Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming are checked below.

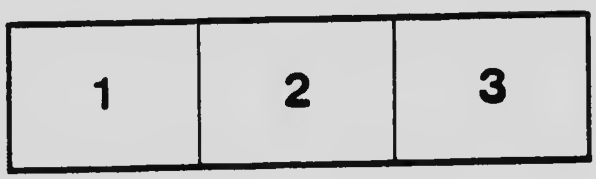
- [x] Coloured covers / Couverture de couleur
- [ ] Covers damaged / Couverture endommagée
- [ ] Covers restored and/or laminated / Couverture restaurée et/ou pelliculée
- [ ] Cover title missing / Le titre de couverture manque
- [x] Coloured maps / Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black) / Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations / Planches et/ou illustrations en couleur
- [ ] Bound with other material / Relié avec d'autres documents
- [ ] Only edition available / Seule édition disponible
- [ ] Tight binding may cause shadows or distortion along interior margin / La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure.
- [ ] Blank leaves added during restorations may appear within the text. Whenever possible, these have been omitted from filming / Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [x] Additional comments / Commentaires supplémentaires: Various pagings.

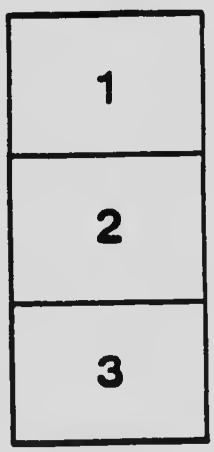
L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

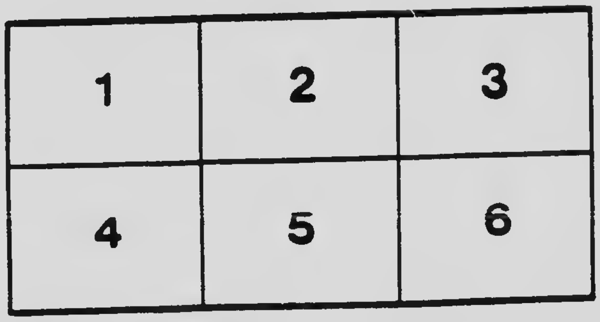
- [ ] Coloured pages / Pages de couleur
- [ ] Pages damaged / Pages endommagées
- [ ] Pages restored and/or laminated / Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed / Pages décolorées, tachetées ou piquées
- [ ] Pages detached / Pages détachées
- [x] Showthrough / Transparence
- [ ] Quality of print varies / Qualité inégale de l'impression
- [ ] Includes supplementary material / Comprend du matériel supplémentaire
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image / Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.
- [ ] Opposing pages with varying colouration or discolourations are filmed twice to ensure the best possible image / Les pages s'opposant ayant des colorations variables ou des décolorations sont filmées deux fois afin d'obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below /
Ce document est filmé au taux de réduction indiqué ci-dessous.

10x	12x	14x	16x	18x	20x	22x	24x	26x	28x	30x	32x
							✓				


1
2
3


1
2
3


1
2
3
4
5
6

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)

1.0 2.8 2.5 4.5 5.0 3.2 2.2 5.6 6.3 3.6 2.0 4.0 1.1 1.8 1.25 1.4 1.6

CANADA
DEPARTMENT OF MINES
HON. P. E. BLONDIN, MINISTER; R. G. MCCONNELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

MEMOIR 96

No. 80, GEOLOGICAL SERIES

Sooke and Duncan Map-areas, Vancouver Island

BY

C. H. Clapp

With Sections on the Sicker Series and the Gabbros of East Sooke and Rocky Point

BY

H. C. Cooke

OTTAWA
GOVERNMENT PRINTING BUREAU
1917

No. 1660

Falls of the Cowichan river, over sandstones of the Haslam formation.

CANADA
DEPARTMENT OF MINES
HON. P. E. BLONDIN, MINISTER; R. G. MCCONNELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

MEMOIR 96

No. 80, GEOLOGICAL SERIES

Sooke and Duncan Map-areas, Vancouver Island

BY

C. H. Clapp

With Sections on the Sicker Series and the Gabbros of East Sooke and Rocky Point

BY

E. C. Cooke

OTTAWA
GOVERNMENT PRINTING BUREAU
1917

No. 1660

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

Illustrations.

Sooke and Duncan Map-Areas, Vancouver Island.

CHAPTER I.

INTRODUCTION.

GENERAL STATEMENT.

In response to a demand for information concerning the topography, geology, and natural resources of Vancouver island, owing to its strategic position and rapid development during recent years, the Geological Survey began geological work on the island in 1908 under the direction of the writer. In 1909 a topographical survey was commenced under the supervision of R. H. Chapman, and at the close of 1911 the entire southern part of the island had been mapped on various scales, ranging from about 1 mile to 1 inch to about 4 miles to 1 inch. In 1910 detailed geological mapping, using the topographical maps as a base, was begun under the writer's direction. The geological mapping of three of the map-areas, the Victoria, Saanich, and Nanaimo (scale about 1 mile to 1 inch), was completed in 1910 and 1911, and the geological reports on the map-areas have already been published—Memoir No. 36, 1913, on the geology of the Victoria and Saanich map-areas, and Memoir No. 51, 1914, on the geology of the Nanaimo map-area. During 1912 and 1913 the detail mapping (scale about 2 miles to 1 inch) of the Sooke and Duncan map-areas, adjoining the other three map-areas already completed, was finished and this report, which presents rather fully the facts gathered during field and office work, is the third of the series based on the detailed geological mapping. It is hoped that the geological mapping of the Cowichan Lake and Alberni map-areas (scale about 4 miles to 1 inch) will be undertaken shortly and that eventually the whole of Vancouver island will be mapped both topographically and geologically.

The Sooke and Duncan map-areas are chiefly mountainous and heavily wooded, including the southern part of the greatly dissected plateau, which forms the Vancouver range. The areas contain representatives of nearly all the volcanic, metamorphic, and crystalline rocks of which the range is composed and also areas of the younger (Cretaceous and Tertiary) sedimentary rocks which fringe both coasts. Their geology is, therefore, representative of the geology of the whole of Vancouver island, and indeed with one important exception, the Nitinat formation, virtually all of the known formations of Vancouver island are found in the map-areas; many of the problems suggested by the writer's previous reconnaissance and detailed work on Vancouver island have been solved in these map-areas.

Although the mineral resources of the area are probably not very extensive, they are varied and to a great degree undeveloped. In the Sooke map-area small stocks of gabbro, that are known to be copper-bearing in places, have been mapped and so also has the highly mineralized Sicker series in the northern part of the Duncan map-area. Several large masses of fairly pure, crystalline limestone have been outlined also. Perhaps the negative results obtained in regard to the possibilities for coal and oil in the Cretaceous and Tertiary rocks of the map-area are even more important, for they should have a chastening influence on the extravagant expenditure of words and money in connexion with these supposed deposits.

ACKNOWLEDGMENTS.

The writer is indebted to many residents of Vancouver island for information and assistance, and in particular to the owners of the numerous mineral claims and to the companies exploiting the various mineral deposits. In 1912 the Jordan River Power and Development Company gave the field party much assistance in transportation in the vicinity of Jordan river. Dr. Charles E. Weaver, professor of geology in the University of Washington, carefully studied and determined the Tertiary fossils from Vancouver island, and Dr. W. H. Dall of the United States Geological Survey confirmed Dr. Weaver's determination of the Eocene age of the fossils from the Metchosin

volcanics. Dr. P. H. M. Brinton, professor of chemistry in the University of Arizona, kindly made several chemical determinations, and the Associated Cement Company (Canada) Limited, furnished analyses of the limestone and "shale" used by them in the manufacture of portland cement at Bamberton.

FIELD WORK.

The report is based on the geological field work carried on during the seasons of 1912 and 1913. The geological features were plotted on the Sooke and Duncan topographical maps, prepared in 1910 under the direction of R. H. Chapman, and on the special map of East Sooke peninsula prepared in 1913 by F. S. Falconer. The Sooke and Duncan maps embrace two thirty-minute rectangles or map-areas, and were surveyed on a scale of 1:96,000 (1 inch = 8,000 feet), with topography shown by contours at an interval of 100 feet. For use in the field the maps were enlarged photographically to a scale of 1 mile to 1 inch. Both the topographical and accompanying geological maps are published with the reduced scale of 1:125,000 (about 1 inch = 2 miles). The special map of East Sooke peninsula was topographically and geologically surveyed on a scale of 1:24,000 (1 inch = 2,000 feet) with a contour interval of 20 feet, and is published on this scale. In the field fairly accurate outcrop and drift maps were made and from these bedrock maps have been prepared for publication.

During 1912 an area of 370 square miles, including the southern part of the Duncan map-area and the entire Sooke map-area with the exception of East Sooke peninsula and the southern portion of Rocky Point peninsula, was surveyed. In 1913 the rest of the Duncan map-area, about 500 square miles, was finished, as well as the incompleted portion of the Sooke map-area, about 16 square miles In addition the detailed geological survey of the East Sooke peninsula was made. The field work of this season, although under the supervision of the writer, was almost entirely under the immediate direction of H. C. Cooke, and the portions of this report dealing with the Sicker series in the northern half of the Duncan map-area and with the special survey of the East Sooke peninsula have been written by Mr. Cooke.

During parts of both seasons considerable geological aid was given by Mr. James Caffrey of East Sooke, who has been a very efficient helper in the geological and topographical work on Vancouver island since its initiation in 1908.

LOCATION AND AREA.

The Sooke and Duncan map-areas, as may be seen on the accompanying index map (Figure 1), are situated in the south-eastern part of Vancouver island, although the Sooke map-area,

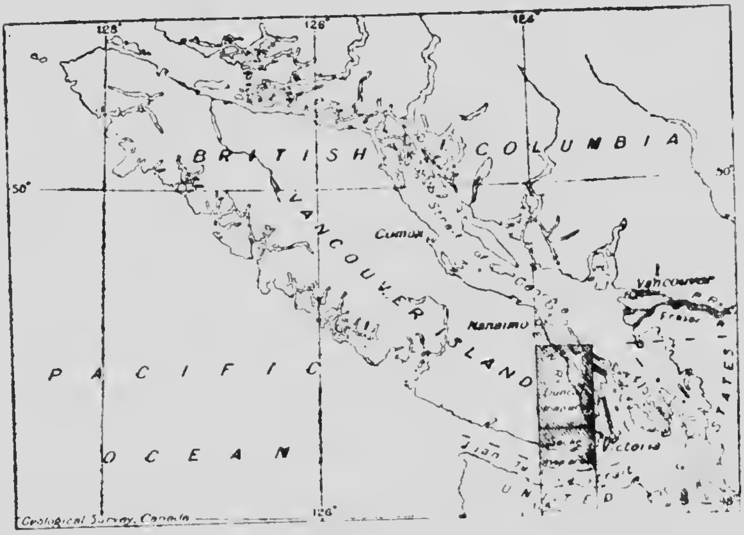


Figure 1. Location of the Sooke and Duncan map-areas.

in its southern part, includes an unmapped portion of the Olympic peninsula of the state of Washington. The map-area consists of the two thirty-minute rectangles between longitudes 123° 30′ and 124° and latitudes 48° (in reality 48° 15′) and 49°. The total land area in Canadian territory is about 900 square miles, about 850 square miles in Vancouver island and about

50 square miles on the smaller islands off the east coast of Vancouver island. This includes the portion of southeastern Vancouver island which lies immediately to the west and northwest of the Saanich peninsula and the vicinity of Victoria, the western half of Saltspring island, portions of Thetis and Galiano islands, and the whole of Kuper island and several other smaller islands in Trincomali and Stuart channels. The following political divisions of Vancouver island are embraced by the map-areas: Chemainus, Seymour, Somenos, Comiaken, Sahtlam, Quamichan, Cowichan, Helmcken, Shawnigan, Otter, Goldstream, Sooke, and Metchosin districts, and parts of Oyster, Cowichan Lake, Malahat, Renfrew, Highland, and Esquimalt districts. The principal towns are Ladysmith, Chemainus, and Duncan, with a population of about 3,500, 250, and 1,300 respectively, all on the east coast of Vancouver island.

PREVIOUS WORK.

Previous to the present investigation no detailed geological work had been done in the Sooke and Duncan map-areas. From 1863 to 1866 Dr. Robert Brown made several scientific explorations on Vancouver island on behalf of the local government and explored a large portion of the map-areas. In 1871 Mr. James Richardson of the Geological Survey commenced a five-year survey of the Cretaceous, coal-bearing rocks of Vancouver island, including some of those of the Duncan map-area, and the rocks of the Sooke formation near Sooke harbour as well. His results are published in the Reports of Progress for the years 1871–72, 1872–73, and 1876–77. His last report summarizes his work, and is accompanied by a map on a scale of 4 miles to 1 inch. In April, 1876, G. M. Dawson of the Geological Survey made a reconnaissance survey of the country in the vicinity of Leech river, paying especial attention to the placer deposits. The result of his work in the southern part of Vancouver island is given in the Report of Progress for 1876–77, and in several papers on the physical, glacial, and general geology of British Columbia. In the summer of 1902 Messrs. Webster and Haycock made a cursory examination of the southwestern coast of the island, including that portion within the Sooke map-area.

Detailed notes on certain mineral claims, mining districts, and mineral industries have been made by the provincial mineralogi. Mr. W. F. Robertson, and by others under his supervision, in the reports of the Minister of Mines of British Columbia. Several magazine articles have been published on the mining districts and mineral industries of the map-areas, the most valuable of which have been listed in the bibliography. Considerable private work had been done by the late W. J. Sutton whose death in May, 1914, is greatly to be regretted, especially as he was about to retire from active business in order to get his information concerning the geology of Vancouver island in shape to publish.

The palæontology of the Cretaceous rocks has been fully described by J. F. Whiteaves in volume I, Mesozoic Fossils, published by the Geological Survey, Part II in 1879 and Part V in 1903; only a few fossils described in the report were from the Duncan map-area. Professor J. C. Merriam described in 1896 fossils collected by Dr. C. F. Newcombe from the Tertiary formations of the southwest coast. In 1912 Mr. Harold Hannibal, under the general supervision of Dr. Ralph Arnold, spent three weeks examining the Tertiary sediments and in collecting fossils from them. The results of the work are given in a paper that is published in the Proceedings of the American Philosophical Society, volume 52, 1913, pages 559 to 605.

In 1908, 1909, and 1910 the writer made reconnaissances over the southern part of Vancouver island, including the larger part of the Sooke and Duncan map-areas. More detailed work was done in the vicinity of Mt. Sicker in 1908 by the writer, and in the vicinity of Mt. Richards, Maple bay, and southern Saltspring island in 1909, by J. A. Allan. The results of Allan's and the writer's work are presented in detail in Memoir 13, of the Geological Survey of Canada, 1912, which includes a reconnaissance geological map of southern Vancouver island.

BIBLIOGRAPHY.

A complete bibliography of all the literature of value bearing on the geology of southern Vancouver island has been given in the preliminary report on southern Vancouver island, Memoir 13, and the following list includes merely those publications bearing directly on the geology of the Sooke and Duncan map-areas.

Allan, J. A., "Saltspring island, and east coast of Vancouver island." Geol. Surv., Can., Sum. Rept., 1909, pp. 98–102.

Arnold, Ralph, "Environment of the Tertiary faunas of the Pacific coast of the United States," Journ. of Geol., vol. 17, 1909, pp. 509–533.

Arnold, ılph, and Hannibal, Harold, "The marine Tertiary stratigraphy of the north pacific coast of America." Proc. Am. Phil. Soc., vol. 52, 1913, pp. 559–605.

Brewer, W. M., "The Copper deposits of Vancouver island," Trans. Am. Inst. Min. Eng., vol. 29, 1900, pp. 483–488.
"Mount Sicker district, Vancouver island, British Columbia." Eng. and Min. Journ., vol. 70, 1900, pp. 65–66.
"Mineral resources of Vancouver island," Journ. Can. Min. Inst., vol. 6, 1904, pp. 188–199.
"Some observations relative to the occurrence of deposits of copper ore on Vancouver island, and other portions of the Pacific coast." Journ. Can. Min. Inst., vol. 9, 190[illegible], pp. 39–48.

Brown, Robert, "On the physical characteristics and geographic distribution of the coal-fields of northwest America." Trans. Geol. Soc. Edinburgh, vol. 1, 1868–69, pp. 305–325.

Clapp, C. H., "Southern Vancouver island." Geol. Surv., Can., Mem. No. 13, 1912.
"Geology of the Victoria and Saanich map-areas." Geol. Surv., Can., Mem. No. 36, 1913.
"Geology of portions of the Sooke and Duncan map-areas." Geol. Surv., Can., Sum. Rept., 1912, pp. 41–54.

Clapp, C. H., and Cooke, H. C., "Geology of a portion of the Duncan map-area." Geol. Surv., Can., Sum. Rept., 1913, pp. 84–105.

Cooke, H. C., "Geology of the Sooke special map-area." Geol. Surv., Can., Sum. Rept., 1913, pp. 106–108.

Dawson, G. M., "Report on a reconnaissance of Leech river and vicinity." Geol. Surv., Can., Rept. of Prog., 1876–77, pp. 95–102.
"On the later physiographic geology of the Rocky Mountain region in Canada." Trans. Roy. Soc., Can., vol. 8, 1890, sec. 4, pp. 3–74.
"Geological record of the Rocky Mountain region in Canada." Bull. Geol. Soc. Am., vol. 12, 1901, pp. 57–92.

Haycock, E., and Webster, A., "Geology of the west coast of Vancouver island." Geol. Surv., Can., Sum. Rept., 1902, pp. 54–92.

Merriam, J. C., "Note on two Tertiary faunas from the rocks of the southern coast of Vancouver island." Bull. Univ. Cal., Dept. Geol., vol. 2, 1896, pp. 101–108.
"New species of Tertiary mollusca from Vancouver island." The Nautilus, vol. 2. 1897. pp. 6[illegible]-65.
"The fauna of the Sooke beds of Vancouver island." Proc. Cal. Acad. Sc., 3d. series, vol. 1, 1899, pp. 175–179.

Musgrave, Robt., "Copper deposits of Mount Sicker, Vancouver island, Victoria, B.C." Eng. and Min. Jour., vol. 78, 1904, pp. 673–674.

Newcombe, C. F., "Pleistocene raised beaches at Victoria, B.C." Ottawa Naturalist, vol. 28, 1914, pp. 107–110.

Richardson, James, "Coal fields of the east coast of Vancouver island." Geol. Surv., Can., Rept. of Prog., 1871–72, pp. 73–100. "Report on the coal fields of Nanaimo, Comox, Cowichan, Burrard inlet, and Sooke, B.C." Geol. Surv., Can., Rept. of Prog., 1876–77, pp. 160–192.

