The belt is more than 150 miles long and throughout most of its extent is 40 to 50 miles wide. It is possible that some of Baranof Island might be included. This anticlinal axis forms the Prince of Wales group of mountain ranges. A northwest extension is found across the northeast end of Chichagof Island and in the vicinity of Glacier Bay.

The formations exposed are exclusively Paleozoic except for a few small isolated areas of Tertiary sedimentary and volcanic rocks. The predominant formations are of Ordovician, Silurian, and Devonian age. Carboniferous formations are exposed only locally in the vicinity of Klawak, Trocadero Bay, and Ulloa Channel, on the west coast of Prince of Wales Island, and at the north end of Kuiu Island. Rocks possibly of pre-Ordovician age are exposed on Prince of Wales Island and on Dall Island.

East of the Prince of Wales-Kuiu anticlinorium lies the Keku-Gravina synclinorium, with its Mesozoic and Tertiary formations, and on the west lies the Pacific Ocean. The formations of Queen Charlotte Island, of Mesozoic and Tertiary age, if extended along their strike, would underlie the Pacific Ocean in this vicinity.

Within this major anticlinorium there are five large structural provinces, comprising three anticlinoria of a second order and two synclinoria.

The Kuiu anticlinorium includes all of Kuiu Island, except the northeastern part, and Warren Island. It is composed almost exclusively of Ordovician (?) rocks, with only a minor amount of Silurian.

The synclinorium of the northern half of Prince of Wales Island includes the Shakan Bay and Kosciusko-Tuxekan-Heceta synclines. Several other synclines with corresponding anticlines are present in the northern part of Prince of Wales Island, but they have been much disturbed by the intrusion of a large stock of igneous rock. The formations within this synclinal province are mostly Silurian, with a little Ordovician and perhaps some Devonian.

The central anticlinorial province includes the southeast side of Noyes Island, Lulu and San Fernando Islands, the central part of Prince of Wales Island, comprising a belt north of Klawak Salt Lake, and the eastern part from a line west of the west arm of Whale Passage to Tolstoi Bay. The Maurelle Islands may belong with this province. The formations of the central anticlinorium are almost wholly of Ordovician age, with some associated lower members of the Silurian system and a little Devonian; they are similar and probably equivalent to those of the Kuiu anticlinorium. The principal structural features are the San Fernando and Kashevarof anticlines.

The southern synclinorium embraces the southern half of Prince of Wales Island south of Thorne Bay and Klawak Inlet, also the adjoining islands, including Baker, St. Ignace, San Juan Bautista, Suemez, and Sukkwan Islands, and the north end of Dall Island. Taken as a whole, this province is a synclinorium of Devonian with locally a little area of younger formations. It is divided into two parts by the Dolomi-Sulzer anticline, which exposes the Wales group of rocks.

The southern anticlinorium includes Long Island, in Cordova Bay, and most of Dall Island. Only rocks of the Wales group and Silurian formations are exposed.

There are several structural elements in the Prince of Wales-Kuiu anticlinorium whose relations to one another and whose significance are not clear. If the area were completely mapped the problem might be solved.

The graywacke formations of Kuiu Island (the core of the Kuiu anticlinorium), El Capitan Passage, Thorne and Stevenson Islands, Lake Bay (the core of the Kashevarof anticline), and Klawak Inlet, and the Salt Lake on Tuxekan Passage constitute one structural element. They are isoclinally folded with nearly vertical to very steep eastward-dipping axial planes. Although locally they have the normal northwest strike typical of southeastern Alaska, the predominant strike is about true north.

The two major structural features along the northwest coast of Prince of Wales Island—the Shakan Bay and Kosciusko-Tuxekan-

Heceta synclinoria—are closely folded, but the folds are much more open than those within the graywacke described in the preceding paragraph. The strike here is northwest and the strike of the Silurian formations on the east side of Kuiu Island is also northwest.

In the south half of Prince of Wales Island and in the great island group to the west, south of the Gulf of Esquibel, the structure is exceedingly complex. There are folds trending approximately east-northeast, such as those in the sandstone at and south of Naukati Bay, the San Fernando anticline of graywacke, and the Devonian formations of the east half of Baker Island and north half of Suemez Island; folds trending north-northeast, such as those in the Devonian and Mississippian formations of San Alberto Bay; folds trending west-northwest, such as those on the north end of Dall Island and the Dolomi-Sulzer anticlinorium, on Prince of Wales Island; and folds trending northwest, such as those in the formations of the south half of Prince of Wales Island and Trocadero Bay. The folds that trend northwest are locally superimposed on those that trend east-northeast—for example, the northwestward-trending San Christoval Channel syncline upon the dominant east-northeast San Fernando anticline.

The graywacke formation with a general northern trend is partly and perhaps wholly of Ordovician and lower Silurian age, and the beds are very closely folded and compressed wherever found, irrespective of their proximity to outlying intrusive masses or to the Coast Range batholith. Their attitude suggests that the structural element which they constitute originated in an orogenic period preceding the deposition of the upper Silurian formations. Apparent marked unconformity at several localities would seem to support this suggestion, but fuller and more exact data are needed before it can be accepted.

The east-northeast, northeast, and west-northwest folds in the island group in San Alberto Bay and Klawak Inlet and south of the Gulf of Esquibel present phenomena for whose explanation the writer has no satisfactory hypothesis. The formations at the south end of Prince of Wales Island have in general a considerably more westerly trend than the dominant northwest strike of the formations farther east, and on the west they reach the Pacific Ocean at angles of 60°–90°. The northwest structure may have been superimposed upon the east-northeast and northeast folds, and the west-northwest structure may be a modification of the northwest structure resulting from a preexisting east or northeast trend in underlying or adjacent formations. Another possibility is that the east-northeast and northeast folds are of Tertiary age and were superimposed on the older northwest folds, but it is a question whether the Tertiary folding was sufficiently strong to accomplish this task.

KUIU ANTICLINORIUM

The Kuiu anticlinorium includes all of Kuiu Island, except the northeastern part, and Warren Island. It is composed almost wholly of Ordovician (?) formations and constitutes an anticlinorial core with respect to the Keku synclinorium. The rocks consist predominantly of indurated tuffaceous graywacke with slate partings and local thin-bedded zones of slate, graywacke, and limy sediments. No fossils have been found, but on lithologic similarity the beds are regarded as probably largely of Ordovician age, though some may be early Silurian.

Greenstone conglomerate and volcanic rocks and locally limestone of Silurian age occur at several localities in the troughs of synclines, as on the west side of Port Beauclerc, from Point Amelius northwest to Edwards Island; in a belt northwest through Sumner Island; at Point St. Albans; at the narrows on Pillar Bay; and probably at other localities not visited. These are of only minor volume in comparison with the predominant graywacke.

The Ordovician (?) beds of Kuiu Island, like those of Prince of Wales Island, have a prevailing steep eastward to vertical dip; westward dips are rare. The structural relations are complex. The beds are probably duplicated through isoclinal folding and thrust faulting, and beds with strikes at right angles to each other in adjacent outcrops are noticed. Many of the thin beds between the more competent thick-bedded graywacke have been isoclinally folded, plicated, overthrust, and brecciated; locally they have been completely broken down to a mylonite or fault breccia or even compressed to a schistose aggregate composed of lenses of limestone 1 inch to several inches in length in an argillaceous matrix. For 5 or 6 miles south of Point Amelius the beds strike west and dip in general 30°–60° and apparently constitute a major anticlinal axis, but in general the strike of the beds is north in the southern half of the island and about northwest in the northern half.

NORTH COAST OF PRINCE OF WALES ISLAND

Along the north coast of Prince of Wales Island the formations are repeated by folding but are very much disturbed, and the structure is complex. At Labouchere Bay there is a minor steeply southeastward-pitching anticlinal fold which exposes Silurian volcanic rocks, and Port Protection occupies the site of an anticlinal axis on which Silurian (?) graywacke and volcanic rocks are exposed. For several miles along the coast between Point Baker and Red Bay there are exposures of beds of graywacke, slate, and limestone, which have a general dip of 20°–40° NW. They are interpreted as occupying the trough of a syncline and overlying the Silurian limestone, but they may include both Silurian and Devonian. The relations of the Silurian limestone east of Red Bay to the greenstone volcanic rocks of Point Colpoys and the tuffaceous graywacke farther east are not known. The dip is steep to the west at Point Colpoys, but this may be due to overturning. The beds along El Capitan Passage are very much disturbed by the intrusion of the batholith of igneous rock, as are all the beds surrounding this mass. The major structure here appears to be that of a syncline containing in its trough upper Silurian conglomerates that dip 15°–40°. Graywacke and slate are exposed on the anticlinal core along the west side of El Capitan Passage south of Devilfish Bay and on the islands in the vicinity of Sarkar Cove. The graywacke has generally a steep dip and may be, in part at least, of Ordovician age.

SHAKAN BAY SYNCLINE

The Shakan Bay syncline comprises a belt of graywacke that is assumed to be probably of Silurian age and to occupy a synclinal trough in Silurian limestone; this graywacke is exposed on the Barrier Islands, the adjoining coast of Prince of Wales Island, Hamilton Island, and the peninsula between Shakan Bay and Shipley Bay. The contact between the graywacke and the Silurian formations east of the Barrier Islands is a fault plane. The graywacke has a dip of 70° W. on the east, near the Silurian (?) beds, and changes to 25° or less on the west. The southeast island of the Barrier Island group lies exactly in the trough of the syncline, the beds dipping in on all sides. At the west end of the peninsula between Shakan and Shipley Bays there are several gentle folds. There is evidence of marked faulting within these beds.

KOSCIUSKO-TUXEKAN-HECETA SYNCLINORIUM

South of the Shakan syncline is the Kosciusko-Tuxekan-Heceta synclinorium, which includes Kosciusko, Marble, Orr, Tuxekan, and Heceta Islands, other islands around Davidson Inlet and Sea Otter Sound, and a part of the west coast of Prince of Wales Island. This synclinal basin is 30 to 35 miles long and 20 to 25 miles wide. The strike is northwest. It includes chiefly Silurian formations with Ordovician formations exposed locally around the rims. The structure is complex, with many minor anticlines and synclines. The beds in general dip in toward Davidson Inlet and Sea Otter Sound. Eagle, Owl, White Cliff, and Hoot Islands mark the core of a gentle anticlinal dome within the major basin. The synclinorium includes broad, open folds with limbs dipping 30°–45° and narrow, tightly compressed folds with limbs dipping 60° to vertical or slightly overturned toward the northwest. On Kosciusko Island the east limb consists of graywacke of probable Ordovician age and has a steep dip; the west limb consists of the steeply dipping graywacke of Warren Island.

Edna Bay occupies the site of a northward-pitching synclinal basin with several minor folds. On the west side of the bay there is an anticline the west limb of which is slightly overturned toward the west. The cleavage here dips steeply northeast. The axis of this anticline comes out on Davidson Inlet northwest of Green Island. To the west of this anticline is another synclinal trough in which the beds are gently folded back and forth and in which the youngest Silurian beds found in this area occur.

The graywacke and conglomerate beds (about 2,000 feet thick) at the south end of Marble Island and on the reefs between Marble Island and White Cliff Island occur in a synclinal basin in the Silurian limestone. The prevailing dip is 25°–40°.

At the head of Naukati Bay a formation of interbedded red and green sandstone is gently folded into two anticlines and a syncline. The folds strike approximately east. South of Naukati Bay the same sandstone formation forms a broad synclinal basin whose axis strikes N. 80°–85° E. and pitches about 10° E. The limbs of the syncline dip about 25°. The cleavage throughout has a strike of about N. 70° E., nearly parallel to the axes of the folds. The sandstone overlies the Silurian limestone.

Karheen Passage, the east end of Heceta Island, and the bay southeast of Tonowek Narrows—in a belt that is about 3 miles wide and extends N. 40° W.—are carved out of a southeastward-pitching synclinorium of thin-layered Silurian limestone and overlying sandstone. The sandstone on the east end of Heceta Island has a general north to north-northwest strike and a dip of 40°–60° E. The thin-layered limestone shows abundant drag folds, which are closely compressed, with steep to vertical dips. This syncline is adjoined on the east at the south end of Tuxekan Passage by an anticline that pitches northwest.

Warmchuck Inlet, Heceta Island, is cut out along the nose of a northwestward-plunging anticline in Silurian formations. Graywacke of probable Ordovician age is exposed on the core of the anticline in the Salt Lake on the east side of Tonowek Bay.

MAURELLE ISLANDS

Esquibel, Anguilla, Two Crack, and San Lorenzo Islands, in the Maurelle group, are composed of Silurian and older formations exposed on an anticlinal core. The islands to the west are probably composed of Devonian formations exposed on the flanks of the anticline. The general strike of the Devonian formations is northwest, but that of the Silurian and older formations is east-northeast. There are at least two anticlines and two synclines within the anticlinal core, and it is probable that beds as old as the Wales group are exposed.

SAN FERNANDO ANTICLINORIUM

The San Fernando anticlinal axis strikes across the dominant northwest structural trend and includes the southeastern side of Noyes Island, Lulu and San Fernando Islands, and a belt on Prince of Wales Island east of San Christoval Channel. The core of the anticline trends east-northeast and the beds exposed are graywacke and associated slate and chert of Ordovician and Silurian age. Along Portillo and San Christoval Channels younger Silurian conglomerate and sandstone are infolded into the older graywacke along northwest axes. Noyes Island and the Gulf of Esquibel occupy the trough of a syncline in which Devonian formations occur. The east limb of the San Christoval syncline is vertical to slightly overturned toward the west, and the west limb dips 10°–30° NE.

KASHEVAROF ANTICLINORIUM

The core of the Kashevarof anticlinorium includes Thorne and Stevenson Islands and extends south into an unknown portion of Prince of Wales Island. Kashevarof Passage is cut across its northward-plunging nose. The oldest beds, exposed on the core, are the graywacke-slate series found on Thorne and Stevenson Islands and at Lake Bay. The slate carries Ordovician fossils. These beds are repeated many times by folding. The prevalent dip is steep eastward, but locally the dip is westward and some dips are as gentle as 20°. Beds of thin-layered slate and graywacke are, practically without exception, in an approximately vertical attitude and commonly show very abundant slickensided surfaces, possibly as a result in part of drag folding due to thrust faults with an eastward dip. It is also probable that isoclinal folding has occurred. Overlying the Ordovician beds on the nose and flanks of the anticlinorium is the greenstone-limestone conglomerate and volcanic formation of the Silurian, succeeded on the Kashevarof Islands by the Silurian limestone member, which in turn is succeeded on the northwest end of Prince of Wales Island by the Devonian tuffs and sediments. On the Blashke Islands the beds are domed up by an intrusion of dunite and associated dioritic rocks, and Ordovician graywacke is exposed on the borders of the igneous stock within a belt of the Silurian greenstone. In the vicinity of Ratz Harbor the beds are disturbed and interrupted by a small batholith of diorite. The Ordovician and Silurian beds of the Kashevarof anticlinorium extend southeast to the Kasaan Peninsula, where they are believed to be overlain by Devonian formations. Fossiliferous Ordovician slate is found on the west side of Thorne Bay.

VICINITY OF SAN ALBERTO AND BUCARELI BAYS

Paleozoic rocks younger than Middle Devonian are found in the vicinity of San Alberto and Bucareli Bays and occur within a part of the southern synclinorium. They occupy at least two auxiliary complexly folded synclinal troughs—one along Klawak Inlet and the islands of Trocadero Bay, the other including San Juan Bautista Island, the west side of Ulloa Channel, part of Port Refugio on Suemez Island, and the islands in Soda Bay. The peninsula between Trocadero and Soda Bays is an anticline on which the Middle Devonian formations are exposed. There are two structural trends almost at right angles to each other in the vicinity of San Alberto and Bucareli Bays, one northwest to west-northwest along Ulloa Channel and Trocadero Bay and the other in a general northeast direction along Bucareli and San Alberto Bays.

In the island group west of Klawak Middle Devonian and Mississippian beds are folded with a north-south strike and cross folded on east-west axes. The cleavage is north-south. East of Klawak the beds dip steeply eastward to vertical. At Point Bocas, on Ulloa Channel, Mississippian rocks occupy a closely folded syncline and strike northwest, and on the northeast side of Suemez Island Upper Devonian beds strike northwest. The Middle Devonian beds of St. Ignace Island and the east half of Baker Island strike east to east-northeast, and those on the north end of Suemez Island strike east to northeast.

SOUTHERN HALF OF PRINCE OF WALES ISLAND AND ADJACENT ISLANDS

By Theodore Chapin

The Middle Devonian rocks of the southern half of Prince of Wales Island and the islands to the west appear to occupy a synclinorium, with a great many auxiliary folds which trend generally northwest. The oldest rocks are the greenstone flows and breccias which occupy the southwest flank of the syncline. They cover the north end of Dall Island, Halibut Nose, the west coast of Sukkwan Island, and the southwestern coast of Prince of Wales Island from Keete Inlet to Cape Chacon. They are tentatively correlated with similar rocks on Moira Sound, on the southern branches of Kasaan Bay, and on Bucareli Bay.

The rocks exposed along the shore from Port Johnson to the head of Moira Sound appear to present a conformable sequence composed of three zones of tuffs and sediments and two of igneous beds with a monoclinal dip toward the southwest. The apparent total thickness is 20,000 to 30,000 feet. This section, however, is believed to be a synclinorium composed of closely folded truncated beds overturned toward the northeast. The igneous beds are believed to be the equivalent of the red and green flows and breccias that occur on the southwest coast of Prince of Wales Island along closely compressed anticlines. The tuffs and sediments stratigraphically overlie them and occur along the synclines.

Twelvemile Arm and Polk and McKenzie Inlets are bordered by tuffaceous sediments, black slate, and conglomerate, with beds of lava and breccia apparently interbedded. The structure here, as on Moira Sound, is believed to be that of closely compressed and overturned folds. The belt of igneous rocks that extends from the mouth of McKenzie Inlet across Skowl Arm to the Jervais Islands, if correctly correlated with the red and green andesite and breccia of the lower group, occupies the crest of a truncated anticlinal fold and is stratigraphically overlain by tuffaceous sediments and black slate. Toward the east end of Skowl Peninsula the beds are more dominantly sedimentary. They are essentially conglomerate, slate, and graywacke and are free from igneous and tuffaceous material. They comprise the base of the upper group of Middle Devonian rocks and are higher stratigraphically than any beds exposed on Moira Sound or Klakas Inlet. They are apparently conformable with the intermediate group into which they grade by an increasing amount of tuffaceous material. Interbedded with the conglomerate is considerable limestone, and overlying the limestone and conglomerate is the massive limestone of Long Island.

Long Island, a small island about 2 miles long in Kasaan Bay, is made up essentially of massive fossiliferous limestone of Middle Devonian age. The rocks of Long Island appear to occupy a syncline, but the structure is very complicated in detail. They are locally overlain unconformably by rhyolite flows of Tertiary age.

The rocks of Kasaan Peninsula consist chiefly of the igneous mass to which the term Kasaan greenstone was applied by Brooks,[22] who described the formation as composed largely of effusive rocks but stated that intrusive rocks were also probably included and that some associated narrow belts of limestone were not separated from the greenstone on the map. Kasaan Peninsula was regarded by Wright[23]

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[22] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, p. 49, 1902.

[23] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 72, 1915.

as a closely folded synclinorium in which the beds in general strike northwest and dip northeast, and no doubt some of the older tuffaceous and igneous beds of Middle Devonian age were involved in this close folding and now appear as if interbedded with the younger conglomerate and limestone.

Clover Bay is a small indentation 4 or 5 miles north of the mouth of Cholmondeley Sound, Prince of Wales Island. A mass of sedimentary rocks too small to map occurs near the head of the bay, inclosed within a mass of intrusive quartz diorite; it comprises beds of conglomerate, graywacke, argillite, and fossiliferous limestone which

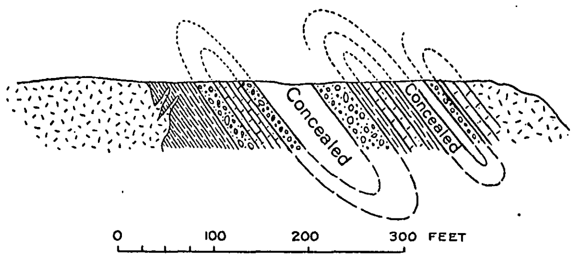

FIGURE 2.—Structure section on Clover Bay, Prince of Wales Island

strike N. 60° W. and stand at a steep angle. The following sequence of rocks is exposed:

Apparent section on Clover Bay, Prince of Wales Island

	Feet
Quartz diorite.	
Limestone with Middle Devonian fossils	15
Conglomerate graywacke with fossils (probably Triassic)	12
Concealed	25
Argillite	20
Limestone with Middle Devonian fossils	10
Argillite	10
Graywacke	30
Concealed	43
Graywacke with fossils (probably Triassic)	10
Limestone with Middle Devonian fossils	22
Graywacke	17
Argillite with dikes of quartz diorite	43
Quartz diorite.	

In the field this section was regarded as interbedded limestone and graywacke, but from the fossils it appears that the limestone is Middle Devonian and that the graywacke is probably Mesozoic and therefore younger. From these facts the structure is interpreted as shown in Figure 2. The beds are closely folded and overturned. The Middle Devonian limestone comes to the surface along the crests of the anticlines and is overlain by the younger sediments which occupy the synclines.

DOLOMI-SULZER ANTICLINORIUM

By Theodore Chapin

The Dolomi-Sulzer anticlinorium extends between Hetta Inlet and Cholmondeley Sound and along the east side of the northern part of Cordova Bay and the west side of Hetta Inlet. The crest of the anticlinorium extends from Dolomi to a point near Sulzer, at the head of Hetta Inlet, where it pitches steeply northwest beneath upper Paleozoic rocks. A belt of limestone and schist of the Wales group extends from Dolomi to Copper Mountain and occupies the crest of the fold which has brought these beds to the surface. The anticlinorium trends a little north of west. Its structure is not simple, as it includes many minor folds. South of Dolomi the beds dip southwest along the south limb and disappear beneath the upper Paleozoic greenstone, slate, and conglomerate of Moira Sound. The Wales group is unconformably overlain by Devonian and Silurian formations.

DALL ANTICLINORIUM

The Dall anticlinorium includes the southern half of Dall Island and Long Island, in Cordova Bay. Its trend in the southern part of Dall Island is northwest, but in the northern part it swings around to true west and is cut off by the Pacific Ocean. The structural relations are very complex, and a combination of synclinal and anticlinal folds locally overturned toward both the southwest and the northeast is indicated. With the probable exception of narrow belts of Silurian rocks only the Wales group is exposed in this area. The beds of the Wales group contain a great number of minor folds and sharp flexures. The schist and greenstone are twisted and contorted, and even the massive limestone beds are closely folded or foliated. Bodies of intrusive rock have caused extensive recrystallization locally within the Wales group, and contact zones are common.

On Dall Island, between Cape Augustine and the Diver Islands, there is a large area of lower Silurian slate which is overlain on the north by upper Silurian limestone. The beds of lower Silurian slate strike true west or a little north of true west. They are isoclinally folded, with a prevalent dip of 60° S. in and south of Sakie Bay and a prevalent dip of 45°–70° N. in Sea Otter Sound. The limestone belt of Thunder Mountain lithologically resembles the upper Silurian limestone, but it appears to occupy a poorly defined synclinal trough in the lower Silurian slate, owing either to unconformable relations or to close folding of the underlying weaker beds.

CHICHAGOF-GLACIER BAY ANTICLINORIUM

The Chichagof-Glacier Bay anticlinorium is a northwest extension of the anticlinal axis that passes through Prince of Wales and Kuiu Islands. The formations on the northeastern half of Chichagof Island and on the islands and coasts of Glacier Bay are, so far as known, wholly of Paleozoic age. This belt constitutes, therefore, an anticlinorial core with respect to the Mesozoic formations of the Juneau and Sitka belts. The present knowledge of the geology of this part of southeastern Alaska is, however, inadequate for defining how much of the territory adjacent to Glacier Bay, how much of Chichagof Island, and how much, if any, of Admiralty Island should be included in this belt. The predominant rocks of the belt are Silurian limestone and underlying graywacke-like beds and slate. A great belt of Silurian recrystallized limestone passes northwest through Willoughby and Drake Islands and the east side of Rendu Inlet, Glacier Bay. Similar limestone is found on the east side of Tenakee Inlet.

FRESHWATER BAY SYNCLINE

Knopf [24] reports that chert and banded quartzite resembling graywacke form the north shore of Chichagof Island between Idaho Inlet and Flynn Cove and from Port Frederick to Point Augusta. These beds are overlain by Silurian limestone and these in turn by Upper Devonian melaphyre lava flows and tuff, which form a belt extending northwest from the northeast side of Freshwater Bay to Port Frederick. These beds are overlain by 1,000 feet of Mississippian limestone, which forms the Iyoukeen Peninsula and is exposed also in Port Frederick. It therefore appears that a synclinal trough, here called the Freshwater Bay syncline, in which Upper Paleozoic formations are exposed, strikes northwest through Freshwater Bay and Port Frederick. The beds on Freshwater Bay have been described by Kindle.[25]

Upper Paleozoic beds (Permian) are exposed also east of Glacier Bay in the Porcupine district,[26] and cobbles of upper Paleozoic formations are found in the glacial moraines at the head of Muir Inlet and Adams Inlet.

SITKA MESOZOIC BELT

The Sitka Mesozoic belt extends northwestward through Sitka along the west coast of Baranof and Chichagof Islands. It has been

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[24] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, pp. 11–12, 1912.

[25] Kindle, E. M., Notes on the Paleozoic faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, p. 322, 1907.

[26] Eakin, H. M., The Porcupine gold placer district, Alaska: U. S. Geol. Survey Bull. 699, p. 11, 1919.

described by Knopf[27] and Overbeck.[28] Knopf reports that at Silver Bay, Sitka, and Klag Bay, on Baranof Island, the strike is northwest and the dip commonly 70° or more southwest. Overbeck describes the beds on the west coast of Chichagof Island as striking, in general, between west and N. 45° W., with a few striking N. 30° W., and as dipping almost unversally south to southwest at angles of 40°–70°. Extensive faulting has occurred. Overbeck states that with the data available it is impossible to interpret the structure, but that there is undoubtedly duplication of beds due to folding and faulting, and that these beds may form the limb of an anticline.