Robertson, W. F., "Mount Sicker camp." Rept. of Minister of Mines, B.C., 1902, pp. 238H and 254H.

Sutton, W. J., "The geology and mining of Vancouver island." Trans. Manchester Geol. and Min. Soc., vol. 28, 1904, pp. 307–314.

Weed, W. H., "Notes on the Tyee copper mine." Eng. and Min. Jour., vol. 85, 1908, pp. 199–201.

Whiteaves, J. F., "On the fossils of the Cretaceous rocks of Vancouver and adjacent islands in the Straits of Georgia." Geol. Surv., Can., Mesozoic Fossils, vol. I, pt. II, 1879, pp. 93–190.

CHAPTER II.

SUMMARY AND CONCLUSIONS.

GENERAL GEOLOGY.

The Sooke and Duncan map-areas embrace the southern end of the Vancouver range and portions of the coastal lowland of Vancouver island and a few of the islands off the "east" coast. The range is a greatly dissected plateau of deformed and metamorphosed volcanic and sedimentary rocks which have been replaced by granitic rocks; and the coastal lowlands have been developed by the more rapid erosion of sedimentary rocks which rest unconformably upon the more resistant metamorphic and granitic rocks.

The oldest rocks are a series of metamorphic, schistose, fine-grained sediments at least 5,000 feet thick, and a series of volcanics, largely fragmental, estimated as 2,500 feet thick, called respectively the Leech River formation and Malahat volcanics. The two formations are presumably of marine origin and conformable, and the Malahat volcanics appear to overlie the Leech River sediments. The two formations are separated by a transitional zone 500 feet thick, containing rocks of both sedimentary and volcanic origin; and sedimentary rocks, argillites, and cherts are found also throughout the Malahat volcanics. The rocks have been closely folded into a northeasterly dipping homocline, which is composed of numerous, small, appressed folds, and may form the southeastern limb of a large synclinorium. The formations are correlated with a group of similar sedimentary and volcanic rocks widely distributed throughout the Pacific Coast region, and called in the interior of British Columbia the Cache Creek group of Carboniferous, largely Pennsylvanian, age.

Apparently unconformable upon the Leech River and Malahat formations, although separated from them either by a large fault or by intrusive granitic rocks, are the bulk of the metamorphic, volcanic, and sedimentary rocks composing the Vancouver range. They are of lower Mesozoic age and constitute the Vancouver group. The Vancouver group is subdivided into the Vancouver volcanics, Sutton formation, and Sicker series.

The Vancouver volcanics, which adjoin the Leech River and Malahat formations, comprise the larger part of the Vancouver group. The series is at least 10,000 feet thick, and was accumulated largely under submarine conditions. It consists of flow and fragmental rocks, chiefly pyroclastic, of medium basicity, largely andesites, with intrusive porphyrites. The rocks have been metamorphosed, mineralized, and, near intrusive granitic rocks, partly recrystallized and replaced to form silicified and feldspathized varieties, amphibolites, and garnet-diopside-epidote rocks. Intercalated in the Vancouver volcanics are numerous lentils of crystalline limestone which constitute the Sutton formation. None of the lentils is more than 500 or 600 feet thick, but the total thickness of all the limestones at different horizons would be much more than 1,000 feet. The limestones were formed by the accumulation of marine organisms that lived on the shores of volcanic islands built during the eruption of the Vancouver volcanics. They have been metamorphosed with the volcanics not only into crystalline limestones, some of which contain diopside and wollastonite, but also into contact-metamorphosed and mineralized varieties virtually identical with those derived from the metamorphism of the volcanics. One of the lentils to the west of the map-areas contains a fauna of lower Jurassic age, and it is concluded that the limestones and associated volcanics of the Sooke and Duncan map-areas are of the same general age, lower Jurassic and presumably upper Triassic. They are correlated with the greater part of the pre-batholithic, volcanic, and calcareous rocks of the coast region and with the Nicola group of the interior of British Columbia.

The Sicker series consists of metamorphic, volcanic, and conformably overlying metamorphic sedimentary rocks; but closely associated with them are intrusive rocks, the Tyee quartz-feldspar porphyrite and the Sicker gabbro-diorite porphyrite. The Sicker volcanics closely resemble the Vancouver volcanics, but usually may be distinguished by conspicuous phenocrysts of hornblende. The sediments consist in ascending order of basal tuffs, cherty tuffs, and black slates, and are composed of both sedimentary and fine-grained pyroclastic material which was silicified and albitized during the deposition by volcanic emanations. The sediments are at least 2,000 to 3,000 feet thick and the volcanics appear to have a maximum thickness of about 3,700 feet.

Since the lithological character and structural relations of the Sicker series and the Vancouver volcanics are similar, the two formations are considered provisionally to be conformable. It is possible that the Sicker series is the younger and of lower to middle Jurassic age, and is correctly correlated with the Maude argillites of Queen Charlotte islands.

The rocks of the Vancouver group and underlying Leech River and Malahat formations were greatly deformed during the period of deformation general to the Pacific coast in upper Jurassic and possibly Lower Cretaceous times. They were flexed into two main synclinoria with a general strike of north 65 degrees west, the southern now involving the rocks of Leech River, Malahat, Vancouver, and Sutton formations, and the northern the rocks of the Sicker series. Faulting in the southern synclinorium has brought the Leech River and Malahat formations on the south against the Vancouver volcanics; and apparent faulting along the crest between the synclinoria probably brought the Vancouver volcanics against the Sicker series. However, the crest between the synclinoria has been denuded and is now covered by younger rocks which also occur both to the northeast and southwest of the two synclinoria, perhaps in similar, eroded anticlines or anticlinoria.

During and following the deformation, the rocks of the Vancouver group and of the Leech River and Malahat formations were invaded and partly replaced by plutonic rocks. These may be subdivided into three main types which were irrupted in a definite sequence as follows: Wark gabbro-diorite gneiss, Colquitz quartz diorite gneiss, and Saanich granodiorite. In addition, there are minor intrusives of two principal types, quartz-feldspar porphyrites and gabbro-diorite porphyrites. The latter is injected only into the Sicker series and is called the Sicker porphyrite; most of the quartz-feldspar porphyrite is also injected only into the Sicker series, and such porphyrites are given the distinctive name Tyee. Other quartz-feldspar porphyrites are closely associated with the Saanich granodiorite and hence are termed granodiorite porphyrites; and it is probable that there are dykes of diorite porphyrite also associated with the Saanich granodiorite. Dykes of gabbro, quartz diorite porphyrite, and hornblende-augite andesite porphyrite, which are not clearly associated with the other plutonic rocks, cut the metamorphic rocks and the latter cut the Wark and Colquitz gneisses as well.

The Wark and Colquitz gneisses, although intruded separately, form virtually a single batholith which, since its component rocks are apparently primary gneisses, was probably irrupted during deformation. The principal rock of the Wark type is a gabbro-diorite gneiss; but it varies in composition and is cut by numerous apophyses of the Colquitz gneiss. It has been contact metamorphosed into rocks with large recrystallized, and frequently poicilitic hornblendes. The Colquitz gneiss is a foliated quartz diorite and in places is conspicuously banded. It has mica granite facies which are intruded into the Leech River schists only.

The Saanich granodiorite forms a few small batholiths and several much smaller stocks. It is a fairly normal, chiefly unfoliated granodiorite with diorite and gabbro contact facies. Associated with the Saanich granodiorite are dykes of granodiorite and diorite porphyrite which cut not only the intruded rocks but the Saanich grandiorite itself.

The Tyee quartz-feldspar porphyrite and Sicker gabbro-diorite porphyrite form sills, dykes, and large irregular masses in the Sicker series, and the former is clearly older and intruded by the latter. The Tyee porphyrite has been deformed with the enclosing Sicker series and has been converted into sericitic schists; and, although the Sicker porphyrite is less deformed, and is schistose only along the contacts and faults, it too may have been deformed with the Sicker series. Both porphyrites are almost certainly younger than the Saanich granodiorite which appears to replace the deformed rocks.

With the exception of the independent minor intrusives already mentioned, it is quite clear that all of the plutonic rocks were irrupted during the same general period, which is correlated with the irruption of the upper Jurassic Coast Range batholith. Perhaps all of the types are derivatives of the same magma; but, if so, the first derivatives of the parent magma underwent still further differentiation independently of each other before intrusion. In general the Mesozoic igneous rocks conform to the general eruptive cycle of (1) the volcanic phase, (2) the batholithic phase, and (3) the phase of minor intrusives. The volcanics are composed almost entirely of basalts and andesites of a remarkably uniform composition; the batholiths are made up of a number of rocks irrupted in a general sequence from basic to acid; and the minor intrusives consist of a few rocks irrupted in a general sequence from acid to basic. The volcanic rocks may have resulted from the eruption through deep vents of a but slightly differentiated, primary basaltic magma. The composite batholiths may have been formed by the more complete differentiation of the primary magma in chambers of various sizes, the older and smaller and hence more quickly crystallized and less differentiated portions solidifying to form the more basic rocks. The minor intrusives on the other hand, produced by the injection of residual liquids, would be drawn successively from lower and lower levels as crystallization of the batholithic masses progressed downward, and for that reason they appear to have been more and more basic.

Resting unconformably upon a surface of considerable relief cut in the metamorphic and irruptive rocks is a series about 10,000 feet thick, of fragmental sediments, conglomerates, sandstones, and shales, of Upper Cretaceous age, called the Nanaimo series. The Nanaimo series is quite definitely correlated with the other Upper Cretaceous rocks of Vancouver island, and is further correlated with the Queen Charlotte series of Queen Charlotte islands. The series has been subdivided into various members or formations most of which have been definitely correlated with the formations in the adjoining Nanaimo map-area. However, all the formations cannot be distinguished and hence a few new and more comprehensive formations have been mapped. As shown by the sudden lateral and vertical gradations of the sediments, and by the presence of marine organisms and of coaly beds, the series was deposited rapidly under varying conditions, marine or estuarine and terrestrial. It seems as if the sediments were first deposited in the down-warped basin between Vancouver island and the mainland; but the sedimentation progressed inland, first filling the anticlinal valleys cut in the deformed metamorphic rocks and later possibly covering even the higher residual elevations. At present they are confined largely to two basins: one, the southern or Cowichan basin, partly fills the denuded anticlinorium between the two main synclinoria into which the older metamorphic rocks are folded; and the northern or Nanaimo basin may fill a similar valley eroded in a supposed anticlinorium to the northeast of the northern of the two synclinoria.

The Nanaimo series was presumably uplifted toward the close of the Cretaceous; but, before it was folded, a series of basic volcanics, called the Metchosin volcanics, was piled up farther south during the upper Eocene period, to a depth of at least 7,500 feet. It appears as if the Metchosin volcanics filled a valley that was similar to the valleys filled by the Nanaimo series and that was eroded in a supposed anticlinorium to the southwest of the southern of the two synclinoria into which the older metamorphic rocks were flexed. The Metchosin volcanics are chiefly basalts but they are interbedded with many fragmental rocks ranging from coarse agglomerates to very fine, in places, cherty tuffs, and they are injected by many dykes, sills, and masses of diabase. The volcanics accumulated under marine conditions and certain island volcanoes were subject to wave erosion forming basaltic conglomerates and sandstones, one bed of which is crowded with upper Eocene organisms which are identical with the fauna in the Crescent basalts of the Olympic peninsula of Washington; with the Crescent basalts the Metchosin volcanics are correlated. The pillow lavas, which are numerous in the Metchosin volcanics, appear to have been formed by a sort of hydroid-like or bulbous budding which was produced by the rapid chilling action of the water on submarine flows of highly fluid lavas; the lavas were erupted in just the right quantities to maintain the proper balance between their cooling and their onward flow. Emanations from the submarine flows, mingled with the heated oceanic waters, filled the inter-pillow spaces of the pillow lavas with quartz, albite, siderite, calcite, and zeolites. Such solutions did not greatly affect the massive flows, but they did replace the minerals of the fine-grained tuffs, presumably during the deposition of the tuffs, and at times a direct precipitation of silica and siderite may have taken place to form the ferruginous, cherty tuffs.

At the close of their deposition, presumably in lower Oligocene time, the Metchosin volcanics were folded with the Nanaimo series apparently by forces which acted from the northeast, perhaps having their origin beneath the downfold between Vancouver island and the mainland. In general the rocks are flexed into three synclinoria that were overturned slightly to the southwest. The synclinoria are now completely separated by erosion. The rocks of the central synclinorium, which constitutes the Cowichan basin, were most closely compressed and overturned and are further broken by two longitudinal faults, the northern wall of both faults being uplifted and thrust to the southwest. The southern synclinorium was broken by a still greater fault, called the Leech River fault; and the older metamorphic rocks were thrust over the northeasterly dipping Metchosin volcanics.

During, or directly following their deformation, the Metchosin volcanics were intruded by several small stocks of gabbro with differentiates of granite and anorthosite, which have been termed the Sooke intrusives. Differentiation seems to have been caused by fractional crystallization after intrusion, and in the stocks which were undisturbed during crystallization the differentiated portions are arranged according to their specific gravity. In the largest stock, however, that of East Sooke peninsula, movements during its solidification have forced the various rock types into exceedingly intimate and complex relations with one another. Continued movements sheared the earlier crystallized gabbros, and emanations from deeper and unsolidified portions of the gabbro have converted the sheared rocks into hornblendites. In places the hornblendites have themselves been sheared and partly replaced by metallic minerals.

During the erosion cycle initiated by the lower Oligocene deformation, in later Oligocene and Miocene times all of the deformed rocks were peneplained in the southern part of the map-areas and reduced to a subdued surface in the northern part. During the cycle, in lower Miocene times, a coastal plain of rather coarse detritus, the Sooke formation, was built along the southwest coast, probably against a submerged mountainous slope; and it looks as if at the close of sedimentation the peneplain and coastal plain formed a continuous surface sloping towards the Pacific ocean. The remnants of the Sooke formation now occurring in isolated basins are only from 500 to 600 feet thick, except in deep embayments of the old Sooke coast, but the Sooke formation is correlated with lower Miocene sediments along the north side of the Olympic peninsula of Washington, which are a few thousand feet thick.

The Sooke formation was uplifted with very little folding, but with rather extensive minor and usually normal faulting, probably during the Pliocene, and at the same time the peneplained and subdued, older, deformed rocks were also uplifted. During the erosion cycle initiated by the uplift, called the pre-Glacial cycle, the deformed rocks were maturely dissected, and the relatively unresistant sedimentary rocks of the Nanaimo series and Sooke formation were reduced to lowlands.

During the Glacial period the upland of the map-areas was covered by a thick ice-cap, and valley glaciers descending from the ice-cap scoured out some of the larger valleys, deepening some into lake basins and others into fiords. The valley glaciers mingling with glaciers from the Coast range and Olympic mountains formed large piedmont glaciers which overrode the lowlands. Following the retreat of the earlier and larger glaciers of the Admiralty epoch, the Puyallup interglacial deposits, composed of glacial detritus but of marine origin, were deposited on the coastal lowlands. They were partially eroded by the smaller piedmont glaciers of the Vashon epoch; and upon the rapid retreat of the Vashon glaciers were left partly covered by the Vashon drift, which mantles a large part of the upland as well, and by the Colwood sands and gravels which were deposited at the front of retreating valley glaciers.

Following the retreat of the Vashon glaciers the region was uplifted some 250 to 400 feet to its present position. The transverse streams crossing the lowlands, revived by the uplift, have terraced the glacial deposits and have cut narrow canyons in the hard rocks. Alluvium has been deposited in lakes and swamps which formed in the poorly drained hollows of the drift mantle and in dammed glaciated valleys; and at the mouths of some of the larger streams deltas have been built. Along the shore, the uplifted glacial deposits have been retrograded to form steep wave-cut cliffs and small beaches and bars of coarse sand and gravel.

ECONOMIC GEOLOGY.

Of the mineral resources of the Sooke and Duncan map-areas only a few of the non-metallic resources are now utilized: chiefly the Sutton limestones and tuffaceous argillites of the Malahat volcanics for the manufacture of portland cement, to a slight extent the superficial clays for common brick, and sands and gravels for road and railway ballast and for constructional uses. The Sutton limestones have been used for the manufacture of lime, and building stone has been quarried from the Nanaimo sandstones. There has been a moderate production of copper and some gold. Other resources which have been or are of prospective value are silver, zinc, iron, and sulphur, fuels, fluxes, pigments, clay shales, and crushed stone.

Gold occurs in the gravels of the streams that drain the area underlain by the Leech River slaty schists; and has been derived from the numerous, but very low grade quartz veins in that formation. Although the gold-bearing gravels are usually of fair grade, they occur only in small deposits, and the larger gravel deposits carry, so far as known, very little gold. Quartz and quartz-feldspar veins in other formations have been prospected for gold without success, and many of them are clearly aplitic in character and unlikely to contain gold in commercial quantities. Mineralized shear zones in the metamorphic and granitic rocks, although usually of more importance as possible sources of copper, carry also small amounts of gold.

The copper deposits of the map-area are either closely associated with the upper Jurassic batholiths and minor intrusives or with the Sooke intrusives irrupted in lower Oligocene time into the Metchosin volcanics. The same metallic minerals, pyrrhotite, magnetite, pyrite, and chalcopyrite, are found in nearly all of the deposits. Sphalerite and galena are more restricted and less abundant and tetrahedrite is confined to a single deposit. The deposits are found chiefly in the metamorphic volcanic and sedimentary rocks at the contacts with or in the vicinity of the intrusive igneous rocks. They are found, however, in the intrusive rocks themselves, especially in those which have themselves been intruded by younger rocks. The deposits are as a rule irregular, and are confined largely to shear zones but may be classed in four types—(1) contact deposits, (2) impregnated and replaced shear zones with accompanying quartz veins, (3) quartz veins, and (4) the Tyee type.

The contact deposits are developed in contact metamorphosed Sutton limestones and Vancouver volcanics near the intrusive Saanich granodiorite and Wark and Colquitz gneisses. They may be further subdivided into (1) those near the main contacts of the intrusive bodies and (2) those at some distance from the main contacts. The former, characterized by a higher percentage of magnetite and pyrrhotite, occur chiefly as irregular masses in garnet-diopside-epidote rocks; and the latter occur more commonly in shear zones in silicified, feldspathized, and diopside-bearing rocks, as disseminations and small replacement bodies. The former are too small and low grade to be likely sources of copper ore; but the latter, owing to the facility with which the metallic minerals may be concentrated are of prospective importance.

The deposits appear to have been formed by emanations from the intrusives which brought about the replacement of relatively pure limestones and the associated volcanics. Although the deposits are apparently the result of one continuous process, nevertheless the metallic minerals have replaced earlier-formed metamorphic silicates, some of which in turn have replaced still earlier-formed silicates. Hence it seems as if the emanations varied in composition as well as in temperature and pressure, as the crystallization of the intrusive magma progressed. The earlier emanations appear to have been gaseous and dilute, carrying chiefly silica, alumina, and soda; and the later emanations, probably liquid, carried a large load of non-volatile matter with relatively large amounts of metals, chiefly iron, copper, and sulphur. The stage of metallization was short and was followed by a long but ineffective period during which veinlets of quartz, calcite, and epidote were formed.

The shear-zone deposits, accompanying which are quartz veins carrying small amounts of pyrite and chalcopyrite, contain relatively larger amounts of pyrite and chalcopyrite than the contact deposits. They are, however, less well-defined and usually less richly mineralized. Although there has been no commercial production in spite of extensive prospecting and some development, some of the deposits in the Sicker series and associated schistose porphyrites and in the Malahat volcanics, carrying bornite and chalcocite, are of prospective value. The deposits in the Sooke gabbro of East Sooke peninsula and the adjoining portions of the Metchosin volcanics are of considerable prospective importance and hence have been studied and described separately by Cooke.

High temperature quartz veins, some of them aplitic in character, traverse the Sicker gabbro-diorite porphyrite and the Saanich granodiorite. They have been prospected somewhat, but appear to be unlikely sources of copper.

The only known deposit of the Tyee type consists of a large lens of fairly massive ore, that occurs in Mt. Sicker, in a synclinal trough of schists derived from the Sicker sediments and associated Tyee porphyrites. There has been a considerable production from the deposit, but it is now largely worked out. Like the other copper deposits its metals appear to have been derived from emanations from the intrusive igneous rocks, but they also appear to have been deposited by ascending thermal solutions at somewhat lower temperatures and pressures.

The iron deposits are of four types: (1) contact deposits, (2) impregnated schists, (3) replacement deposits in the Sooke gabbro, and (4) bog ore deposits. The contact deposits of the Sooke and Duncan map-areas are too small and irregular, and contain too large a percentage of sulphide minerals to be of value for iron. Certain magnetite-bearing, jaspery schists of the Sicker series, contain as much as 10 to 15 per cent of magnetite, and if found in large amounts would be of great prospective value. The other two types are apparently of no value for iron, and it is not likely that the replacement deposits in the Sooke gabbro, composed largely of magnetite and sulphides, will be utilized for sulphur or for the manufacture of sulphuric acid.

Coal of commercial value probably does not occur in the Nanaimo series of the Duncan map-area, and neither does it seem as if oil will be found in the series in sufficient quantities to be commercial. It is certain that the Tertiary sediments along the southwest coast of the island, in the Sooke map-area, contain no coal of commercial value, and the conditions for the accumulation of oil in them are distinctly unfavourable.

The Sutton limestones furnish excellent material for flux, and for the manufacture of lime and cement. As mentioned, they have been used fo[illegible] and at present are quarried on the west shore of Saanic[illegible] Bamberton by the Associated Cement Company, and u[illegible]r the manufacture of portland cement. The "shale" which is mixed with the limestone is quarried on the west shore of Finlayson arm and is one of the tuffaceous argillites of the Malahat volcanic[illegible]

A recent bog deposit of yellow ochreous clay in the Sooke district, is a possible source of material for a base for coloured paints.

Clays may be obtained from the Nanaimo shales and from the stratified superficial deposits. The clays of the superficial deposits are plentiful and occur in beds 10 to 20 feet thick. They are, however, suitable only for the manufacture of common brick and drain tile. They are used only at Somenos for common brick. Most of the shales of the Nanaimo series are sandy and impure, but a few of them might be used for brick and for various kinds of semi-porous ware and stoneware.

The sands and gravels of the stratified superficial deposits furnish an abundant supply of these materials. The deposits have been quarried near the railways and roads for filling and grading purposes, and they have been used for structural and building materials on the shore of Saanich inlet and Parry bay where they can be quarried and transported cheaply.

The fractures and sheared character of the metamorphic and granitic rocks of the map-areas, with the possible exception of portions of the Ladysmith batholith of basic granite or granodiorite, renders them unfit for building stones. Most of the rocks of the Nanaimo series are of no value, but some of the sandstones furnish a stone of fair quality; they have been quarried for building stone, but not for several years.

The less altered basic volcanic rocks or traps, especially those of the Metchosin volcanics, afford abundant material for an excellent quality of crushed stone, but there has been no commercial production from the map-areas.

CHAPTER III.

GENERAL CHARACTER OF THE DISTRICT.

TOPOGRAPHY.

GENERAL ACCOUNT.

Regional.

Vancouver island, in the southern part of which the Sooke and Duncan map-areas are situated, is almost entirely mountainous and constitutes one of the border ranges of North America. It is separated from the mainland by the submerged northern portion of the great marginal depression of North America, known as the Pacific Coast downfold,[1] which extends from the Gulf of California to Alaska and is flanked on both sides with great mountain ranges. It is above sea-level in California, Oregon, and Washington, but its ends are submerged. In British Columbia the flanking mountain ranges are the Coast range to the east, and the ranges of Vancouver island and Queen Charlotte islands to the west. The Vancouver range trends north 55 degrees west and the entire island is 290 miles long and 50 to 80 miles wide, and has a total area of about 15,000 square miles. It is, as stated, separated from the Coast range of the mainland by the submerged, northern end of the Pacific Coast downfold which is occupied from south to north by Haro, Georgia, Johnstone, and Broughton straits, and Queen Charlotte sound. It is separated from the mainland to the south, that is from the Olympic mountains of Washington, by a smaller transverse downfold striking about north 70 degrees west now occupied by the strait of Juan de Fuca.

The Vancouver range is composed of a heterogenous group of deformed rocks having a general northwest strike, that were

[1] Willis, Bailey, Tacoma folio, No. 54, U.S. Geol. Surv., 1899.

apparently reduced to a subdued surface which was uplifted to form the plateau-like upland of Vancouver island, and then greatly or maturely dissected. Looking across the upland one can still see in the wide, relatively smooth interstream areas, the outlines of the subdued surface. In the southern part of Vancouver island it looks as if this surface was nearly a plain before uplift, with only a few rounded hills composed of especially resistant rocks remaining a few hundred feet above the general level. In the central part of the island, however, the surface was one of considerable relief with larger and higher residual hills and small ranges of mountains. The present elevation of the plateau-like upland is less than 1,500 feet near the southern coast but increases rapidly to the northwest; so that in the central part of the island its elevation is about 4,000 feet, while the old residuals are now, since uplift, 5,000 to 7,000 feet above sea-level, a few peaks being even higher. As stated, the upland has been maturely dissected. Most of the dissection was accomplished during a pre-Glacial erosion cycle, by large transverse streams with tributaries which followed less resistant rocks. In the southeasternmost portion of the island, although the region is largely underlain by rocks of the same character as those forming the greater part of the Vancouver range, the upland was entirely destroyed, and reduced to diversely arranged hills of subequal height, and in the extreme southeastern portion to another subdued surface several hundred feet lower than the upland surface. Along the coasts of Vancouver island are relatively narrow areas underlain by sedimentary rocks which are less resistant than the crystalline rocks forming the larger part of the island, and which were, therefore, during the pre-Glacial cycle, reduced to a lowland also. It seems as if at some time following mature dissection, in this same pre-Glacial cycle, the southeastern part of the island was depressed partly below sea-level, drowning the valleys, but leaving the higher elevations above sea-level as islands and promontories, thus forming the irregular drowned coast characteristic of that part of the island.

During the Glacial period the island was apparently smothered by a thick ice-cap which smoothed and rounded all the mountains under 4,000 or 5,000 feet high, while the pre-Glacial valley heads in the higher mountains were excavated by local glaciers so that these higher mountains now have characteristic serrated summits. Valley glaciers occupied and scoured out the larger valleys, converting some of them, chiefly the transverse valleys flowing southwestward from the main range to the Pacific, into fiords, and deepening some of the interior valleys into large lake basins. The valley glaciers flowing eastward from the east slope of the Vancouver range joined with the larger and more numerous glaciers flowing westward from the ranges of the mainland and formed an extensive piedmont glacier which occupied the downfold between the Vancouver range and the ranges of the mainland. The southward flowing portion of this piedmont glacier, called by Dawson[1] the Strait of Georgia glacier, overrode the lowland along the east coast of Vancouver island, removed virtually all surface soil, and smoothed off the angularities produced by normal erosion. On the retreat of the glaciers both the East and the West Coast lowlands were left covered by a more or less persistent mantle of unconsolidated superficial deposits. A recent uplift of some 250 to 400 feet has revived the streams crossing the lowlands, and the revived streams have terraced the superficial deposits, and in places have cut gorges in the underlying consolidated rocks. Along the shores the uplifted superficial deposits have been retrograded to form steep cliffs, while the coast, where composed of hard rocks, presents the initial irregularities of the drowned surface.

Local.

The greater part of the Sooke and Duncan map-areas (see Figure 2) is mountainous and forms the southern part of the plateau-like upland of the Vancouver range. It appears as if the southern part was nearly a plain before uplift, and the even sky-line of this upland plain, broken only by the few rounded hills which surmount the general level, and by deep, and in places, very steep-walled valleys, is the most characteristic feature of the topography. The southeastern portion of the

[1] Dawson, G. M., "On the later physiographical geology in the Rocky Mountain region in Canada," Trans. Roy. Soc., Can., vol 8, 1890, sec. 4, p. 29.

map-areas, however, includes that portion of the Vancouver range where the upland surface has been destroyed and the region reduced to diversely arranged hills of considerable but subequal height, varying from 500 to nearly 1,800 feet above sea-level. The elevation of the upland plain is about 1,500 feet in the southeastern portion but increases to the northwest to 2,500 feet, and in the western part of the Duncan map-area to over 3,000 feet. The upland attains its maximum elevation

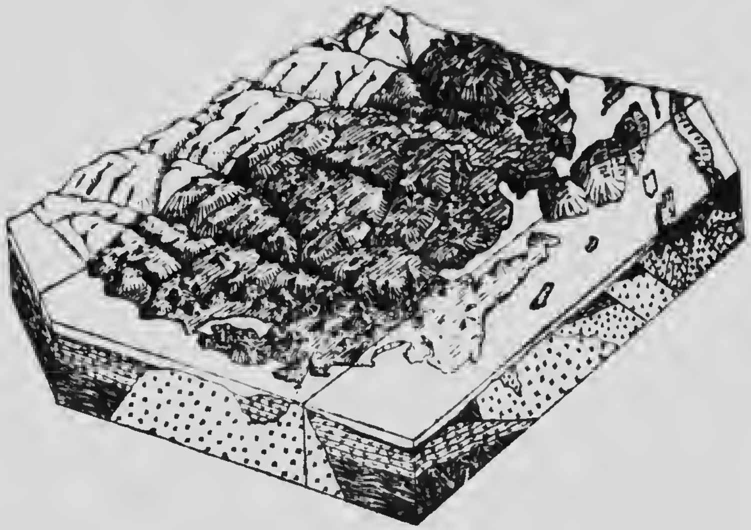


Figure 2. Block diagram, illustrating character of topography of the Sooke and Duncan map-areas, looking northwest.

of 3,500 to nearly 4,000 feet, in the northwestern part of the Duncan map-area; but here the plain was apparently never well developed and the region appears to have retained considerable relief when uplifted.

The northeastern portion of the Duncan map-area is a part of the east coast lowland of Vancouver island, that has been formed by the rapid erosion of the less resistant sedimentary rocks fringing the east coast of the island. Since the sedimentary rocks are of varying resistance, with a general northwest strike and northeast dip, the lowland has considerable relief, extensive valleys having been cut in the soft rocks between cuesta-like ridges of hard rocks. Extending west from the lowland, and virtually a part of it, since it is underlain by less resistant sedimentary rocks, which have a general strike of north 70 degrees west, is a wide valley which crosses the central part of the Duncan map-area and divides the upland into two portions. Through this valley, called the Cowichan valley, the Cowichan river drains Cowichan lake, a large lake in a glacially over-deepened portion of the valley west of the map-area; the river empties into Cowichan bay which is formed by the submerged eastern end of the valley. Also along the southern coast, in the Sooke map-area, are remnants of the west coast lowland of Vancouver island, formed by the erosion of the non-resistant sediments which fringe the west coast.

The irregular shore-line and islands, as mentioned, appear to have been the result of a depression, sufficiently great to drown the valleys, of the eastern and southern portions of the map-areas. Since these portions of the map-areas include most of the various types of country, the shore-line topography is varied. In the northeast portion of the Duncan map-area, only the cuesta-like ridges of hard rock remain above sea-level as long points and islands which are characteristically long and occur in chains separated by long, wide channels, passes, and harbours. In the eastern and southeastern portion of the Duncan map-area, the eastern end of the Cowichan valley and a large, conspicuously glaciated, north-south valley, the northern and southern ends of which dissect the upland plain, have been depressed below sea-level to form Cowichan bay, to the south of Cowichan bay, Saanich inlet, and to the north, Sansum narrows. The southern portion of Saanich inlet, called Finlayson arm, is narrow and fiord-like, as is also Sansum narrows which forms a narrow passage separating Saltspring island, the largest of the small islands off the east coast of Vancouver island, from the main island. The southern coast appears to be largely the result of the depression of the diversely arranged hills of subequal height. The lowland areas of the southern coast, remnants of the west coast lowland, have been retrograded, since the recent slight elevation, by the severe wave attack to which they have been subject, and now they border on bays with nearly smooth shore-lines between headlands of the more resistant rocks.

DETAILED ACCOUNT.

Upland.

The upland of the Sooke and Duncan map-areas is divided into two parts, a southern and a northern, by the wide Cowichan valley which crosses the central part of the Duncan map-area. These two parts are not only geographically separated from one another but differ physiographically. The southern upland is lower and more plateau-like, and its dissection has been accomplished by smaller but more numerous streams. The northern upland is, therefore, characterized by larger features; and the prospectors and timber cruisers recognize this in their pertinent and suggestive name "big country."

Southern Upland. The southern upland itself may be further divided for purposes of description into two parts—a southern or southeastern part where the upland plain has been destroyed by erosion and a northern part where portions of the upland plain still remain to form the plateau like upland. The two topographic types merge into one another along their indefinite boundary which crosses the Sooke map-area, with a somewhat south of west trend, not far north of the southern boundary (see topographical map) of the Esquimalt and Nanaimo land grant, which is also the boundary between Malahat and Otter and Goldstream districts. The southern part is, therefore, the smaller, extending only 1 to 6 miles north of the southern coast of the island, and narrowing towards the west. The northern part widens towards the west and is from 6 to 12 miles wide. Its northern boundary is the Cowichan valley, while its eastern boundary is Saanich inlet and Finlayson arm.

Apparently over the entire northern or main portion of the upland south of Cowichan valley the upland plain was before uplift nearly smooth, that is it was a peneplain, although it was surmounted by a few hills composed of especially resistant rocks, such hills being known as monadnocks (Plate II). The monadnocks although conspicuous, were comparatively low, surmounting the upland plain by only 150 to 900 feet, and were few in number, only seventeen or eighteen occurring within the Sooke and Duncan map-areas. The elevation of this old plain is now about 1,500 feet in the southeastern part, but is 3,000 feet in the northwestern part in the vicinity of Waterloo mountain. The larger monadnocks which surmount the upland plain consequently attain elevations of 2,100 to nearly 3,500 feet, the most prominent being Empress (2,184 feet), Trap (2,304), and Muir (2,905) mountains in the Sooke map-area, and Survey (3,102), Valentine (3,180), Todd (3,140), and Waterloo (3,487) mountains in the Duncan map-area. Although greatly dissected by numerous valleys, some of which are from 1,500 to nearly 2,000 feet in depth, those portions of the upland that remain form the broad summits and comparatively wide and smooth interstream areas characteristic of the region. These comparatively smooth interstream areas are, however, surmounted by numerous rock ledges, 50 to 60 feet high, situated in the midst of drift-covered areas in the hollows of which are many small marshy ponds and lakes. Of these lakes the larger are the Goldstream lakes in the southeastern part of the Duncan map-area, Spectacle lake and other small lakes in the east central part of the map-area on Malahat ridge, and Jarvis lake in the central part of the map-area.

The dissection of the upland has been accomplished by a few transverse and presumably consequent streams flowing in a general north or south direction, with large, subsequent tributaries that follow the bedding or foliation of the underlying rocks, and numerous comparatively small tributaries (Plate II) which, although flowing in many directions, are fairly well adjusted to the less resistant parts, joints, shear zones, and contacts, of both the massive and bedded or foliated rocks. The smaller tributary streams have as a rule steep gradients and numerous falls.

The main transverse valleys although having a general north-south trend, vary from the true north and south by several degrees. With the exception of Shawnigan Lake valley, a glaciated valley in the eastern part of the upland, and three or four short valleys draining northward into Cowichan valley, virtually all of the transverse valleys drain southward. The larger of the streams draining these valleys are, from east to west, Sooke river draining Sooke lake and emptying into Sooke harbour, Muir creek, and the upper portions of both the Jordan and San Juan rivers which empty into Juan de Fuca strait, west of the map-areas. The largest of the north-south valleys is the easternmost, which has been drowned to form the fiord-like Saanich inlet and Finlayson arm.

Nearly all of the larger transverse valleys and several of the smaller, tributary ones, appear to have been rather severely glaciated, since they have steep, smooth sides, wide floors which are more or less drift covered, and low gradients. In addition some of them afford low passes between adjoining larger valleys, for example Grant Lake valley between Sooke lake and Koksilah river, and the valley 3 miles southwest of Cowichan station between Koksilah river and Cowichan valley. For all of these reasons the glaciated valleys have been selected, when possible, for the railways traversing the upland region. In the Shawnigan and Sooke valleys are large lakes, 2 miles in length, called respectively Shawnigan and Sooke lakes, which appear to have collected in glacially over-deepened portions of their valleys.

Another large transverse valley, over 7 miles long and from one-half to over one mile wide, extends somewhat east of south from Waterloo mountain to the headwaters of Jordan river. The valley is drift filled and much of it flat and marshy with numerous small ponds and a few large lakes, such as Trout lake, occurring near the southern end. The valley is drained by several small streams, which have low and, in places, almost imperceptible divides. The northern and central portions are drained by three of the tributaries of the Koksilah river, and the southern portion is drained by the Middle fork of Leech river and by Jordan river. The elevation of the floor of the valley varies from 1,500 to 1,800 feet above sea-level. On the west, the valley is bordered by an almost unbroken wall 1,000 to nearly 2,000 feet high, but the east flank of the valley is much lower, from 500 to 1,000 feet high, and is broken by the valleys of the streams which drain the main valley. Although it is heavily wooded in places, extensive areas of the flat, marshy floor are almost devoid of trees. These open areas are covered with a thick growth of coarse grass and are locally called "meadows." The largest of the meadows is situated at the southern end of the valley, and, since it is largely drained by Jordan river, is known as Jordan meadows. The wide, flat-bottomed character of the valley, its comparative straightness, and the steepness and smoothness of the western slope, all tend to show that, although it is doubtless of pre-Glacial development, the valley was severely glaciated and that upon the retreat of the glaciers it was left filled with drift. Since the flat, open meadows are composed of muddy clays and silts, clearly deposited in quiet, if not in standing water, it seems as if large, but shallow lakes collected in the undrained hollows of the drift, and that these have become filled with alluvium, although a few remnants, such as Trout lake, still remain.