MINERAL DEPOSITS

The mineral deposits of southeastern Alaska will be discussed in a general way with respect to the types of deposit, their relation to formations and to rock structure and character, their tendency to localization in belts or areas, and their relation to igneous rocks. Detailed descriptions may be found in the publications cited.

TYPES OF DEPOSIT

The types of deposit include contact deposits, fissure veins, stringer lodes, stockworks, replacement veins and impregnation zones, shear-zone deposits, breccia veins, certain complex lode types, and placer deposits.

The most important known contact deposits are the copper and iron ores of the Ketchikan district. They usually occur at or near the borders between the intrusive masses and the surrounding rocks, which are chiefly limestone, graywacke, greenstone tuff, and schist, but locally they are found in blocks of country rock included within the intrusive masses. Among the best examples are those at the Mount Andrew, Mamie, Poorman, and It mines, on the Kasaan Peninsula; one of the Rush & Brown mines, on Karta Bay; and the Jumbo and Copper Mountain mines, on the west side of Prince of Wales Island. The marble deposits at the north end of Prince of Wales Island and the garnet deposits at the mouth of Stikine River are likewise due to contact metamorphism. Wright[29] summarizes the occurrence of the contact deposits as follows:

> At the time of their intrusion the igneous rock masses or dikes forced their way through the sedimentary and volcanic rocks, to some extent folding and fracturing them. While they were cooling both the intruded and intrusive rocks

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[27] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, pp. 13–14, 1912.

[28] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 95–112, 1919.

[29] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, pp. 86–87, 1915.

naturally shrunk somewhat, and the shrinkage caused cracks and fissures to form near the contacts. These fissures became channels for mineral-bearing solutions, derived presumably from great depths, where the temperature was high. On ascending along the contacts where the temperature was lower these solutions deposited their mineral content and to some extent replaced the rocks along their courses. The contact deposits therefore lie within the contact zone, between the intrusive and the intruded rocks, and are believed to have been derived from the same magma that formed the adjacent igneous rock. * * * The contact deposits are generally small irregular masses and are no more persistent in depth than they are laterally, but where masses have been found in a wide contact zone further exploration will probably reveal similar ore masses, both laterally and in depth.

The fissure veins occur along distinct fractures in the rocks and may be found at considerable distances from the surface exposures of the intrusive rock, or they may occur within the intrusive igneous rock itself. Examples of fissure veins are found in the gold quartz veins on the west coast of Chichagof Island, such as the Chichagoff, Hirst-Chichagof, and Apex-El Nido; certain of the gold quartz veins in the diorite stock at Berners Bay, such as the Comet, Ophir, and Jualin; certain of the gold quartz veins in the Juneau district, such as the Bald Eagle, at Sumdum, and the veins at Funter Bay; the gold-silver-lead veins of the Hyder district, such as the Fish Creek, Mountain View, Riverside, Ibex, Homestake, and Comstock; the copper veins at the Cymru property, on the north end of Moira Sound, Prince of Wales Island, and at the head of Port Houghton, in the Juneau district; the molybdenite vein at Shakan, Kosciusko Island; the stibnite (antimony) lode at Point Camaano, Cleveland Peninsula; and the barite veins at the north end of Kuiu Island.

In the Juneau district gold veins assigned by Lindgren [30] to the high-temperature, deep-seated type occur with a similar type of mineralization throughout a vertical range of over 4,500 feet. In the Hyder district gold-lead-silver veins assigned by Westgate [31] to a type representing intermediate temperature and depth occur with similar mineralization throughout a vertical range of over 5,000 feet. The veins at the highest altitudes, 5,000 feet, must have been formed at considerable depth beneath the surface, for erosion has been active over the mainland area since the intrusion of the batholith and must have removed a cover of very considerable thickness—at least several thousand feet. It may therefore be reasonably assumed that exploration for ore shoots at depth is warranted on fissure veins of considerable length that show workable ore shoots at or near the surface.

The stringer lodes are narrow belts of schistose or slaty country rock ribboned with veinlets and lenses of quartz, mostly parallel to

[30] Lindgren, Waldemar, Mineral deposits, McGraw-Hill Co., 1919.

[31] Westgate, L. G., Ore deposits of the Salmon River district, Portland Canal region: U. S. Geol. Survey Bull. 722, p. 130, 1922.

the foliation or bedding, but in part reticulating. They are common in the slate and graywacke of the Juneau gold belt.

The stockworks are chimneylike or cylindrical masses of broken rock with a very large number of irregular small quartz stringers that intersect in an intricate manner. They are relatively scarce; examples are the gold quartz deposits at the Kensington and Eureka lodes, in the Jualin diorite of the Berners Bay district, and one of the gold quartz lodes in the Lisianski stock of diorite at the Apex-El Nido property, on Chichagof Island.

Replacement veins and impregnation zones consist, in part, of more or less tabular veins or zones that have resulted either from the partial or complete metasomatic replacement of a bed that is relatively more easily replaceable owing to its physical or chemical characters, or from impregnation or complete replacement of the rock adjoining a fracture which has permitted the ingress of the solution. They consist also in part of replacement and impregnation deposits along shear zones. The zinc deposits of the Groundhog Basin, east of Wrangell; the barite deposit on the Castle Islands, in Duncan Canal; the silver-lead-zinc deposit of the Daly-Alaska property, in the Hyder district; and the Point Astley copper prospect, on Holkham Bay, belong in this group.

The shear-zone deposits are in zones of rock crushed so that it has usually a fine foliation; the crushed rock may be replaced by metalliferous minerals; it contains closely spaced, generally small tabular veinings parallel to the foliation, either with or without replacement of the intervening wall rock. Brooks[32] has described the cupriferous shear-zone deposits of the Ketchikan district as follows:

> The shear-zone deposits follow zones of fracture that are parallel to the schistosity of the country rock. They are found in various kinds of country rock, but primarily in greenstone schist, graywacke, and sheared diorite. There are two phases of the shear-zone deposits. One consists of lenses or tabular deposits, many of which are made up largely of rich massive sulphide minerals. These have well-defined walls and are not unlike the cupriferous quartz veins described below. The other phase consists of disseminated deposits in which the sulphides are distributed through wide zones of sheared country rock, generally without well-defined walls. In some of the disseminated deposits the sulphide mineralization is rather evenly distributed throughout the entire mass, which may thus be a large body of low-grade ore. More commonly, however, the mineralization is concentrated along certain zones determined by the intensity of the shearing. * * * Examples of the shear-zone deposits, including both the concentrated and disseminated phases, are found at the Rush & Brown mines, on Karta Bay; at Niblack Anchorage and McLean Arm, on the east side of Prince of Wales Island; at the Corwin and Red Wing properties, near Hetta Inlet; and on Big Harbor (Trocadero Inlet), on the west side of Prince of Wales Island; and on McLeod Bay, Dall Island.

[32] Brooks, A. H., Mineral resources of Alaska: U. S. Geol. Survey Bull. 714, pp. 17–20, 1921.

Breccia veins are usually tabular in form and are found along a fault or fracture zone. They comprise masses of broken rock or breccia cemented and impregnated by quartz, calcite, or metallic sulphides. Some of the copper deposits on Prince of Wales Island and the gold lodes near Dolomi are examples of this type. They are not common.

Ladder veins are rare in this district. One of this type on the Keku Islets consists of a dike of basalt with cross fractures filled with narrow veinlets of sphalerite; it is of no commercial value.

The ore bodies of the Treadwell mines on Douglas Island, in the Juneau district, are dikes of albite diorite veined with metalliferous quartz and calcite and impregnated with auriferous pyrite. They constitute one of the complex types.

Deposits which do not fall readily into any of the foregoing types are found within the gabbroic and highly ferromagnesian igneous rocks. These include the nickel-copper deposits of Chichagof and Baranof Islands; the copper-palladium deposit at the Salt Chuck mine, in the Ketchikan district; and the titaniferous magnetites at Haines, in the Skagway district, at Snettisham, in the Juneau district, and on Union Bay, Cleveland Peninsula.

The auriferous quartz veins of the Juneau gold belt are usually solid masses through which the sulphides are leanly distributed; but veins with drusy cavities or interlocking comb structure are also found. Banding is rare. In the veins of the Funter Bay-Hawk Inlet gold belt the quartz is mostly milky white and massive, but locally it is of comb or drusy structure.

The veins of the Apex-El Nido mine, on Chichagof Island, on the other hand, show a characteristic sheeted or ribbon structure that parallels the walls. The sulphides, on the average, form only a small percentage of the vein and are in streaks parallel to the banding. Thin shear zones and slickensiding are common within the veins, and new sulphides have been introduced along such planes. It is possible that such reopened veins will be found to be those that carry the richest ore shoots. At the Chichagoff, on Chichagof Island, the lodes show a well-marked ribbon structure, which is accentuated by the fact that the separate ribbons of quartz alternate with thin slabs of schistose graywacke. From the structural features of this body Knopf[33] suggests that

> From a principal level driven along the general trend of the shear zone numerous crosscuts should be made into both the hanging wall and the footwall. Not only do the apparent walls prove unreliable guides concerning the ore bodies but it is conceivable that where large horses of graywacke occur in the shear

[33] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, pp. 21–22, 1912.

zone the ledge may split and curve around the massive rock, and on resuming its general trend may follow a parallel course at a distance of some feet in either the footwall or the hanging wall of the original course.

In the veins associated with the Texas batholith in the Hyder district there is a very marked banding of the sulphides in the solid quartz, giving a ribbon structure parallel to the walls. In some veins, as on the Homestake prospect, the veins have been subjected since their formation to intense stresses, as indicated by flowage and mashing. The original medium-crystalline galena has been mashed to a densely crystalline aggregate, which has flowed and carried out into bands or lenses the associated more or less crushed pyrite and chalcopyrite. In the so-called steel galena of the Homestake prospect the solid sulphide mass resembles an augen gneiss, with eyes of granulated pyrite in a flow-banded galena. The quartz shows local crushing and strain shadows. At another prospect the galena has been recrystallized into long bands parallel to the walls. Faulting has also affected some of these veins, to what extent has not yet been determined.

METALLIFEROUS DEPOSITS

ORES AND ASSOCIATED MINERALS

The basis for a considerable part of the discussion of the occurrence and economic importance of the metallic and nonmetallic minerals has been drawn from the reports of Spencer,[34] Wright,[35] Knopf,[36] and Brooks,[37] as well as from the more recent work of the present writers. To avoid repetition specific citations of these reports are generally omitted in the following pages.

GOLD

The gold occurs in quartz veins, in sulphide impregnation zones, and in lodes comprising both veins and metallized country rock. The impregnation zones are usually of very low grade. Gold in noteworthy amount has not been found in the contact-metamorphic copper deposits, though it is recovered as a by-product.

Gold lodes do not appear to be concentrated in any particular formation but rather to be governed in distribution by structural conditions and the relations to intrusive bodies.

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[34] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, pp. 33–38, 1906.

[35] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 77–203, 1906.

[36] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 29–31, 1911.

[37] Brooks, A. H., The future of Alaska mining: U. S. Geol. Survey Bull. 714, pp. 1–57, 1921.

Gold occurs in the veins and lodes in two ways. In some of the veins it is found almost entirely in fine flakes or spangles of native metal irregularly distributed in pockets or shoots. In the majority of deposits, however, most of the gold is invisible and is supposed to be distributed through the sulphides in minute films and particles; in this condition a part of the gold may be still free to amalgamate with quicksilver, but in many of the deposits the gold is so intimately associated with the sulphides that fine milling and amalgamation fail to extract it. With the gold some silver is usually present. Gold has been found to occur in pyrrhotite, pyrite, chalcopyrite, arsenopyrite, sphalerite, and galena. In the upper parts of some lodes it appears in bright-yellow particles embedded in iron ocher, where it has evidently been derived from the oxidation of a pyritic mineral. The gold usually occurs in a quartz gangue but has also been found in calcite.

In the Berners Bay region the presence of chalcopyrite in the vein is reported to be favorable to good tenor in gold; in the Windham Bay region high gold content is commonly associated with the presence of sphalerite and galena; in the region around Klag Bay, on Chichagof Island, according to Knopf, the presence of galena with pyrite indicates everywhere high gold; at the Londevan prospect, on George Inlet, gold is said to increase markedly where galena is abundant; and at the Dunton mine, near Hollis, on Prince of Wales Island, gold is said to be most plentiful where pyrite is most abundant in the quartz. Spencer reports that as a general rule in the Juneau region an increase in the amount of sulphides in a given deposit or vein is accompanied by an increase in the value of the ore. In the Hyder district gold occurs in quartz veins that carry shoots of solid sulphide, predominantly galena and pyrite, or shoots heavily metallized with sulphides. High gold tenor here is also shown by the tetrahedrite in the quartz fissure veins and locally by sphalerite that occurs in replacement and impregnation lodes in greenstone or in porphyry dikes.

Brooks wrote in 1919:

> Auriferous lodes in Alaska have yielded $92,000,000 worth of gold, of which more than 80 per cent has come from the six large low-grade mines of the Juneau district. * * * Successful lode mining at Juneau, in complete contrast to most of the placer operations, has been based on the exploitation of low-grade deposits on a very large scale. The mines have, indeed, been operated at a lower unit cost than any others in the world. The average value per ton of the gold and silver recovered from the ore produced in these mines since 1882 [to 1919] is $1.95. The small margin of profit was offset by the very large tonnage handled.

Gold occurs also in placers in southeastern Alaska. A little placer gold was taken out in the early days from local deposits throughout the Juneau, Ketchikan, and Wrangell districts. Hill and gulch placer deposits near Juneau are reported by Spencer to have yielded between $600,000 and $800,000 in gold prior to 1890, when they were practically exhausted and abandoned. A description of these placers is given by Spencer.

Other placer deposits were worked in the creeks tributary to Windham Bay in the early days. The placer deposits on Shuck River are being investigated with a view to the installation of a hydraulic plant or a dredge. The deposits are described by Wright in the report by Spencer.

Valuable placer deposits have been found in the Porcupine district on the tributaries of Chilkat River, particularly those of Glacier and Porcupine Basins, at the head of Chilkat Inlet, Lynn Canal. It is estimated that between 1898 and 1916 about $1,200,000 in gold was taken out here. The geology has been described by Wright [38] and Eakin.[39]

Placer gold is also won from the beach placers northwest of the entrance to Lituya Bay.

A little gold has been recovered from residual weathered deposits near the outcrop of auriferous veins, as on the west side of Helm Bay, in the Ketchikan district.

COPPER

The copper minerals found in southeastern Alaska include the primary minerals chalcopyrite, bornite, tetrahedrite, and chalmersite; and the secondary minerals metallic copper, malachite, azurite, chrysocolla, chalcocite, and covellite.

Metallic copper has been observed at only a few localities, where it usually occurs in insignificant amount, as an oxidation product at or near the surface outcrop of copper pyrites. In this mode of occurrence the copper is in thin sheets along clay seams or slipping planes. At the Salt Chuck mine, at the head of Kasaan Bay, Prince of Wales Island, it has been found as low as 200 feet beneath the surface but is slight in amount.

Malachite and azurite are often found as alteration products at the surface outcrops or along fractures in or adjacent to the ore body, but do not anywhere themselves occur in sufficient quantity to constitute ore. Chrysocolla is reported by Wright from the surface workings of the Copper Mountain mine, on Prince of Wales Island. Chalcocite and covellite are occasionally found as secondary alteration products of chalcopyrite or bornite, but they nowhere occur in

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[38] Wright, C. W., The Porcupine placer district, Alaska: U. S. Geol. Survey Bull. 236, 1904.

[39] Eakin, H. M., The Porcupine gold placer district, Alaska: U. S. Geol. Survey Bull. 699, 1919.

sufficient amount to constitute an ore pocket. At the Salt Chuck mine chalcocite occurs as low as 200 feet beneath the surface.

Chalcopyrite forms the bulk of the copper ores in the deposits of all types. It is also common as an accessory mineral in the gold lodes. In the Berners Bay region it is, according to Knopf, next to pyrite, the most common metallic sulphide in the gold quartz veins. In the gold lodes of the Juneau district, as reported by Spencer, chalcopyrite is present in relatively small amounts as compared with the sulphides of iron, zinc, and lead. The association of chalcopyrite with pentlandite in pyrrhotite masses occurring in gabbroic or ultrabasic rocks has previously been described. It is the most valuable ore mineral at the present time in most of the contact deposits and is common in shear zones, in greenstones, and in impregnation lodes.

Bornite is present rarely as an accessory in the mineral deposits of southeastern Alaska. Only in a few places does it form the major mineral of an ore deposit; one such occurrence is at the Goodro or Salt Chuck mine, at the north end of the Kasaan Peninsula, Prince of Wales Island, and another is at the copper prospect east of Point Astley, on Holkham Bay, in the Juneau district. In the Salt Chuck mine the bornite carries palladium and occurs as disseminations and veinlets in pyroxenite. At the Point Astley prospect the bornite is associated with pyrite, sphalerite, and galena and occurs in metallized quartz stringers in greenstone schist and in impregnated schist and partly replaced limestone layers. A small pocket of bornite was found on Francis Island, in Glacier Bay, at the contact of a diorite dike with limestone. In the vicinity of Dall Head, on Gravina Island, a little bornite is associated with chalcopyrite and stringers of specularite in a quartz gangue. At the Spik claim, 2 miles south of the head of McLean Arm, on Prince of Wales Island, bornite, chalcopyrite, and pyrrhotite occur in irregular masses in greenstone. Bornite is reported also from prospects on the ridge between Chilkat and Chilkoot Valleys, in the Skagway district, about 10 miles northwest of Haines. The quartz veins that carry bornite usually carry also hematite.

Tetrahedrite, though a copper ore mineral (often called gray copper), has not been observed in the deposits mined largely for their copper content. It is common and valuable where it occurs in veins, mainly because of the gold and silver which usually accompany it. Tetrahedrite may occur in very minor amounts in some of the gold quartz veins of the Juneau and Sitka districts, but if so it is very rarely reported. It has been found in gold quartz veins near Dolomi, on Prince of Wales Island; as narrow stringers in limestone and schist west of Crab Bay, on Annette Island; and as seams and veinlets in limestone at Mount Vesta, on Vesta Bay, Dall Island; and it is reported to occur in veins in diorite on the west side of Rendu Inlet, Glacier Bay. Tetrahedrite is an abundant mineral in certain of the gold-lead-silver veins of the Hyder district. It is present locally in considerable amounts on the Cantu, Fish Creek, Mountain View, and Ibex properties, in the Salmon River district, and has been found in the veins on the Riverside property. The silver content usually increases with an increase in the amount of tetrahedrite in these veins; the tetrahedrite may carry as much as 700 ounces of silver a ton. The veins are fissure veins in quartz diorite or granodiorite and consist of quartz with shoots of galena, pyrite, tetrahedrite, and locally sphalerite, chalcopyrite, or pyrrhotite.

Chalmersite has been identified at only one locality, where it is in association with pyrrhotite.

A general discussion of the copper deposits in southeastern Alaska has been given by A. H. Brooks:

> All the productive copper mines, as well as the largest developed cupriferous ore bodies of southeastern Alaska, are in the Ketchikan district. Copper is widely distributed in the Ketchikan district and, as will be shown, occurs in deposits of several distinct types. The most important so far as present production and extent of proved ore bodes are concerned are the contact deposits, which have yielded more than 98 per cent of the copper produced in the Ketchikan district. * * *
>
> It has been shown that the best developed of the Ketchikan copper deposits are those composed essentially of chalcopyrite, magnetite, and pyrite. Some of these have a considerable percentage of lime. Much of the successful mining of the past has been done because of the smelter demand for base ores and the premium paid for a high iron content. The change in metallurgic practice has decreased this demand, producing an adverse effect on copper mining in the district. Limestone is abundant in southeastern Alaska.
>
> The Ketchikan copper deposits are not far from tidewater and are on good harbors open to navigation throughout the year. They are connected by sheltered waterways with the smelters at Anyox, Tyee, and Tacoma. This condition should give cheap freight rates. The strong topographic relief, excellent timber, and good water powers of the district all favor low mining costs.
>
> A total of 543,498 tons of copper ore has been produced in the Ketchikan district since mining began in 1901. This ore yielded 34,056,376 pounds of copper, gold to the value of $545,000, and 255,440 ounces of silver. The average copper content of this ore is 62.66 pounds to the ton, equal to 3.13 per cent. The average value of the gold and silver content is $1.31 a ton. The average value of the total metallic contents of the ore is $12.71 a ton. No attempt has been made to concentrate the Ketchikan ore except by hand sorting. The small mines have normally maintained their shipping grade of ore at 5 per cent or more.
>
> The facts above set forth clearly indicate that the Ketchikan district contains copper deposits which are well worth investigating by those who have the capital to develop and reduce ores on a large scale. The physical conditions seem almost ideal for cheap operations. Special attention should be directed to devising methods by which the iron content of the chalcopyrite-magnetite ores, as well as the copper, can be utilized.

IRON

The iron minerals include pyrrhotite, pyrite, magnetite, hematite, limonite, and marcasite.

Pyrite is the commonest metallic sulphide. It is present in the form of small but perfect cubes or irregular grains throughout most of the metamorphic schists, slates, and greenstones. In the intrusive masses it is usually present near contacts. It is the most common sulphide in the gold quartz veins and is the next most abundant mineral to galena in the fissure veins of the Hyder district. It is practically always associated with sulphide masses to a greater or less extent. Alone it is of little commercial value, except as a raw material for the manufacture of sulphuric acid, but where associated with gold it may form a valuable ore. Where it occurs as disseminated or replacement deposits it rarely carries more than very little gold. It gives rise on weathering to limonite and the characteristic brown, yellow, or reddish stains. Very large masses of pyrite occur at the Khayyam mine, on the summit of a mountain 2.8 miles southwest of Kiam, on McKenzie Inlet, Skowl Arm, Prince of Wales Island, as described by the Wrights.

Pyrrhotite is similar in mode of occurrence to pyrite, but it is not quite so widely distributed. It is abundant in all the copper contact-metamorphic deposits, in high-temperature fissure veins, and as disseminations and lenses in the gabbroic and ultrabasic group of rocks. Wherever pyrrhotite occurs either in or associated with the basic igneous intrusive rocks it should be tested for nickel, for at many places pyrrhotite in such association is known to carry noteworthy percentages of nickel. (See pp. 348–351.) Pyrrhotite in association with diorite or more granitic rocks, on the other hand, is not known to carry nickel, and the pyrrhotite of the contact and vein deposits genetically connected with this group of intrusive rocks carries only 0.1 to 0.2 per cent of nickel. Chalcopyrite is commonly associated with pyrrhotite in small amounts and at certain places in sufficient quantity to constitute an ore. Pyrrhotite is the predominant metallic mineral in the zinc deposits and most of the sulphide lodes in the Wrangell-Revillagigedo belt of metamorphic rocks. It occurs in small amounts in many of the gold quartz veins and may be gold bearing but is by no means as common in such veins as pyrite.

Magnetite occurs in sufficient quantity to constitute ore bodies. It is rarely found in the gold quartz veins. Its principal mode of occurrence is in association with contact-metamorphic copper deposits and as disseminations or vein dikes in the pyroxenite and hornblendite. It is almost universally present as an accessory constituent in the igneous rocks. In the quartz diorite, granodiorite, quartz monzonite, and granite magnetite is rarely present in amounts greater than 2 per cent and normally is less than 1 per cent; in the diorite and monzodiorite it averages between 1 and 2 per cent and may be as high as 5 per cent; in the gabbro it ranges from a trace to 12 per cent and averages about 5 per cent; and in the pyroxenite and hornblendite it reaches 30 per cent and may occur as vein dikes of almost solid magnetite. There is thus, in general, a very marked increase in the percentage of magnetite in the less siliceous and more basic rocks. In the diorite, however, magnetite appears normally to form only a small percentage. In the ultrabasic group of rocks a little ilmenite is associated with the magnetite as grains and in small amount is intergrown with it on a microscopic scale. The ilmenitic magnetite deposits are of future potential value and are described in connection with the Upper Jurassic or Lower Cretaceous intrusive rocks. (See pp. 193–198, 351–353.)

Brooks has discussed the magnetite ores of southeastern Alaska as follows:

In the absence of any considerable iron industry on the Pacific coast there has been no incentive to search for iron ores in Alaska. The largest deposits known consist of magnetite associated with copper ores—the contact-metamorphic deposits of the Ketchikan district. J. B. Mertie, jr., who has made a rough estimate of the quantity available from these deposits, places the minimum reserve at 10,000,000 tons, with possibly an average copper content of 0.5 per cent. This estimate is based on an appraisal of the probable depth of the known deposits and on the assumption that all the ore would be available for mining. There are no accurate data at hand on the mean iron content of these ores, nor is it known whether the phosphorus contents are everywhere below the Bessemer limit. Some analyses of the Mount Andrew magnetite ore made many years ago gave a phosphorus content of 0.02 per cent. The possibility that these ores contain titanium should also be considered. On account of the presence of sulphides the sulphur content of the ores will be high. Similar deposits have been mined on Texada Island, in British Columbia, and these contain an average of 55 to 60 per cent of metallic iron,[40] and the phosphorus content of most of them is low enough to make them fall within the Bessemer limit, but the sulphur content is high. * * *

The above brief review indicates that Alaska contains a number of iron-ore deposits, of which the most promising are those of the Ketchikan district. It would appear that the value of the Ketchikan deposits will depend on finding a commercial method of recovering the low copper contents as well as utilizing the iron.

Hematite occurs as disseminated grains or rosettes of specularite in the contact-metamorphic deposits and in a few quartz veins, in part associated with bornite and in part with pyrite. It has not been observed in the gold quartz veins.

Limonite is nowhere found in quantity, although it occurs wherever iron minerals are altered under surface conditions. It forms a noteworthy capping on many of the pyritic or pyrrhotitic

[40] Lindeman, Einar, Iron-ore deposits of Vancouver and Texada Islands, British Columbia: Canada Dept. Mines, Mines Branch, No. 47, 1910.

sulphide bodies and is present in many rusty belts within the slates, phyllites, schists, and gneisses.

Marcasite is common in small amounts in the sulphide bodies as an alteration product along fractures or locally replacing the sulphides, especially pyrrhotite, in the upper portions of the deposits. The nickeliferous pyrrhotite bodies in particular are partly replaced by marcasite in the outcrop. Marcasite of this mode of occurrence is of secondary origin under surface conditions. Marcasite occurs also as a primary mineral associated with sphalerite in and near a basalt dike on one of the Keku Islets.[41]

SILVER AND LEAD

Native silver occurs in small amount at the Point Astley copper prospect, on Holkham Bay, and at the Daly-Alaska and Mountain View properties in the Salmon River district, but most of the silver occurs in association with gold and with silver-bearing galena and tetrahedrite. Electrum, a pale alloy of gold and silver, with silver in excess, is reported by Spencer to occur in ore from the Reagan shaft, and pyrargyrite is reported as a secondary mineral in the Silver Queen and Glacier mines, on Sheep Creek, in the Juneau district. Proustite has been identified as a rare secondary mineral in a vein on the Mountain View property, in the Salmon River district.