Only two, large, subsequent valleys intersect the upland south of Cowichan river. The larger and more typical, called the Leech River valley, crosses both map-areas with a general east-west trend near the boundary between the two areas; and the other, the Koksilah valley, is found 4 to 5 miles to the north. The former valley has been developed in the nearly vertical-dipping, slaty schists of the Leech River formation close to their contact with resistant, massive volcanics of the Metchosin formation. The Leech River valley is occupied by several paired streams, most of which drain southward by transverse streams that flow in deep but relatively narrow valleys, and empty into Juan de Fuca strait. This paired arrangement of drainage develops on belted structures of hard and soft rocks by the rapid headward growth of the tributaries of transverse streams along the belts of soft rock. In time the divides between the adjoining river systems in the tributary, soft rock, or subsequent valleys are greatly reduced, and if the soft rock belts are wide the subsequent valleys become correspondingly so. This stage has been reached by the valley under consideration; for the divides have become so greatly reduced below the level of the upland surface, that the result is virtually one continuous valley extending entirely across the map-areas. It has been called by the writer from its best known stream, the Leech River valley. The streams which occupy the valley within the map-areas are from west to east, Y creek, the central part of Jordan river, Bear creek drained south by Jordan river, Leech river, Wolf creek drained south by Sooke river, Waugh and Goldsteam creeks both flowing east, and a small creek flowing west from Glen and Langford lakes which are drained to the north into Finlayson arm by the lower portion of Goldstream creek. The divide between Bear creek and Leech river, or strictly speaking the West fork of Leech river, is almost flat, but half a mile east of the divide there is an almost vertical fall of 400 feet in the West fork. Bear creek, on the other hand, flows westward with a fall of only a little more than 50 feet to the mile. As the fall in the West fork is progressing headward by sapping, the West fork will eventually divert the headwaters of Bear creek so that they will flow east; and indeed, from the low divide and the abrupt angle in the upper part of West fork, it appears as if the upper part of West fork had already been captured from Bear creek by the Leech river.

The Leech River valley although wide has been severely glaciated only in its eastern portion. The western portion is V shaped, with widely flaring sides, although below the 400-foot fall mentioned above, the West fork of Leech river flows in a narrow gorge cut in the floor of the main valley. The eastern portion of the valley, east of the junction of the three forks of Leech river, is much wider, and the floor and comparatively low sides are heavily drift-covered. Leech river and Wolf creek have been entrenched in this portion of the valley and have cut terraces in the drift. The terraces along the Leech river are from 30 to 50 feet high and are found as high as 300 feet above the river.

It appears as if the relatively large, southward moving valley glacier which scoured out Finlayson arm, turned eastward when it reached the Leech River valley and followed it. As a result of the greater erosion by this glacier, the extreme eastern end of the Leech River valley was not only greatly widened, but was deepened considerably, thus leaving the main portion of the valley hanging above its eastern end. Waugh creek, therefore, drops abruptly for 350 feet before it joins with Goldstream creek in the more greatly eroded portion of the valley; but Goldstream creek, containing more water, has been able, owing to its increase in gradient, to cut a narrow gorge in the upper, western portion of its valley so that its fall is rather evenly distributed throughout the greater part of its course.

The greatly eroded easternmost portion of the Leech River valley has been filled with drift, and a short distance to the east the drift deposit widens into Colwood delta,[1] in which there are several kettle or ice block holes. Similar but smaller kettles, and kames as well are found within the Sooke map-area to the north of Goldstream post-office. Within the map-area the drift deposit is from 1 to 1½ miles wide and nearly 4 miles long, and its surface is from 200 to 300 feet above sea-level. Longitudinal terraces 20 to 30 feet high extend along its sides, and the lower northward flowing portion of Goldstream creek has not only terraced it but has cut a narrow valley and gorge through it into the hard rocks below. In shallow hollows in the deposit are three small lakes, Florence, Glen, and Langford lakes, which overflow and drain northward by way of Goldstream creek.

The Koksilah valley is much smaller than the Leech River valley. It has a general trend of about north 60 degrees east and has been developed only by the growth of one stream, the Koksilah river. The Koksilah river drains the northern portion of the Jordan Meadow valley, flows northeastward, and empties into the Cowichan river near the head of the Cowichan delta. It appears as if the course of the valley was determined by a belt of soft sedimentary rocks, although at present only remnants of these rocks are to be found. The lower half of the valley, widened by glaciation, has been filled with drift to a depth of at least 150 feet, but the drift has been terraced by the river, which like many of the other large rivers has also cut a narrow gorge, 20 to 50 feet deep, in the hard rock floor.

The diversely arranged hills of subequal height which characterize the southern or southeastern part of the upland south

[1] "Geology of the Victoria and Saanich map-areas," Mem. 36, 1913, p. 15 and pp. 112–113.

of Cowichan valley vary from 600 to 1,800 feet in elevation. The height of the hills increases rather regularly from the southeastern coast to the northwest; thus, along the coast are Mt. Metchosin (600 feet), Mt. Blinkhorn (797 feet), Garibaldi hill (549 feet), and Signal hill (735 feet), and from 2 to 6 miles to the northwest are Mt. McDonald (1,407 feet), Buck hill (1,100 feet), Mt. Redflag (1,000 feet) Mt. Matheson (1,000 feet), and Broome hill (915 feet). The northern part of the Highland district to the east of Finlayson arm is plateau-like, with a general elevation of 1,100 feet, but is overlooked by Jocelyn hill (1,300 feet) and Mt. Finlayson (1,342 feet). Along the boundary with the main portion of the southern upland, Mt. Shepherd (1,758 feet) and Ragged mountain (1,900 feet) clearly surmount the upland surface, while the summit of Braden mountain (1,533 feet) is at the same elevation as the upland surface.

The dissection of the former upland has been accomplished by numerous, rather small streams. These were well adjusted to the less resistant parts of the crystalline rocks; such as joints and shear planes, striking chiefly in a north-south direction; foliation planes, striking about north 60 degrees west, and altered and weakened zones near intrusive and, in places, fault contacts. As a result the valleys and a few ridge like hills have a general north-south and northwest-southeast trend.

The hills have been smoothed by glaciation, and in small hollows in the drift mantling some of the broader topped hills are small marshy ponds or swales. The valleys have been deepened sufficiently in a few places to form small lake basins such as the basin of Matheson lake. More commonly, however, the valley sides have been steepened and the valley floors slightly widened and covered with drift. In small hollows in the drift are rather numerous ponds and small lakes some of which have been filled.

Northern Upland. The general elevation of the northern upland, which is terminated rather abruptly to the south by the steep slope into Cowichan valley, increases from 1,800 feet in the southern part of Saltspring island to about 3,800 feet in the northwestern corner of the Duncan map-area. Even when viewed from its own level this upland surface, as already stated, does not appear, especially in its northwestern part, to be as smooth as the surface of the southern upland. Instead it is marked by several low rounded hills, most of which are conical in shape. In a few places on the upland there are, however, some comparatively large, nearly smooth areas, such as the broad summit of Mt. Brenton in the west central part of the upland. Although surmounted in it[illegible]stern portion by a low conical hill, the greater part of th[illegible]mmit, which is 1½ square miles in area, is nearly smooth, with [illegible] small lakes in shallow hollows. The general elevation of [illegible] summit is now from 3,500 to 3,700 feet, while the low conical hill attains an elevation of 3,937 feet.

Mt. Brenton is situated at the southeastern end of a more or less continuous range of mountains which extends nearly 50 miles to the northwest far beyond the limits of the map-area. It culminates in Mt. Arrowsmith, the highest mountain of southern Vancouver island. Although the development of the mountains by the uplift and dissection of a subdued surface is clearly shown, none of the summits are as broad and as smooth as that of Mt. Brenton. Three miles to the northwest of Mt. Brenton is the highest mountain of the map-area, Coronation mountain. Its general elevation is about 3,800 feet, but four low hills rising above the general level attain elevations of 4,100 to 4,262 feet above sea-level, the easternmost summit, called Mt. Hall, being the highest. To the southwest of Mt. Brenton, the mountains are lower, 3,200 to 3,400 feet, but their rounded summits still remain at the general elevation of the upland surface.

To the southeast of Mt. Brenton, with the exception of Mt. Bruce in Saltspring island, which is 2,400 feet high and overtops the upland surface by 600 feet, the mountains which are of subequal height, 1,100 to 2,643 feet, appear to have been reduced below the general level of the former upland surface. The more important mountains of this portion of the northern upland are —Big and Little Sicker (2,400 and 2,100 feet), Mt. Prevost (2,643 feet), Mt. Richards (1,100 feet), Maple mountain (1,600 feet), Mt. Tzuhalem (1,600 feet), Mt. Maxwell (1,800 feet), Mt. Belcher (1,300 feet), and Mt. Erskine (1,426 feet). Some of the mountains, notably Mt. Prevost, Mt. Tzuhalem, Mt. Maxwell, Mt. Erskine, and Mt. Belcher consist of heavy bedded conglomerates and sandstones dipping gently to the northeast and overlying massive or steeply dipping rocks. In consequence these mountains have rather broad, gently northeasterly sloping summits which terminate abruptly to the southwest in steep and in places almost vertical cliffs 500 to 600 feet high. These cuesta-like summits rest upon broader pedestals cut in the underlying rocks.

A large portion of the upland is drained, and presumably was dissected by the Chemainus river and its tributaries. In the upper part of its course the Chemainus river follows a belt of soft sediments striking somewhat south of east, between resistant crystalline rocks on either side, and it looks as if the river at one time followed the soft rocks to the south of Mt. Prevost, into Cowichan valley. At present the supposed former valley is abandoned, possibly because of the ice tongue which filled Cowichan valley during glacial times, and the river has taken a northeasterly course and has cut a narrow canyon, called Copper canyon, between Mt. Brenton and Mt. Sicker. North of Mt. Sicker the river enters the east coast lowland and, after wandering across it, empties into the salt water, 2 miles south of Chemainus, where it is building a rather large delta.

The principal tributary of Chemainus river, Boulder creek, rises in the northwestern portion of the map-area and, perhaps due to the prevalent north-south jointing already referred to, flows slightly east of south into the Chemainus river. In common with the other north-south valleys of southeastern Vancouver island it has been smoothed, widened, and in its upper portion clearly deepened by glaciation, so that now the valley forms a low pass only 1,600 feet high across the Brenton-Arrowsmith range. On the east side of the wide, flat-bottomed, and steep-sided valley is Coronation mountain, 4,200 feet high, and on the west side the summit of an unnamed mountain is over 3,400 feet high. This deep and steep-sided portion of the valley is known as Coronation canyon.

Two other glaciated north-south valleys cross the upland—one followed by the railway, extends from Cowichan valley north to the east coast lowland; and the other, as already described, has been deepened below sea-level to form Sansum narrows which separates the upland of southern Saltspring island from the upland of the main island.

Besides the larger valleys there are several small tributary valleys, all of which have steep, and many of them very steep, gradients.

Cowichan Valley.

The Cowichan valley is underlain by steeply dipping sediments, of nearly uniform resistance, flanked on either side by resistant metamorphic rocks. The wide valley that was cut by stream erosion in the less resistant sedimentary rocks was, during the Glacial period, still further widened and deepened by glaciation. On the retreat of its glacier the valley was left partly filled with drift to a depth of at least 100 to 300 feet. As in the other large valleys, since the recent uplift, the drift fill has been terraced, so that now, throughout the greater part of its 20 mile course, the Cowichan river meanders in its valley floor, some 2 to 3 miles wide, between cut banks and terraces of drift. The terraces are from 10 to 30 feet high and the uppermost occur at elevations of 400 to 550 feet above sea-level. For a few miles in the middle part of its course the river flows in a narrow rock gorge 100 to 150 feet high. The rock gorge terminates up-stream in a series of small falls (Plate I) with a total drop of 100 feet, and it is quite evident that the gorge has been formed by the headward recession of the falls. The tributary streams have not had time to entrench themselves to any great extent in the rock and hence in the middle part of its course the tributaries cascade into the Cowichan over the walls of the gorge. In the drift, however, the tributary streams have cut narrow, steep-sided valleys, and enter the main stream at grade. In its lower, eastern part, the valley widens to 8 miles, and here a large, very smooth area, nowhere over 50 feet above sea-level, appears to have been the result of the uplift of a former delta. In a shallow hollow in the north-western portion of the uplifted delta is a lake over a mile in length called Somenos lake. Another, larger lake 2 miles long and named Quamichan lake, is situated 1½ miles east of Somenos lake in a shallow hollow in the drift fill. The elevation of its surface is 101 feet above sea-level, while that of Somenos lake is only 18 feet. At its present mouth the Cowichan river is building a rather extensive delta which has already filled a large portion of Cowichan bay.

East (Northeast) Coast Lowland.

Although the Cowichan valley is virtually a portion of the east coast lowland of Vancouver island, the lowland proper is restricted to the northeastern part of the Duncan map-area. Furthermore, although a narrow strip of the lowland, ½ to 3 miles wide by 13 miles long and lying between Crofton and Ladysmith, still fringes the northeast or, as it is known locally, the east coast of the main island, most of the lowland within the Duncan map-area has been depressed below sea-level, so that only the higher cuesta-like ridges remain above sea-level to form islands.

On Vancouver island the lowland fringe presents few topographic features; in general it is a nearly smooth plain 100 to 300 feet above sea-level, which on one side terminates rather abruptly at the coast in a cliff 30 to nearly 100 feet high, and on the other side is steeply surmounted by the upland slope. North of Chemainus is a low ridge of northwesterly-striking resistant conglomerates and sandstones, that attains an elevation of 400 feet. Of a similar structure is the long point east of Chemainus that forms and protects Chemainus bay or harbour, and a larger and much wider ridge forms and protects Ladysmith harbour.

Four streams flowing in shallow valleys cross the lowland. These are from north to south—a small creek draining the country north of Coronation mountain and emptying into Ladysmith harbour, another draining Stocking lake, Askew creek draining Askew lake, and Chemainus river the largest of the four streams. The streams are situated in relatively broad, shallow valleys, but in parts of their courses, like much of the Chemainus, they flow in narrow gorges. In very shallow hollows in the drift mantle are Fuller and Askew lakes; and near Wilson, to the north of Chemainus, are swamps which appear to be old lake basins filled with alluvium.

West (Southwest) Coast Lowland.

The lowland fringing the southwest or, as it is called locally, the west coast of Vancouver island, is carved out of sediments which were deposited off a mountainous coast with bold promontories. Erosion has again exposed the steep slope and bold promontories against which the sediments were deposited, so that at present they steeply surmount the nearly smooth lowland. Furthermore, retrogression by wave attack has almost destroyed the lowland, since its recent uplift, so that within the Sooke map-area the larger of the old promontories are once more lapped by the ocean, and form the headlands of an otherwise rather regular shore. Between the headlands, East Sooke peninsula, Otter, Sheringham, and Glacier[1] points, which are from 3 to 5 miles apart, are the remnants of the once extensive lowland. The remnants are from 1 to 5 miles long and extend inland only ¼ to 3 miles. The lowland is largely covered by drift, and presents little relief, although on the lowland between Otter and Sheringham points there is an esker-like ridge 40 feet high and 1,000 feet long. The lowland is now, since uplift, from 150 to over 300 feet above sea-level, and is drained by southward flowing streams, which have been revived by the recent uplift so that they now flow in comparatively narrow gorges, 50 to nearly 200 feet deep. The streams draining the lowland between Otter and Sheringham points are typical. These are from east to west, Tugwell, Muir, and Kirby (Coal) creeks. The largest stream crossing the lowland, Sooke river, which with its tributary, Demaniel creek, drains the basin north of Sooke harbour between East Sooke peninsula and Otter point, has cut the sediments to grade, has even widened its valley, and built a flood-plain, the earlier formed portions of which as well as the drift deposits have been terraced.

[1] Formerly called Point Nopoint.

Shore-lines and Islands.

The generally irregular shore-lines and islands of the map-areas, which appear to be the result of a depression of the region followed by a partial recovery, may be divided into four types, corresponding to the nature of the depressed or uplifted surfaces. First and greatest in extent, are those of the northeastern part of the Duncan map-area that have been formed by the flooding of the broad, longitudinal valleys of the east coast lowland. Second are the fiord-like shore-lines of the eastern portion of the Duncan map-area and northeastern portion of the Sooke map-area, formed by the drowning of the large north-south, glaciated valley cut into the upland near the eastern boundary of the map-areas. Of the third type are those of the eastern portion of the Sooke map-area, formed by the drowning of the wide, but rather shallow valleys of the southeastern, greatly reduced portion of the upland; and of the fourth type are those regular shore-lines of the western part of the Sooke map-area which appear to have been formed rather by the recent uplift than by the former depression of the drift covered west coast lowland.

Long points and chains of islands separated by long, wide channels, passes, and harbours, are the most characteristic coastal features of the northeastern part of the Duncan map-area. These are, of course, elongate in direction of the strike of the rocks, about north 50 degrees west. Many of the points and islands are cuesta-shaped; that is, they have long, gentle, back slopes, corresponding to the dip or bedding of the rocks, and steep front slopes, nearly at right angles to the bedding. The front slopes of the islands, usually the southwestern, since the prevailing dip is to the northeast, are in most cases very steep, while in places the dip is so gentle that the northeast shore of many of the islands is shallow and marked by many reefs. The greater part of the shore-line is cut in the indurated rocks and presents virtually all of the initial irregularities of the depressed, glaciated, rock surfaces, although, owing to the regular attitude of the rocks, the shores are for short distances straight. Small coves and wave chasms bordered by narrow beaches have been cut in the softer rocks and along joints and shear z nes. Also, in places where the shore is cut in sandstones with a calcareous cement, the cement has been partially dissolved by salt water spray and the wind and waves have fashioned the sandstones into hemispherical or hemicylindrical caves or galleries with fantastic, laceworked, and honeycombed surfaces.

There are two principal island chains—an outer chain, which within the Duncan map-area is represented only by a portion of Galiano island; and an inner one which consists of Thetis and Kuper islands and the northern part of Saltspring island. Between the two island chains is Trincomali channel and between the inner chain and Vancouver island is Stuart channel. Beyond, to the northeast of Galiano island, is the wide Strait of Georgia. Galiano island, built of thick-bedded sandstones, dipping uniformly to the northeast at angles of from 20 to 30 degrees, is conspicuously cuesta-shaped and attains an elevation of over 800 feet. The island averages slightly more than a mile in width and is 16 miles long, although only 6 miles of its length is included in the Duncan map-area. The Thetis-Kuper Islands ridge is anticlinal, the outward dip averaging about 25 degrees, but in the southern part of Kuper island the southwestern dip is only a few degrees, so that the shore is relatively very low. The rocks are of varying resistance and the harder beds form a few long points and a ridge on Thetis island which is 120 feet high. Only at high tide are Thetis and Kuper islands separated by water, and the narrow pass has been bridged; but to the southwest of the pass, a long bay, called Telegraph harbour (Plate III B) has been cut in a soft shale between the islands. The islands average 1 to 2 miles in width and have a total length of 7 miles, but Thetis island extends for nearly 2 miles north of the northern boundary of the map-area. Northern Saltspring island is triangular-shaped, and the long northeastern shore, corresponding with the strike of the rocks, is comparatively straight, although some minor irregularities have resulted from the erosion of the soft beds in the complexly folded rocks. The western shore bevels across the rocks and hence it is characterized by points and headlands of hard rocks separating bays cut in the softer beds. Northern Saltspring island is separated from the southern upland portion by a deep, narrow valley, only the central portion of which remains above sea-level. The narrow inlets resulting from the drowning of the ends of the valley are Booth bay to the west and Ganges harbour to the east. The northern part of the island retains considerable relief, one of the sandstone ridges having two summits each of which is nearly 1,000 feet high. Surrounded by three of the sandstone ridges is the triangular-shaped St. Mary lake, at an elevation of about 150 feet above sea-level.

In Trincomali channel are two chains of small islands, the northern chain composed of Reid and Hall islands, and the southern composed of five islands known as the Secretary islands. The rocks of both chains dip to the northeast, but those of the Secretary islands dip at steeper angles, and hence the Secretary islands are narrower and have steeper shores, with more irregularities. The individual islands of the Secretary chain which is 5½ miles long are close together, so that they divide Trincomali channel into two parts. That part between the chain and Kuper and Saltspring islands is known as Houston passage, while the name Trincomali is retained for the wider more continuous channel between the chain and Galiano island. Several small islands are found in Stuart channel, especially near Thetis and Kuper islands on the northeast, and near the main island to the southwest. But the only well-defined chain of islands in this channel is the Shoal islands, a group of small islands totalling 3 miles in length, and situated within a mile of the shore between Crofton and Chemainus, that are built of steeply, northeasterly dipping sandstones.

The shore-line of Vancouver island between Crofton and Ladysmith is fairly regular, a large portion of it being cut in the recently uplifted and retrograded drift deposits. However, a long narrow point called Bare point, extending west of north, protects Chemainus bay which lies to the west; and a much wider headland projecting southeast and terminating in a narrow rock point, called Coffin point, protects Ladysmith (Oyster) harbour lying to the southwest of the headland.

Only the northern and southern portions of the drowned valley extending along the eastern boundaries of the map-areas are typically fiord-like. The southern portion, or Saanich inlet, extends for 12 miles into the upland which, in the vicinity, is 700 to 1,000 feet high. The average width of the inlet is about 2 miles and its average depth is 350 feet, but it narrows in its southern portion, Finlayson arm, to less than a mile in width, and the depth increases to 600 feet. The shores are, of course, steep and fairly regular, especially along Finlayson arm.

The northern portion of the valley is the narrow pass, called Sansum narrows, between the upland portion of Saltspring island and the main island. The narrows are somewhat less than a mile wide and 600 feet deep. In its central portion the pass widens, where it crosses a belt of the less resistant sedimentary rocks of the Nanaimo series, to form Maple bay on the west and Burgoyne bay on the east. The shore, like that of Saanich inlet, is fairly regular and steep, although it is much lower and gentler in the vicinity of Maple and Burgoyne bays. Between Saanich inlet and Sansum narrows is Cowichan bay, the drowned eastern extremity of Cowichan valley. Although Cowichan bay and its southeastward continuation, Satellite channel, are steeply surmounted to the north by Mt. Tzuhalem and southern Saltspring island, on the south they border the wide, drift-covered lowland of Cowichan valley. The drift deposits of the lowland have been retrograded by wave attack, so that the southern shore of Cowichan bay and Satellite channel, and the western shore of the northern part of Saanich inlet as well, is a steep cliff 100 to nearly 200 feet high. At the base of the cliff is a narrow, rather steep, bouldery beach, or in places a narrow outcrop of the indurated rocks underlying the drift deposits.

The shore-line of the eastern portion of the Sooke map-area is characterized by rather broad, irregular, shallow bays between equally broad and irregular, low headlands, with several small rocky islands not far off the main shore. The larger bays are, from east to west, Parry, Pedder, Becher, and Sooke harbour and basin. The shore-line is cut largely in the hard rocks, and presents all the initial irregularities of the depressed, glaciated rock surface, with added minor irregularities such as small coves and wave chasms produced by the more successful attack of the waves on shear zones, joints, and dykes. The inner shore of Parry bay and the north shore of Sooke harbour are, however, cut in the drift deposits. The drift deposits have been retrograded, and sea-cliffs nearly 100 feet high have been cut in them. Some of the retrograded material has been carried northward along the shore of P[illegible] bay, presumably by shore currents, and has been depos[illegible] corner of the bay to form a small spit which nearly [illegible] ll lagoon to the south of Albert head. At Sooke ha[illegible] trograded drift has been built into a spit almost a [illegible] alled Whiffen spit, which nearly closes the rather narrow [illegible] nce to Sooke harbour. At one place the inner shor[illegible] ay is being extended by the deposition of a small cusp[illegible] th[illegible] of a small creek, and a much larger [illegible] been built out into Sooke harbour by [illegible] The Sooke River delta has almost completely separ[illegible] larger eastern part of the bay, called Sooke basin, fro[illegible] ller western part, called Sooke harbour.

West of Sooke harbour the shore-line is fairly regular although it is not so straight and regular as it is to the west of the map-area. There are three large, sharp-pointed promontories of resistant rocks, Otter, Sheringham, and Glacier points, between which are broad, shallow, crescentic shaped bays, cut in the soft sedimentary rocks that overlie the resistant rocks. The shore-line of the promontories, like that of those farther east, presents virtually all of the irregularities of the depressed, glaciated rock surfaces, with many added minor irregularities. Between the promontories, the soft sedimentary rocks have been rapidly retrograded to form steep shore cliffs up to 100 feet high. The cliffs have been dissected by Tugwell, Muir, and Kirby creeks. The creeks have cut their channels nearly to sea-level, but they have been unable to build deltas beyond the steep, narrow, bouldery beach at the base of the shore cliffs.

CLIMATE AND VEGETATION.

Because of the controlling influence of the ocean and notably of the Japan current on the climate of the north Pacific coast, the temperature of southeastern Vancouver island, especially of the lowland portions, is temperate and remarkably uniform. The average temperature is about 45 degrees Fahrenheit in winter and from 55 degrees to 60 degrees in summer, and the extremes of temperature, except on the higher portions of the upland, are comparatively small. The rainfall varies greatly in different parts of the Sooke and Duncan map-areas. Along the west coast, in common with most of the north Pacific coast, the rainfall is heavy, from 80 to nearly 100 inches a year. Although the rainfall on the upland is greater than on the lowlands, in general, the rainfall decreases towards the south and east, since the eastern portions of the map-areas are protected by high mountains in the paths of the prevailing and moisture laden winds—the Olympic mountains to the southwest, the Vancouver range to the west, and the Coast range of the mainland to the north. Hence in the Cowichan valley and on the east coast lowland, the rainfall is comparatively light, from 30 to 40 inches per year. The greater part of the rain falls during the winter, while the summer is comparatively dry.

With the exception of the cleared areas, and the occasional open meadow lands, such as Jordan meadows, virtually the whole of the Sooke and Duncan map-areas is heavily forested. The principal forest trees are Douglas fir, cedar, hemlock, and spruce. The forest, in places, is of little value for timber, on account of old windfalls, snowslides, and forest fires; but a large part of it is of excellent quality, and is the chief natural asset of the region. Where the forest is thick on the upland the underbrush is not very abundant, but in the more open and damper areas of the lowlands and valleys it is extremely thick, and is a great impediment to travel. It consists of dense shrubs such as salal, salmon, and huckleberry, varieties of maple and alder, and in the poorly drained places, high, broad-leaved ferns, and devil's club.

Only relatively small areas have been cleared and cultivated and indeed only a small proportion of the region is adaptable for agriculture. Farming has been developed most extensively in the Cowichan valley, but is carried on also on the coastal lowlands of the map-areas, and to some extent in the wide glaciated valleys, chiefly in the vicinity of Shawnigan lake. Small fruit, garden truck, and grain are the chief agricultural products.

CHAPTER IV.

GENERAL GEOLOGY.

GENERAL STATEMENT.

REGIONAL.

Vancouver island is composed of deformed metamorphic and sedimentary rocks, intruded and replaced by numerous irregular bodies of granitic rocks, and it is fringed along both coasts with fragmental sediments which rest unconformably upon the older metamorphic and granitic rocks. Covering the hard rocks to various depths is a mantle of drift which although partially stratified consists largely of glacial detritus. The metamorphic rocks are largely of Mesozoic age, presumably upper Triassic and lower Jurassic, but they probably include some Palæozoic members. Apparently the oldest rocks, considered provisionally as of late Palæozoic (Carboniferous) age, are a series of slates and quartzose schists and schistose, largely fragmental volcanics. These greatly metamorphosed rocks are called the Leech River formation and the Malahat volcanics.

The lower Mesozoic rocks constitute the Vancouver group. They consist chiefly of metamorphosed, basic volcanics called the Vancouver volcanics, principally meta-andesites. Associated with the Vancouver volcanics and occurring chiefly in small intercalated lentils is a formation of crystalline limestone called the Sutton formation. In the southwestern part of the island is a thick formation of calcareous rocks, apparently free from volcanic members, called the Nitinat formation. Besides the limestones there is associated but not interbedded with the Vancouver volcanics, a series called the Sicker series, of andesitic volcanics and stratified slaty and cherty rocks composed partly of volcanic material. These rocks and their associated volcanics have been greatly metamorphosed and converted in places into schists.

All of the above-mentioned rocks have been intruded and partly replaced by batholithic and dyke (minor intrusive) rocks. The batholithic rocks are chiefly granodiorite with marginal facies of diorite, and in the southeastern part of the island there are also gabbro-diorite and quartz diorite gneisses. All of the batholithic rocks are closely related and appear to have been irrupted during the same general period of intrusion. Nevertheless they may be subdivided into four types that were irrupted in a definite sequence apparently as follows: Wark gabbro-diorite gneiss, Colquitz quartz diorite gneiss, Beale diorite, and Saanich granodiorite. It is probable that the minor intrusives, consisting of acid and basic porphyrites, were irrupted during the same general period.

Unconformable upon an erosion surface of the metamorphic and granitic rocks, and confined for the greater part to the east coast of the island, is a thick conformable series of fragmental sediments, the Nanaimo series, largely of Upper Cretaceous age, although the uppermost portion may be of lowermost Tertiary (Eocene) age. The series consists of conglomerates, sandstones, and shales, with some coal. In general, it has been deformed into broad open folds with a northwest-southeast strike, and a general northeast dip; but in places it has been closely folded, overturned to the southwest, and broken by reverse and overthrust faults.

The deformation of the Nanaimo series probably occurred in lower Oligocene times. Previous to that period during the upper Eocene, a thick formation of volcanic rocks, the Metchosin volcanics, which are chiefly basalts, was accumulated in the southern part of the island. These volcanics were involved in the lower Oligocene deformation and at the same time were intruded by stocks composed chiefly of gabbro, called the Sooke intrusives.

Along the southwest coast of the southern part of the island, confined to small narrow basins, is a series of sediments of Tertiary, probably lower Miocene age, the Carmanah and Sooke formations. These sediments, largely coarse conglomerates and sandstones, were deposited under marine conditions and are remnants of a once more extensive Miocene coastal plain.

In Pleistocene times Vancouver island was covered by a thick ice cap and large piedmont glaciers, fed by valley glaciers from the ice caps on the island and the mainland, filled the straits of Georgia and Juan de Fuca. The resulting glacial till remains on the upland; but in the larger valleys and on the coast lowlands the drift, although consisting largely of glacial detritus, is stratified, having been sorted by river, lake, and marine agencies. A second, but lesser period of glaciation followed the deposition of the stratified deposits, so that they have been partially eroded and covered with a younger glacial till. A recent uplift of some 250 to 400 feet has taken place, bringing the coastal lowlands, with their covering of stratified deposits, largely of marine origin, to their present position some 200 to 600 feet above sea-level.

LOCAL.

The oldest known rocks of Vancouver island, presumably of late Carboniferous age, the Leech River slaty schists and the Malahat volcanics, extend across the northeastern part of the Sooke map-area and the southern part of the Duncan map-area, in a belt 1½ to nearly 9 miles wide. The Malahat volcanics outcrop along the northern edge of the belt, and they appear to conformably overlie the Leech River schists. The Leech River schists consist chiefly of fine-grained sediments that have been converted by dynamic metamorphism into slaty and quartzose, largely quartz-biotite schists, and by igneous agencies into garnet-staurolite-sillimanite schists. Near the contact with the Malahat volcanics are interbedded, chloritic, quartz-feldspar schists which appear to be in part tuffaceous. The Malahat volcanics are chiefly dacite tuffs, varying from fine-grained, carbonaceous, and argillaceous tuffs, partly of sedimentary origin, to coarse-grained, sandy tuffs and tuff-breccias. There are a few flow rocks, such as andesites and dacites, and also numerous beds of chert, some of which have been brecciated and recemented. The cherts are clearly fragmental, although very fine-grained, and appear to have been silicified and albitized during their slow accumulation by emanations from submarine volcanic flows. The other fragmental rocks have been silicified and albitized also, but to a less degree. Like the Leech River formation the Malahat volcanics are prevailingly schistose, and many of them, chiefly near the intrusive igneous masses, are highly silicified and mineralized.

The Leech River formation is about 5,000 feet thick and the Malahat volcanics are at least 2,500 feet thick. The two formations are separated by a transitional zone about 500 feet thick, consisting of interbedded, chloritic, feldspar schists, cherts, quartz-biotite schists, and tuffaceous argillites—rocks of both sedimentary and volcanic origin. Thus it seems as if towards the close of the deposition of the Leech River sediments, volcanism was initiated and that volcanic material, chiefly pyroclastic, was deposited with the sediments. With increased volcanism the volcanic products greatly predominated over the sedimentary, resulting in the Malahat volcanics.

The rocks of both formations are greatly deformed. Their general strike varies from north 65 degrees west in the eastern part of the map-areas to due west in the extreme western part. The dips are steep, ranging chiefly from 60 degrees to 90 degrees, and the prevailing dip is to the north. In addition, the rocks are broken by numerous shear zones and small faults, most of which are parallel to the bedding and foliation. The major features of folding and faulting have not been determined, but it appears as if the rock· have been compressed into a great number of small isoclinal, similar folds, and that they form the southern limb of a great synclinorium involving both formations and probably the overlying formations of the Vancouver group as well. The rocks appear to have been folded during several periods, once before the deposition of the Vancouver group and again with the Vancouver group in upper Jurassic time when they were also intruded by batholithic and dyke rocks. The Malahat volcanics have been intruded by the large composite batholith of Wark and Colquitz gneisses, but the Leech River schists are intruded only by two or three small bosses of a granite facies of the Colquitz gneiss. As a result of the intrusion of the igneous rocks, both formations were metamorphosed and cut by a large number of non-persistent veins and lenses of quartz, which carry small amounts of gold. Still later the formations were faulted so that now they are separated from the Metchosin volcanics to the south and the Vancouver volcanics to the northwest by profound faults.

The rocks of the Vancouver group in the Sooke and Duncan map-areas are subdivided into the Vancouver volcanics, Sutton formation, and Sicker series. The Vancouver volcanics underlie a belt 2 to 13 miles wide, widening to the west, to the south of Cowichan valley. The formation consists largely of metamorphic volcanic flow rocks of medium basicity, chiefly meta-andesites with some meta-basalts. Interbedded with the flow rocks are amygdaloids, pillow-lavas, and fragmental volcanics, agglomerates, tuff-breccias, and slaty and cherty tuffs, and cutting them all are dykes and sills of volcanic porphyrites. All of the volcanics have been metamorphosed and greatly altered, and some of them have even been recrystallized or replaced, to form various metamorphic types, such as silicified and feldspathized volcanics, amphibolites, and garnet-diopside-epidote rocks. They are also seamed with veins of quartz and of quartz and epidote, and in places are impregnated with metallic sulphides, chiefly pyrite. The thickness of the Vancouver volcanics cannot be determined, but may be conservatively estimated as 10,000 feet.

The Sutton formation is composed of crystalline limestone, and occurs as numerous lentils intercalated in the Vancouver volcanics throughout the entire thickness and lateral extent of the volcanics. The lentils are small, varying from 100 to 1,000 feet wide and from 200 to 4,500 feet long. There are also a few lenses entirely enclosed in the intrusive granitic rocks. The crystalline limestones are grey or greyish blue to white, compact to medium-grained, and, where unmetamorphosed, are composed almost entirely of calcium and magnesium carbonates, the former greatly predominating. The only impurities are small amounts of argillaceous and carbonaceous matter and pyrite. Near the intrusive, granitic rocks the Sutton limestones have been contact-metamorphosed into light coloured, coarsely crystalline marbles carrying diopside and wollastonite, and even into garnet-diopside-epidote rocks and silicified and mineralized varieties. The thickness of any single occurrence of Sutton limestone is probably not much more than 500 or 600 feet, but the total thickness of all the limestones, including different horizons, would be considerably more than 1,000 feet. The Sutton limestones and Vancouver volcanics are in general contemporaneous and conformable, the limestones probably having been built by marine organisms that lived on the shores of volcanic islands formed during the eruption of the Vancouver volcanics. However, the actual contacts between the two formations are intrusive, the volcanics cutting the limestones and the limestones frequently occurring as inclusions in the volcanics. At one place on the north bank of Koksilah river, at the crossing of the Canadian Northern railway, is a breccia consisting of angular fragments of meta-andesite in a matrix of fossiliferous limestone. This breccia has apparently been formed by volcanic fragments, blown into the air by an eruption and falling into beds of marine organisms chiefly corals or crinoids.

The age of some of the Vancouver volcanics and Sutton limestones is lowermost Jurassic, but others are doubtless of upper Triassic age.