Galena occurs in extremely variable amounts in the gold quartz veins. Where it is present in considerable quantity the proportion of silver is likely to be higher, and it is in many places associated with sphalerite and a little chalcopyrite. Galena occurs also associated with sphalerite, pyrite, and tetrahedrite in complex sulphide deposits. It is the principal ore in the fissure veins at the Lake and Glacier Basin claims, east of Wrangell; in the replacement deposits at the Moonshine prospect, on Cholmondeley Sound, Prince of Wales Island; in the fissure veins in the quartz diorite and granodiorite of the Salmon River district, where pyrite is associated with it as the next most abundant mineral; and in a fissure vein in dolomite at a prospect on Whiting River. In all these localities it carries moderate to low percentages of silver. Ore rich in tetrahedrite from the Fish Creek veins, in the Salmon River district, is reported to carry as much as 700 ounces of silver to the ton, and at some of the properties in this district freibergite is present.

Most of the lead produced in southeastern Alaska up to the present time has come from the gold mines of the Juneau district, but it seems highly probable that a considerable amount will in the future

[41] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 138–139, 1925.

come from the veins of the Salmon River district, and that properties in other districts will be developed.

Cerusite commonly occurs as a white coating on the weathered surface of galena masses and particles, and anglesite occurs locally as a surface alteration product.

Galena, argentiferous galena, and argentiferous tetrahedrite are far more abundant in the mineral deposits along the east side of the Coast Range batholith than they are within or west of the batholith. Native silver, pyrargyrite, proustite, and argentite are common ore minerals in the deposits on the east side of the batholith in British Columbia. These are thought to have been formed mainly as a result of enrichment but may in small part be primary.

ZINC

Practically the only zinc mineral in southeastern Alaska is sphalerite, commonly known as zinc blende. It is usually dark brown, red, or nearly black. When examined with the microscope much of it is found to contain abundant dots or rods of chalcopyrite oriented along its cleavage planes. The sphalerite from the zinc deposits of the Groundhog Basin is reported to be the variety martite with considerable iron.

Sphalerite is a common accessory mineral in the gold quartz veins of southeastern Alaska and is usually associated with sulphide bodies, including galena or chalcopyrite, where they occur in fissure veins and shear and impregnation zones. It is not an abundant constituent of the contact copper deposits and is usually present there only as an accessory mineral. At the Complex mine, between Mineral and Dora Lakes, on Kitkun Bay, Prince of Wales Island, some of the ore is essentially sphalerite, with a little chalcopyrite and galena, in a banded quartz fissure vein carrying gold and silver. Sphalerite has been found in considerable amounts at some prospects on Beaver Mountain, Prince of Wales Island. At no place in the Alexander Archipelago has sphalerite yet been mined by itself as an ore.

At the Groundhog Basin,[42] east of Wrangell, on the mainland, extensive low-grade deposits of sphalerite with pyrrhotite and a little galena have been found as tabular replacement veins in a band of the metamorphic complex; they are discussed on page 361. Sphalerite is abundant in other metalliferous zones in this formation, and it seems highly probable that zinc will eventually be produced from bodies occurring in the Wrangell-Revillagigedo belt of metamorphic rocks.

[42] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaksa: U. S. Geol. Survey Bull. 739, pp. 57–63, 1923.

NICKEL

There is only one known nickel mineral, pentlandite, that is of economic value in southeastern Alaska. It occurs usually in small amount within certain pyrrhotites and can not normally be seen in the ore, but on polished surfaces and under the microscope it is plainly visible. At the surface outcrops the pentlandite is altered to a secondary nickel mineral which may be bravoite,[48] but this is only a local modification. Gray efflorescent salts are characteristic of the weathered outcrops. The nickel ores are described in connection with the Upper Jurassic or Lower Cretaceous intrusive rocks. (See pp. 348–351.) The pentlandite is always associated with pyrrhotite and generally with chalcopyrite in genetic connection with gabbroic or ultrabasic intrusive masses or dikes. Only one prospect has been developed to any extent. It is highly probable that other nickel deposits of similar type will be found in southeastern Alaska.

The ore reserves in the Sudbury mines are stated to be 150,000,000 tons, and the New Caledonia deposits are estimated to contain 160,000 tons of nickel. In view of these large reserves in the present major producing regions, it would be exceedingly difficult for a large new concern entering the field to dispose of its nickel, but a small producer would not have the same difficulty. The Alaskan deposits show a grade of ore and geologic associations which warrant their further investigation and prospecting when economic conditions justify an intensive search for new sources of nickel ore.

MOLYBDENUM

Molybdenum in the form of molybdenite is widely distributed in small amounts, but it is known in noteworthy concentrations at only a few localities. It occurs disseminated in contact-metamorphic deposits, as on Lemesurier Island, in Icy Strait; in pegmatitic quartz veins, as at Shakan; in quartz fissure veins in the dioritic and more granitic intrusive rocks; as facings of fractures in local areas; and disseminated in aplite and pegmatite veins. There is no record that any molybdenite has been produced in Alaska for sale.

Molybdenite has not been observed in general in the gold quartz veins of the Juneau district, according to Spencer, but occurs in certain zones of sheeting in the diorite of that district and was found in all parts of the Treadwell ore bodies. It also occurs here and there in small quartz fissure veinlets and as fracture facings in the granodiorite stock of the Salmon River district and in schist at the north end of Noyes Island. On Prince of Wales Island it occurs both in the contact copper deposits and in the altered dioritic rock near these deposits. Very fine specimens of molybdenite quartz

[48] Buddington, A. F., Alaskan nickel minerals: Econ. Geology, vol. 19, pp. 521–541, 1924.

veins have been brought from float on Brady Glacier and from Geikie Inlet, Glacier Bay. Molybdenite also occurs facing fractures in metamorphic rock at the entrance to Adams Inlet on the north side, and it is reported from the region north of the east fork of Skagway River extending from mile 6 eastward for 8 miles.

Development work has been carried on at only three molybdenite prospects—a contact deposit in limestone on Lemesurier Island, in Icy Strait;[44] a deposit in the granitic rock of the Coast Range batholith on the White Pass & Yukon Route about 25 miles from Skagway,[45] and a fissure vein in diorite near Shakan.[46] Hess[47] says that near Shakan the mineralized zone crops out for 500 feet and quotes F. W. Bradley as authority for the statement that the ore averages from 1 to 2.28 per cent of MoS_2 in large lots, that 100,000 tons of ore assaying 1.58 per cent of MoS_2 was indicated, and that 6,270 tons of high-grade ore was blocked out. Hess writes further:[47a]

> The world contains innumerable molybdenum deposits, mostly small, all of which, except in the oxidized parts, carry the metal, so far as is now known, in the form of molybdenite. Some of the molybdenite deposits, however, are extensive and contain large quantities of the metal. * * * A few, like those at Climax, Colo., and Yetholme, New South Wales, are very large, though of comparatively low grade, carrying only about 1 per cent or less of MoS_2, and it is likely that under the stimulus of a continuous demand a larger number of such deposits might be found. There are numerous areas where such developments would not be surprising, such as the mountain region extending from Mexico to Alaska.

TUNGSTEN

Tungsten in the mineral scheelite has been found at the Apex-El Nido property, on Lisianski Strait, Chichagof Island, and is reported by Brooks to have been found in a vein on Baranof Island near Sitka. At the Apex-El Nido property the scheelite occurs in disseminated form in high-grade gold quartz veins associated with arsenopyrite and also in a shoot of solid scheelite 5 inches wide in a quartz stringer. The veins are in aplite dikes in diorite. In the Hyder district scheelite occurs also as abundant disseminated crystals associated with pyrite, barite, and tetrahedrite in a vein on the Mountain View property and less abundantly in other veins. A shoot of scheelite has also been found in a vein on the Riverside property.

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[44] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 783, pp. 55–56, 1926.

[45] Brooks, A. H., The Alaska mining industry in 1916: U. S. Geol. Survey Bull. 662, p. 25, 1918.

[46] Chapin, Theodore, Mining developments in the Ketchikan district: U. S. Geol. Survey Bull. 692, p. 89, 1919. Mertie, J. B., Mining developments in southeastern Alaska: U. S. Geol. Survey Bull. 714, pp. 118–119, 1921.

[47] Hess, F. L., Molybdenum deposits: U. S. Geol. Survey Bull. 761, pp. 14–15, 1924.

[47a] Idem, p. 33.

ANTIMONY

Antimony is found in the minerals stibnite, tetrahedrite, and bindheimite. Bindheimite (?) is a local yellowish alteration product of tetrahedrite in the surface outcrops of some veins in the Hyder district and has no commercial value. The occurrence of tetrahedrite has been discussed in connection with the copper ores. (See pp. 323–324.) Stibnite is the only commercially valuable antimony ore. It has been found in quantity at only one locality, as a fissure vein of solid stibnite 3½ feet wide where exposed in limestone at Camaano Point, at the south end of Cleveland Peninsula. A small test shipment of ore has been made from this locality. Stibnite occurs as abundant radiating clusters of needles or blades in certain low-grade gold quartz fissure veins in schist on the Clark prospect, 6½ miles east of Juneau, and is reported by Spencer to occur in minute radiating crystals in calcite at the Queen mine, in the Juneau district.

TITANIUM

The titanium minerals include ilmenite and rutile.

Rutile is reported by Spencer to be present in gold quartz veins which contain albite in the Juneau district and to have been characteristic of the Treadwell ores. In the veins that have been opened at several points along Gastineau Channel it occurs in drusy cavities in the veins or penetrating the albite, quartz, or calcite. A quartz vein near the head of Farragut Bay carries disseminated perfect crystals of rutile as much as half an inch in diameter. It has not been found in commercial amount.

Ilmenite occurs for the most part associated with magnetite in the gabbroic and ultrabasic group of igneous intrusive rocks and in the andesitic and basaltic lavas. In a vein dike of magnetite at Snettisham it forms 8 per cent of the vein matter. It has also been noted in large plates associated with albite and calcite in gash veinlets in a basalt dike east of Point Coke, on Holkham Bay.

ARSENIC

The arsenic minerals include arsenopyrite, native arsenic, realgar, and orpiment. Spencer reports that in the Alaska-Treadwell mine a single specimen of native arsenic weighing several ounces was found with a coating of the secondary minerals realgar and orpiment. This is the only reported occurrences of these three minerals.

Arsenopyrite occurs in many places in sparse amounts in the gold quartz veins of the Juneau district and in some places is reported to carry much gold. It is the major sulphide in the high-grade gold quartz veins at the Apex-El Nido mine, on Chichagof Island. It also occurs as one of the major sulphides in a low-grade gold quartz fissure vein on Thomas Bay and in a silver-lead fissure vein on Whiting River. In the Silver Bay area, Sitka district, according to Knopf, arsenopyrite occurs in sparse amount in the low-grade gold quartz veins, associated with insignificant amounts of pyrite and pyrrhotite. Arsenopyrite is not reported by Wright from the contact copper deposits on the Kasaan Peninsula or the Copper Mountain area, on Prince of Wales Island. Arsenopyrite is associated with sphalerite and pyrrhotite in certain veins in the sedimentary and volcanic rocks that form the roof and borders of the Texas batholith, in the Hyder district.

BISMUTH

The only bismuth mineral so far reported in southeastern Alaska is tetradymite, a telluride of bismuth. This is said by F. E. and C. W. Wright to occur with the gold ores at the Hoadley claims, north of Ketchikan, and at the mines on Cleveland Peninsula. It is in insufficient quantity to have commercial value.

GYPSUM

The only deposit of gypsum known in southeastern Alaska is the bed at Iyoukeen Cove, on the east side of Chichagof Island,[48] which has been worked since 1906. Neither the hanging wall nor the footwall is exposed. The bed overlies Carboniferous beds and is regarded as of Permian or possible Triassic age. The gypsum, because of its relatively great solubility, occurs in a valley, and prospecting is therefore difficult. It is possible that there are other similar occurrences of gypsum. If the stratigraphic succession of the beds at Iyoukeen Cove could be worked out in detail, it might be possible to indicate favorable areas for prospecting elsewhere in southeastern Alaska.

GARNET

Garnet occurs almost exclusively in two associations—as massive aggregates in the contact-metamorphic deposits and as disseminated crystals in the rocks of the Wrangell-Revillagigedo belt. It is locally present in sparse amounts in the intrusive bodies near their contacts. Rarely it is a prominent mineral in high-temperature quartz fissure veins, as in a copper vein on Port Houghton. The garnet in the crystalline schist at the garnet mine north of Wrangell is the iron-aluminum variety, almandite. (See also p. 363.) It is probable that most of the garnet in the crystalline schist is this variety. The occurrence of a widespread belt of garnetiferous schist in Port Houghton is described on page 67.

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[48] Wright, C. W., The building stones and materials of southeastern Alaska: U. S. Geol. Survey Bull. 345, pp. 124–125, 1908.

Garnet is one of the predominant gangue minerals in the contact-metamorphic copper and magnetite deposits. In the Copper Mountain region it is the calcium-iron variety, andradite. Though it commonly occurs in massive form, it appears also in crystal aggregates embedded in the altered limestone and in veins crosscutting the limestone beds and penetrating the intrusive rock. Garnet for use as an abrasive has been produced intermittently at the mine north of Wrangell. Production of garnet in southeastern Alaska could be markedly increased if demand should arise. Information concerning garnet in general is given by Myers and Anderson.[49]

BARITE

Barite occurs locally in fissure veins, where it forms practically the whole vein; as replacement deposits in limestone beds; and locally as a common gangue mineral in the gold-silver-lead veins of the Hyder district.

Barite[50] in fissure veins in limestone, conglomerate, and volcanic rocks occurs on Kuiu Island along the north side of the Cornwallis Peninsula and the south side of Saginaw Bay and in the Ketchikan district at the northeast end of St. Ignace Island. These veins may be 200 feet in length and as much as 2 feet wide, but they have not been prospected because of their small size.

Barite[51] as a replacement deposit in limestone beds occurs on the Castle Islands on Duncan Canal, Kupreanof Island, and at Lime Point, the south end of the peninsula between Hetta and Nutkwa Inlets, Prince of Wales Island. The Castle Island prospect is reported to have about 60,000 tons exposed above tide level, averaging about 93 per cent of barium sulphate. At the Lime Point locality, according to Chapin, the country rock is semicrystalline blue-weathering white limestone interbedded with schist. An opening has been made along the deposit for 100 feet, exposing a roughly tabular, nearly vertical body of barite about 30 feet wide. It is a finely crystalline white rock containing practically no visible impurities. Some of the barite was shipped to San Francisco and tested with satisfactory results.

GRAPHITE

The slate of the sedimentary formations and the phyllite are prevalently black from their carbonaceous content. With increasing intensity of metamorphism and recrystallization toward the northeast

[49] Myers, W. M., and Anderson, C. O., Garnet—its mining, milling, and utilization: U. S. Bur. Mines Bull. 256, 1925.

[50] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 136–138, 1925.

[51] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, pp. 72–73, 1922. Burchard, E. F., A barite deposit near Wrangell: U. S. Geol. Survey Bull. 592, pp. 109–117, 1914.

as the border of the Coast Range batholith is approached the carbonaceous material is increasingly segregated and recrystallized. In the incipient stages of this process, in the phyllite, the carbonaceous material first appears as disseminated dust; at a more advanced stage, in the phyllite and crystalline schist, this dust has collected into microscopic spherules or into clotlike aggregates of spherules; and finally in the injection gneiss it is found as individualized crystalline flakes of graphite. The graphitic schist and gneiss containing crystalline flakes of graphite occur only in the belts of thoroughly recrystallized schist and injection gneiss such as occur within or adjacent to the mainland batholith. (See p. 363.)

Carbonaceous material is occasionally found in sparse amount in gold quartz veins, and as it occurs also in the black slate that forms the wall rock for many of the veins it finds its way in considerable amount into the ore, where it interferes both with amalgamation and with the separation of finely divided sulphides.

Graphite is disseminated in certain beds of the crystalline limestone. No prospecting for this mineral has been carried on in southeastern Alaska. There is, however, a very large potential source of supply if demand for it arises in the future.

MICA

The micas include the varieties sericite, biotite, muscovite, and phlogopite.

Sericite is one of the most common minerals resulting from the alteration of the wall rock by vein-forming solutions. It also occurs sparsely disseminated through the gold quartz veins. A pale-green variety called mariposite occurs in small amounts in some of the veins.

Biotite (black mica) is a constituent of almost all the igneous rocks, but muscovite (light-colored mica) is found only in the granite, and there only rarely. Biotite and muscovite were noted in pegmatite veins as crystals 2 inches or more in diameter. Biotite occurs in larger crystals in some pegmatite veins associated with hornblendite masses but has no commercial value at the present time. Muscovite, to be of commercial value under present conditions, should be in crystals of such size that it can be punched to yield disks at least 1½ inches in diameter.[52] A yield of 5 to 10 per cent of sheet mica from all the pegmatite mined is considered very good if the sheets average at least 3 inches square.

Phlogopite (brown mica) occurs as disseminated flakes and nests in certain beds of the crystalline limestones of the Wrangell-Revilla-

[52] Sterrett, D. B., Mica deposits of the United States: U. S. Geol. Survey Bull. 740, p. 26, 1923.

gigedo belt of metamorphic rocks. It is possible that pockets of phlogopite of commercial value occur near the contacts of the intrusive rocks with the crystalline limestones within the Coast Range batholith, though none have yet been found.

SILLIMANITE, CYANITE, AND ANDALUSITE

Sillimanite, cyanite, and andalusite are used as raw materials in the manufacture of certain refractory products. At the present time deposits of these minerals must be of high grade to warrant working. In southeastern Alaska sillimanite and cyanite have been found only in certain schists in the metamorphic complex, where they are common to abundant constituents. Andalusite is found only as disseminated crystals in slate at or near the contact with intrusive stocks. The largest sillimanite crystals seen by the writer are in crystalline schist at the south end of Deer Island.

QUARTZ

The principal nonmetalliferous mineral in the metalliferous veins is a white quartz of fairly coarse texture. Some of the veins exhibit a drusy structure; in these the quartz is partly bounded by crystal faces, and terminated crystals project into the vugs. In the veins of the Hyder district and the Apex-El Nido property, on Chichagof Island, the sulphides show a tendency toward banding in the quartz parallel to the walls.

In the crystalline schist adjacent to the injection gneiss of the Coast Range batholith seams of thin glassy quartz occur parallel to the foliation of the schist in such a way as to form a quartz injection gneiss analogous to an aplite injection gneiss. Farther away from the batholith the veins are, in general, local and larger and the quartz is more milky and white and may carry sulphides and be otherwise metallized.

Quartz in the form of chalcedony and agate is found mainly in the Tertiary lavas as amygdules or small gash veins.

CARBONATES

The carbonates include calcite, ferriferous calcite, ankerite, and dolomite. Calcite is the major mineral in all the limestones and forms 95 to 99 per cent of the thick massive Silurian limestone. It occurs in subordinate amounts in the metalliferous quartz veins and as an alteration product in the wall rocks of the contact-metamorphic deposits. It usually does not form the predominant gangue mineral in veins except where it occurs in small stringers. Knopf reports that the altered diorite wall rock in the Berners Bay region contains sparry masses of reddish-brown carbonate which is easily soluble in cold hydrochloric acid and is probably a ferriferous calcite. In the Heckla Blanket gold quartz vein, on the Admiralty-Alaska property, Admiralty Island, there are sparry masses of brown-weathering carbonate which are difficultly soluble in cold hydrochloric acid. The indices of refraction are those of ankerite, a ferriferous dolomite. Dolomite is reported by Knopf as an alteration product of the diorite adjoining quartz veins in the Berners Bay region. In the absence of chemical tests it is readily confused with calcite. Dolomite also forms the major constituent of certain beds of marble in the Wrangell-Revillagigedo belt of metamorphic rocks.

EPIDOTE

Epidote, a hydrous aluminum silicate of calcium and iron, is a mineral of bright yellowish-green color. It occurs largely as an alteration product of the igneous rocks and as a gangue mineral in the contact-metamorphic deposits. In the hydrothermally altered diorite and quartz diorite in the belts containing metalliferous veins it is present in a finely disseminated condition and in considerable measure causes the greenish hue that the dioritic rocks assume in the vicinity of ore bodies. It does not normally occur in the gold quartz veins. It forms under a wide range of conditions, for it has been found as a primary mineral of magmatic origin in a monzodiorite on the east side of Portage Bay, Kupreanof Island, and it is abundant as an alteration product and as deposits in amygdules by solutions and vapors of volcanic origin in the basic Tertiary lavas.

PYROXENE

Pyroxene is the predominant gangue mineral in some of the contact-metamorphic deposits and is common in all. It occurs also as local disseminated deposits, nests, and bands in the crystalline limestone of the Wrangell-Revillagigedo metamorphic belt. Diopside is reported to be the variety on Prince of Wales Island, and the iron-rich variety hedenbergite is the gangue of a copper contact deposit on Kupreanof Island.

Pyroxene also forms large masses of the intrusive rock pyroxenite. The pyroxene of the pyroxenite is in part almost pure diopside, usually where associated with dunite; in part diopside with a percentage of an aluminous molecule (diallage) or a hedenbergite molecule, usually where associated with hornblendite or gabbro; and in part bronzite, where associated with norite. The pyroxenite is noteworthy because of the local association of magnetite with the diallage varieties and of nickeliferous pyrrhotite with the bronzite varieties.

AMPHIBOLE

The hornblende variety of amphibole, a calcium-magnesium-iron silicate, is a prominent gangue mineral in some of the contact-metamorphic deposits. Hornblende occurs also as a prominent gangue mineral in a high-temperature copper quartz vein on Port Houghton. Hornblende forms large masses of the intrusive rock hornblendite, which locally carries magnetite deposits, as at Snettisham, or nickeliferous pyrrhotite deposits, as at Snipe Bay, Baranof Island.

The tremolite variety of amphibole, a calcium-magnesium silicate, occurs as a metamorphic mineral in some of the crystalline limestone of the Wrangell-Revillagigedo belt of metamorphic rocks. Veinlets of fibrous tremolite with fibers as much as 18 inches in length are found in soapstone about 2½ miles southwest of the head of Hobart Bay.

ALBITE

Albite occurs in small amounts in some of the gold quartz veins of the Juneau belt; at the Lon de Van claims, at the head of George Inlet, Revillagigedo Island; at the Birdseye claim, south of Ketchikan; and at other localities. At Glacier Basin, east of Wrangell, it forms veinlets cutting veins of sphalerite and galena. In the quartz veins mentioned it is associated with the carbonates calcite and dolomite, several metallic sulphides, and rutile. Albite forms veinlets in the dunite and hornblendite, where it may be associated with contemporaneous calcite. Albite occurs also as the result of alteration of the plagioclase in the diorite wall rock of veins in the Berners Bay region and as veinlets with quartz and calcite or dolomite in the altered diorite.

CHLORITE

Deep-green chlorite occurs in the wall rocks of the metalliferous veins as an alteration product of hornblende, biotite, or pyroxene and in part replacing the feldspars; in some of the copper-bearing magnetite deposits on Kasaan Peninsula, where it occupies small druses and occurs in finely disseminated form; as crystals in the magnetite deposits occurring in the pyroxenite and hornblendite; in the greenstones and altered basic lavas; and as amygdules of the Tertiary andesite and basalt.

APATITE

Apatite occurs as a minor accessory mineral in practically all the igneous rocks. It may form as much as 1 per cent in the dioritic and more alkalic or siliceous rocks, but it is locally concentrated to form several per cent in the hornblendite and hornblende-rich gabbro. It occurs as an accessory gangue mineral in the disseminated magnetite deposits at Haines. It is abundant in the wall rocks of the magnetite vein at Snettisham and may occur in the vein itself in minor amount.

TOURMALINE

Spencer reports the presence of tourmaline in some of the quartz veins of Gold Creek, in the Juneau district, where it occurs in minute needles. He suggests that its presence may indicate the possibility that the mineralization of the region was one of the effects of the great dioritic intrusions. Tourmaline and apatite occur also as minor accessory minerals in the crystalline schists, where they are thought to have been introduced by vapors and solutions given off by the Upper Jurassic or Lower Cretaceous intrusive magma. Very rarely tourmaline is found in the pegmatite veins.

LITHOLOGIC AND STRATIGRAPHIC ASSOCIATION OF ORE DEPOSITS

Mineral deposits are shown on Plate 1 by appropriate symbols. From this map it may be seen that metallization is very widespread and is not confined to certain rock formations or to any group of formations. Mineral deposits of value occur in schist, limestone, greenstone, tuff, quartzite, black slate, granodiorite, quartz diorite, diorite, hornblendite, pyroxenite, norite, peridotite, conglomerate, graywacke, and quartz porphyry. The general distribution of these deposits, however, bears a definite relation to the rock structure and to the igneous masses, and certain formations appear to be favorable to certain types of mineralization. The following descriptions are intended to show this relation as well as the stratigraphic distribution of the mineral deposits.

WALES GROUP

By Theodore Chapin

The oldest rocks of the region are the schist, limestone, and greenstone of Prince of Wales, Dall, and Long Islands. The schist is composed of highly altered sediments with possibly some igneous rocks, all more or less recrystallized into mica and quartz schists. The schist is seamed with many quartz veins which in places are gold bearing and some of which have produced. The schist appears to be a promising formation for future prospecting for gold lodes.

The limestone beds are largely recrystallized into white marble and in the vicinity of the intrusive bodies into metamorphic contact rock consisting principally of garnet, epidote, and calcite. It is in the metamorphic bodies that the contact ore bodies of copper occur. In the search for these deposits the prospector should be guided first by the bodies of intrusive granitic rock and more specifically by the presence of the contact-metamorphic minerals which are indicative of metallization. The limestone also incloses some of the best bodies of commercial marble of both white and ornamental varieties. The overlying greenstone schist contains both gold-bearing fissure veins and shear-zone deposits of copper.

WRANGELL-REVILLAGIGEDO BELT OF METAMORPHIC ROCKS

The Wrangell-Revillagigedo belt of metamorphic rocks includes phyllite, various types of crystalline schist, schistose greenstone, limestone, marble, and injection gneiss. These rocks border the Coast Range batholith or are included as bands within the batholith. Within this group metallization is scattered and only locally concentrated in belts, and prospects are not as common as in some other formations. It is probable, however, that other metalliferous deposits will be found within the Wrangell-Revillagigedo belt of metamorphic rocks included within the batholith as they are further prospected.

In the more thoroughly crystalline schist and the injection gneiss sulphide deposits carrying chalcopyrite and sphalerite or both together have been formed by replacement or impregnation. Locally galena may be associated with them. Quartz fissure veins carrying chalcopyrite, gold, and argentiferous galena are also found.

In the phyllite and less intensively metamorphosed schist gold quartz fissure veins predominate.

Nonmetallic minerals or deposits of present or potential economic importance within the Wrangell-Revillagigedo metamorphic belt include garnet, graphite, marble, and perhaps phlogopite mica. The marble is described on page 394, graphite on page 363, and garnet on pages 67 and 363.

Phlogopite mica occurs locally as disseminated deposits and as nodular aggregates or nests in the crystalline limestone and dolomite of the bands inclosed within the batholith, but pockets of phlogopite with crystals of sufficient size to be of commercial value have not been found. It is not improbable, however, that such pockets may occur along or near the contacts with the batholithic intrusive rock or with dikes.

Soapstone, associated with actinolite schist, crops out on the shores of the cove about 2½ miles southwest of the head of Hobart Bay, just inside of the first conspicuous point on the west side of the bay going north. The soapstone and associated actinolite schist are bordered on one side by phyllite and on the other by granitic intrusive rocks. The soapstone forms the central part of the green actinolite schist, and about 50 feet of soft uniform rock is exposed. The soapstone consists of intergrown talc, chlorite, and siderite, with a little accessory magnetite. The siderite weathers with a rusty color. Veinlets of coarsely crystalline talc and chlorite several inches wide cross the soapstone, and veinlets of carbonate are common. Veinlets of fibrous tremolite (slip fiber) with fibers as much as 18 inches in length occur along slippage faces. The soapstone has a distinct schistose structure but breaks out in large massive blocks. The actinolite rocks are cut by a dike of diorite, which is in turn cut by an aplite dike. Much of the actinolite schist shows conspicuous black hornblende crystals scattered through the rock. The evidence seen was insufficient to determine whether the soapstone and actinolite schist represent a metamorphosed bed of impure limestone intercalated in the phyllite or a metamorphosed igneous rock.

ORDOVICIAN AND SILURIAN GRAYWACKE AND SLATE

The indurated graywacke with dark to black slate partings, the thin-bedded zones of black slate with graywacke or limy beds, and the thin-layered black chert of the Ordovician and Silurian systems are, so far as now known, almost barren of metallization. There is a copper prospect in a brecciated zone in graywacke near Lake Bay, on Prince of Wales Island, and locally there are quartz veins which may be metallized but have not been prospected; but taken as a whole these formations appear to afford relatively poor ground for prospecting. This is certainly due in considerable part to the relative sparsity of intrusive masses in them.

SILURIAN GREENSTONE AND LIMESTONE

The Silurian rocks, exclusive of the graywacke-slate formation in the lower part, consist of greenstone and conglomerate, a thick limestone member that is massive to thick bedded, and graywackelike sandstone and shale. These rocks are locally cut by Mesozoic intrusions, and in places the limestone and greenstone are considerably altered and mineralized.

The marble quarries operated by the Vermont Marble Co. at Tokeen, on Marble Island, off the west coast of Prince of Wales Island, are in contact-metamorphosed Silurian limestone. The great belt of metamorphosed medium to coarsely crystalline limestone, with some marble on Glacier Bay, likewise belongs to the Silurian. The quarries of the Pacific Coast Cement Co. on Dall Island are in the Silurian limestone. Indeed, the Silurian limestone is a great potential source of high-grade limestone in southeastern Alaska.

On Lemesurier Island, in Icy Strait, there is a molybdenite prospect of contact-metamorphic type at the contact of limestone with diorite, and in Glacier Bay there are copper and molybdenite prospects.

MIDDLE DEVONIAN ROCKS

By Theodore Chapin

The Middle Devonian rocks contain altered volcanic flows and tuffs, limestone, black slate, graywacke, and conglomerate, all of which carry mineral deposits of value. The altered volcanic flows and breccias, which comprise the lowest members of this series, contain shear-zone deposits and appear to be a favorable locality to prospect for this type of ore deposit.

The overlying members of the Middle Devonian appear to be the most highly mineralized rocks of the Ketchikan region and contain deposits of various types. The contact and shear-zone deposits of Kasaan Peninsula, Karta Bay, and many other localities occur within this formation. The black slates and associated tuffaceous sediments are favorable for the deposition of gold-bearing quartz fissure veins. In the vicinity of Hollis on Twelvemile Arm veins of this type are prevalent. The sediments are cut by a large boss of quartz diorite and by associated porphyry dikes and veined by many quartz fissure veins which in places have bordered or cut the porphyry dikes mineralizing and replacing them. This area has yielded considerable ore from several small mines and offers possibilities for future output. The black slates all show more or less sulphide mineralization and should be prospected for possible gold-bearing lodes.

Both the thin-bedded and massive limestone members of this formation contain deposits of marble, some of which have been quarried.

In the Wrangell district the belt of Middle Devonian rocks that extends across Woewodski Island and along Duncan Canal, on Kupreanof Island, northwest to Frederick Sound contains gold and copper deposits, also limestone in beds of sufficient size to afford a supply of this material if desired.

UPPER DEVONIAN ROCKS

By Theodore Chapin

The Upper Devonian rocks consist of basalt, conglomerate, fossiliferous limestone, and probably also chert, green grit, and tuff. These rocks are not widely distributed and are not known to be mineralized.

MISSISSIPPIAN ROCKS

By Theodore Chapin

The Mississippian rocks are composed essentially of black chert and interbedded blue, gray, and brown limestone. These rocks are not known to be metallized but contain bodies of very handsome brown semicrystalline limestone that is composed of large flashing crystals of calcite and contains a great number of fossils. The rock takes a brilliant polish and makes a beautiful ornamental stone.

PERMIAN ROCKS

By THEODORE CHAPIN

The Permian rocks are not known to be metallized, but this may be due to their small area of occurrence and lack of known intrusious rather than to their physical or chemical character. The limestone of the upper division of the Permian contains some thick beds fairly free from chert and affords a potential source of supply. The gypsum beds of Iyoukeen Cove, Chichagof Island, appear to be associated with Carboniferous formations.

TRIASSIC ROCKS

By THEODORE CHAPIN

The rocks of Triassic age comprise limestone, conglomerate, slate, and sandstone and their metamorphosed equivalents. On Gravina Island the Triassic rocks inclose deposits of both gold and copper. The Triassic limestones are soft gray rocks and do not contain any marble deposits.

JURASSIC (?) GREENSTONE AND SLATE

The greenstones of Jurassic (?) age are mineralized at a number of places in the Ketchikan district and carry both gold and copper in fissure veins and shear-zone deposits. A mineralized belt occurs along the west side of Helm Bay, on the Cleveland Peninsula, in rocks of this age. Another mineralized zone extends along the shore of Tongass Narrows, northwest of Ketchikan, for about 2 miles; in this zone some locations have been made and a little prospecting done. The ore deposits are mineralized zones in the greenstone and black slate along the contact of quartz diorite and fissure veins of quartz in the intrusive rock. The veins contain free gold associated with pyrite, chalcopyrite, and arsenopyrite. The ore bodies are very rich in pockets but are not persistent; very little development work has been done upon them.

In the Wrangell district practically no prospects have been located in this formation.

The greenstones are well exposed on Douglas Island, in the Juneau district, and with respect to them Spencer[53] writes:

Fractures filled with quartz and other vein minerals are present in many places on Douglas Island, but up to the present no strong or regular veins have been developed. From the manner in which veins occur in the corre-

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[53] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 90, 1906.

sponding rocks on the mainland to the northwest it is believed that the most promising situations for the occurrence of strong veining are along the contacts of the greenstone masses with the slate. * * * All of the veins observed in the greenstones which form the mountain seem to be irregular and discontinuous gashes, and even these, though widely distributed, are by no means numerous. * * * In many places on Douglas Island considerable masses of greenstone contain large amounts of pyrite in disseminated crystalline grains. * * * Some of these bodies of impregnated rock have been prospected in the past, and they are thus known to contain a small amount of gold, though none of them have ever been successfully mined.

No prospects worthy of note have been found in the greenstones of the Fanshaw and Glass Peninsulas.

In the Hyder district greenstones form much of the country rock between Salmon River and the international boundary. Small shoots of sulphide consisting of galena, sphalerite, pyrrhotite, and pyrite or of pyrrhotite and chalcopyrite are found as replacement lodes and impregnation deposits parallel to the schistose structure of the greenstones. Locally the sphalerite in this rock carries a very high tenor in gold. A little arsenopyrite is commonly associated with the sulphides, and quartz and calcite are abundant gangue minerals. Quartz fissure veins with shoots of sulphide in which galena predominates also occur.

JURASSIC (?) GRAYWACKE AND SLATE

Stringer lodes of quartz are present in much of the graywacke and slate of Jurassic (?) age and are locally very abundant. They are generally low-grade gold veins and have been exploited mainly in the Eagle River portion of the Juneau belt.[54] Rich gold shoots are very sporadic in the veins; generally the ore is of low grade.

On the west coast of Chichagof Island, however, according to Overbeck,[55]

Graywacke is economically the most important rock of the region at the present time, because all the gold prospects so far located are in graywacke, although there is no apparent reason why mineralization should not have taken place in the schistose series as well. One possible reason for the seeming localization of the mineralization in the graywacke is that the physical properties of the massive graywacke under great forces may have caused it to break with big, clean fractures that were of great extent and that furnished excellent pathways for the ore-bearing solutions.

The famous Chichagoff mine is on a metallized quartz vein occupying a shear zone which has been followed for more than 4,500 feet in argillitic graywacke. The Hirst-Chichagof mine is operating on

[54] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 1912.

[55] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, p. 113, 1919.

quartz fissure veins that occupy shear zones in black carbonaceous slate near the contact with a sheet of greenstone. The veins near Sitka are likewise in the graywacke-slate series of the Jurassic (?) rocks.

A very rough estimate was made of the amount of quartz in the Jurassic (?) slate at a locality on the north end of Kupreanof Island. The quartz occurs in stringer leads in shear zones within the slate. The shear zones are from several feet to several hundred feet apart and average about 25 feet apart. The quartz forms from one-fifth to one-third of the shear zone, and quartz veins form about 0.75 to 1 per cent of the total belt of rock. The beaches are in places composed wholly of quartz pebbles. The quartz is milky white and carries accessory calcite, but sulphides are rare, and the veins presumably are not sufficiently metallized to be of commercial value.

In the Hyder district, along the West Fork of Texas Creek, quartz fissure veins are found in the graywacke and slate carrying shoots of sulphide in which galena predominates. There are also base-metal veins parallel to the structure of the slate and graywacke. Sphalerite is a major mineral in many of these veins and may be associated with a little arsenopyrite.

UPPER JURASSIC OR LOWER CRETACEOUS INTRUSIVE ROCKS

A number of valuable mineral deposits are known within the intrusive rocks of Upper Jurassic or Lower Cretaceous age where these rocks occur as outlying dikes, stocks, and batholiths east and west of the main Coast Range batholith. Practically no metalliferous deposits have been located within the igneous part of the main core of the mainland batholith. It seems probable, however, that metallized veins will eventually be found within the quartz diorite or granodiorite in the vicinity of included belts of country rock, particularly where the included rock has not been intensively metamorphosed.

In the dioritic types, such as quartz diorite, granodiorite, diorite, gabbro-diorite, and aplite, veins carrying gold, gold-silver, silver-lead, and molybdenite have been found. In the gabbroic and ultrabasic group—including gabbro, pyroxenite, dunite, hornblendite, and norite—copper-palladium, nickel-copper, and titaniferous iron deposits occur.

The metalliferous deposits within the dioritic and granodioritic igneous rocks occur predominantly as fissure veins in well-defined fractures and in zones of intense shearing, also to a minor extent as stockworks. In the aplite dikes metallization has produced fissure veins, impregnations, or a combination of veinlets and impregnations. A significant point to be borne in mind in prospecting is that the parts of the igneous mass in which metalliferous veins occur are altered—the feldspars are decomposed and dull and waxy in color, the ferromagnesian minerals are partly chloritized or altered to carbonates or other secondary minerals and are soft, and the rock has lost its fresh appearance. Narrow dark-colored schistose zones that include powdered or slickensided rock of greenish hue are common, and veinlets of yellowish-green epidote or white zoisite occur.

These relations have been observed near the gold-silver-lead veins in quartz diorite and granodiorite of the Hyder district, near the gold veins in the Jualin diorite of the Berners Bay district, and near the gold veins in the Lisianski stock of diorite on Chichagof Island.

Rarely quartz veins or siliceous variants are developed locally in bodies of pegmatite and carry deposits of molybdenite, as at Shakan, on Prince of Wales Island, or copper in the form of bornite or chalcopyrite, as at the Drum Lummon mine, in British Columbia.

GOLD

In the Berners Bay region, according to Knopf,[56] the largest number of gold-bearing ore bodies lie within a stock of gabbro-diorite, the Jualin diorite, which is intrusive into graywacke, slate, and metamorphosed basalt just west of the western border of the Coast Range batholith. Knopf describes 10 properties that have been located in this mass. The fissure veins are marked by a tendency to swell and pinch gradually along the strike and dip. In the Jualin diorite of the Berners Bay region the average vein has a mean thickness of 5 feet, and the maximum width of solid quartz known at any point is 15 feet. The gangue is usually almost wholly quartz with a little associated calcite and sparse sericite. The metallic minerals of the veins comprise pyrite, which is most abundant, chalcopyrite, the next commonest metallic sulphide, a little galena, and at two properties sphalerite. Gold is rarely visible in the low-grade ores but is reported to have been found intergrown with quartz in pockets in the Comet mine. The presence of chalcopyrite seems favorable to a good tenor in gold. The ores are in general of low grade.

The stockworks in the Jualin diorite are described by Knopf as consisting of masses of broken country rock intricately penetrated and gashed by quartz stringers that commonly average a few inches in thickness. At the Kensington mine the ore body approximates an ellipse, 160 feet long and 80 feet wide, and is known from development work to have a depth of at least 800 feet. The whole mass of country rock and included network of quartz veins constitutes the

[56] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 1911.

ore body. The Eureka stockwork is said to average $7 a ton over a width of 18 feet, and the Kensington from $3 to $5 over a width of 80 feet. The strike of individual veins is reported to be fairly regular, but no system in the strike of the veins as a whole can be observed. The greater number, however, strike between north and northwest, with east or northeast dips ranging from 40° to 70°.

The Lisianski stock of diorite[57] occurs in the western part of Chichagof Island. Several gold quartz properties have been located within this mass of intrusive rock, but the best-known and only producing mine is the Apex-El Nido, on Lisianski Inlet. The metalliferous veins here are for the most part in dikes of altered aplite (or soda trachyte) in the diorite. Veins occur also in albite-quartz diorite variants of the stock at the Pinta Bay prospects and on Lisianski Strait, northwest of Miner Island, and in the diorite at other places. On the Apex-El Nido property the metallized fissure veins average from 1½ to 2½ feet in width, and the Apex vein has been traced for 2,000 feet in length and has been exposed through a vertical range of more than 600 feet. These veins range from milky-white quartz with free gold and only a trace of sulphides to quartz with local pockets of arsenopyrite as much as 2 feet in width. In general the sulphide metallization is small. Arsenopyrite predominates, and pyrite, galena, chalcopyrite, gold, and scheelite are the metallic minerals. The gangue is uniformly a milky-white granular quartz, with here and there a little sericite and calcite, and with numerous vugs lined with quartz crystals. Usually the gold is not visible to the eye, but the rich shoots yield gold when the quartz is crushed and panned. The most gold is found where the quartz veins have been crushed and slickensided, and gold and sulphides have been introduced along cracks in the original vein. Some of the gold and sulphides are, however, of contemporaneous crystallization with the quartz. The Apex and El Nido veins show a sheeted or ribbon structure parallel to the walls. Ore shoots are reported to have given average assay values for lengths of a hundred feet of $33 to $57 a ton in gold. A small stockwork on the El Nido property consists of brecciated altered diorite with many stringers of quartz. The stockwork is pear-shaped with diameters of 20 and 30 feet. The veins range in width from a fraction of an inch to 4 feet, and carry a considerable percentage of coarse pyrite and black sphalerite. It is reported that a 13-foot sample across the stockwork, consisting of about 30 per cent of diorite and 70 per cent of quartz stringers, averaged $6.82 in gold and 0.44 ounce in silver to the ton. Of eight veins examined in the diorite stock all strike between N. 15° E. and

[57] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 114–124, 1925.

N. 60° E.; the average is about northeast. The dip is from 50° to 80°, about equally divided between east and west.

The gold ores of the famous Treadwell mines, on Douglas Island, consisted of dikes of albite diorite, which had been fractured, the openings filled with metallized quartz, and the rock impregnated with auriferous pyrite; the dike as a whole was mined.

On Granite Mountain, on the west side of Twelvemile Arm, Prince of Wales Island, there is a small intrusive mass of quartz diorite which carries quartz veins metallized with free gold, pyrite, chalcopyrite, and galena; and near by, in the vicinity of Hollis, the associated porphyritic dikes are veined and replaced by auriferous quartz veins.

Another gold mine in granitic rock is the Surf Inlet mine, on Princess Royal Island, in British Columbia.[58] The ore bodies are large pyritized quartz veins, in places 37 feet in width, in a zone of intense shearing in the rocks (mainly quartz diorite) of the western part of the Coast Range batholith. In 1920, 108,082 tons of ore was mined, yielding 9,687 tons of concentrates, which gave 44,051 ounces of gold, 20,104 ounces of silver, and 685,259 pounds of copper.

GOLD-SILVER-LEAD

In the Hyder district, on or near the eastern border of the Coast Range batholith, there is an older batholith of granodiorite, the Texas batholith, in which many metallized quartz fissure veins are found.[59] The sulphides are predominantly galena and pyrite, with variable amounts of sphalerite and tetrahedrite and other sulphides. Galena is the major sulphide. Where tetrahedrite is present the ores are usually richer in silver. The commercial ore usually forms shoots in the quartz veins. The gold occurs both as visible flakes and in invisible form. The gold and silver contents of the ores are variable, but the gold content is on the whole unusually high for mineralization of this type. Concentrates from the Riverside mine in 1926 are reported by R. G. Mellin to have contained 1.4 ounces in gold and 32 ounces in silver to the ton and 60 per cent lead.

MOLYBDENUM

The only mineral carrying molybdenum found in southeastern Alaska is molybdenite, which occurs in veins within diorite and more siliceous granitoid types, both in outlying stocks and on the borders

[58] Dolmage, Victor, Coast and islands of British Columbia between Burke and Douglas Channels: Canada Geol. Survey Summary Rept. for 1921, pt. A, p. 29, 1922.

[59] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 73–95, 1925; Geology and mineral deposits of the Salmon River area: Eng. and Min. Jour.-Press, vol. 123, pp. 525–530, 1927.

of the main batholith. The best known prospect is near Shakan, on Prince of Wales Island. It has been described by Mertie.[60] The vein is in hornblende diorite near the contact of an intrusive stock with the country rock and is genetically allied to a pegmatite vein. The gangue is partly pegmatite and partly quartz, with a little calcite, epidote, and chlorite. The metallic minerals comprise molybdenite, pyrrhotite, pyrite, and chalcopyrite.

Molybdenite is reported to occur also in a quartz veinlet in the quartz diorite of the eastern border of the batholith at the Texas Creek-Comstock property, on Texas Creek in the Hyder district, and in the Coast Range batholith near Skagway.

NICKEL-COPPER[61]

Mineral deposits carrying nickel and copper have been found at several localities on Yakobi Island; on Fleming Island and the west coast of Chichagof Island about 25 miles northwest of Chichagof; on Snipe Bay, Baranof Island; on Tenakee Inlet, Chichagof Island; and on Funter Bay, Admiralty Island. In all these localities the metalliferous deposits occur exclusively within ultrabasic rocks or their gabbroic variants. The nickel-copper lodes at Bohemia Basin, Yakobi Island, occur in norite or bronzitite segregations of the norite; those at the Alaska Nickel mines in hornblende gabbro and norite; at Snipe Bay in an amphibolite dike with a high percentage of ilmenitic magnetite; at Tenakee Inlet in a schistose basic dike; and at Funter Bay in a troctolite or olivine diabase dike.

The lodes usually consist mainly of pyrrhotite, with a little pentlandite (Fe,NiS) and chalcopyrite, and with varying amounts of the minerals of the country rock, particularly pyroxene, hornblende, and labradorite, as gangue. Magnetite occurs as residual remnants in the sulphides at Snipe Bay and as a minor accessory of early crystallization in the sulphides at Funter Bay. In the surface outcrops the pentlandite is as a rule partly or completely altered to a secondary mineral, possibly bravoite[62] (Fe,NiS_2), which often weathers with a copper-red hue resembling niccolite. Marcasite partly or completely replaces the pyrrhotite in some of the surface outcrops. The rock with disseminated sulphides is conspicuous at the surface because of the iron stain on its weathered outcrop.

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[60] Mertie, J. B., jr., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, pp. 118–119, 1921.

[61] Overbeck, R. M., Geology of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 125–133, 1917. Kerr, P. F., A magmatic sulphide ore from Chichagof Island, Alaska: Econ. Geology, 1924, pp. 369–376. Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 98–113, 1925; U. S. Geol. Survey Bull. 783, p. 46, 1926.

[62] Buddington, A. F., Alaskan nickel minerals: Econ. Geology, vol. 19, pp. 521–541, 1924.

The metalliferous minerals occur as almost solid sulphide lenses or bodies and also as disseminated blebs throughout a considerable portion of the rock. The relatively pure solid sulphide may carry 4 per cent or more of nickel and as much as 3 per cent of copper. The disseminated ore has from 1 to 2½ per cent of nickel with 1 per cent or more of copper. Lodes of the disseminated type of ore occur in considerable volume. It is reported that on the 75-foot level at the Alaska Nickel mines there has been exposed and sampled 37 feet of ore with an average width of 5 feet. The whole body has not been exposed. The nickel content is reported to range from 1.85 to 5.05 per cent, and copper from 0.4 to 4 per cent, with an average of 3.42 per cent of nickel and 1.58 per cent of copper.

The distribution of the sulphides throughout the mass of igneous rock in which they occur is not uniform but heterogeneous and local. The sulphides are interpreted as having been originally more or less homogeneously in solution in the molten magma. As the magma cooled the sulphides separated as immiscible drops and were concentrated locally to varying degrees. The disseminated type of ore represents a relatively slight concentration of the sulphide where the sulphides remain molten longer than the silicates and crystallized at a late stage interstitial to the silicates. The more concentrated or solid sulphide masses represent a more complete concentration or segregation of the sulphides where they remained molten longer than the silicates and through subsequent movements came to bear a veinlike intrusive relation to the country rock.

Such variation in relations need not, therefore, be interpreted as indicating more than the complex phenomena which may result during the solidification of a single magma essentially in place. In the Tenakee prospect, however, the sulphides, as they now occur, are definitely later than the dike that contains them; they occur in part as seams in a sheared zone within the dike and in minor part in metallized quartz or quartz-calcite stringers in the shear zone. Pyrrhotite, pentlandite, and chalcopyrite occur in the quartz-calcite fissure veinlets.

Analyses for nickel have been made on a number of samples of pyrrhotite from contact-metamorphic and fissure-vein deposits associated with diorite or more alkalic-siliceous rocks in southeastern Alaska, but they show only 0.1 to 0.2 per cent of nickel and a trace of cobalt. In the light of the present data it seems improbable that nickel deposits will be found associated with diorite or more siliceous variants, such as quartz diorite, granodiorite, quartz monzonite, or granite. On the other hand, it is highly desirable that all pyrrhotite or copper-bearing pyrrhotite sulphide masses found in association with gabbroic or ultrabasic masses or dikes (hornblendite, dunite, pyroxenite, etc.) should be investigated as to their possible nickel content. The nickeliferous sulphide masses so far found are all within the basic intrusive rock itself; but in the Sudbury region of Ontario the sulphide ore masses are found also in the adjoining country rock. It seems highly probable that there are on Chichagof and Baranof Islands and, perhaps, on other islands of the Alexander Archipelago many dikes and masses of gabbro, norite, and ultrabasic rocks which have not yet been discovered and with which nickel ores may be associated. Nickeliferous pyrrhotite has recently been reported from a basic pyroxenite dike on the east side of the Coast Range batholith in the Yale mining division, B. C.[63]

The nickel-bearing intrusive masses so far discovered are closely allied in size and mode of occurrence with basic bodies carrying nickeliferous sulphide, such as those at the Friday claim, Julian, Calif., the old Gap mine, Lancaster County, Pa., and many masses in Norway and Sweden. Vogt[64] has made a careful study of the Norwegian deposits and has arrived at the conclusions that the variety of gabbro which favors the nickel-pyrrhotite deposits is one that carries hypersthene, that the deposits which are associated with small bodies of norite and peridotite are themselves of very small dimensions, and that the large deposits always accompany large intrusive masses, especially of norite; but that it must not be inferred that all large norite masses are necessarily accompanied by large deposits of nickel pyrrhotite or that the deposits which accompany large norite bodies are themselves necessarily large. Vogt cites the norite mass at Erteli, Norway, which has an area of about 240,000 square yards and from the ore bodies of which has been produced about 110,000 tons of nickel ore containing 1,250 tons of nickel and 600 tons of copper.

The Gap mine, in Lancaster County, Pa., was actively operated from 1863 to 1885 and was for a time the chief nickel producer of its day, but after the development of the nickel deposits in New Caledonia and at Sudbury, Ontario, it was closed. Its total production was 4,000,000 to 4,500,000 pounds of nickel.[65] The ore as mined ran about 1 to 3 per cent of nickel and one-third to one-fourth as much copper. The deposit is described by Kemp[66] as pyrrhotite carrying pentlandite and chalcopyrite and occurring on the borders of a lens of amphibolite or hornblendic rock which yields evidence that it is an altered gabbro or norite or peridotite. This lenticular mass or stock is about 1,500 feet long and 500 feet in maximum width and is an intrusion in mica schist.