The Vancouver volcanics and Sutton limestones are folded and greatly fractured and sheared. They have a general strike of almost north 65 degrees west, and dip at rather high angles, but low dips occur. Southerly dips are more common than northerly ones but do not greatly predominate. The larger structural features were not determined, but it appear as if the rocks were folded into several rather close folds. Furthermore, they are intruded along their southern boundary by the Wark and Colquitz gneisses, and along their northern boundary by the Saanich granodiorite. Small isolated stocks of these intrusive rocks are also found at some distance from the main contacts.

The Sicker series consists of metamorphic, volcanic, and conformably overlying sedimentary rocks; but closely associated with them are intrusive rocks, the Tyee quartz-feldspar porphyrite and the Sicker gabbro-diorite porphyrite. The Sicker series and its associated porphyrites, occur in the northern part of the Duncan map-area, and outcrop in three roughly parallel belts averaging about 3 miles wide, and striking about north

65 degrees west. The belts, which are synclinal in structure, are separated from the Vancouver volcanics to the south, and from each other, by bands of Nanaimo sediments which also cover the central portion of the middle belt. The volcanic rocks are fine to coarse-grained andesites, usually distinguished from the Vancouver andesites by conspicuous phenocrysts of hornblende. Fragmental and amygdaloidal varieties are common. The volcanics have been greatly altered both by dynamic metamorphism and by percolating solutions, so that they now contain large amounts of epidote, calcite, chlorite, and other secondary products, and have been converted locally into chloritic schists. The sediments consist in ascending order, of basal tuffs, and hard and soft cherty tuffs, and black slates. The cherty tuffs are composed of some purely sedimentary material, mixed with more or less fine pyroclastic material, and were silicified and albitized during their deposition by volcanic emanations. The slates and soft, cherty tuffs have been greatly metamorphosed, the latter having been converted in places into sericitic schists. The sediments are at least from 2,000 to 3,000 feet thick, while the underlying volcanics have a maximum thickness of about 3,700 feet.

The Sicker series has been complexly folded, the axes of the major folds striking about north 55 degrees west. As mentioned, the three belts of the Sicker series are synclinal, while the separating bands of Nanaimo sediments occupy the position of eroded anticlines. These folds, although fairly close, are of the normal and parallel type and their axial planes dip to the south, so that it appears as if they are secondary major folds on the north limb of an anticlinorium. The major folds have been further cross folded so that in the western part of the map-area they plunge west at angles of from 10 to 15 degrees, and in the eastern part of the map-area they plunge towards a synclinal axis which follows Sansum narrows. The rocks have also been sheared and faulted, and many of their contacts with the overlying Nanaimo series are faults.

The Sicker series has been intruded by the Tyee quartz-feldspar porphyrite and Sicker gabbro-diorite porphyrite. The Tyee porphyrite, intruded first, forms sills in the sedimentary rocks and dykes in the volcanics. The Sicker porphyrite forms irregular masses and dykes in the volcanics and sills in the sediments where the injected masses are small, but irregular cross-cutting masses, elongate in a direction parallel to the bedding, where the masses are large. In addition, the Saanich granodiorite is intrusive into the deformed Sicker series and has replaced large volumes of those rocks.

The Sicker series is considered, provisionally, as conformable with the Vancouver volcanics, but the structural relation of the two formations is indefinite. The Vancouver volcanics are cut by hornblende-augite porphyrite dykes resembling the Sicker volcanics, but to this occurrence little weight may be given; and at one place south of Cowichan valley, where the rocks of the two formations are in close association, the outcrops are poor and intrusive porphyrites have been injected along the contacts. However, the structural relations of the two formations with other formations are identical and the lithological character of the lavas is similar. Furthermore the sedimentary rocks of the Sicker series resemble rocks which are conformable with the Vancouver volcanics in other parts of Vancouver island and on Queen Charlotte islands. Fossils found recently in the similar rocks of Queen Charlotte islands have been determined to be of lower to middle Jurassic age, while the Vancouver volcanics are lower Jurassic and upper Triassic in age. Hence it appears as if the Sicker series was conformable with the Vancouver volcanics and younger.

During and following the upper Jurassic period of deformation all of the rocks described above were deformed and intruded by batholiths and stocks of granitic rocks and by smaller masses of injected rocks. Three of the four principal granitic rocks of southern Vancouver island are found in the Sooke and Duncan map-area, viz., the Wark gabbro-diorite gneiss, Colquitz quartz diorite gneiss, and Saanich granodiorite. The injected masses consist of dykes and small injected bodies of porphyrites of two principal types, granodiorite or quartz-feldspar porphyrites, and gabbro-diorite porphyrites. The latter is injected only into the Sicker series and is called the Sicker porphyrite. Within the map-area the quartz feldspar porphyrite is also largely confined to the Sicker series and is called the Tyee porphyrite. In addition there are dykes of granodiorite and presumably of diorite porphyrite closely associated with the Saanich granodiorite, but not with the Sicker series, and dykes of gabbro, quartz diorite porphyrite, and hornblende-augite andesite porphyrite, which are not clearly associated with the granitic rocks.

The Wark and Colquitz gneisses are very intimately involved and form virtually a single batholith. The batholith extends across the northeastern part of the map-area and the southern part of the Duncan map-area from the east side of Finlayson arm for nearly 20 miles to the headwaters of Koksilah river, north of Jordan meadows. It has a maximum width of 9 miles near Sooke and Shawnigan lakes but narrows to an apex towards the northwest. A granite gneiss, probably a facies of the Colquitz gneiss, occurs in small bosses and stocks intrusive into the Leech River formation near Goldstream and Jordan rivers. The older type, the Wark gneiss, is a fairly typical, dark greenish, fine to coarse-grained gabbro-diorite composed chiefly of plagioclase (labradorite-andesine) feldspar, and hornblende with more or less biotite and quartz. The composition varies, in places the feldspar predominating and in other places the hornblende. Although large masses of the typical gabbro-diorite gneiss occur, it is nearly everywhere cut by numerous apophyses of quartz diorite and quartz-feldspar gneisses, and frequently a complex of the gabbro-diorite and quartz diorite gneisses has been formed in which the two types cannot be mapped separately. The Colquitz quartz diorite gneiss occurs in lenticular masses up to 5 or 6 miles long and 1 to 1½ miles wide, which are intrusive into the gabbro-diorite gneiss, so that a series of alternating irregular belts of the two rocks is the result. The Colquitz gneiss is a grey, medium-grained rock of gneissic to schistose texture, consisting essentially of altered plagioclase (andesine) feldspar, quartz, hornblende, and biotite. It has certain acid and basic facies, the former of which is light coloured, consisting essentially of quartz and feldspar only, while the latter is dark, consisting almost entirely of hornblende. The facies commonly occur interbanded, the separate bands ranging in size from a fraction of an inch up to several yards wide, thus forming a conspicuously banded gneiss. The stocks and bosses intrusive into the Leech River formation are composed of granite gneiss, which consists largely of quartz and clear feldspar with white and brown mica.

The Wark and Colquitz gneisses have been dynamometamorphosed by movements after their intrusion, but much of their gneissic and banded structure appears to be primary, and to have been caused by movements during their intrusion or before they became completely crystallized. In places, near contacts with the Colquitz gneiss are certain contact-metamorphic varieties of the Wark gabbro-diorite with large recrystallized and frequently poicilitic hornblendes. The gneisses are also considerably altered, fractured, cut by quartz and calcite veinlets, and impregnated slightly with pyrite.

The youngest batholithic rock, the Saanich granodiorite, forms a few small batholiths and several much smaller stocks, which are intrusive into the Vancouver volcanics and Sicker series, including the Tyee and Sicker porphyrites. Two batholiths, 6 and 7 miles long, one in the eastern part of the map-area, bordering Saanich inlet, and the other south of the middle portion of Cowichan valley, are intrusive into the Vancouver volcanics. Besides these there are several small stocks, which are apparently protuberances of a much larger batholith which may underlie the Vancouver volcanics at no great depth. With the exception of a batholith 7 miles long and 4 miles wide, to the west of Ladysmith, the masses intrusive into the Sicker series are small, 2 to 4 miles long and less than a mile wide. They occur in the western portion of the map-area north of Chemainus river and on the ridge between Chemainus and Cowichan rivers.

The Saanich granodiorite is a light coloured, fine to rather coarse-grained granodiorite, typical of the batholiths of the coast region of British Columbia. It consists essentially of feldspar, orthoclase and andesine, quartz, accessory hornblende, and usually biotite. It contains also numerous small rounded segregations, darker than the normal rock and consisting chiefly of plagioclase and hornblende. Near its contacts the granodiorite passes into quartz and quartz-bearing diorites, and at one place, to the southwest of Cowichan, east of King Solomon mine, into a quartz gabbro. The granodiorite although less metamorphosed than the Wark and Colquitz gneisses is considerably altered, greatly fractured, and in places somewhat gneissic. At the contacts with the intruded rocks, contact shatter breccias have been developed and apophyses of a lighter coloured rock cut not only the intruded rocks but the granodiorite itself.

The Tyee quartz-feldspar porphyrite forms sills, dykes, and some irregular masses, that are intrusive into the Sicker series. It is a light coloured porphyritic rock, characterized by a dense groundmass, which consists essentially of quartz and feldspar, chiefly albite-oligoclase, and phenocrysts of quartz and plagioclase, quartz phenocrysts being absent from some varieties. It has been dynamo-metamorphosed and passes into schistose varieties and even into sericitic schists. The Sicker gabbro-diorite porphyrite also forms sills, dykes, and large irregular masses intrusive only into the Sicker series and earlier injected Tyee porphyrite. It is dark green, holocrystalline, and consists essentially of plagioclase (labradorite-andesine) and hornblende. It varies greatly in texture from fine to medium-grained, porphyritic rocks, with feldspar phenocrysts that frequently have a tendency to a radial arrangement, to very coarse-grained varieties without a pronounced porphyritic texture. It varies also in composition, some varieties, especially the coarse-grained rocks, consisting almost entirely of hornblende, while others are distinctly feldspathic. It is also foliated but not nearly so much so as the Tyee porphyrite, although in places it has been converted into a chlorite schist. The Tyee porphyrite has clearly been folded with the stratified rocks of the Sicker series and the Sicker porphyrite also may have been deformed with them.

Dykes of unfoliated granodiorite porphyrite, otherwise similar to the Tyee porphyrite, are intrusive into the Vancouver volcanics, but unlike the Tyee porphyrite, are probably, as in the adjoining Victoria and Saanich map-areas, chiefly younger than the closely associated Saanich granodiorite. It is also probable that dykes of diorite porphyrite that cut the Saanich granodiorite and associated rocks in the Victoria and Saanich map-areas and elsewhere on Vancouver island occur, with similar relations, in the Duncan map-area, but they have not been distinguished.

Resting unconformably upon a surface of considerable relief cut in the rocks of the Vancouver group and in the irruptive rocks as well is the Nanaimo series of fragmental sediments of Upper Cretaceous age. The Nanaimo series occurs in two principal areas or basins: one, in the northeastern part of the Duncan map-area, is the southeastern extension of the Nanaimo basin; and the other, extending across the central portion of the Duncan map-area, is known as the Cowichan basin. There is also a small outlier of the lower shales of the series in the upper portion of the Koksilah valley. The rocks of the Nanaimo series consist of conglomerates, sandstones, and shales, with in places, thin coaly streaks and lenses. The conglomerates usually consist of sub-rounded pebbles, chiefly of quartz and quartzose rocks, although the basal conglomerates contain larger and angular fragments of the underlying schists, meta-volcanics, and granitic rocks. The sandstones are largely medium to coarse-grained, yellowish or brownish grey to greenish grey in colour, although those of one formation, the Protection, are greyish white. They are composed of angular to sub-rounded grains of quartz, feldspar, and rock fragments in an argillaceous matrix, and are commonly cemented by calcite. Many of them are concretionary and some of them are cross-bedded. The shales are virtually all sandy and many are carbonaceous, varying from olive grey to dark grey or black. They are composed chiefly of small angular quartz grains in an argillaceous and carbonaceous matrix. Calcite is usually present although rarely in large amounts. The shales are rather massive and weather concentrically. The shales of the upper formation, especially those with a large number of thin sandstone interbeds, are cut by sandstone dykes, up to 3 or 4 feet wide.

The total thickness of the Nanaimo series varies considerably but averages about 10,100 feet. The upper portion of the series is missing, presumably eroded, in the Cowichan basin, where the thickness averages about 4,950 feet. The various rocks of the Nanaimo series grade rather rapidly into each other in both vertical and lateral directions. Nevertheless the series has been subdivided on a lithological and stratigraphical basis into various members or formations (enumerated in the following table of formations) each with its more or less distinguishing characteristics. Most of the formations may be definitely correlated with the formations of the Nanaimo basin in the adjoining Nanaimo map-area, but all of the formations in the Nanaimo map-area can not be distinguished and hence a few new and more comprehensive formations have been mapped.

The Nanaimo series has been moderately deformed almost entirely in the zone of fracture during the lower Oligocene deformation, by forces which seem to have acted from the northeast. The rocks of the Nanaimo basin have a general northwest-southeast strike and a prevailing dip to the northeast. They are, however, involved in a few large, open, longitudinal folds and several smaller ones. The southwesternmost large fold is the southeastward continuation of the Kulleet syncline of the Nanaimo map-area and its axis extends across the Duncan map-area to the southwest of Kuper and Thetis islands and crosses Saltspring island near the southern end of St. Mary lake. The corresponding anticline, called the Thetis anticline, crosses Thetis and Kuper islands and follows the northeastern shore of Saltspring island. Another syncline and anticline crosses the northeastern corner of the map-area between Norway, Secretary, and Wallace islands to the southwest and Reid, Hall, and Galiano islands to the northeast. The anticline is the southeastward continuation of the Trincomali anticline of the Nanaimo map-area, and the syncline, named the Channel syncline, also starts in the Nanaimo map-area. Only the DeCourcy and Northumberland formations are involved at the surface in these folds. The limbs of the folds dip at angles varying from 5 to 60 degrees, averaging about 20 degrees. To the southeast of the folds the rocks, except for minor wrinkles in the weaker ones, dip uniformly to the northeast, at angles varying from 15 to 90 degrees, averaging about 35 degrees. Where crumpled the weaker rocks of the Nanaimo series are broken by small strike faults. There are also a few small cross faults, but so far as known there are no larger faults in the Nanaimo basin.

The rocks of the Cowichan basin have a general north 60 to 70 degrees west strike and steep dips of 30 to 80 degrees to the north. Apparently the eastern portion of the basin has been folded into two rather closely folded synclines slightly overturned to the southwest, and the northern limb of each syncline has been broken by a fault which brings the underlying crystalline rocks against the rocks of the Nanaimo series. The southern syncline extends across the map-area and is followed by the Cowichan valley, and apparently preserves its structure, since a similar faulted syncline is observed west of the map-area at Cowichan lake. Whether the fault that breaks across the northern limb of the southern syncline extends across the map-area is problematical; all the evidence available goes to prove that it does, but with insufficient throw in its middle portion to bring the underlying crystalline rocks to the surface, so that in its middle portion the fault separates the Haslam shales on the north from the overlying Duncan shales on the south.

The fault that breaks across the northern syncline has a large throw only in its eastern portion, near Maple bay. It dies out to the west; for, along the Chemainus river, the Haslam shales grade downward into a rather metamorphic sandstone and somewhat schistose basal conglomerate, which rests directly upon the Tyee porphyrite. Although nearly parallel to the syncline the fault bevels across it at a slight angle; for, at Maple bay, it cuts across the northward dipping, southern limb of the fold, while on Mt. Sicker the axis of the syncline occurs in Mt. Prevost, over a mile to the south of the fault. In Mt. Prevost the Haslam shales forming the lower portion of the mountain are isoclinally folded, so that they all have a nearly vertical dip, but the overlying, competent Extension conglomerates are folded into a small open synclinorium, consisting of three or four short folds, the limbs of which dip at angles varying only from 15 to 40 degrees. The conglomerates, therefore, appear to rest unconformably upon the shales, and the structure was formerly interpreted in this way, but farther west in the Mt. Prevost ridge, where the syncline is not so closely compressed, the conglomerates are clearly conformable with the underlying shales.

In the western part of the Cowichan basin the rocks occur in three narrow basins, and apparently fill anticlinal valleys in the Sicker series. The southern and largest basin, that forming the Cowichan valley, is probably a rather closely folded syncline that is overturned so that most of the rocks dip to the north, that is they are broken by a fault along the northern boundary of the basin. The other two basins are apparently rather closely folded synclines also. The southern of the two, which is followed by the Chemainus river, appears to be a continuation of the northern of the two eastern synclines and strikes about north 65 degrees west; and the northern, which crosses the south slope of Coronation mountain, strikes about north 55 degrees west. It is doubtful whether any of the contacts of these two basins with the underlying rocks are persistent faults; but considerable minor faulting has taken place along the contacts.

Besides the larger folds and faults in the Cowichan basin there are rather numerous, smaller, chiefly longitudinal folds, and doubtless there are also many smaller faults.

Underlying the greater part of the Sooke map-area are the upper Eocene Metchosin volcanics. They are all basic, chiefly basalts and diabase, the latter occurring as dykes or irregular injected masses in the basalts. The basalts vary from coarsely porphyritic and ophitic varieties to amygdaloids, and frequently exhibit pillow and columnar structures. They are interbedded with fragmental varieties ranging from fine, in places cherty tuffs, to very coarse agglomerates, some of which occur in old volcanic pipes. Some of the fragmental rocks are water-worn and at least one bed of tuff on the south shore of Albert head, near the eastern boundary of the map-area, is fossiliferous. The total thickness of the volcanics is very great and is conservatively estimated at 7,500 feet. The volcanics have been deformed and more or less altered. They have a general northwest-southeast strike and are evidently involved in folds, although the prevailing dip is about 20 degrees to the northeast. They are extensively sheared and faulted, and their northern contact is the profound thrust fault that separates them from the Leech River formation. They are also intruded by masses of the Sooke intrusives. The deformation and intrusion must have taken place at or near the close of Eocene time for the volcanics are unconformably overlain by the Sooke formation of lower Miocene or possibly upper Oligocene age.

Intrusive into the Metchosin volcanics are several small masses and stocks from less than a mile to nearly 6 miles long; they are composed chiefly of gabbro and are called, from their principal occurrence in the East Sooke peninsula, the Sooke intrusives. The intrusive masses are grouped along two principal axes, corresponding with the strike of the Metchosin volcanics, and although irregular in outline, they are elongate in the same general direction. The rocks composing the Sooke intrusives are chiefly gabbros, but range to feldspathic gabbros and anorthosites, and to granite. The normal gabbros are medium to coarse-grained rocks composed largely of angite and labradorite feldspar in about equal amounts. The augite has partly altered to hornblende, and in the field the impression is gained that the gabbros are chiefly hornblendic. The special types of gabbro, viz., olivine, hornblendic, and feldspathic gabbros and anorthosites are virtually confined to the stocks of East Sooke and Rocky Point peninsulas, and appear to be due both to differentiation and metamorphism. The feldspathic gabbros and anorthosites occur as irregular dykes, and the hornblende gabbros or hornblendites as replacement veins. The granite facies is more widespread, but is confined largely to the smaller less eroded stocks. It is a fine to medium-grained rock composed largely of alkaline feldspars and quartz with accessory hornblende. In places the granite and gabbro are transitional and in one locality, at least, the granite clearly overlies the gabbro and grades abruptly downward into it. The rocks, while sheared and metamorphosed and mineralized in places, are not greatly altered. On East Sooke peninsula, where metamorphism has been most intense, there are, however, extensive shear zones in the gabbro, that have been replaced by sulphides of iron and copper.

The Sooke intrusives were uncovered by erosion before the deposition of the lower Miocene or upper Oligocene sediments of the Sooke formation, which rests unconformably upon the intrusives. Therefore, since the intrusives were irrupted into the upper Eocene Metchosin volcanics, they must have been irrupted during or directly following the deformation in lower Oligocene time.

In the Sooke map-area, fringing the southwestern coast of Vancouver island, are the marine sediments of lower Miocene or upper Oligocene age, the Sooke formation. They occur in isolated basins separated by ridges of the Metchosin volcanics and Sooke intrusives, upon which they rest unconformably, and are apparently remnants of the once more extensive coastal plain, that was built along the west coast of Vancouver island. The larger basins occur north of Sooke harbour and north of Sooke bay, underlying the lower portions of Muir Creek and Kirby (Coal) Creek valleys. Three small basins occur farther west and there are several outliers of Muir and Kirby Creek basins.

The sediments consist chiefly of sandstone and conglomerate with thin beds of sandy shale and marl. The basal conglomerate, composed of boulders of the Metchosin volcanics and Sooke gabbro, is usually very coarse, and rests on an uneven erosion surface. In places there are thin seams of lignite usually 1 to 2 inches thick, but occasionally, as near the bridge crossing Kirby, (Coal) creek, nearly a foot in thickness. Thin, cigar-shaped lenses of lignite also are found. The sediments are only slightly deformed, the individual basins having a broad synclinal structure, with a general plunge to the southwest. The beds are, however, broken by rather numerous faults, usually normal faults with a displacement of only a few feet. The average thickness of the sediments in any one basin is probably not more than 500 or 600 feet, but the maximum thickness as shown by the bore near the mouth of Muir creek, is over 1,500 feet, indicating that the sediments must have been deposited in old, deep embayments in the Metchosin volcanics and Sooke intrusives.

A large part of the Sooke and Duncan map-areas is covered by superficial deposits of various kinds, which consist largely, however, of glacial detritus. They are classified according to their lithological character, and mode and time of deposition, as follows: Admiralty till, Puyallup clays, sands, and gravels, Vashon drift, Colwood sands and gravels, and Recent alluvium and rock debris. Little remains of the Admiralty till deposited by the earlier glaciers. On the retreat of the earlier glaciers, the Puyallup interglacial deposits were formed, in part below sea-level, and they now occur chiefly below elevations of 300 or 350 feet. They consist of stratified clays, sands, and gravels, the clays occurring, in general, near the base of the deposits. The interglacial deposits were partially eroded during the later but less intense period of glacial advance, the Vashon. During this period the Vashon drift was formed, largely by ice alone, but in part by water. The Vashon drift is ordinarily an unsorted till, but in places it is rudely stratified. It forms a mantle a few feet thick covering the hard rocks and interglacial deposits, and is the most extensive of the superficial deposits. During the retreat of the Vashon glaciers, deposits of coarse sand and gravel, the Colwood sands and gravels, were deposited by the streams issuing from the larger retreating valley glaciers, and they now fill the larger valleys to a depth of 100 to 300 feet. Since the recent uplift of Vancouver island, the larger revived rivers have terraced the Colwood sands and gravels, developing narrow flood-plains, and have built deltas at their mouths. Alluvium has been deposited also in the lakes and swamps which formed in the poorly drained hollows of the drift mantle and in dammed glaciated valleys, and at one place an impure clayey bog iron ore or ochreous clay was deposited. Some of the bare glaciated rocks have been broken by mechanical weathering into a coarse debris, which has accumulated at the base of steep cliffs and on the islands of the northeastern part of the Duncan map-area. Along the shores the sand and gravel, derived by the retrogression of the uplifted drift deposits, have been deposited to form narrow beaches and a few spits and bay bars.

TABLE OF FORMATIONS.

Quaternary	Recent	Post-Glacial	Rock debris Alluvium
	Pleistocene	Later Glacial epoch Stage of glacial retreat Stage of glacial occupation Interglacial epoch Earlier Glacial epoch	 Colwood sands and gravels Vashon drift Puyallup clays, sands, and gravels Admiralty till
		Unconformity	
Tertiary	Lower Miocene?	Sooke formation	Chiefly sandstones and conglomerates
		Unconformity	
	Lower Oligocene	Sooke intrusives Granite Anorthosite Augite gabbro Olivine gabbro	 Bosses, stocks, and apophyses Bosses and apophyses Stocks, peripheral facies of olivine gabbro Stocks
		Intrusive contact	
	Upper Eocene	Metchosin volcanics	Ophitic basalt flows, agglomerates, tuffs, cherts, and diabase dykes
		Unconformity?	
Mesozoic	Upper Cretaceous	Nanaimo series Gabriola formation Northumberland formation DeCourcy formation Cedar District formation Duncan formation (equivalent of Cedar District, Protection, and Ganges formations) Protection formation Ganges formation Extension formation Haslam formation Benson formation	 Chiefly sandstones Conglomerates, sandstones, and shales Chiefly sandstones Chiefly shales Sandstones and shales Chiefly sandstones Shaly sandstones and sandy shales Conglomerates and sandstones Shales and sandstones Basal conglomerate and arkose

	Unconformity	
Doubtfully upper Jurassic or Lower Cretaceous	Minor intrusives	
	Hornblende-augite andesite porphyrite	Dykes
	Quartz diorite porphyrite	Dykes
	Gabbro	Dykes
	Intrusive contact ?	
Upper Jurassic and possibly Lower Cretaceous	Batholithic and minor intrusives	
	Diorite porphyrite	Dykes
	Intrusive contact	
	Granodiorite porphyrite	Dykes
	Intrusive contact	
	Saanich granodiorite	Batholiths and stocks, with contact facies of quartz; quartz-bearing and monzonitic diorites and quartz gabbro
	Intrusive contact	
	Sicker gabbro-diorite porphyrite	Masses, sills, and dykes
	Intrusive contact	
	Tyee quartz-feldspar porphyrite	Masses, sills, and dykes
	Intrusive contact?	
	Colquitz gneiss	
	Granite gneiss	Stocks
	Quartz diorite gneiss	Batholiths, stocks, apophyses, and dykes

		Intrusive contact	
		Wark gabbro-diorite gneiss	Batholith and stocks
		Intrusive contact	
	Jurassic and Triassic	Vancouver group	
	Lower and middle Jurassic?	Sicker series	
		Sicker sediments	Basal tuffs, cherty tuffs, and slates
		Sicker volcanics	Hornblende-augite andesites
	Lower Jurassic and probably upper Triassic (may include some Palæozoic limestones)	Sutton formation	Lentils of crystalline limestone in the Vancouver volcanics
		Vancouver volcanics	Meta-andesite and meta-basalt, flows and injected rocks, tuff-breccias, and cherty tuffs
		Unconformity?	
Palæozoic	Carboniferous?	Malahat volcanics	Meta-andesites, dacite tuff-breccias, tuffaceous argillites, and cherts
		Leech River formation	Slaty and quartzose schists

DESCRIPTION OF FORMATIONS.

LEECH RIVER FORMATION AND MALAHAT VOLCANICS.

The schistose sediments and fragmental volcanics that extend across the northeastern part of the Sooke map-area and the southern part of the Duncan map-area are the oldest rocks of the map-areas and probably the oldest of Vancouver island. Their age is doubtful, but they are almost assuredly Palæozoic, and are assigned provisionally to the Carboniferous. The great age and conformability of the schistose sediments.

chiefly slaty and quartzose schists, has been previously recognized and they have been called the Leech River formation.[1] To the north of the Leech River rocks and conformable with them are schistose fragmental volcanics, largely of the composition of dacite. These volcanics have been previously mapped and described with the Vancouver volcanics, although the possibility of their being older than the Vancouver volcanics and conformable with the Leech River formation was pointed out.[2] Now that further field work has shown that they are conformable with the Leech River sediments, and unlike the Vancouver volcanics in many ways, they are grouped separately and called the Malahat volcanics, after the district in which they occur most extensively.

The distribution and the lithological characters of the two formations are described separately, but since the formations are conformable, the structural relations, age and correlation, and mode of origin are considered together.

LEECH RIVER FORMATION.

DISTRIBUTION.

The rocks of the Leech River formation underlie a belt which extends across the northeastern part of the Sooke map-area and the southwestern part of the Duncan map-area, with a strike of about north 70 degrees west. The belt in its eastern portion, in the vicinity of Goldstream, is not much over half a mile wide, but it widens toward the west so that in the western portion of the map-area it is over 7 miles wide, extending north from the Jordan river to the San Juan river. The easternmost exposures are found half a mile west of Goldstream post-office in Goldstream creek. However, the formation doubtless extends farther east beneath the thick deposit of sand and gravel composing the Colwood delta. To the west the rocks are well exposed in the deep valleys and canyons which dissect the upland, but on the upland itself, which is fairly smooth and heavily drift-covered, the outcrops are comparatively small and not

[1] Geol. Surv., Can., Mem. 13, 1912, p. 35.
[2] Geol. Surv. Can., Mem. 13, 1912, p. 93 and p. 145.

very numerous. The southern boundary has, for the greater part, been located with considerable accuracy, since it follows the large subsequent valley, called the Leech River valley. Except in its western part, the northern boundary is rather poorly located although actually exposed in the stream beds which afford a continuous rock section across the contact. In its western part the northern boundary is a well-defined fault which is followed by the San Juan river and its eastward extension, Meadow creek, and hence is well located.

LITHOLOGICAL CHARACTERS.

The formation consists chiefly of argillaceous and arenaceous sedimentary rocks which have been metamorphosed by dynamic and igneous action into slaty and quartzose schists. There are in places, especially near the Malahat volcanics, cherty rocks and feldspathic and chloritic schists which are in part, at least, of volcanic origin. These rocks, together with interbedded rocks of purely sedimentary origin, form a transitional zone into the Malahat volcanics which are, of course, largely of volcanic origin. Although as a whole the formation possesses a uniform lithological character, yet in detail the individual beds differ considerably, especially as regards accessory minerals, texture, and power of resistance to corrasion. This last difference is well shown along the creeks which cross the formation, the hard quartzose beds often forming vertical walls over which the water spills into deep pools worn in the weaker slaty schists. The various rocks may be subdivided according to their mineral composition, not always evident in the hand specimen, as follows: quartz-biotite schists, quartz-sericite schists, garnet-staurolite-sillimanite schists, quartz-hornblende schists, and quartz-feldspar schists, some of which are chloritic.

Quartz-biotite Schists.

The principal rock type is the quartz-biotite schist. It varies greatly in texture and appearance from a thin-bedded, dark to black, slaty schist to a thick-bedded, rather light coloured (usually grey, but brownish weathering) fine to almost medium-grained, quartzite-like rock which is everywhere schistose and frequently laminated. The rocks are not only foliated, but in places are plicated and contain interfoliated lenses of quartz. They owe their dark colour to the presence of carbonaceous matter, biotite, and, in some varieties, partly to magnetite. Some of the slaty schists are so carbonaceous, black, and lustrous, as to resemble a graphitic coal, and may perhaps be best called graphitic schists, although none of the schists contain crystallized graphite.

The essential constituents are seen microscopically to be quartz, a light brown variety of biotite, and carbonaceous matter. The quartz occurs in fine irregular grains (0·02 to 0·5 mm. in diameter) with interlocking boundaries, and, with the exception of the quartz of the interfoliated lenses, is, as a whole, fractured and distorted. The biotite occurs in elongate flakes parallel to the foliation and bedding, and predominates in certain bands. The carbonaceous matter occurs in extremely fine amorphous grains. In some rocks it is fairly uniformly distributed in clouds of greater or less density, but in other rocks it is confined to irregular streaks parallel to the foliation. The accessory minerals are muscovite or sericite, garnet, which occurs sparingly in small colourless grains, calcite, and magnetite.

Quartz-sericite Schists.

In some of the quartz-biotite schists, muscovite or sericite is essential, and these rocks pass into light coloured schists, which consist essentially of quartz and sericite, and in which biotite is almost or entirely absent. In most of the quartz-sericite schists the quartz predominates, the sericite occurring in narrow layers as thin flakes elongate parallel to the foliation. In a few places, however, schists are found composed largely of soft, talcose sericite. In many of the quartz-sericite schists a part of the quartz appears to be secondary, occurring in much larger and less distorted grains; and indeed the field relations indicate that in places the quartz-sericite schists, which may form large lentils, have resulted from the replacement of quartz-biotite schists. The secondary quartz is almost invariably accompanied by pyrite, which has been altered, to a greater or less extent, to limonite.

Garnet-staurolite-sillimanite Schists.

In a few places, notably near the intrusive Colquitz granite gneiss in the southwestern portion of the Duncan map-area in the vicinity of Jordan river, the quartz-biotite and quartz-sericite schists contain relatively large amounts of garnet, staurolite, and sillimanite, and these minerals, although not predominating, are the most characteristic. Except for the presence of garnet, staurolite, or sillimanite, these schists do not differ in their appearance from the more normal schists, although some weather to a dark red colour. The sillimanite, as seen in the hand specimen, occurs in short to long slender prisms, of rectangular or hexagonal cross section, that are rudely orientated parallel to the foliation. They have a maximum length of about 5 cm. and a maximum width of 4 or 5 mm. Garnet occurs in small (average less than 2 mm. in diameter) pinkish, dodecahedral crystals. Staurolite, which is not usually conspicuous in the hand specimen, forms small, yellowish brown grains between the lamellæ of biotite and quartz; in a few places, however, distinct, single and twin crystals are seen. In addition, on microscopic examination, andalusite is detected, and in the rocks from west of the map-area, cyanite[1] has previously been found.

Quartz-hornblende Schists.

In a very few places, notably in the divide between Bear creek and the west fork of Leech river, and near the Malahat volcanics, quartz-hornblende schists occur in the Leech River formation. They are dark greyish green, fine-grained and foliated, and even somewhat laminated rocks. They are seen on microscopic examination to consist essentially of quartz and a pale green, weakly pleochroic variety of hornblende; with accessory clear, and only slightly twinned plagioclase feldspar, probably albite; zoisite; and magnetite or ilmenite. The rock is distinctly foliated, both magnetite and hornblende having a parallel

[1] Geol. Surv., Can., Mem. 13, 1912, p. 59.

arrangement, but irregular streaks of quartz cross the rock at an angle to the foliation.

Quartz-feldspar Schists.

The quartz-feldspar schists which are frequently chloritic, are confined chiefly to the neighbourhood of the Malahat volcanics, and more especially to the transitional zone between the two formations. However, they are found at a few places throughout the Leech River formation. They are light greyish green, fine-grained to dense, schistose rocks, apparently quartzose, some varieties being almost cherty. The dense light coloured minerals are usually interfoliated with darker micaceous minerals.

They consist essentially of quartz and plagioclase, probably a sodic variety, albite-oligoclase. Quartz is usually predominant, but in some rocks is hardly more than accessory. Minerals such as uralite, chlorite, epidote, zoisite, sericite, and carbonaceous matter are usually abundant, and biotite, magnetite, titanite, and calcite are also present. The rocks are invariably foliated and very fine-grained, averaging about 0·02 to 0·05 mm. in diameter, and contain more or less argillaceous matter not resolved by the microscope. Scattered through the fine-grained matrix are, however, larger grains of quartz and feldspar from 0·1 to 0·5 mm. in diameter. Although the rocks are unquestionably fragmental in character, there is not much doubt but that they are in part of volcanic origin, and contain tuffaceous material mixed with truly sedimentary material.

Metamorphism.

All of the rocks of the Leech River formation, as indicated by the petrographic description given above, have been greatly metamorphosed by dynamic and in places by contact action. All of the rocks are schistose, and although not common, some of the weaker rocks are minutely contorted or plicated. Veins and lenses of quartz up to 6 inches in width are exceedingly numerous, especially near the intrusive masses of granite gneiss and the fault contact with the Metchosin volcanics. These

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)

1.0 2.8 2.5
3.2 2.2
3.6
4.0 2.0
1.1
1.8
1.25 1.4 1.6

quartz veins and lenses are usually parallel to the foliation, but in places break across it. A few of the quartz veins are crenulated, perhaps due in some places to the veins crossing at short intervals, from one foliation plane to another, after the manner of some Nova Scotia quartz veins[1], but in other places are due clearly to crumpling. This is shown under the microscope by the wavy extinction of the quartz of the distorted veins and the sharp extinction of the quartz of the other veins. The microscope shows also that some of the veins, perhaps many, contain albite. These quartz veins are also gold-bearing and although very low grade, the gold found in the streams traversing the Leech River formation has doubtless been derived from them.

MALAHAT VOLCANICS.

DISTRIBUTION.

The Malahat volcanics underlie an extremely irregular but persistent belt, varying from 200 feet to 5 miles in width, which extends, north of the Leech River formation, across the northeastern part of the Sooke map-area and the southern part of the Duncan map-area, from Langford lake, east of Goldstream, to west of Jordan meadows. The southern boundary of the Malahat volcanics with the conformable Leech River formation is regular, and hence, although definitely located only where crossed by streams affording a good rock section, may be fairly well determined. The northern boundary with the intrusive Wark and Colquitz gneisses is extremely irregular, and except where actually exposed can only be assumed. Roof pendants of the Malahat volcanics in the Wark and Colquitz gneisses presumably occur at several places, although they are definitely exposed only near the dam of the upper (No. 3) Goldstream lake. The Malahat volcanics are more resistant than the Leech River schists and consequently are better exposed, but there are large areas in which only a few small outcrops are found. A notable, and by far the best section, over

[1] T. A. Richard, "The domes of Nova Scotia." Can. Min. Jour., vol. 33, 1912, pp. 273–276.

4½ miles long, is afforded by the almost continuous cuts along the Esquimalt and Nanaimo railway to the west of Finlayson arm, from south of 13-mile-post to north of 17-mile-post.

LITHOLOGICAL CHARACTERS.