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[63] Cairnes, C. E., An occurrence of nickel ore in Yale mining division, B. C.: Canadian Min. Jour., vol. 45, p. 1164, 1924.

[64] Vogt, J. H. L., On the content of nickel in igneous rocks: Econ. Geology, vol. 18, p. 334, 1923.

[65] U. S. Geol. Survey Mineral Resources, 1882–1886.

[66] Kemp, J. F., The nickel mine at Lancaster Gap and the pyrrhotite deposits at Anthony's Nose, on the Hudson: Am. Inst. Min. Eng. Trans., vol. 24, pp. 620–633, 888, 1895.

Vogt[67] states that:

For the larger noritic nickel deposits in Norway and Sweden it appears that the highest percentage of nickel is found in the norite richest in hypersthene, the lowest percentage of nickel in the norite relatively poor in hypersthene, and intermediate percentages of nickel in the rocks having an intermediate content of hypersthene. In other words, the percentage of nickel in the sulphides is dependent essentially on the content of hypersthene (or hypersthene plus diallage, primary amphibole, and biotite) in the rock.

The nickel content of the sulphide ores was also found to increase with the percentage of magnesium oxide in the rock. The norites adjacent to the ore at the Bohemia and Tasmania claims, on Yakobi Island, are hypersthene segregations in which the hypersthene (bronzite) is rich in magnesia (80 to 86 per cent $MgSiO_3$). Indications are therefore favorable for a high percentage of nickel in the sulphides, if Vogt's conclusions are of general application. At the Snipe Bay locality the rock appears to be made up largely of hornblende, which according to Vogt is likewise a favorable indication of nickel in the sulphides.

Wagner[68] has shown that many nickeliferous sulphide deposits accompany igneous masses that show pronounced magmatic differentiation. This is confirmed by the wide variation shown in the intrusive masses in the Chichagof belt.

COPPER AND COPPER-PALLADIUM

The association of copper with nickel in certain of the gabbroic and ultrabasic group of igneous rocks has been described. At the Salt Chuck mine, near the north end of Kasaan Peninsula, Prince of Wales Island, there is a deposit unique because of its metallization with copper and palladium. The property has been described by Mertie.[69] The ore occurs in a pyroxenite with gabbroic variants. The ore minerals consist of copper sulphides distributed in grains, small patches, and veinlets as ore shoots in the pyroxenite. Bornite is the chief copper mineral, but a small proportion of chalcopyrite also occurs locally. Practically no gangue minerals are found with the ore. In addition to the copper, gold, silver, platinum, and palladium are recovered. The ore deposit is believed to have formed later than the containing country rock and is of epigenetic rather than direct magmatic origin, as some of its features seem to indicate.

IRON

The locations of many small masses of black hornblendite and some of green pyroxenite have been described elsewhere. Near Union

[67] Vogt, J. H. L., op. cit., p. 348.

[68] Wagner, P. A., Magmatic nickel deposits of the Bushveld complex, Rustenburg district, Transvaal: South Africa Geol. Survey Mem. 21, p. 148, 1924.

[69] Mertie, J. B., jr., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, pp. 121–127, 1921.

Bay, on the Cleveland Peninsula, in the Ketchikan district; Snettisham, in the Juneau district; and Haines, in the Skagway district, ilmenitic magnetite is associated with the ultrabasic rocks pyroxenite and hornblendite.[70] The magnetite with a little associated ilmenite occurs both as disseminations in the rock and as vein dikes and veinlets. In the disseminated type the magnetite and ilmenite occur as irregular-shaped blebs interstitial to the silicates. The iron oxides may form as much as 30 per cent of the rock, equivalent to about 20 per cent of metallic iron. The disseminated type of metalliferous deposit occurs at all three localities in considerable volume. At Snettisham there is a 6-foot vein dike of practically solid ilmenitic magnetite. The ilmenite occurs in part as grains 0.2 to 1 millimeter in diameter, associated with the magnetite, and in part as lamellae of microscopic size parallel to the parting planes of the magnetite. At Snettisham the ilmenite in a typical specimen constituted about 8 per cent of the ore. The ore at Snettisham is reported to have carried 4 or 5 per cent of titanium dioxide, and a magnetic concentrate from the deposit at Haines is reported to contain 3.91 per cent of titanium dioxide. Apatite is associated with the disseminated deposits.

These ultrabasic rocks with contained magnetite produce marked centers or zones of local magnetic attraction, which are noted in the Coast Pilot.[71]

Local attraction of the compass is very evident on the east side of Union Bay, where there is a belt three-eighths of a mile offshore in which the variation is 32°–39° E. On the small islet off the northeast point of the bay, to the south of Union Point, a variation of 68° E. was observed in 1922.

On the east side of Port Snettisham a local attraction of considerable strength has been observed. The disturbance is felt over an area of 20 square miles of land and water and is strong over 8 square miles.

In Chilkoot Inlet local magnetic disturbances have been observed from Seduction Point to Indian Rock. The disturbance is 20° W. at Battery Point, 12° W. at Seduction Island, and 7° W. at Chilkat Inlet, south of Jenkins Rock.

As possible indications of other magnetite-bearing bodies the following additional areas of local magnetic attraction are noted: A magnetic disturbance has been observed in the vicinity of East Island, the small island which lies 2½ miles south-southeast from the easternmost point of Duke Island, Dixon Entrance. It may be noted

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[70] Knopf, Adolph, The occurrence of iron ore near Haines: U. S. Geol. Survey Bull. 442, pp. 144–146, 1910. Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 133–134, 1925.

[71] U. S. Coast Pilot, Alaska, pt. 1, Dixon Entrance to Yakutat Bay, 7th ed., 1925.

that bodies of pyroxenite occur in this group of islands. Local attraction has been observed at Shakan Strait and in Peril Strait between Otstoia and Povorolni Island.

CHROMIUM

A little chromium in the mineral chromite occurs in the serpentine rocks of Duke and Percy Islands and of the Cleveland Peninsula, but it has not been found in commercial amounts.

LOWER CRETACEOUS (?) ROCKS

The slate, graywacke, and conglomerate mapped as Lower Cretaceous (?) nowhere carry veins that have been exploited. Stringer leads of quartz are locally very abundant in the slate, as in the vicinity of Rocky Bay, on Etolin Island, and Point Pybus, on Admiralty Island. They have presumably been tested and found to be of very low grade, though there appears to be very little information concerning them. They carry very lean to no metallization with sulphides. By some geologists these beds are considered younger than the Mesozoic intrusive rocks and therefore younger than the period of metallization. This conclusion has not been proved, however, and to the writer it seems doubtful.

TERTIARY ROCKS

The Tertiary formations consist of sandstone, conglomerate, and shale, with rhyolitic, andesitic, and basaltic volcanic rocks. They were formed after the intrusion of the Coast Range batholith and therefore do not contain any metalliferous deposits associated with the magmas of the Upper Jurassic or Lower Cretaceous intrusive rocks. Indeed, no metal deposits of economic value have been found in the Tertiary formations. A little sphalerite of no commercial importance has been found in a Tertiary dike on the Keku Islets.[72] Veins of chalcedony and fluorite are found in the Tertiary volcanic rocks on the west side of Zarembo Island.[73]

Thin coal beds or seams are associated with Eocene formations on Kootznahoo Inlet and Murder Cove, Admiralty Island;[74] on Port Camden, Kuiu Island; on Hamilton Bay, Kupreanof Island;[75] and at Coal Bay, Prince of Wales Island. It is reported that efforts are

[72] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 138–139, 1925.

[73] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, p. 75, 1922.

[74] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, pp. 151–154, 1906.

[75] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts: U. S. Geol. Survey Bull. 347, pp. 59–61, 1908.

being made to produce coal on a commercial scale from the beds on Admiralty Island. Coal beds are reported to occur in the Tertiary beds of Lituya Bay.

QUATERNARY DEPOSITS

The Quaternary formations consist of glacial, marine, and stream deposits. The stream deposits are the only ones which have any economic importance. They include some interglacial stream deposits in the Porcupine placer region, but are mainly of Recent (postglacial) age; they are of value because of the local occurrence of gold placer deposits where streams that have traversed wide mineralized belts meet with other conditions favorable for the formation of placers. A little placer gold has been taken out from many little local deposits throughout the Ketchikan, Wrangell, Juneau, and Skagway districts, but the three most profitable localities are the Porcupine placer district,[76] the Gold Creek placers, back of Juneau,[77] and the placers in the drainage basins of Spruce Creek and Shuck River, on Windham Bay.

The belt of mineralization from which the Porcupine placers have been derived is wide and consists of large areas of lean or barren rock and also wide belts in which sulphide minerals are abundant. One belt of this sort in a slate formation is 1,200 feet wide and shows abundant quartz veining and sulphide mineralization; a large number of samples taken at random across the belt assayed between $1 and $2 a ton. The Gold Creek placers of the Juneau district are derived from gold quartz veins which occur in a band of slate and phyllite 2,000 to 3,000 feet in width. The placer deposits of the Shuck River Basin are likewise derived from metallized quartz stringers and sulphide-impregnated zones in black slate and schistose greenstone.

Gold placer deposits in Alaska have been discussed by Brooks,[78] and the following statements are based on his work. A placer is a deposit of sand, gravel, or other loose material containing a sufficient percentage of gold or other valuable minerals to permit profitable recovery. Southeastern Alaska has been intensely glaciated, and glaciation of a region is usually unfavorable to the formation of placers, as the decomposed bedrock and stream gravel with local placers are eroded and the gold contents dissipated. There are, however, some glacio-fluviatile deposits that contain gold placers. These have resulted from the water sorting and transportation of material derived,

[76] Eakin, H. M., The Porcupine gold placer district: U. S. Geol. Survey Bull. 699, 1919.
[77] Spencer, A. C., The Juneau gold belt: U. S. Geol. Survey Bull. 287, pp. 42–43, 77–85, 1906.
[78] Brooks, A. H., Alaska's mineral resources and production: U. S. Geol. Survey Bull. 773, pp. 15–28, 1925.

often in very large bulk, from glacial scouring. The gold derived from glacial débris may be concentrated by stream or wave action. The floods that accompanied the retreat of the ice were favorable to stream sorting of this kind. There are three types of glacio-fluviatile placer deposits in southeastern Alaska—(1) placers formed during an interglacial stage and preserved from ice scouring in canyons, such as part of the placers in the Porcupine district; (2) placers resulting from flooding during the disappearance of the ice sheets, such as most of those in the Porcupine district and some of the creek placers in the Juneau district; (3) placers formed entirely in post-Pleistocene time from reworking of débris originally scoured from the bedrock by glaciers. The placer deposits in amphitheaterlike basins or cirques, such as that of the Silver Bow Basin, near Juneau, are derived both from reworking of glacier-scoured material and from the product of rock weathering.

In addition to the glacio-fluviatile placers, residual, eluvial, and beach deposits are found.

Residual deposits rest directly on the bedrock source of gold and have resulted from weathering of the auriferous outcrop in place. A little gold has been taken from placers of such type in the belt of metallization on the west side of Helm Bay, in the Ketchikan district, but these placers are rare and their total yield is small.

Eluvial placers are deposits of loose rock containing a considerable amount of gold. The rock consists of angular and subangular fragments derived by weathering of bedrock and accumulated by soil and talus creep not far from its source. The "hill-slope" placers of the Juneau district were of this type and were found directly on or near the slope below the auriferous lodes that were later developed in the Alaska-Juneau, Perseverance, and Treadwell mines. The gulch deposits of the Juneau district are the result of a combination of eluvial and fluviatile concentration.

Beach placers are the result of concentration of gold by wave action. Most of the few beach deposits in southeastern Alaska are the result of reworking of auriferous glacial débris. A little gold has been taken from beaches near Yakutat, and valuable beach placers have been worked along the shore for a distance of about 10 miles northwest of Lituya Bay. The auriferous deposits consist of magnetite and garnet sands occurring in layers from a few inches to a few feet thick and extending in places for 100 yards back from tidewater. During periods of high tide and storms these auriferous sands are concentrated by the waves in layers high on the beach. Local beach placers have been found elsewhere, but little gold has been taken from them.

The placers are all dependent upon the presence of an auriferous mineralized belt as a source from which the gold is derived and concentrated.

Spencer[79] writes of the placers in Gold Creek Valley, near Juneau, as follows:

The early miners classified their locations as hill, gulch, and creek claims. * * * The hill deposits are local masses of soil mixed with fragments of the country rock and veins, accumulated either practically in place or at no great distance from the parent outcrops. They represent the surface wash derived from the gold-bearing rocks, lodged at the base of declivities and in minor hollows on the hillsides. * * * In the formation of the gulch placers surface wash from considerable areas has been brought into the gulches from the side slopes and concentrated to a greater or less extent along the stream beds, where the rock and vein fragments are comminuted and the gold set free to lodge in natural riffles in the slaty bedrock. The materials which compose the creek deposits have been washed in from the side gulches and from the main tributaries of the creek. The tenor of these placers is lower than in the hill and gulch deposits, because the sources of the material are more widely distributed, and large amounts of débris have been furnished from practically barren rocks. * * * The gulch and hill deposits are no longer of economic importance, but the gravel fillings in the main valley have yielded only a part of the gold which they originally contained. * * * The accumulation of gravels in certain reaches of Gold Creek Valley and not in others has resulted from an irregular distribution of grade along the bedrock profile; * * * where the grade is low or where depressions exist deposition went on until a slope was built sufficiently steep to allow the current to carry off all material subsequently washed into the stream.

Of the Porcupine district Eakin[80] writes:

The gold placers occur only in conjunction with the intrenchment of streams in the hanging valleys left after glaciation wherever their courses traverse zones of mineralized bedrock. The concentrations are generally found in a thin stratum of stream gravels on the bedrock bottoms of the canyons. The gold-bearing stratum is generally overlain by barren or very low-grade gravels that are progressively deeper downstream. Their deposition is due to the rising base level afforded by the aggrading Klehini River.

The canyons appear to be of two ages, postglacial and interglacial. Eakin says:

The stream gravels in the bottoms of the older canyons, which are gold-bearing in places, are overlain by glacial detritus the depth of which is generally equal to the height of the canyon walls.

BELTS OF MINERALIZATION

Throughout southeastern Alaska and the adjoining territory of British Columbia metallization tends to occur in part in localized belts or areas. (See pl. 1.) Within each such belt deposits valuable

[79] Spencer, A. C., op. cit., pp. 77–78.
[80] Eakin, H. M., The Porcupine gold placer district: U. S. Geol. Survey Bull. 699, 1919.

for a certain metal or group of metals may predominate, and the type of metallization may differ for each belt. The tendency toward localization is, however, only a tendency, not a rule, for mineral deposits that differ in character from the prevalent one are found in each belt, and mineralization is by no means confined to these localized belts.

The map shows a very obvious grouping of metalliferous deposits around or in the vicinity of masses of intrusive rock, though mineral deposits have not been discovered in association with all the intrusive masses. Intrusive rocks are relatively sparse in the Kuiu-Heceta belt, including Kuiu Island, the western part of Kosciusko Island, Heceta, Tuxekan, San Fernando, and Suemez Islands, and the adjacent western coast of Prince of Wales Island. It is surely significant that not a single metalliferous deposit of commercial value has been discovered in that belt.

EASTERN BORDER BELT

A metalliferous belt lies near or within the inland border of the Coast Range batholith, and its course may be traced by the prospects located wherever this eastern border is accessible, as at Alice Arm, at the head of Portland Canal, and on Salmon, Unuk, Iskoot, Stikine, and Taku Rivers.

The mineral deposits of this belt are described by Schofield,[81] Dolmage,[82] Hanson,[83] Cairnes,[84] Westgate,[85] and Buddington.[86] They are of the following types: (1) A type rich in silver minerals, such as tetrahedrite, pyrargyrite, proustite, polybasite, argentite, and at some places native silver; examples of this type are the Premier and certain bodies in the Forty-nine, Big Missouri, and other mines at the head of Portland Canal, on the Canadian side of the boundary, which occur as veins and veinlike replacement deposits in quartz porphyry and at the contact of the porphyry and tuff, also the Esperanza, Golkish, and Dolly Varden, near Alice Arm, which occur as veins in argillite; (2) a low-grade complex type that contains predominantly pyrite, chalcopyrite, sphalerite, and galena with copper, lead, and zinc and locally a high content of gold or silver; this type

[81] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, pp. 61–62, 1922.

[82] Dolmage, Victor, Coast and islands of British Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept. for 1922, pt. A, pp. 9–34, 1923.

[83] Hanson, George, Reconnaissance between Kitsult River and Skeena River, B. C.: Canada Geol. Survey Summary Rept. for 1922, pt. A, pp. 35–51, 1923.

[84] Cairnes, D. D., Portions of Atlin district, B. C.: Canada Dept. Mines Mem. 37, 1913.

[85] Westgate, L. G., Ore deposits of the Salmon River district: U. S. Geol. Survey Bull. 722, pp. 117–140, 1921.

[86] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 71–139, 1925.

occurs usually as replacement or disseminated deposits in beds of greenstone or tuff and tuffaceous conglomerate and forms roughly tabular lodes, such as certain bodies in the Hercules, Big Missouri, Forty-nine, Daly Alaska, and other mines; the base-metal type occurs also in fissure veins; (3) quartz fissure veins in granodiorite and in sedimentary and volcanic beds metallized with ore shoots that consist largely of galena and pyrite with locally associated tetrahedrite, chalcopyrite, pyrrhotite, a little sphalerite, or native gold and that are valuable for lead, silver, and gold; examples are the Riverside, Fish Creek, Mountain View, and Homestake properties in the Hyder district; a similar type is found also, according to Cairnes, as the most widely distributed type of vein in the Atlin district, where the veins occur in schist, basic volcanic rocks, and granodiorite; (4) gold quartz veins, such as are found in the Engineer mine, in the Atlin district, to the north, and in the Kitsumgallum district, to the south; (5) molybdenite-bearing quartz veins in a series of argillite, arkose, and argillaceous sandstone, such as occurs 4 miles east of Alice Arm.

In the Salmon River district, on the Alaskan side of the international boundary, observations on the strike and dip of 122 veins were obtained. Almost half of these strike northwest (N. 30°–60° W.) and dip 45°–70° NE.; a fifth of them strike between north and north-northwest (N. 0°–30° W.) and dip 45°–70° E.; and another fifth strike within about 15° of east (N. 75° E.–N. 70° W.). In one narrow localized belt parallel to Casey Glacier and Homestake Gulch the veins strike N. 0°–35° E. In the Texas batholith of granodiorite about two-thirds of the veins strike within 15° of northwest, whereas in the graywacke, tuff, slate, and greenstone about half the veins strike within 15° of east, parallel to the bedding and the structure.

CENTRAL COAST RANGE BATHOLITH

The Coast Range batholith in southeastern Alaska and the adjoining part of British Columbia consists essentially of granodiorite, quartz monzonite, and quartz diorite, with a little associated diorite and more basic rocks and included belts of schist and injection gneiss. Few mineral deposits have been discovered within the core of the Coast Range batholith. In the past this has commonly been ascribed to an actual scarcity of metallization there; but it is now being recognized that the exceeding ruggedness of the country and its inaccessibility, with consequent slight prospecting, may also be a contributing factor. Mineral deposits of economic importance occur in the belts of metamorphic rocks inclosed within the batholith, as previously described, and there is no doubt that others will be found;

but it will probably still be found to hold true that mineral deposits of commercial value are relatively sparse within the Coast Range batholith.

Prospecting has been carried on mainly along the western border of the Coast Range batholith, in the vicinity of outlying stocks on the islands of the Alexander Archipelago, and along the eastern border of the batholith at places where it is accessible. Recent developments are now directing attention to the fact that many blocks and belts of schist or gneiss are found within the batholith and that locally they may contain ore deposits.

The abundance of schist and gneiss inclusions in the Coast Range batholith is indicated by the fact that along the east side of Portland Canal about half of the batholith, along a cross section of 100 miles, is schist or gneiss. In a length of about 11 miles along Tracy Arm one-third of the batholith is schist or gneiss.

The predominant types of metalliferous deposits within the belts of crystalline schist and injection gneiss in the core of the Coast Range batholith include replacement and impregnation deposits carrying copper or copper and zinc (chalcopyrite and sphalerite). Quartz fissure veins with copper, rarely molybdenite, and bands of mineralized schist with galena, sphalerite, and tetrahedrite are also present.

Within the belts of schist and gneiss included in the batholith bands of oxidized rusty-weathering sulphide-impregnated rock are common. Most of these bands carry only pyrite or pyrrhotite or both, with a little chalcopyrite and a very low content in gold, and under present conditions they are of no value; but some carry combinations of pyrrhotite, chalcopyrite, sphalerite, and galena and deserve consideration. Both types of deposit—the bands impregnated with iron sulphide and the bands of base metal—have a similar weathered appearance, and the pyrite-pyrrhotite bands are so predominant that the base-metal bands carrying chalcopyrite, sphalerite, or galena, or a combination of these, are liable to be passed over through lack of careful examination of the fresh rock.

Sphalerite and pyrrhotite are the most abundant minerals in several metallized zones in the belt of schist and gneiss at or near the western border. It seems highly probable that other similar deposits will be found as these belts of metamorphic rock are more thoroughly prospected.

The low-grade copper deposit of the Hidden Creek mine, at Anyox, British Columbia, occurs in a belt of greenstone and argillite inclosed within the central portion of the batholith. In this mine there has been developed to date 13,215,000 tons of copper ore averaging 2.14

per cent of copper.[87] Seven miles west of the Hidden Creek mine, at Maple Bay, on the east side of Portland Canal, another copper mine is being developed in the same belt of schist. This schist belt is reported to occur also on the west side of Portland Canal. The common metallic minerals are pyrite, pyrrhotite, chalcopyrite, zinc blende, magnetite, and arsenopyrite. They are believed to be the result of the replacement of greenstone and argillite.

Wright[88] reports a 2-foot vein of copper ore in a belt of schist included within the Coast Range batholith on Unuk River about 1 mile below the international boundary. The vein consists of pyrite, pyrrhotite, and chalcopyrite.

A vein carrying considerable quantities of sphalerite is reported to occur on Taku River about 1 mile from the international boundary. The predominant minerals are pyrrhotite and sphalerite with a little pyrite, galena, and locally chalcopyrite. The ore gives low assays for gold and silver.

At the Whiting River prospect, in the Juneau district, there is a quartz fissure vein in a belt of marble inclosed in quartz diorite. The metallic minerals comprise arsenopyrite (predominant), pyrite, galena, sphalerite, and chalcopyrite. The silver content is moderate, and there is considerable gold. Quartz porphyry dikes cut the marble near the vein.

On Quartz Creek, a tributary about 30 miles from the mouth of Iskut River, there are bands of schist that are metallized with sphalerite and galena and have locally stringers of tetrahedrite carrying considerable silver.

Despite the known and probable occurrence of mineral deposits within the core of the Coast Range batholith it is still true that the batholith itself is not as favorable an area for prospecting as the eastern and western border belts or the Alexander Archipelago.

WESTERN BELT OF SCHIST AND GNEISS

The western belt of schist and gneiss comprises the metamorphic rocks west of the Coast Range batholith. It includes practically the same general area as the Wrangell-Revillagigedo belt of metamorphic rocks and, in addition, the narrow belt of schist and gneiss adjacent to the western border of the batholith, which tapers to a few hundred feet in width near Berners Bay.

The predominant metalliferous deposits in the more intensely metamorphosed crystalline schist and gneiss immediately adjacent to the

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[87] Dolmage, Victor, Coast and islands of British Columbia between Douglas Channel and the Alaskan boundary: Canada Geol. Survey Summary Rept., pt. A, p. 20, 1922.

[88] Wright, F. E., The Unuk River mining region of British Columbia: Canada Geol. Survey Summary Rept. for 1905, p. 50, 1906.

western border of the batholith include sphalerite replacement veins associated with pyrrhotite, chalcopyrite, or a little galena; a few low-grade quartz fissure veins; and a copper quartz fissure vein. In the less intensely recrystallized, more characteristically mechanically sheared beds at the south end of Revillagigedo Island there is a belt in which a number of gold quartz veins are found, and in the phyllite east of Wrangell silver-lead veins occur.

Schist and gneiss that contain disseminated crystalline flake graphite, garnet, and beds of marble or medium to coarse crystalline limestone are found within this belt.

A localized belt of mineralization occurs on the mainland about 13 miles east of Wrangell. It includes the tabular zinc replacement veins at the Groundhog Basin, the silver-lead and zinc replacement veins at Glacier Basin, and the gold quartz fissure veins at Bergs Basin. The mineral deposits are associated with intrusive sheets and dikes of quartz porphyry. The replacement veins are of a high-temperature type and are associated with typical contact-metamorphic minerals. This belt very probably extends northwest toward Stikine River, for quartz porphyry is found in considerable quantity as float in Andrews Creek. The belt deserves further prospecting.

Zinc.—The extensive low-grade zinc replacement veins of the Groundhog Basin,[89] about 13 miles east by northeast of Wrangell, occur in a belt of gneiss and schist within the western border zone of the Coast Range batholith. The main vein has been traced for a length of about 3,200 feet, through a range in altitude of 1,140 feet, and has been sampled for a length of 1,600 feet. The width for the 1,600 feet sampled ranges from 1½ to 9 feet and averages about 3 feet; the average of 24 assays, each made on the full width of the vein, is approximately zinc 17 per cent, lead 2.5 per cent, silver 1.25 ounces to the ton. The metallic minerals comprise pyrrhotite and dark-brown sphalerite, with small and variable amounts of pyrite and galena. The gangue is made up largely of unreplaced remnants of the country rock and includes plagioclase, pyroxene, hornblende, epidote, quartz, and biotite. The sphalerite is reported to be a variety carrying considerable iron. The veins are of the high-temperature type and are allied to contact-metamorphic deposits in origin. Small replacement bodies of magnetite slightly earlier in age than the sulphides are locally associated with the sulphide veins. The sulphide veins have a tabular form parallel to the banded structure of the inclosing crystalline schist and gneiss and are not located on a contact. The deposits in part replace intercalated limestone beds and in part replace injection gneiss.

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[89] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, pp. 57–63, 1922.

On Tracy Arm, in the Juneau district, about 1 mile south of the point at the first elbow, there is a prospect known as the Neglected Prize. The vein lies within a narrow belt of injection gneiss between the quartz diorite of the western border of the Coast Range batholith and an outlying quartz diorite sill. Assays of samples from the full width in several prospect pits are reported to range from 1.5 to 4.1 per cent of copper and from 4.7 to 14.6 per cent of zinc. The sulphides predominate over the gangue and comprise pyrrhotite, sphalerite, chalcopyrite, and pyrite.

On Lynn Creek,[90] north of Vancouver, in British Columbia, in a belt of crystalline schist bordering the west side of the Coast Range batholith, a zinc body is being developed. The veins occur near the contact with quartz diorite and are tabular deposits that have replaced limestone beds. The metallic minerals comprise a large amount of sphalerite, chalcopyrite, pyrite, and pyrrhotite.

Silver-lead.—Silver-lead veins within the belt of schist, gneiss, and crystalline limestone are found at the Lake claims,[91] 10½ miles east of Wrangell, at the claims in Glacier Basin,[91] 14 miles east of Wrangell, and at the Whiting River prospect.[92] At Glacier Basin they occur in part as tabular replacement bodies in gneiss and in part as veinings throughout a part of a brecciated felsite sheet. The ore minerals comprise galena and sphalerite, with associated pyrrhotite, chalcopyrite, and pyrite. At the Whiting River prospect the lode is a metallized quartz fissure vein in crystalline dolomite and limestone. The metallic minerals comprise arsenopyrite, pyrite, galena, sphalerite, and chalcopyrite, with arsenopyrite predominant. Quartz porphyry dikes cut the marble near the vein.

Gold.—The following descriptions of gold belts in the Ketchikan district are given by Chapin:

A strongly mineralized zone in the Wrangell-Revillagigedo belt of metamorphic rocks occurs along the south end of Revillagigedo Island from Tongass Narrows northwestward to the head of Thorne Arm and George Inlet. The gold-bearing lodes occur in the greenstone, slate, and schist that border the wide belt of quartz diorite that extends nearly across the island from the mouth of Thorne Arm to Survey Point. The gangue of the lodes is essentially quartz which carries pyrite and galena. Pyrrhotite, sphalerite, and chalcopyrite are also found. The gold occurs both free and combined with sulphides and carries silver in varying amounts. The lodes are fissure veins.

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[90] Burwash, E. M. J., The geology of Vancouver and vicinity, pp. 56–60, Univ. Chicago Press, 1918.

[91] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, pp. 63–67, 1922.

[92] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, p. 135, 1925.

A strongly mineralized belt lies along the west side of Helm Bay, on the Cleveland Peninsula. The lodes are chiefly gold-bearing and occur as quartz fissure veins and as impregnated zones with gash veins in schistose greenstone with interstratified argillaceous beds. An unusual feature of certain of these lodes is the presence of the rare mineral tetradymite. The common association of minerals is free gold, iron pyrite, and a little galena in a quartz gangue. Chalcopyrite and bornite occur as accessory minerals in some veins.

Extending along the shore of Tongass Narrows northwest of Ketchikan for about 2 miles is a mineralized zone in which some locations have been made and a little prospecting done. The ore deposits occur as mineralized portions of the greenstone and black slate along the contact of the quartz diorite and as fissure veins in the intrusive rock. The veins contain free gold associated with pyrite, chalcopyrite, and arsenopyrite. The ore bodies are rich in pockets but are not persistent, and very little development work has been done on them.

At the Clark prospect, 6½ miles east of Juneau, there are low-grade gold quartz veins some of which are unusual because of the association of considerable stibnite in the veins.

Graphite.—Beds of schist and gneiss with crystalline flakes of graphite were particularly noted north of Wind Point, on Thomas Bay; at the head of Knygs Lake, on Stikine River; in the schist belt crossed by Andrews Creek, on Stikine River; and near Duck Island Cove on Bradfield Canal. A specimen from Thomas Bay is a graphitic feldspathic quartz schist consisting of 54 per cent of quartz, 26 per cent of feldspar, 9 per cent of biotite, 6 per cent of graphite, and 5 per cent of pyrrhotite. Other beds carry a very low content of mica. The graphite occurs as disseminated flakes with a diameter ranging from 0.2 to 0.7 millimeter and averaging 0.4 millimeter, and with an average thickness of 0.08 millimeter.

Garnet.[93]—Garnet has been mined at only one locality, the property of the Alaska Garnet Co., 7½ miles north of Wrangell. This is the locality from which come the garnets found in museums all over the world and many of them labeled "Fort Wrangell." The garnets are from one-fourth to three-fourths of an inch in diameter and occur disseminated through beds of quartz-mica schist 10 feet or more in thickness. They lie near intrusive quartz diorite and are of contact-metamorphic origin.

Another richly garnetiferous belt occurs on Port Houghton and has been described on page 67 of this report.

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[93] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, pp. 73–74, 1922.

JUNEAU GOLD BELT

Another well-defined belt, often referred to as the Juneau gold belt, lies along the west side of the Coast Range batholith, beginning north of Thomas Bay and extending for 175 miles to the northwest parallel to the contact, with a width of 5 to 10 miles. The main product of this belt has been gold, though this is always accompanied by varying amounts of silver. The geology of this belt has been described by Spencer,[94] from whose report the following quotations are taken:

The gold occurs in various forms of lode deposits and in placers which have been formed by the breaking down of the lodes during general erosion of the rocks and the concentration of their contents through the sorting action of streams. * * * The lode deposits may be divided into three classes—(1) veins; (2) impregnated masses of rock; (3) mixed deposits consisting of veins and impregnations together. * * * The vein stuff is ordinarily quartz or calcite, one or both, with variable proportions of other minerals, particularly sulphides of the metals which are commonly accompanied by gold and silver, * * * the most noteworthy differences being seen in the amounts of metallic sulphides present. As a rule these vary from little or none up to 3 or 4 per cent, or in ore shoots of limited extent up to a much higher proportion. * * * Throughout the district probably the greatest number of veins, and in general the larger ones, occur in fissure openings which follow the structure of the inclosing rocks. Practically all of the veining has been formed since the schistose and slaty structures were developed. * * * Those veins which occur between two sorts of rock possessing different rigidity (as between soft slate and greenstone or diorite) are apt to be the strongest and most continuous. In most cases, however, instead of solid veins lying between two different beds, one finds typical stringer leads composed of numerous nearly parallel veinlets occupying irregular openings in the slates adjacent to the contact. Stringer leads are characteristic of the slaty rocks, and they occur in many places irrespective of the proximity of massive strata. These stringer leads are commonly composed of series of parallel overlapping veinlets occupying openings along the slaty cleavage or in some places cutting across the structure. * * * In another form of stringer leads gashlike fractures have been opened in some rigid rock, and commonly these are confined to the vicinity of contacts with the inclosing slates. * * * Vein aggregates of this sort are sometimes traceable for several hundred feet. * * * Instances of cross-cutting veins are comparatively rare, though they have been noted. * * * In the vicinity of Yankee Cove several transverse veins have been prospected, and here they are confined to a certain band of massive greenstone. * * *

In this form of mineralization the metallic minerals are disseminated more or less irregularly through masses of country rock. * * * In many instances one of the products of this replacement is iron pyrites and other sulphide minerals also occur. * * * In most cases where rock masses containing disseminated sulphides have been prospected it has been found that the gold present is not sufficient to constitute an ore. * * *

Veining and impregnation are combined in the ore bodies of the Treadwell mines on Douglas Island. * * * In the Treadwell deposits the masses of

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[94] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, pp. 22–38, 1906.

igneous rock which have been transformed into ore have the form of dikes lying parallel with slate and an interbedded stratum of greenstone, between which they have been intruded. These dikes were fractured and in their broken condition became channels for the circulation of mineral-bearing waters, which deposited vein stuff in the open spaces and, soaking into the fragments of the broken rock, attacked them as they were able, destroying to a degree certain of the minerals present and depositing new minerals in their stead. Among these introduced minerals are various sulphides, of which the principal one is pyrite, which is accompanied by a small amount of gold. Pyrite and gold also occur in the veinlets, and the whole recemented mass constitutes the ore of the mines which comprise the famous Treadwell group. * * *

From the observable range of the vein fillings from elevations above 3,000 feet to a depth of more than 1,000 feet below tide it may be safely assumed that the same sort of veins must have been removed with the rocks which have been carried away by erosion and must be present in the existing rocks to a considerable depth. * * * In general, then, metalliferous veins and impregnations are probably distributed through the rocks to depths of several thousand feet in very much the same manner as to number and form as in the rocks which are exposed above tide level. * * * Continuous, well-defined outcrops and wide bodies of quartz may be regarded as indications favorable for continuance in depth, though, as shown by the Bald Eagle vein at Sumdum, this is no infallible rule, and it is regarded as especially liable to fail in soft, flexible rocks like slates. Swells and pinches, both horizontal and vertical, are common features of fissure veins in all regions where they have been followed by the miner. * * * Throughout the Juneau region the contacts between rocks of different rigidity are regarded as favorable situations for permanence in depth, though even in such cases great changes in the width of veins and their solidity are to be expected. * * *

The ores of the Juneau region usually carry more than half of their gold in a free-milling condition. * * * A general rule, to which a few exceptions could be noted, is that in a given deposit or vein an increase in the amount of sulphides is accompanied by an increase in the value of the ore. * * * Free gold and the gold and silver bearing sulphides occur either in veins of quartz and calcite or disseminated through masses of more or less altered rock. In general the vein ores contain the largest values per ton, deposits combining vein and impregnation features are intermediate in gold contents, and masses consisting entirely of disseminated sulphides are of low grade and commonly too poor to be mined with profit.

In the region here considered quartz forms the characteristic filling of the veins and is the principal nonmetalliferous mineral of the ores, though calcite is usually present and certain veins contain considerable amounts of albite.

The accessory gangue minerals include ankerite, rutile, sericite, and in places tourmaline and others derived from the wall rocks. Among the metallic minerals, pyrite is the most common, and pyrrhotite is present in many of the quartz veins. Galena and sphalerite are extremely variable in amount and are commonly associated with an increase in the proportion of silver. Chalcopyrite is nearly everywhere present but in small amounts. Arsenopyrite occurs in many places in the veins and in some places carries much gold. Gold occurs in two ways—as flakes or spangles of the native metal and in an invisible form in the sulphides. Other primary metallic minerals restricted to one or a few veins include stibnite, tetrahedrite, and molybdenite.

FUNTER BAY-HAWK INLET BELT

A belt of schist and phyllite that shows considerable dynamic metamorphism and contains a great number of well-defined quartz fissure veins extends from Funter Bay to Hawk Inlet and perhaps farther south on Admiralty Island. This belt appears to be geologically similar to the Juneau belt. The mineralized belt on Funter Bay has been described by Wright,[95] Eakin,[96] Mertie,[97] and Buddington.[98]

The schist includes three general types—greenstone schist composed of combinations of chlorite, epidote, zoisite, mica, quartz, and albite, with a little calcite, titanite, and apatite; light-colored micaceous quartz schist; and black crinkled graphitic phyllite. Several varieties of igneous rock occur as sheets or dikes, including albite-quartz diorite, albite diorite, and albite trachyte.

Near Funter Bay there are two sets of veins, one of which strikes N. 45°–60° E. and the other N. 20°–35° W., the latter approximately parallel to the strike of the schist. On the Hawk Inlet side of Mount Robert Barron the veins strike prevalently N. 15°–30° E., which is 20°–30° more eastward than the strike of the schist and phyllites, and have a steep eastward dip.

Some of the quartz veins are very large; one has been traced for 2,300 feet and is 20 feet wide at one point; another is over 2,000 feet long and 20 to 50 feet wide; and another has at one point a width of 57 feet, said to be ore. Some of the large veins have been proved to carry gold ore shoots of low or medium to high grade and some to have large volumes of quartz that yields low assays in gold. In general, the quartz is white, milky, and massive, but locally it shows comb or drusy structure and is associated with masses of ankerite or, in the weathered oxidized surface outcrop, with limonite. The gold-bearing quartz is commonly iron-stained or sparsely metallized with one or more of the minerals pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, specularite, and native gold.

PRINCE OF WALES BELT

The Prince of Wales belt of metallization is in part coincident with the Prince of Wales-Chichagof belt of intrusive rocks. The

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[95] Wright, C. W., A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, pp. 147–150, 1906.

[96] Eakin, H. M., Mining developments and water-power investigations in southeastern Alaska: U. S. Geol. Survey Bull. 662, pp. 84–92, 1917.

[97] Mertie, J. B., Mining developments and water-power investigations in southeastern Alaska: U. S. Geol. Survey Bull. 714, pp. 113–118, 1921.

[98] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 783, pp. 42–50, 1926.

bedded rocks comprise dynamically metamorphosed schist, local contact-metamorphic zones around the intrusive bodies, graywacke, tuff, greenstone, limestone, and slate. The average of the Mesozoic intrusive rocks is equivalent to a quartzose diorite, and the predominant rocks are of dioritic types as compared with the more siliceous quartz diorite to the east.

The southern half of Prince of Wales Island is especially well metallized. The most abundant metals are iron and copper and to a less extent gold. The developed prospects or mines are predominantly magnetite-chalcopyrite contact deposits, chalcopyrite impregnated or veined shear zones, gold quartz fissure veins, and copper-bearing quartz veins and brecciated zones. Other types, of which there are only one or a few of each, comprise copper-palladium, silver-lead, molybdenite, and a base-metal type that includes zinc, lead, and copper with silver and gold. The greater production of gold and silver has come from the copper lodes. A little silver has been won from the argentiferous galena, but most of the silver recovered has come from the gold.

On the north end of Prince of Wales Island there are at least two large stocks of dioritic rock, one back of Ratz Harbor and another in the vicinity of Shakan. The belt in the vicinity of these two stocks deserves further prospecting. The Shakan stock is highly differentiated; evidences of metallization in it or in its vicinity were noted in several places and include arsenopyrite veinlets, galena, and specularite in local contact-metamorphic pockets, the molybdenite lode at Shakan, and gold-bearing quartz veins. The country rock also is in part favorable to the formation of contact copper deposits.

The graywacke formations belonging to the Ordovician and Silurian systems appear to be relatively barren.

The extension of this metallized belt is indicated by the metallization in a belt parallel to Duncan Canal on Kupreanof Island extending northwest to Frederick Sound. The gold lodes of Woewodski Island and the copper deposits near the head of Duncan Canal and on Frederick Sound are included here. They have been described by the Wrights [99] and by Buddington.[1]

The copper-palladium and molybdenite deposits are described in connection with the Upper Jurassic or Lower Cretaceous intrusive rocks (pp. 347, 351). The silver-lead deposits are known as the Moonshine and Hope prospects and are located on the west side of the South Arm of Cholmondeley Sound. At the Hope claims the surface exposures show a lode cutting quartzite, schist, and limestone

[99] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 140–142, 182–184, 1906.

[1] Buddington, A. F., Mineral deposits of the Wrangell district, southeastern Alaska: U. S. Geol. Survey Bull. 739, pp. 67–73, 1922.

country rock. The lode appears to be continuous but widens where it crosses the calcareous rocks. The ore bodies are due to the replacement of limestone and calcite lenses in the schist by epidote, garnet, and galena. The Moonshine vein has been described by the Wrights.[2]

The Complex prospect is midway between Mineral and Dora Lakes, on the south side of Cholmondeley Sound. The country rock is limestone and schist, and the lode is a fissure vein of banded quartz with considerable galena, sphalerite, chalcopyrite, and pyrite carrying gold and silver. Some of the ore is essentially sphalerite, with a little chalcopyrite, galena, gold, and silver; and in most of the ore zinc, copper, lead, gold, and silver all occur in sufficient amounts to be essential recoverable products.

Copper.—The copper deposits have been described by Brooks and others.[3] Brooks writes:

All the productive copper mines as well as the largest developed cupriferous ore bodies of southeastern Alaska are in the Ketchikan district. Copper is widely distributed in the Ketchikan district and, as will be shown, occurs in deposits of several distinct types. The most important so far as present production and extent of proved ore bodies are concerned are the contact deposits, which have yielded more than 98 per cent of the copper produced in the Ketchikan district.

The largest of the developed contact lodes are essentially chalcopyrite-magnetite deposits. Others which are less common consist mainly of chalcopyrite and pyrrhotite. All the ores carry pyrite, molybdenite, and specularite as accessory minerals. Some of the ores contain small amounts of nickel and traces of cobalt. The ores that have been mined carry enough gold to increase their value materially. In some localities a shallow surface zone of copper carbonates and other secondary minerals has been formed, but these deposits are not large enough to be of commercial importance.

These deposits occur in or near the contact-metamorphic zone caused by the intrusion of granitic and dioritic material into the sedimentary rocks among which limestone predominated. Such deposits have also been found in the contact zone of schists, greenstone tuffs, and graywackes.

The gangue of the contact deposits consists principally of minerals resulting from the alteration of the country rock and includes garnet, epidote, pyroxene, amphibole, and calcite. Calcite is sufficiently abundant in some of the ores to give them special value as flux. Quartz also occurs in all the deposits but is usually not abundant.

The typical contact deposits are masses of irregular outline, and some have very poorly defined boundaries. In some places a little copper occurs in zones about 200 feet wide, but the ores thus far mined have been taken from the smaller and much richer shoots, which are irregularly distributed through the

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[2] Wright, F. E. and C. W., op. cit., p. 187.

[3] Brooks, A. H., The future of Alaska mining: U. S. Geol. Survey Bull. 714, pp. 12–19, 1921. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 1908. Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, 1915. Chapin, Theodore, Mining developments in southeastern Alaska: U. S. Geol. Survey Bull. 642, pp. 83–100, 1916; Mining developments in the Ketchikan and Wrangell districts: U. S. Geol. Survey Bull. 662, pp. 63–75, 1918. Smith, P. S., Lode mining in the Ketchikan district: U. S. Geol. Survey Bull. 592, pp. 75–94, 1914.

contact rock or the larger bodies of low-grade ore. One difficulty that has beset the miner is the great irregularity in occurrence of the rich ore shoots. It is not uncommon to find an ore body whose horizontal cross section is almost square and which ends abruptly at the bottom. In many places search will reveal another ore shoot at greater depth. Hence there is little guide to the search for ore except the zone of contact metamorphism. The largest deposits thus far developed consist of huge bodies of magnetite in which chalcopyrite occurs both finely disseminated and in shoots of massive sulphides.

Incidentally to the search for rich ore shoots, which are as yet the principal source of the copper produced, a considerable tonnage of concentrating ore has been blocked out. There are also much larger bodies of low-grade ore which contain too little copper to be now classed as commercial ores. The reserves of such ore have not been determined, and little is known of their average copper content. It is probably true, however, that if a magnetite ore carrying 0.5 per cent copper could be utilized, the developed reserves would be very large; also that the hope of finding other similar deposits is well founded.

Among the best examples of the contact copper deposits in the Ketchikan district are those at the Mount Andrew, Mamie, Poorman, and It mines, on Kasaan Peninsula; the Rush & Brown mines, on Karta Bay; and the Jumbo and Copper Mountain mines, on the west side of Prince of Wales Island.

Another type of the copper deposits of the Ketchikan district is represented by those occurring in cavities formed by shear zones. Though those deposits appear to be largely cavity fillings, there is evidence in some places that they are in part formed by replacement of the country rock. The principal metallic minerals of the shear-zone deposits are chalcopyrite and pyrite, but they also contain some magnetite, pyrrhotite, sphalerite, and galena, as well as some gold and silver. Country rock, quartz, and calcite form the gangue of these deposits. The shear-zone deposits follow zones of fracture that are parallel to the schistosity of the country rock. They are found in various kinds of country rock but primarily in greenstone schist, graywacke, and sheared diorite.

There are two phases of the shear-zone deposits. One consists of lenses or tabular deposits, many of which are made up largely of rich, massive sulphide minerals. These have well-defined walls and are not unlike the cupriferous quartz veins described below. The other phase consists of disseminated deposits in which the sulphides are distributed through wide zones of sheared country rock, generally without well-defined walls. In some of the disseminated deposits the sulphide mineralization is rather evenly distributed through the entire mass, which may thus be a large body of low-grade ore. More commonly, however, the mineralization is concentrated along certain zones determined by the intensity of the shearing. In some of the deposits there has been marked silicification over a considerable width, but the sulphide minerals occur chiefly in ore shoots and stringer leads limited to certain parts of the whole mass. Practically all these disseminated deposits include ore shoots in irregular and tubular masses, and some are of sufficient size to form commercial ore bodies, as defined by the methods of mining and recovery that have existed in the past.

Up to the present time mining of the copper ore in shear zones has been confined to the lenses and tabular masses occurring either as separate deposits or as a part of the lower grade disseminated ore bodies. The larger bodies of low-grade disseminated ore have received relatively little attention, and little is known of their copper content. It will require much prospecting and careful sampling to determine whether they are of commercial importance.

Examples of the shear-zone deposits, including both the concentrated and disseminated phases, are found at the Rush & Brown mines, on Karta Bay; at

Niblack Anchorage and McLean Arm, on the east side of Prince of Wales Island; at the Corwin and Red Wing properties, near Hetta Inlet, and on Big Harbor (Trocadero Inlet), on the west side of Prince of Wales Island; and on McLeod Bay, Dall Island.

There are also in the Ketchikan district some copper-bearing quartz veins and brecciated zones. The deposits of this type thus far developed are small and have been exploited chiefly because of their silica content. They are essentially chalcopyrite-bearing quartz veins but contain also pyrite, sphalerite, tetrahedrite, and galena. All carry gold and silver. In some the gangue includes calcite and barite. These veins occupy true fissures with well-defined walls and cut both sedimentary and igneous country rock. In some the sulphides are well disseminated, but more commonly they occur in massive shoots separated by more or less barren vein matter. Chalcopyrite-bearing quartz veins are found in many places in the Ketchikan district, but most of them are too small to warrant development. The largest developments on this type of deposit are at the Cimru property, on the north arm of Moira Sound and at the south end of Gravina Island.

One other type of copper deposit in the Ketchikan district deserves mention, even though as yet only one example of it has been developed. This occurs in pyroxenite with gabbroic phases and appears to have been deposited in a very irregular zone of fracture. It carries bornite, chalcopyrite, and metals of the platinum group, chiefly palladium. The gangue is practically all country rock. This deposit, on which the Salt Chuck mine is located, was first opened as a low-grade copper deposit, but its present importance is due to its content of palladium and platinum.

Gold.—Gold veins predominate in the area northwest of Dolomi and in the vicinity of Hollis, on Twelvemile Arm of Kasaan Bay, extending northwest toward Klawak Salt Lake. Gold quartz veins are reported in the diorite at Ratz Harbor and in the diorite near Shakan. On Woewodski Island, in Duncan Canal, several veins have been prospected for gold. The mineralized belts near Dolomi and Hollis are described below by Chapin.

The Dolomi mineral belt is grouped around the two convergent valleys of Paul and James Lakes, which drain into the stream that enters the bay near the town. The ore deposits occur in the limestone, greenstone, and schist of the Wales group, and it is not unlikely that they are on the same mineralized belt in which occur the Dora Lake and Kitkun Bay deposits. The ore minerals are gold, pyrite, chalcopyrite, tetrahedrite, sphalerite, and galena, which occur in well-defined veins of quartz that are fairly persistent and may be traced on the surface for some distance. Some of the veins are of the breccia type and are formed along fracture planes or zones by the cementation of the broken-rock fragments by quartz and calcite, with some replacement of the country rock by mineralizing solutions.

Twelvemile Arm, on which Hollis is situated, is bordered by lava, tuffaceous sediments, and black slate of Middle Devonian age and by intrusive quartz diorite. The ore deposits are fissure veins, which occur largely in the black slate and associated sediments, and shear-zone deposits in the greenstone. The fissure veins are valuable mainly for their gold content. The vein matter is essentially quartz with a little calcite. The veins fill persistent joint planes and in places are associated with porphyry dikes. The ore minerals are free gold, pyrite, chalcopyrite, galena, zinc blende, and locally a little tetrahedrite. The shear-zone deposits in this vicinity are less valuable and have not been developed commercially. They consist of brecciated zones in the greenstone metallized by pyrite and chalcopyrite. The principal mining activity has been in the vicinity of Hollis, in a mineralized area that lies just south of the quartz diorite of Granite Mountain and extends from Hollis northwest for 7 miles or more. In this area gold lodes predominate. The country rock is mainly black slate and argillite, with some interbedded tuff and limestone and associated greenstone flows and breccias. A number of lodes have been opened in this gold quartz belt and several small plants installed, but none have made large production. This strongly mineralized region has never received the attention which it has deserved, but it will no doubt be developed in the future. The Kassan Gold Mining Co. is now operating the Dunton mine, on Harris Creek.

On Woewodski Island there are impregnated shear zones in greenstone and altered gabbro carrying auriferous pyrite and strongly defined quartz fissure veins metallized with sphalerite, pyrite, galena, and a little chalcopyrite and free gold. The mineralized belt on Kupreanof Island, in the Wrangell district, includes gold and copper lodes, none of which are now being worked. At the head of Duncan Canal there is a sulphide replacement deposit consisting largely of pyrite and pyrrhotite with a little chalcopyrite. At the northwest end of this belt, on Frederick Sound, float consisting of slate with chalcopyrite veinlets has been found, and quartz veins occur in the greenstone. The geologic conditions in this belt are such as to warrant further prospecting for new lodes of copper or gold, particularly within the belt of the Middle Devonian beds; these beds crop out along both sides of Duncan Canal and extend northwest from Duncan Canal to Frederick Sound, where they are exposed for 6 or 7 miles to the east of the Pinta Rocks.

CHICHAGOF GOLD BELT

All of Chichagof Island except the western part appears to be very similar geologically to Prince of Wales Island, both in the character of the country rock and in that of the intrusive masses. The number of mineral deposits so far found on Chichagof Island, however, is not comparable with the number found on Prince of Wales Island. It would seem that there should be contact-metamorphic copper or iron deposits on Chichagof Island locally where some of the intrusive rocks come against greenstone and limestone; that shear zones with copper minerals should occur in the greenstones; and that gold-bearing quartz veins should occur in local belts of slate or graywacke, or even in the intrusive masses themselves near their borders. The possibility of nickel-copper deposits occurring within basic intrusive masses should also be borne in mind.

The Chichagof gold belt has been described by Knopf,[4] Overbeck,[5] and Buddington.[6] As now known it includes the belt of bedded graywacke, slate, and metamorphic rocks along the west coast of the island, west of the igneous batholith, and a part of the batholith itself, particularly the northern part. One of the most famous mines in southeastern Alaska, the Chichagoff, is in this belt, in the vicinity of Klag Bay. Another operating mine, the Hirst-Chichagof, is in the same general area, and a third, the Apex-El Nido, is in the dioritic batholith near Lisianski Strait.

Overbeck,[7] writing of the vicinity of Klag Bay, says:

> Graywacke is economically the most important rock of the region at the present time, because all the prospects so far located are in graywacke, although there is no apparent reason why mineralization should not have taken place in the schistose series as well. One possible reason for the seeming localization of the mineralization in the graywacke is that the physical properties of the massive graywacke under great forces may have caused it to break with big clean fractures that were of great extent and that furnished excellent pathways for the ore-bearing solutions. The soft schistose rocks, on the other hand, would not give clean breaks or persistent pathways, so the solutions would dissipate through the schist and would not concentrate at any one place. * * * The Chichagoff ore body is a vein deposit that has formed along a shear zone in the argillitic graywacke; * * * it has been followed for over 4,500 feet [and] may range in width from less than a foot to 10 feet. The ore * * * is distributed in shoots. * * * The gold is associated with quartz, which is white and glassy in appearance. * * * Sulphide mineralization and gold mineralization in the quartz seem to be genetically connected.

The Hirst-Chichagof mine is in gold quartz veins in black slate near a sheet of greenstone. There are many other prospects on auriferous quartz veins in the slate and graywacke. At the head of Falcon Arm a sulphide-impregnated diorite aplite dike is being prospected.

The gold veins in the dioritic stock are described on page 346.

Knopf,[8] in discussing the economic geology of the Sitka district in 1912, wrote: "The indications afforded by present developments

[4] Knopf, Adolph, The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, 1912.

[5] Overbeck, R. M., Geology and mineral resources of the west coast of Chichagof Island: U. S. Geol. Survey Bull. 692, pp. 91–136, 1919.

[6] Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 773, pp. 114–125, 1924.

[7] Overbeck, R. M., op. cit., pp. 113, 115.

[8] Knopf, Adolph, op. cit., p. 32.

point strongly to the conclusion that the entire strip of territory contiguous to the west coast of Chichagof Island offers a more encouraging inducement to the search for new ore bodies than any other part of the region." This conclusion has been confirmed by later developments and still holds true.

In addition to gold, there are several nickel-copper properties associated with norite, bronzitite, and gabbroic rocks located in this belt at Nickel, also at Bohemia Basin and Surge and Takanis Bays, on Yakobi Island. These are described on pages 348–351.

SITKA BELT

In a northwestward-trending belt that parallels Silver Bay, near Sitka, on Baranof Island, there is a series of graywacke and slate carrying auriferous quartz lodes. This belt has been described by Knopf [9] as follows:

> The ore bodies occupy shear zones in graywacke and strike parallel to the stratification of the country rock. The lodes form massive outcrops of white quartz up to 15 feet or more in thickness, which are apt to show a short lenticular structure along the strike and to split up into stringer lodes. They are irregular in shape, bellying out and constricting abruptly. Near the lodes the country rock is much sheared and is penetrated by numerous transverse stringers as well as by veins parallel to the shear planes.
>
> A characteristic feature of the ore bodies is in the insignificant amount of metallic sulphides—in many ledges almost a vanishing quantity—contained in the vein quartz. Pyrite, pyrrhotite, and arsenopyrite are the principal sulphides; galena and sphalerite have been observed but are extremely rare. The sulphides are at many places concentrated in and around fragments of slate or sheared graywacke included in the ledges, even though the quartz itself is barren.

There is no producing mine in this belt at the present time, though some development work is being carried on.

GENETIC RELATIONS OF THE METALLIFEROUS DEPOSITS

A genetic association of most of the ore deposits in southeastern Alaska with the magmas that formed the intrusive rocks of Upper Jurassic or Lower Cretaceous age has been postulated by many geologists who have worked in this area.[10] Succeeding work has tended to confirm this hypothesis. All the ore deposits except those formed as magmatic deposits within the basic or ultrabasic rocks are thought to have been formed by solutions that had their origin in these molten

[9] Knopf, Adolph, op. cit., pp. 26–27.

[10] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 30, 1906. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 41, 76, 1908. Brooks, A. H., Geologic features of Alaskan metalliferous lodes: U. S. Geol. Survey Bull. 480, pp. 43–74, 1911. Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 35–36, 1912.

magmas. The solutions may have varied in character from a magmatic type such as that of a pegmatite to a more highly fluid and dilute type.

Accepting this generalization concerning origin as valid, we face the question whether a particular type of mineralization is prevalently associated with a particular type or mode of occurrence of igneous rock; or with a particular type or stage of differentiation of the magma; or with a particular type of country rock that has certain specific characters, chemical or physical, or both; or with a particular environment of temperature and pressure; or whether it is dependent upon two or more of these factors to varying degrees.

Hanson [11] has presented a very good statement of a part of the problem in a discussion of the origin of the ore deposits on the east side of the Coast Range batholith between Skeena River and Stewart, B. C.:

> Although the mineral deposits along the interior mineral belt have a general similarity, the valuable metals are restricted to certain areas in the belt. The localization of certain metals into definite areas is of interest, and it would be of great importance to discover the explanation for such concentrations. The source of the metals is considered as all-important in this connection. If the source contains metals, mineral deposits may form. It is not certain that ore deposits will result, as other conditions may prevent the deposition and concentration of the metals into ore bodies. The main source of the mineral deposits of the interior belt is believed to be the magma of the Coast Range batholith. It is probable that there are valuable metals in one part of the batholith which are lacking in another part. By very careful discrimination between rock types in the batholith in areas of known mineral deposits, some general rules may be established which can be applied to other parts of the interior belt.
>
> The country rock in which the ore bodies occur is also of importance, but the influence of the country rock pertains chiefly to the size and persistence of the veins and to the presence of ore shoots in the vein. The rock in which the ores are found has probably not had much influence on the localization of metals into areas within a mineral belt. The physical nature of the country rock, which has a bearing on the size of fracture, and the chemical nature, which influences replacement of the rock and precipitation of the metals, are here the two main factors. The depth at which the ore was formed is also important but will not explain the localization of certain metals into areas in one mineral belt.

This subject has been discussed by the writer in another publication.[12]

CHARACTER OF COUNTRY ROCK

When fluid metalliferous solutions are present the character of the country rock has no doubt a very considerable influence in deter-

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[11] Hanson, George, Reconnaissance between Skeena River and Stewart, B. C.: Canada Geol. Survey Summary Rept. for 1923, pt. A, pp. 44–45, 1924.

[12] Buddington, A. F., Coincident variations of types of mineralization and of Coast Range intrusives: Econ. Geology, vol. 22, pp. 158–179, 1927.

mining the type of ore deposit—contact, impregnation, fissure vein, "stringer lead," or others—and under some conditions in localizing its formation within certain types of rock or bed—for example, the formation of the contact type of deposit in limestone or certain greenstone tuffs. The general relations of ore deposits to the formations in southeastern Alaska have been discussed on pages 338–356.

The copper-iron contact deposits of Prince of Wales Island occur predominantly in limestone, greenstone tuff, and tuffaceous graywacke. The copper impregnation deposits tend to occur in schistose varieties of greenstone or tuffaceous graywacke and in limestone layers or lenses interlayered with them. The chemical character of the rock appears to have been a very potent factor here in localizing the ore deposits. Where schistose rock forms the walls of contact deposits the mineralization is less concentrated, and the sulphides are more disseminated in the contact rock and penetrate the schist for some distance from the contact with the intrusive.

Mineralized quartz veins are relatively uncommon in the limestone. In the Hyder district, where mineralized veins occur in granodiorite, graywacke, slate, and greenstone, pyrrhotite is abundant only in the replacement veins in the greenstone, and its relative restriction to rock of this type appears to be definitely related in some way to the composition of the greenstone.

The strength of the rock, of course, has its effect. Quartz veins in slate usually do not persist to great length and depth, though several or many may occur together to form a "stringer lead." However, along the contact between slate and a strong bed of graywacke or a dike, the veins may develop to great length and depth. Here the physical character of the country rock is the determining factor.

TYPE OF ASSOCIATED IGNEOUS ROCK AND TYPE OR STAGE OF MAGMATIC DIFFERENTIATION

The genetic association of certain kinds of mineralization with certain kinds of ultrabasic and gabbroic igneous rock is clear and definite. Many of the metalliferous minerals or solutions did not travel outside of the igneous mass that gave them birth. Thus the nickel-copper deposits are absolutely restricted to and occur actually within rocks of the ultrabasic or gabbroic group; the ilmenitic magnetite tends to occur in concentrated amounts with the hornblendite and pyroxenite; the only copper-palladium deposit that has been found occurs in an ultrabasic rock, pyroxenite; apatite tends to be concentrated with the hornblende.

For the more siliceous and alkalic rocks, however, the problem of relating kinds of mineralization to kinds of igneous rock becomes immensely more complicated. The metalliferous solutions may have wandered far from their parent magma; external factors may thereby have had a great influence; differentiation may have taken place within the solutions themselves; and there may have been overlapping effects due to the various stages of differentiation reached by individual bodies of magma within a particular region or by the magma of the same stock or batholith at successive times.

The relation of magnetite to the type of rock and degree of magmatic differentiation is especially clear, as shown by the table below:

Relation of magnetite to stage of magmatic differentiation

Type of rock	Content of magnetite (per cent)	
	Range	Average
Oligoclase-quartz monzonite	Trace to 1	±0.5
Quartz diorite and granodiorite	Trace to 2	±1
Diorite and monzodiorite	Trace to 5	1 to 2
Gabbro	Trace to 12	5
Pyroxenite	Trace to 30	
Hornblendite	Veins of solid ilmenitic magnetite	

There is a very marked increase in the percentage of magnetite in the more basic and less siliceous types of rock. In the dunite, however, magnetite normally forms at most only a few per cent of the rock. In the basic and ultrabasic rocks ilmenite is associated with the magnetite in small amounts. In the pyroxenite the magnetite occurs predominantly in disseminated interstitial blebs. In the hornblendite, which is believed to owe its origin in part to a relatively high content of volatile materials, the magnetite may occur as veinlets and vein dikes. The mobility of the iron solutions from the hornblendite magma has thus evidently been increased by the higher percentage of volatile material. In the diorite, monzodiorite, granodiorite, and more granitic masses this mobility of the metalliferous solutions is apparently still further increased, as indicated by the fact that magnetite and specularite occur locally in large amounts replacing the country rock near or adjacent to the intrusive mass.

The relationship of copper, which occurs predominantly in the form of chalcopyrite, forms a very interesting problem. It is found associated with a little pentlandite and a relatively large amount of pyrrhotite within certain types of gabbroic and ultrabasic rocks, where it occurs disseminated and in solid lenses; locally within certain gabbroic rocks it also forms veinlets in fractured zones. Bornite occurs at one place as disseminated deposits and veinlets in pyroxenite. Copper minerals are not concentrated along with magnetite and are not associated with it in the pyroxenite or hornblendite. In association with gabbroic and ultrabasic rocks chalcopyrite has a greater tendency than magnetite to occur in veinlike form, even where the associated rock is of the same type.

In association with diorite, monzodiorite, and granodiorite chalcopyrite, like magnetite, exhibits the results of a greater mobility than in association with basic and ultrabasic rocks, inasmuch as it occurs typically in the country rock as contact deposits adjacent to the intrusive body or in shear zones or impregnation deposits at considerable distances from the intrusive. Here also the chalcopyrite shows a relatively greater tendency to move out farther away from the same general magma than the magnetite.

Dolmage[13] has suggested as a possibility that chalcopyrite tends to occur to a greater extent with granodiorite than with diorite. He writes:

> Copper occurs at numerous places along this part of the west coast. The occurrences are, without exception, of the contact-metamorphic type and are formed near the contacts between the limestones of the Vancouver group and the intrusions of granodiorite or diorite of the Coast Range batholith. At or near every observed contact of these two rocks copper and iron minerals were found in the altered limestones and in some places in large amounts. At the diorite contacts less copper and more iron are found, but at the granodiorite contacts copper predominates. * * *
>
> The deposits may be found within a few feet of the granitic contact or at a distance of several thousand feet. They may be formed in thick beds of metamorphosed limestone free from any volcanic rock or, as is more often the case, they are in thin beds of limestone between beds of volcanic rocks which are also highly metamorphosed and metallized.

The Treadwell gold deposits on Douglas Island occur in fractured and metallized albite diorite and albite monzodiorite sheets. Knopf[14] reports a number of albite diorite dikes between Juneau and Auke Lake, some of which have been mineralized and altered. He writes of them as follows:

> This highly interesting kind of mineralization is essentially similar to that which has affected the Treadwell dikes, * * * but it by no means follows that mineralization of this character was everywhere accompanied by the formation of gold deposits of commercial value. Nevertheless, it is a favorable feature, and in view of the fact that such dikes contain enormously valuable ore bodies on Douglas Island, efforts should be made to prospect thoroughly the albite diorite dikes of the mainland.

Mertie[15] reports albite granite (or albite-quartz diorite), albite syenite (or albite diorite), and albite trachyte associated with gold veins at Funter Bay, on Admiralty Island. He writes:

> All the acidic and intermediate types of intrusive rocks examined by the writer contain albite or oligoclase-albite plagioclase feldspar. * * * This

[13] Dolmage, Victor, West coast of Vancouver Island between Barkley and Quatsino Sounds: Canada Geol. Survey Summary Rept. for 1920, pt. A, p. 19, 1921.

[14] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, p. 36, 1912.

[15] Mertie, J. B., Lode mining in the Juneau and Ketchikan districts: U. S. Geol. Survey Bull. 714, pp. 114–115, 1921.

feature is of more than passing interest when considered in relation to the sodic character of the intrusive rock at the Treadwell mines, on Douglas Island, about 15 miles to the east. It is not unlikely that mineralization at these two localities took place at the same general period and had a similar origin.

The gold-bearing veins with high-grade shoots at the Apex-El Nido mine, on Chichagof Island, are in fissures in aplite dikes which are so altered as to be indeterminate but may have been originally albite aplite or albite trachyte. Albite trachyte dikes are found near by. At the Pinta Bay and Miner Island prospects albite-quartz diorite is the country rock. Gold-bearing lodes are thus associated with highly sodic rocks at several widely separated localities, and the relation suggests that both may have had a more or less common genetic origin and have been dependent upon a certain type of magmatic differentiation. The local association of gold deposits with albite diorite and albite-quartz diorite in the Mother Lode district of California has been described by Turner[16] and Reid.[17] McCann[18] has described an association of gold quartz veins with albitite dikes in the Bridge River area, on the east side of the Coast Range batholith.

Gold quartz veins occur within the igneous rock of several stocks, such as the Jualin diorite stock, in the Berners Bay district; the Lisianski stock of diorite, on Chichagof Island; and the quartz diorite stock on the west side of Twelvemile Arm, Prince of Wales Island. Quartz veins with gold-silver-lead shoots whose predominant value is in lead occur within the Texas batholith of granodiorite, in the Hyder district. This batholith must have had a relatively low percentage of water, as is indicated by its pronounced gneissic structure, the occurrence of hornblende almost to the exclusion of biotite, the practical lack of pegmatite dikes, the lack of contact metamorphism, and the sparseness of aplite dikes and their restriction to a zone within 500 feet of the contact.

It has been shown on pages 177–181 that there is a progressive though somewhat irregular change in the average character of the igneous rocks from the southwest in the Prince of Wales-Chichagof belt (quartzose diorite) through the Wrangell-Revillagigedo belt (quartz diorite) and the western part of the core of the main batholith (granodiorite) to the northeastern part of the core of the main batholith (quartz monzonite). The question arises whether these rocks, representing as they do increasingly more advanced stages of magmatic differentiation, can be correlated with a corresponding change in metallization.

[16] Turner, H. W., Replacement ore deposits in the Sierra Nevada: Jour. Geology, vol. 7, pp. 389–400, 1899.

[17] Reid, J. A., The east country of the Mother Lode: Min. and Sci. Press, vol. 94, pp. 279–280, 1907.

[18] McCann, W. S., Geology and mineral deposits of the Bridge River map area, B. C.: Canada Geol. Survey Mem. 130, p. 67, 1922.

The largest number of copper deposits are on Prince of Wales Island, where they are associated with rocks which, as exposed, represent an intermediate stage in the differentiation sequence of southeastern Alaska and which occur as small batholiths, stocks, and sheets. These rocks are described on pages 183–186. Their average composition is approximately that of a quartzose diorite. Gold veins are also common in this belt. Magnetite or pyrrhotite is associated with the copper deposits to such an extent that copper and iron may be said to be the predominant metallic elements.

To the east, between the Prince of Wales-Chichagof belt and the Coast Range batholith, is the Wrangell-Revillagigedo belt of intrusive rocks, in which, on the average, a more advanced stage of differentation is represented and the igneous rocks have the average composition of quartz diorite. Metalliferous deposits in this belt are relatively sparse, though quartz veins are abundant. Gold is predominantly the metal sought in what mineral deposits there are. Only two copper deposits are reported in this entire belt. The gold veins are mainly in the western part of the belt adjacent to the batholith. The intensely recrystallized metamorphic rocks represent relatively high temperature and high pressure; and it seems probable that the chief causes of the relative absence of metalliferous deposits here may be temperature and pressure and the schistose character of the rock. Many zones impregnated with sulphides of iron carrying a little gold occur in the schist, and it is possible that the gold was disseminated through a large volume of rock rather than concentrated in workable veins. The Wrangell-Revillagigedo belt may overlie an upward outward major bulge in the batholith where most of its upper surface is now at only shallow depths and the exposed stocks and batholiths are equivalent to hills on its surface. The country rock immediately above the batholith would be relatively highly heated by conducted heat and by the passing of highly heated vapors, and the metals might not be deposited in concentrated form until the solutions reached a less schistose and cooler rock higher up, which has since been eroded.

The Wrangell-Revillagigedo belt of schist and gneiss, with its associated abundant intrusive rocks, dies out toward the northwest. Its place is taken by the Juneau gold belt, with slate, graywacke, dynamically metamorphosed schistose greenstone, and relatively sparse associated intrusive rocks similar to those of the Prince of Wales-Chichagof belt. This decrease in number of intrusive bodies, their change in character, and the decrease in metamorphism and practical disappearance of aplitic injection gneiss are explicable on the assumption that the Wrangell-Revillagigedo bulge in the batholith has an irregular shelf or terrace-like form and drops away relatively abruptly northwest of Thomas Bay, giving the western border of the batholith in the Juneau district a very steeply plunging slope that carries it to great depth. The rocks that now form the Juneau gold belt would therefore have been at a greater distance above the batholith and in a cooler environment than those to the southeast; what intrusive bodies there were would extend a long way vertically from their source, and the same would be true of the auriferous quartz veins. Such a hypothesis would suggest that temperature was the determining factor and that the ore deposits and the exposed dioritic and sodic intrusive rocks were both genetically associated with a common deeper-seated magma. Copper deposits are rare, perhaps in part owing to the relatively few intrusive stocks and in part to the character of the intrusions or of the country rock. Copper occurs in limestone and schistose greenstone at Point Astley and at William Henry Bay, on Lynn Canal.

Very few mineral deposits have been discovered in association with the quartz diorite of the western part of the batholith. There is a copper-zinc deposit at Tracy Arm and zinc and silver-lead deposits at Groundhog and Glacier Basins, east of Wrangell. The deposits at Groundhog and Glacier Basins are associated with quartz porphyry sheets, and it might be questioned whether they are genetically connected with the quartz diorite or with the porphyry. There is a silver-lead deposit on Whiting River. To the southeast,[19] near Vancouver, in British Columbia, there is a zinc deposit with some galena at the contact with a basic marginal variant of the quartz diorite, and between Powell River and Lund there is a prospect in which zinc is the prevailing metal. Copper deposits are also known. The data are too few to afford adequate evidence as to what is the predominant type of metallization in association with the western portion of the batholith. The occurrence of two contact-metamorphic zinc deposits is in marked contrast to the typical copper-iron contact deposits of the Prince of Wales belt. The few data available suggest that copper and zinc and to a lesser extent gold and silver-lead prevail.

The rocks within the core of the Coast Range batholith are predominantly granodiorite and quartz monzonite, with local developments of quartz diorite and other types, and they represent on an average a more advanced stage of differentiation than the rocks of the western border. Relatively few metalliferous prospects are known. The copper deposits of Anyox and Maple Bay, on Portland Canal, British Columbia, are the best known. Silver-lead and zinc, copper, and lead veins are found in the included sedimentary belt along Unuk and Iskoot Rivers. The known metallization is such as

[19] Brewer, W. M., Some ore deposits of the Coast Range: Canadian Inst. Min. and Met. Monthly Bull., vol. 127, pp. 1176–1191, 1922.

to suggest an increasing abundance of lead in the form of galena relative to zinc and copper.

The northeastern border belt of the Coast Range batholith between Portland Canal and Chickamin River is quartz monzonite. Quartz fissure veins carrying hematite or martite and pyrite are found, but no metalliferous deposits of economic value are known within this belt.

In the belt east of the batholith there are locally outlying masses of intrusive rock, but information as to their exact character is lacking. The problem is further complicated by the presence of Jurassic or Lower Cretaceous intrusive rocks of two ages. However, a number of stocks are known which consist predominantly of quartz diorite or granodiorite, or quartz monzonite. Galena and tetrahedrite are far more abundant in the veins here then in any other belt, and sphalerite and chalcopyrite are common. Native silver, pyrargyrite, proustite, and argentite are valuable ore minerals, but they are thought to have been formed mainly through processes of enrichment and are only in small part of primary origin. The metallization is marked by the relative predominance of silver and silver-lead ores in contrast to any of the other belts. Gold and base-metal (copper, lead, and zinc) lodes are also common. Mineral deposits with galena in association with typical contact-metamorphic minerals such as andradite garnet are reported to occur on Stikine River near Devils Elbow.

Green-gray to green-black dike rocks cut across many of the ore bodies. In part these dikes are of lamprophyric character, in part they may be younger basalt dikes of Tertiary age, and in part they may be malchite dikes genetically associated with a younger facies of the Coast Range batholith, as in the Salmon River district.

From the foregoing description it would appear that certain types of metallization are characteristic of certain belts and that the changes in the predominant types of metallization from one belt to another are in part coincident with changes in the predominant type or types of associated igneous rocks. But the type of metallization within a given belt is not wholly uniform; for instance, lead deposits and silver-lead veins are known within the Prince of Wales copper-iron belt. Neither is the composition of the igneous rocks within a given belt completely uniform; albite-quartz diorite or granodiorite occurs within the Prince of Wales belt where andesine diorite or quartzose dioritic rocks predominate, and diorite is found within the core of the Coast Range batholith where granodiorite and quartz monzonite predominate. If the stage or type of magmatic differentiation is a determining factor in the type of associated metallization we should therefore expect to find as wide a range in the types of metallization within a belt as in the types of igneous rocks within that belt.

The known facts do not prove whether the change in the type of metallization is genetically related to the difference in stage of magmatic differentiation represented by the associated or underlying rocks, or whether the magmatic differentiation is only one of a number of factors; or whether the relation is one of mere fortuitous coincidence and some other factor or factors, such as temperature or rock type, and mode of occurrence of the igneous mass, has exercised the predominant control.

MODE OF OCCURRENCE OF IGNEOUS MASS

Emmons [20] has classified mineral deposits with relation to the contour of the roof of the parent batholith—that is, with respect to the mode of occurrence of the genetically associated igneous mass. This grouping is given below:

1. Cryptobatholithic, near hidden batholiths which have not been exhumed by erosion.
2. Acrobatholithic, in and near cupolas or domes of batholiths, high points of larger underlying masses.
3. Epibatholithic, on batholiths, near their rims but below eroded cupolas or below the highest points of the roofs.
4. Embatholithic, among closely spaced outcrops which are probably parts of a single batholith. The outcrops of invaded rocks predominate.
5. Endobatholithic, in and near roof pendants of large batholiths. The invading rocks predominate.
6. Hypobatholithic, in deeply eroded batholiths where even roof pendants have been eroded.

In a general way the mineral deposits of the eastern border belt are in groups 2 and 3, acrobatholithic and epibatholithic; those of the Prince of Wales-Chichagof belt are in groups 3 and 4, epibatholithic and embatholithic; those of the Wrangell-Revillagigedo belt are in groups 4 and 5, embatholithic and endobatholithic; and those of the Coast Range batholith belt in groups 5 and 6, endobatholithic and hypobatholithic.

Emmons [21] gives a diagram, reproduced here as Figure 3, which shows the relative amounts of metals developed, as a rule, in each of the six groups.

The mineral deposits within the belts described in this paper conform in a general way to the appropriate mineralization for the type to which they belong, as described by Emmons, with the exception of the Coast Range batholith belt. Within this belt, according to Emmons's table, gold should predominate, but so far as the present information goes, this is not the case. Emmons says, how-

[20] Emmons, W. H., Relations of the disseminated copper ores in porphyry to igneous intrusives: Am. Inst. Min. Eng. Trans., vol. 75, pp. 797–809, 1927.

[21] Emmons, W. H., Relations of metalliferous lode systems to igneous intrusives: Am. Inst. Min. Eng. Trans., vol. 74, p. 33, 1926.

ever, that in the endobatholithic group "gold deposits greatly predominate, but a few valuable copper deposits and a small number of lead, silver, zinc, and other metals are found." Emmons states further that in groups 2 and 3 gold deposits are commonly found around and outside of the area of copper deposits, but that in group 4 the order may be reversed, with gold close to the batholith and copper farther out. Emmons's generalizations suggest that in the prospecting of the Coast Range batholith gold deposits might be sought for in the vicinity of included blocks of country rock.

Within each group of deposits, as classified by Emmons according to their environment, the stage and type of differentiation reached by

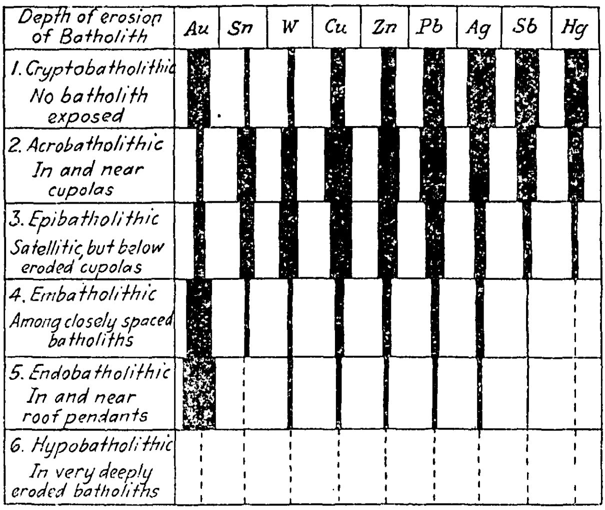

FIGURE 3.—Diagram showing the relative amounts of different metals deposited in lodes at six different positions on their parent batholiths. (After W. H. Emmons)

the intrusive magma must differ considerably within the same or different regions. Certainly this must introduce a factor that tends, even though only in a slight degree, to modify the character of the accompanying mineralization.

TEMPERATURE AND PRESSURE

All the metalliferous deposits associated with the intrusive rocks of Upper Jurassic or Lower Cretaceous age have been formed under conditions of intermediate to high temperature, as indicated by their associations and mineral content and by the type of alteration of the wall rock accompanying the introduction of the veins. They have been formed throughout a vertical distance of 5,000 feet, as determined by actual observation, and by inference throughout 10,000 feet or more. They must have crystallized at considerable depth, for, so far as we know, erosion has been taking place over the uplands ever since the intrusion of the Coast Range igneous masses in Upper Jurassic or Lower Cretaceous time. They are therefore intermediate to deep-seated and were formed under high pressure.

Schofield[22] has discussed the occurrence of different types of metallization in belts in British Columbia as follows:

> There are two main mineral belts in British Columbia separated from each other by an elongated and curved area of granite batholiths belonging mainly to the early part of the Mesozoic era. This mass includes the Coast Range batholith and the majority of the batholiths occurring in the southern part of British Columbia. The belt which follows along the Pacific coast, including the island fringe, may be called the Pacific mineral belt; that on the eastern side of the same batholith the Interior mineral belt. It will be remarked that the two belts differ in the mineralogical composition of their ore bodies. The ore deposits of the Pacific belt are sought mainly for their copper content; those of the Interior belt are sought mainly for their gold, silver, and lead content. * * *
>
> The reason for the separate occurrence of copper on the one border and of gold, silver, and lead on the other border of the great complex of igneous intrusions is not at once apparent. A fact that may throw some light on the subject is that the copper deposits resemble conditions of high temperature and pressure, even bordering on those of contact deposits, whereas the gold-silver and silver-lead deposits are usually, though not always, associated with fissure veins filled under conditions of a moderate temperature and pressure. * * * Not only is there a contrast between the ore deposits on the two sides of these batholithic masses but also a contrast in the degree of metamorphism exhibited by the prebatholithic rocks.

The Wrights[23] ascribe the greater metamorphism on the west flank as compared with the east flank to deeper burial at the time of intrusion of the batholith. Schofield,[24] on the other hand, thinks that the difference in types of metallization and metamorphism is due not to deeper burial on the west as compared to the east but to differences in the slope and relations of the upper surface of the batholith to the present topographic surface. He assumes that, owing to relatively less deep erosion, a relatively flat upper surface of the batholith is present at or beneath the surface on the west and, owing to deeper erosion, a steeply plunging contact on the east. Thus on the east the veins, except a few adjacent to the batholith, would be at considerable heights above the batholith, in a cooler zone, and would be of intermediate-temperature type, whereas those on the west would everywhere be only a relatively short distance above the surface of the batholith and therefore in a hot zone and of the high-temperature type.

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[22] Schofield, S. J., and Hanson, George, Geology and ore deposits of Salmon River district, B. C.: Canada Geol. Survey Mem. 132, pp. 63–64, 1922.

[23] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 65–68, 1908.

[24] Schofield, S. J., and Hanson, George, op. cit., pp. 65–66.

Schofield's broad generalizations for British Columbia need to be considerably modified to be adaptable to the phenomena in southeastern Alaska. Slopes on the west side of the batholith are locally just as steep as those on the east side, and it seems probable that the differences are original and are not due to differences in depth of erosion. The main copper belt here is not associated directly with the western border of the batholith but with a belt of outlying stocks that are in general considerably more basic. A gold belt lies between the copper belt and the batholith, and zinc as well as copper appears to be abundant along the western border of the batholith. Schofield's explanation would make temperature conditions at the time of deposition the controlling factor in causing the differences in type of metallization found within the separate belts. This is also the factor considered in general to be of major importance in producing the variation in metallization of veins at increasing distances from a magmatic center with which they are connected, and also in producing the variation in metallization of veins with increasing depth—types of phenomena both of which are found in many other metalliferous regions. The sequence in the types of predominant metallization in southeastern Alaska is similar to the usual sequence of ores occurring in zones, in both a vertical and a horizontal sense, the high-temperature iron-copper-gold types being on the southwest, nearer the magmatic center, and the intermediate-temperature silver-lead-gold types on the northeast. These relations, therefore, seem to support Schofield's hypothesis, and there is no doubt that temperature is a major factor in the problem.

The relation of the western border of the batholith to the Juneau gold belt is similar to the relation of the eastern border of the batholith to the gold-silver-lead belt as described by Schofield. The gold veins in the Juneau belt are classified as high-temperature veins by Lindgren, though they must be close to the border line of intermediate-temperature veins, and the gold-silver-lead veins of the Salmon River district are intermediate. Temperature may therefore be a chief cause of the difference between them, though the degree of differentiation of the genetically associated magmas may also have been a cause.

The occurrence of contact copper deposits in the belt of dioritic rocks on Prince of Wales Island, of contact zinc deposits with the quartz diorite of the western border of the batholith, and of a contact lead-bearing deposit on the eastern border of the batholith associated with quartz monzonite, all in limestone, necessitates an appeal to some factor other than temperature to explain such differences in metallization. This factor may be original differences in the composition of the magmas or in the stage of magmatic differentiation with which the ore deposits were genetically connected. The magma that produced the lead deposit may itself have been at a lower temperature than the magma that produced the copper deposits, but both kinds of deposits are associated with typical contact-metamorphic minerals.

The origin of the contact deposits of Prince of Wales Island has been described by Wright[25] as follows:

In the limestone tremolite (or wollastonite) and diopside were formed by the introduction of silica; later, and in part contemporaneously, garnet was formed by the combination of lime (already present) with silica, ferric iron, and alumina, introduced by solution. While the quartz and feldspars were being removed from the diorite calcite, garnet and pyroxene (diopside) were added. Afterward chalcopyrite and pyrrhotite replaced part of the calcite in the contact zone without notably affecting the other minerals. Later the fissures, which probably held the solutions during the period of active metamorphism, were filled with pyrite, chalcopyrite, magnetite, and the other minerals above enumerated. Finally upon the older vein minerals were deposited notably zeolite and calcite. * * *

The garnet, some of which probably formed almost contemporaneously with the wollastonite, is a variety having distinct double refraction. Experiments made with this garnet by Doctor Merwin at the Geophysical Laboratory of the Carnegie Institution of Washington show that it loses its birefringence after it has been heated for a few hours at about 800° C., and does not regain it after several hours heating at 600° C. This fact indicates that most of the metamorphism took place at temperatures lower than 800° C.

Quartz occurs in the contact zone only in veins. Tests made on some of this vein quartz by F. E. Wright * * * indicated that it was formed at temperatures below 575° C.

Eskola[26] quotes Goldschmidt as authority for the statement that where wollastonite is present the temperature during metamorphism has exceeded a certain limit that varies with the pressure. At atmospheric pressure this limit should be about 500° C.; at increasing pressure the limit would rise, at first rapidly, then more and more slowly, being about 850° C. at 300 atmospheres and 950° C. at 15,000 atmospheres. The temperature during the period of contact metamorphism, therefore, probably lay between 500° C. and 800° C.

HYDROTHERMAL ALTERATIONS IN THE IGNEOUS ROCKS

The igneous rock of the Coast Range batholith is in general only very slightly altered except in local areas where metalliferous veins are present. The alteration products commonly found include chlorite altered from biotite in such a way as to resemble parallel intergrowths of biotite and chlorite and probably formed at a late mag-

[25] Wright, C. W., Geology and ore deposits of Copper Mountain and Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 108, 1915.

[26] Eskola, Pentti, On the petrology of the Orijarvi region in southwestern Finland, pp. 160–162, Helsingfors, 1914.

matic stage, chloritically altered hornblende, here and there plagioclase slightly sericitized, and very rarely a bit of muscovite replacing biotite.

The outlying stocks of granodiorite, monzodiorite, and diorite, however, commonly show a noteworthy degree of alteration, at some places with accompanying metallization, at some places without. The feldspars and ferromagnesian minerals are considerably altered epidote with some zoisite and flecks or aggregates of sericite. Many of the very small stocks and the sheets and dikes are so altered that the determination of the original character of the rock is in doubt. The albite-leucoquartz diorite bodies are as a rule very highly altered, and muscovite is as abundant as epidote and zoisite in these smaller altered masses. A peculiar character of these alterations is that most of the potassic feldspar is fresh and unaltered, and the biotite is fresh and only sparsely replaced by epidote.

In a belt adjacent to Stephens Passage, from Port Houghton north to Point Astley, the igneous rocks have been subjected to considerable crushing and the inclosing schist has been isoclinally folded and plicated. The minerals of the igneous rocks have been almost entirely replaced by muscovite and zoisite with a little epidote or by muscovite and epidote with a little zoisite. The muscovite is commonly in plates forming a latticework parallel to the cleavage of the feldspar. The potassic feldspar is practically unaltered. On the contrary, many other highly mashed shear zones in the ultrabasic and more alkalic-siliceous granitic rocks, both in the stocks and within the Coast Range batholith itself, do not show any intensification of alteration.

Alterations such as those noted would suggest that the invading solutions were of magmatic origin, highly heated, and with a relatively high potassic content to form the high-potassium mica muscovite and to leave relatively unaltered the iron-potassium mica biotite and almost completely unaltered the potassic feldspars microperthite, microcline, and orthoclase. These alterations, at most places, do not appear to have been associated with metalliferous veins.

On the other hand, in all the areas of intrusive rocks of Upper Jurassic or Lower Cretaceous age in which metalliferous veins occur the rock is more or less highly altered and has a consequent dull, dead appearance even on a fresh surface. Areas of such rock warrant prospecting.

In the Hyder district the belt of quartz diorite and granodiorite in which the gold-silver-lead quartz veins occur is much altered. The plagioclase is partly to completely altered to sericitic aggregates with associated epidote and carbonates, and the hornblende and biotite are altered to chlorite with associated epidote, zoisite, ilmenite, and locally muscovite or biotite. The potassic feldspars are practically unaltered. The quartz is usually strained and ribboned by stress and crushing.

Similarly, the belt of the Lisianski stock of diorite on Chichagof Island in which the auriferous quartz veins occur is considerably altered. Veinlets of yellowish-green epidote and white zoisite are common. Adjacent to the veins the feldspars are almost completely altered to aggregates of sericite with a little chlorite and carbonate. Sericite, epidote, carbonates, and chlorite, with a little ilmenite, are the common alteration minerals.

The hydrothermal alteration of the adjoining igneous rocks that accompanied the invasion of the metalliferous vein-forming solutions in the Juneau gold belt at the Treadwell mine, in the Jualin diorite, and in other igneous rocks has been described in detail by Spencer [27] and Knopf.[28]

At the Treadwell mine the original rock contained albite-oligoclase, microperthite, a little hornblende, and biotite. The original minerals are clouded with alteration products, and the secondary minerals include abundant albite (which in part replaces or veins microperthite), quartz, calcite, sericite, epidote, zoisite, chlorite, uralite, rutile, magnetite, and introduced sulphides.

In the Jualin diorite, according to Knopf, the general course of the alteration consisted in the chloritization and destruction of the ferromagnesian minerals, the partial sericitization of the plagioclase feldspar, the formation of albite, and the introduction of carbonates (dolomitic in part) and pyrite. Away from the most intensely altered parts epidote and chlorite appear as alteration products of the hornblende and epidote of the plagioclase. The biotite is partly chloritized. Knopf writes:

> The chemical work done by the ore-depositing agencies shows that they were hot ascending solutions carrying carbon dioxide, sulphur (probably as hydrogen sulphide), silica, potash, gold, iron, and several heavy metals in small quantities, and doubtless other constituents that have left no record. * * * At one locality the solutions were capable of causing the formation of tourmaline as well as producing sericitization and carbonatization.

In the Eagle River region, near a network of auriferous veinlets, as described by Knopf, an amphibolite consisting mostly of actinolite with associated epidote and albite and a little biotite has been altered to an aggregate of albite and biotite with considerable associated

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[27] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, pp. 99–103, 1906.

[28] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 36–41, 1912; Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, pp. 31–34, 1911.

zoisite and new apatite. It is believed that the chemical changes were a large addition of soda and potash for the formation of albite and biotite, heavy losses in magnesia, lime, and iron, and an enrichment in phosphoric pentoxide to form apatite.

The work of Spencer and Knopf shows that in the Juneau gold belt albitization was a common and noteworthy mode of alteration of the wall rock and that sericite, epidote, zoisite, chlorite, and carbonates were other common secondary minerals formed. Locally rutile, apatite, or tourmaline was introduced, or a biotite-albite rock with zoisite was formed from an amphibolite with associated epidote and albite.

Throughout the crystalline schist and much of the phyllite tourmaline and apatite occur as accessory minerals in a manner suggesting that they have been introduced by solutions or vapors which permeated them. Albite similarly appears to have been introduced into schist during its metamorphism at many places, as in the belt containing auriferous quartz veins between Funter Bay and Hawk Inlet, on Admiralty Island.

The rocks in which the nickel deposits occur are in places considerably altered. At the Bohemia Basin claims, on Yakobi Island, and at the deposit on Funter Bay pyroxene and olivine have locally been altered to or veined by serpentine. This alteration was later than the introduction of the sulphides. Kerr[29] reports that at the Alaska Nickel mines, on Chichagof Island, the hornblende and pyroxene are locally replaced by tremolite that is later than the sulphides. These phenomena indicate that in these deposits the sulphide masses bearing nickel and copper are of magmatic origin, and that their segregation and concentration preceded the stages of hydrothermal alteration and tremolitic replacement.

CONCLUSIONS

On the whole, the phenomena are too complex and the data at hand are insufficient for an evaluation of the relative influence upon type of metallization of such factors as rock character and structure, stage or type of magmatic differentiation, mode of occurrence of the associated igneous rock and of the mineral deposit, and temperature and pressure. All the factors mentioned must enter to some extent into the formation of every deposit, and further study of the problem must await more detailed investigations and more extensive knowledge of territory that is as yet geologically unknown and unprospected.

[29] Kerr, P. F., A magmatic sulphide ore from Chichagof Island, Alaska: Econ. Geology, vol. 19, p. 375, 1924.

LIMESTONE[30]

The development of a pulp and paper industry in southeastern Alaska will cause a demand for limestone for use in the manufacturing processes. It is reported (1928) that the Pacific Coast Cement Co. has installed a large plant for the manufacture of cement at Seattle and that the limestone is to be quarried at View Cove, on Dall Island, Alaska, and brought to Seattle by vessel. The successful development of uses for limestone in southeastern Alaska will be of great benefit to that region, as large quantities of high-grade limestone are available at or near tidewater, in situations favorable both for a harbor and for quarrying.

The largest areas and thickest beds of uniformly pure, very high calcite limestone occur in the islands off the west coast and at the north end of Prince of Wales Island. They are of Silurian age. Silurian limestone forms many of the islands in the Kashevarof group, in Clarence Strait. On the north end of Prince of Wales Island it forms the marble beds at Calder and El Capitan, in Dry Pass; the Mount Calder Range, which extends northwest from Calder Bay to Labouchere Bay; the coast north of the Barrier Islands; the east side of Port Protection; several miles of coast 1½ miles east of Point Baker; the coast in the vicinity of Red Bay nearly as far east as Point Colpoys; and a belt north of Sarheen Cove and west of Aneskett Point, on El Capitan Passage. The largest area in which this limestone is exposed lies in the vicinity of Davidson Inlet and Sea Otter Sound and includes most of Kosciusko, Marble, Orr, Tuxekan, Eagle, White Cliff, Owl, Hoot, and Heceta Islands, the east side of Tuxekan Passage in the vicinity of Tuxekan, and the southern part of Staney Island. The limestone is exposed also on Dall Island and forms belts that strike northwest from Breezy Bay to the Diver Islands, from View Cove to Cape Lookout, and probably from Howkan to Waterfall Bay. On Long Island, in Cordova Bay, it forms two belts striking northwest across the island. On Kuiu Island it forms Beauclerc Peak; it is exposed on the passage south of Edwards Island; and a fine belt forms the range of mountains along the southwest side of Saginaw Bay. On Chichagof Island it is found at Basket Bay, Tenakee Inlet, and Freshwater Bay. In Glacier Bay a great range of coarsely crystalline upper Silurian limestone runs through Willoughby and Drake Islands and the east side of Rendu Inlet.

The Silurian limestones are in part of a dense texture and massive, in few places, if anywhere, showing any evidence of bedding; in part they are massive limestone and interbedded thin-layered lime-

[30] This section is reprinted with slight revision from Buddington, A. F., Mineral investigations in southeastern Alaska: U. S. Geol. Survey Bull. 783, pp. 58–61, 1926.

stone and nodular and shaly limestone, with calcareous shaly argillite, green-gray shale, and sparse buff-weathering sandstone. The massive limestone occurs in uniform beds as much as 2,000 feet thick. The fresh rock is white, but the usual color of the weathered surface is a pallid brown. The rock is in most places intensely fractured, and the fractured surfaces are coated with a thin facing of calcite or rarely dolmite, which at many places weathers out in relief as a network of veinlets. Conglomerate beds are commonly associated with the thin-layered zones. Where the limestones are intruded by igneous rocks they are recrystallized and form fine to coarsely crystalline limestones, some of which afford fine marble, as at Tokeen, on Marble Island, and at Calder and El Capitan, on Dry Pass, Prince of Wales Island. The Silurian limestones of Glacier Bay and Chichagof Island are likewise recrystallized by the contact-metamorphic action of intrusive masses.

The Silurian limestones are prevailingly high-calcite limestones with 95 to 99 per cent of calcium carbonate. Of the 11 analyses given in the table on page 393, 8 show 96 per cent or more of $CaCO_3$. It is certain that large quantities of very high grade limestone are available in this formation.

Regarding the limestone on the property of the Pacific Coast Cement Co., on Dall Island, Mr. S. E. Hutton, chief engineer of the company, states[31] that

sampling and diamond drilling has proved the limestone to be of remarkably uniform composition, falling in a very few instances to 95 per cent calcium carbonate and rising in many instances to 99 per cent calcium carbonate. An average of a very large number of samples in the district we propose to work first showed insoluble 1.09 per cent, combined iron and aluminum oxides 0.42 per cent, calcium oxide 53.87 per cent, magnesium oxide 0.69 per cent, as calcium carbonate 96.13 per cent. The average over the whole territory was about 97.5 per cent calcium carbonate.

Limestones of pre-Silurian age in beds from 100 to several hundred or even 1,000 feet thick, as well as a great many thinner beds, occur within a series of schist and greenstone in the vicinity of Sulzer and Copper Mountain and at the head of Cholmondeley Sound, on Prince of Wales Island. The limestone ranges from a white, coarsely crystalline marble to a dark-blue or nearly black limestone that is finely crystalline to granular or locally thin bedded and slaty. The only available analysis is that of a pure magnesian or dolomitic limestone (No. 20 in the table below).

Limestones of Devonian age in beds as much as 600 feet thick are exposed on Long and Round Island, in Kasaan Bay, Prince of Wales

[31] Personal letter to A. F. Buddington, dated Mar. 15, 1928.

Island, and on the islands in San Alberto Bay, opposite Klawak. On Kupreanof Island they are found at the head of Duncan Canal, along the center and west arms, and at the head and along the east side of Emily Island Arm. No chemical analyses of these limestones are available. Some of the limestones in San Alberto Bay seem to be fairly pure, and all are worthy of investigation if their geographic location should make it desirable.

Limestones of Permian age form much of the Keku group of islands and the adjacent shore of Kuiu Island. They also form the line of conspicuous bluffs along the northeast side of Saginaw Bay, on Kuiu Island. They occur in a narrow belt on the mainland in the Juneau district, cropping out along the shore at Point Anmer, at the entrance to Port Snettisham, and striking inland to the southeast. Permian limestones are also exposed in Pybus and Gambier Bays, on Admiralty Island. The Permian limestones, which are about 1,000 feet thick, usually have intercalated layers of chert. Locally, however, thick clean beds are present. On the island opposite the cannery on the east side of Saginaw Bay, Kuiu Island, there is a steep, high bluff of clean limestone. An analysis of a typical specimen (No. 14) shows it to be a high-calcite limestone.

Limestones of Triassic age crop out east of Point Cornwallis, on Kuiu Island, and probably form much of the peninsula inland. An analysis of a specimen obtained about 3 miles southwest of Point Cornwallis, on Keku Strait (No. 15), shows the rock to be an impure calcite limestone that contains about 11 per cent of insoluble matter. Upper Triassic limestones are exposed on the islands in Hamilton Bay, Kupreanof Island; on the Screen Islands, in Clarence Strait; on the west side of Gravina Island; and in Pybus and Gambier Bays, Admiralty Island. These limestones are usually medium to thin bedded and have intercalated layers of black slate. They are probably in the main impure argillaceous and siliceous calcite limestones.

Analyses of limestones from southeastern Alaska

	Locality	Calcium carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Insoluble
	BEDS OF SILURIAN AGE			
1	White marble, Tokeen, Marble Island, Ketchikan district	99.51	0.94	0.01
2	Veined marble, Tokeen, Marble Island, Ketchikan district	81.90	14.93	.20
3	Dark veined marble, Orr Island, Ketchikan district	95.90	1.40	3.50
4	Mottled dark marble, Orr Island, Ketchikan district	95.35	2.04	2.95
5	Limestone, north side of Heceta Island, Ketchikan district	84.46	13.18	13.18
6	Limestone, southwest end of Orr Island, Ketchikan district	98.99	1.01	.12
7	Limestone, north side of Heceta Island, Ketchikan district	99.12	.63	.37
8	Marble, head of Red Bay, Prince of Wales Island	96.90	2.59	1.70
9	Marble, Marble Creek, north of Shakan, Prince of Wales Island	99.26	.63	Trace.
10	Mottled marble, south of Sandy Cove, Glacier Bay	96.16	.89	2.56
11	Marble, near Waterfall Bay, Dall Island	99.59	1.03	.32
	BEDS OLDER OR YOUNGER THAN SILURIAN			
12	Marble, Dickman Bay, Prince of Wales Island	74.61	3.25	22.84
13	Dark-green marble, Dickman Bay, Prince of Wales Island	58.40	6.61	37.32
14	Bluff of Permian limestone at southwest end of island opposite the cannery on the east side of Saginaw Bay, Kuiu Island	96.82	.63	2.79
15	Triassic limestone, about 3 miles southwest of Point Cornwallis on Keku Straits, Kuiu Island	87.19	.84	11.32
16	Talcose marble, Lake Virginia, mainland, east of Wrangell	53.69	26.10	19.06
17	Graphite marble, Basket Bay, Chichagof Island	63.68	8.90	28.19
18	White marble, north side of Marble Cove, Admiralty Island	61.11	39.10	.91
19	White marble, south of Marble Cove, Admiralty Island	95.44	1.45	3.61
20	Limestone, near Jumbo mine, Copper Mountain region, Prince of Wales Island	82.75	15.62	1.84

Analyses 1, 5, 8, 10, 13, and 16–19 made by R. K. Bailey for E. F. Burchard; 6, 7, 14, and 15 by J. G. Fairchild for A. F. Buddington; 9 by E. F. Lass for the Alaska Marble Co.: 20 by George Steiger for C. W. Wright.

BUILDING AND ORNAMENTAL STONE

Wright[82] reports:

The granitic intrusive rocks occupy about one-half the aggregate land area of southeastern Alaska. * * * The metamorphism in the granite, its nonuniformity in color, and the presence of joint cracks, so far as observed, make most of the stone undesirable for building purposes. However, granitic masses of good quality, uniform in color, and favorably located for purposes of quarrying, were observed along the mainland up Portland Canal, in Behm Canal, at Thomas Bay, and Taku Inlet. On Baranof Island exposures of this rock of similar good quality occur at Gut Bay, on the east side, and at the head of Whale Bay and near Silver Bay, on the west side. * * * The prevailing color of the granite rock is a light gray and only in a few places were pink or reddish masses observed. The grains of the component minerals are ordinarily of medium size. * * * Evidence of the durability of the granite is afforded in many places where exposure to the influence of weathering has caused little or no disintegration of the surface.

Numerous stocks of granitoid igneous rocks occur on the islands, parts of which are massive and of uniform texture, though segregations of dark minerals, included fragments of country rock, and disseminated pyrite are present in many places and render the rocks less desirable as building stone.

[82] Wright, C. W., Nonmetalliferous mineral resources of southeastern Alaska: U. S. Geol. Survey Bull. 314, pp. 77–78, 1907.

The masses of true granite, such as those on Canoe Pass, Etolin Island, and elsewhere in the Alexander Archipelago, are massive and uniform and have a characteristic pink color, in contrast to the light gray of the more dioritic rocks referred to by Wright.

Chapin describes certain of the serpentine and ultrabasic rocks of the Duke Island group, in the Ketchikan district, as being suitable for ornamental building stone and as giving a very pleasing effect when polished. In the serpentinized areas some of the rock is green, some is colored black by the presence of considerable magnetite, and some shows a combination with pale-green diopside. The rock composed of pure diopside without serpentine is pale green and somewhat translucent and takes a brilliant polish. Handsome combinations and great variety might be obtained by selecting rocks containing different amounts of the constituent minerals, diopside, olivine, and the magnetite-bearing serpentine, thus combining the different shades of green and black.

The marble deposits of southeastern Alaska have been described by Burchard.[33] Many types are available, and Buchard reports that there are undeveloped deposits which warrant prospecting whenever the demand for marble on the Pacific coast exceeds the present production. Marble and medium to coarsely crystalline limestone locally form thick beds within the Wrangell-Revillagigedo belt of metamorphic rocks on the mainland. Several such occurrences not described by Burchard are referred to by Buddington.[34] The type which has thus far been exploited commercially on the largest scale is a fine to medium crystalline white to bluish-gray marble with gray to dark-bluish veins, bands, and clouded areas. The new State capitol of Washington is being built of marble from southeastern Alaska.

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[33] Burchard, E. F., Marble resources of southeastern Alaska: U. S. Geol. Survey Bull. 682, 1920.

[34] Buddington, A. F., op. cit., pp. 61–62.

INDEX