The Malahat volcanics are chiefly dacite tuffs, varying from fine-grained, carbonaceous and argillaceous tuffs to coarse-grained, sandy tuffs and breccias. These tuffaceous rocks are interbedded with cherts, and, especially near the transition to the Leech River formation, with carbonaceous, shaly rocks composed almost entirely of sedimentary material. There are also some flow rocks, andesites, and presumably dacites. The rocks are prevailingly schistose and many of them, chiefly near the intrusive igneous masses, are silicified and mineralized.

In detail they may be subdivided into flow rocks, chiefly meta-andesites, dacite tuff-breccias, tuffaceous slates or argillites, cherts, and chert breccias, and the extremely metamorphosed rocks.

Flow Rocks (Meta-andesites).

The recognizable flow rocks of the Malahat volcanics are chiefly meta-andesites. It is probable that there are some dacites also, since most of the tuffaceous rocks have the composition of dacite; but no recognizable dacites were encountered in the field, and none of the representative flow rocks selected for microscopic study show essential primary quartz. The meta-andesites are rather light greyish green, brownish weathering, dense to fine-grained rocks, the constituent minerals of which can rarely be detected by the unaided eye. A few of them are amygdaloidal, with amygdules of chlorite, and some are porphyritic. In common with the rest of the rocks of the formation they are foliated and sheared, so that they resemble chlorite schists, and are cut by quartz and calcite veinlets, and mineralized with pyrrhotite, pyrite, and chalcopyrite.

The essential constituents are oligoclase-andesine feldspar, averaging about $Ab_{70}An_{30}$ and originally hornblende, the feldspar greatly predominating. A few small phenocrysts are usually present in a groundmass of lath-shaped feldspars which in some rocks have a rudely radial arrangement. However, the original texture has usually been destroyed, the feldspars broken and distorted, and the feldspar partly and the hornblende completely altered to sericite, actinolite, uralite, chlorite, epidote, zoisite, and calcite.

Dacite Tuff-breccias.

The prevailing rocks of the Malahat volcanics are fragmental, and although stratified, are presumably of explosive origin. They range from rather coarse tuffs to fine breccias, and are best called tuff-breccias[1] to indicate their rather fine-grained character and explosive origin. They are thin to thick bedded, light to dark grey, fine to medium-grained, fragmental and stratified rocks, the finer-grained resembling slates or argillites and the coarser-grained resembling arkosic sandstones. Although well stratified they are not as a rule well sorted. They are commonly composed of angular fragments of quartz, feldspar, and dark chert in a fine-grained and argillaceous and frequently carbonaceous matrix. In a few places they contain some rounded fragments. They are invariably more or less metamorphosed and foliated, and are frequently cut by veinlets of quartz, and quartz and feldspar, and impregnated with pyrite.

The tuff-breccias are seen, on microscopic examination, to consist of angular fragments, varying from 0·1 to 3 mm. in diameter (average about 0·5 mm.), of quartz, feldspar including both orthoclase and sodic plagioclase, and of volcanic rocks, in a fine-grained, carbonaceous and argillaceous matrix. The rock fragments are chiefly fine-grained but occasionally porphyritic, feldspathic andesite, but a few of the fragments are similar to the associated tuffaceous argillites and cherts. The matrix contains also a large amount of accessory and secondary minerals, not clearly distinguished from one another, viz., light to brownish mica, titanite, sericite, uralite, chlorite, epidote, quartz, calcite, pyrite, and limonite. Even under the microscope the stratified structure is evident, and the stratification is parallel to the foliation. The larger fragments are distorted and broken and the feldspar fragments greatly altered.

---

[1] Iddings, J. P., "Igneous rocks, vol. I, 1909, p. 306.

Tuffaceous Argillites.

As already noted the dacite tuff-breccias are interbedded with dark slaty or more massive argillitic rocks largely of sedimentary origin. In many places the argillitic rocks consist merely of relatively thin layers or small lentils, 1 or 2 inches thick, in the tuff-breccias; although in places throughout the formation, as shown by the 4-mile section along the Esquimalt and Nanaimo railway, but more especially near and in the transitional zone into the Leech River formation, beds occur which are several feet thick. The argillitic rocks are dark grey to black, fine to very fine-grained, slaty or massive, homogeneous rocks which, although resembling hornfels, are easily scratched with a knife blade. The only recognizable constituents in the carbonaceous and argillaceous matrix, which is so fine-grained that it is not resolved under the microscope, are tiny angular fragments, 0·005 to 0·05 mm. in diameter, of quartz, feldspar, sericite, chlorite, and epidote. The rocks are, however, clearly stratified, some layers being coarser-grained than others. In the rocks consisting of interlayered tuff-breccia and argillaceous matter, some of the layers are sharply separated from one another while other layers are gradational. Since all the argillitic rocks contain some angular fragments of quartz and feldspar, such as are found in the tuff-breccias, it is probable that most of them are in part of volcanic origin and hence they are called tuffaceous argillites.

The following is a partial analysis, kindly furnished by the Associated Cement Company, of a tuffaceous argillite, quarried from the west shore of Finlayson arm, and used in the manufacture of portland cement. With it is given for comparison the range of composition of twenty-nine slates of sedimentary origin.[1]

	Tuffaceous argillite (presumably dehydrated)	Range of composition of slate
SiO_2	67·[illegible]	55 67
Al_2O_3	20·	11–23
Fe_2O_3	8·58	0·52–7
FeO		0·46–9
CaO	trace	0·33–5·20
MgO	2·16	0·88–4·57

[1] Dale, T. Nelson, "Slate in the United States," Bull. 586, U. S. Geol. Surv., 1914, p. 52.

It is seen that the tuffaceous argillite resembles sedimentary slates in its high silica, alumina, and iron, and also in the preponderance of magnesia over lime.[1] The silica, indeed, is as high as the maximum value given by Dale, owing to the presence of a large amount of quartz. It is impossible to calculate accurately the mineral composition of the rock from the incomplete analysis, since the important constituents, soda, potash, and water, have not been determined, and since the amount of these constituents cannot be approximated, as the difference between 100 and the sum of the percentages of the constituents determined, that is 1·16, is hardly sufficient to account for all the alkalis and water that must occur in the fresh, undehydrated rock. The following is a rough estimate of the mineral composition s determined by the microscope:

	Per cent.
Quartz	40
Feldspar, chiefly albite	10
Sericite and kaolin	38
Chlorite	5
Hematite and magnetite	7

Cherts.

The cherts, as best shown by the Esquimalt and Nanaimo Railway section, are also found throughout the Malahat volcanics, in some places in thin to thick persistent beds totalling a hundred feet or more in thickness. They are light to dark grey and even reddish in colour, and, of course, dense and siliceous looking, some of the clearly bedded varieties resembling quartzites. Some of the cherts are clearly foliated and cut by quartz veinlets which are parallel to the foliation. Other varieties are brecciated and recemented by quartz veinlets. In places the cherts contain pyrrhotite, pyrite, or chalcopyrite, and in a few places, as on the south side of Mt. Skirt, to the northeast of Goldstream post-office, the sulphide minerals occur in rathe-large amounts.

The cherts consist essentially of quartz and feldspar. They are extremely fine-grained and even the larger grains are rarely over 0·02 mm. in diameter. The grains are, as a rule, very

[1] Dale, T. Nelson, op. cit. p. 20.

irregular with interlocking boundaries, and although some cherts are apparently fragmental, no distinctly fragmental textures were observed. The original fragmental texture may have been obscured, however, by metamorphism, both by foliation with accompanying recrystallization, and by silicification. The feldspar is in large part probably albite or albite-oligoclase, but since it occurs in clear grains it can be distinguished from quartz only by its rather infrequent albite twinning. The relative proportion of quartz and feldspar cannot, therefore, be determined microscopically, but an approximate determination was made as follows: a chemical determination of the total silica in one of the typical cherts, from the tunnel on the Esquimalt and Nanaimo railway between 15 and 16-mile-posts, gave as a result 89·91 per cent. Allowing for 1 per cent of pyrite and 3 per cent of sericite, the only other minerals present in the chert besides quartz and feldspar, and assuming that the feldspar contains 67 per cent of silica, the theoretical amount in an albite-oligoclase of the composition of $Ab_{94}An_6$, the amounts of quartz and feldspar were calculated as 74 and 22 per cent respectively. Quartz occurs also in irregular veinlets and replacements composed of larger sized grains. The other minerals present, besides those which clearly were introduced later, are sericite, actinolite, biotite, zoisite and epidote, and chlorite. Besides occurring in disseminated grains most of these minerals occur also in irregular streaks or veinlets. In the mineralized cherts, the metallic sulphides are not only associated with the secondary quartz but with rather abundant calcite.

Chert-breccias.

At several places throughout the Malahat volcanics, but always closely associated and apparently interbedded with the cherts and tuffaceous argillites, are rather peculiar fragmental rocks. They consist of unsorted, angular to sub-rounded, opaque and greyish to nearly white weathering fragments, from 1 mm. to 4 or 5 cm. in diameter, in a dark to black, fine-grained, apparently carbonaceous and argillaceous matrix. The rocks are invariably greatly foliated and some of the fragments have been broken and rounded, while the foliation planes in the matrix curve out around the fragments. In the more metamorphosed varieties the dark matrix is lustrous and schistose, resembling the "graphite schists" of the Leech River formation. It is interleaved not only with stout but with stretched, lens-shaped fragments which since they are opaque and white weathering, are in striking contrast to the black, lustrous matrix. The fragments appear to be feldspathic, with a surface coating of kaolin, but on microscopic examination all the fragments are shown to be chert, so that the opaque, white coating is doubtless powdery silica, such as results from the weathering of cherts. The cherty fragments resemble the cherts of the Malahat volcanics and are of almost sub-microscopic grain, and are composed largely of quartz with some feldspar. Quartz forms also numerous intersecting veinlets and irregular replacements in the chert fragments and later veinlets of quartz and sericite cut both the fragments and matrix. The matrix is not resolved, but is clearly carbonaceous and contains some flakes of sericite and zoisite, and is stained with iron oxide. These peculiar rocks have been called chert-breccias. As the fragments occur in a fine-grained carbonaceous matrix they appear to be of explosive and sedimentary origin, but for the reasons given in the discussion of the mode of origin of the Malahat volcanics, they are believed to be autoclastic or friction breccia .

Metamorphism.

As already stated, all the rocks of the Malahat volcanics are foliated and to a greater or less extent their original chemical and mineral composition has been changed. The ordinary mineral and textural changes, which are the only changes considered since no chemical analyses are available, have already been described; but certain metamorphic rocks occur whose original lithological character has been almost entirely obscured. These more highly metamorphic rocks occur throughout the Malahat volcanics but are developed chiefly near the intrusive Wark and Colquitz gneisses. They are, as a rule, more greatly fractured, silicified, and mineralized, and cut by more numerous quartz and even calcite veinlets. The most common type has apparently resulted from the metamorphism of the flow rocks. They are greyish to brownish green, foliated, and even schistose rocks, some of them siliceous looking, but more frequently resembling chloritic schists. Some are seen on microscopic examination to retain traces of their original texture and minerals, but many are composed of sheared and foliated aggregates of secondary minerals, actinolite, uralite, chlorite, epidote, zoisite, sericite, quartz, and albite mixed with more or less original crushed feldspathic material. In some places they are replaced by quartz, calcite, pyrite, pyrrhotite, and chalcopyrite, [illegible] stained with hydrous iron oxides.

The metamorphosed tuff-breccias are generally much denser, more massive and more siliceous looking than the metamorphosed flow rocks, and are frequently banded and plicated. Under the microscope, however, they are seen to consist of similar sheared and foliated aggregates of secondary minerals, although their original fragmental texture is usually preserved to a greater or less extent, and quartz and micaceous minerals are more abundant. They too are replaced and cut by veinlets of epidote and zoisite and of quartz and calcite accompanied by sulphide minerals. The tuffaceous argillites pass into sericitic schists, the carbonaceous schists being black and highly lustrous; as already noted, even the cherts are mineralized and partly replaced by calcite as well as by secondary quartz.

At a few places, best exposed on the Esquimalt and Nanaimo railway south of the 17-mile-post, near the intrusive dykes and masses of Colquitz quartz diorite [illegible] rocks are not only metamorphosed in the manner [illegible]cribed, but contain lenses and irregular replacemen[illegible]vely coarse-grained quartz and oligoclase, evidentl[illegible] from the intrusive quartz diorite, thus developing hybrid rocks.

STRUCTURAL RELATIONS OF LEECH RIVER FORMATION AND MALAHAT VOLCANICS.

INTERNAL.

As noted, the Leech River sediments and the Malahat volcanics appear to be conformable. The proof of their conformity rests upon the following evidence: (1) their general structural relations are the same, that is they have both been intruded by similar upper Jurassic irruptives and have been deformed and metamorphosed to the same extent, so that their present attitudes are virtually identical; (2) their contact is parallel to their bedding and is marked by a transitional zone containing beds of both sedimentary and volcanic origin. In addition, the Leech River formation contains a few beds of quartz-feldspar schist, apparently of volcanic origin, while the Malahat volcanics contain many beds partly or entirely of sedimentary origin, tuffaceous argillites, cherts, and chert-breccias.

The transitional zone between the Leech River sediments and the Malahat volcanics is exposed at several places, notably along the lower, northward flowing portion of Goldstream creek and along the Esquimalt and Nanaimo railway between 12 and 13-mile-posts. Farther west the contact between the two formations is more abrupt and definite. At a distance of one-half mile from the Malahat volcanics, in the eastern portion of the Sooke map-area, isolated beds, 2 to 20 feet thick, of chloritic quartz-feldspar schists, occur in the Leech River formation interbedded with the ordinary quartz-biotite and quartz-sericite schists. Towards the north, approaching the Malahat volcanics, these beds increase in number and thickness but are not numerous until a distance of less than 500 feet from typical Malahat volcanics is reached. This 500-foot zone is the transitional zone proper, and consists largely of the chloritic feldspar schists and cherts, such as characterize the Malahat volcanics, interbedded with thin layers of the slaty and quartzose schists typical of the Leech River formation. Generally the rocks in the zone grow less schistose towards the north and the chert layers become more numerous, and, instead of interbeds of the typical slaty schists, there are interbeds of tuffaceous argillite, such as are found elsewhere in the Malahat volcanics. Farther north, beds of tuff-breccia occur and even schistose meta-andesite, although the tuff-breccias are interleaved with thin layers or lentils of dark, carbonaceous, tuffaceous argillite. The contact of the two formations is located at the southern boundary of the first well-defined bed of tuff-breccia or schistose meta-andesite. Farther west in the vicinity of Sooke lake, Survey mountain, and Jordan meadows, the tuffaceous rocks in the Malahat volcanics are less numerous and the transitional zone is very much more abrupt. There, although chloritic feldspathic schists are common in the Leech River formation, and grow more numerous towards the Malahat volcanics, the volcanics themselves appear rather suddenly as schistose meta-andesites which may be either amygdaloidal or porphyritic. Even where the contact of the two formations is fairly definite, the sediments and the volcanics are clearly conformable in attitude and there appears to have been an uninterrupted period of change from the conditions under which the sedimentary rocks were deposited to those under which the volcanic rocks were formed. As described below it seems as if the Malahat volcanics overlie the Leech River formation and hence it follows that the accumulation of the Malahat volcanics followed the deposition of the Leech River sediments.

Deformation.

The rocks of the Leech River and Malahat formations have been closely folded and consequently foliated. Their general strike varies from north 65 degrees west in the eastern part of the map-areas to due west in the extreme western part. The rocks have been so closely compressed and were so weak or incompetent that the bedding and foliation planes are virtually parallel throughout the map-areas.[1] They dip in most places steeply to the north at an average angle of about 80 degrees, and with one or two exceptions, a minimum dip of 60 degrees. Southerly dips are encountered in a few places and these are either very steep and presumably due to local overturning, or else about 45 degrees and due to secondary folding. Secondary folding or contortion is not at all common although noted at a few places, notably in the Malahat volcanics along the Esquimalt and Nanaimo railway between 12 and 14-mile-posts, and in the Leech River slaty schists south of Jordan meadows. Secondary folding occurs also in the vicinity of the profound fault separating the Leech River formation from the Metchosin

[1] Cf. Leith, C. K., "Structural geology," 1913, p. 120.

volcanics and near small intrusive masses in both formations. These folds are either the result of movements later than those deforming the entire group or of the relative rigidness or competency of the intrusive masses. Along the Esquimalt and Nanaimo railway the secondary folds plunge to the west at low angles; and their axial planes dip steeply to the north, parallel to the general bedding and foliation of the formation. To the south of Jordan meadows the axial planes of the more competent secondary folds, which also plunge to the west, dip about 45 degrees to the south, but the less competent folds dip from that angle through vertical to 65 degrees to the north. At both these places, however, the character of the folding and of the prominent cross jointing, which dips to the south, indicates a relative upward movement of the more northern rocks.

Although secondary folds corresponding to the major folds are not common, minor cross folds or undulations are rather numerous. These cause the strike of the beds to vary within rather narrow limits, usually within 30 degrees of the general strike. In a few places, however, these undulating cross folds are more closely compressed, so that the edges of the steeply dipping beds exposed in horizontal outcrops are seen to be greatly contorted. The axes of all these small cross folds correspond with the dip of the rocks and are consequently nearly vertical. The larger features of the cross folding were not determined either from the pitch of the secondary longitudinal folds or from the distribution of the rocks; but along the Esquimalt and Nanaimo railway to the south of 17-mile-post, there is an anticline with two corresponding synclines, which strike about north 40 degrees east, and pitch gently to the northeast, with axial planes dipping steeply to the northwest. These folds, like the longitudinal secondary folds, also indicate a relative upward movement of the more northern rocks.

In addition to the folding, the rocks of both formations have been broken by numerous shear zones and small faults. Most of the shear zones are parallel to the bedding and foliation, and like them indicate a relative upward movement of the northern wall. Although the slickensided surfaces indicate as a rule a nearly vertical movement, the movement had a pronounced horizontal component in places, as south of Jordan meadows, and in one place south of Jordan meadows the northern wall has moved, relative to the southern wall, toward the west, thus indicating westward plunging synclines or eastward plunging anticlines. Cross shearing and faulting, sufficient in places to produce change or foliation in the rocks, occur also. In some places, as near Mt. Finlayson and Mt. Skirt, such oblique shearing and consequent foliation in the Malahat volcanics is parallel to the contact with the Wark and Colquitz gneisses and must have been formed by movements during or after the intrusion of those rocks. Such movements seem also to have determined the position of the open cross folds south of 17-mile-post.

On account of the complexity of the folding and faulting, and the general uniformity of each of the two formations, the transitional zone between the two formations being the only horizon marker, it seems almost impossible to determine the major features of folding and the amount of displacement due to faulting. Possibly after extremely detailed work, applying and developing the methods worked out by the Lake Superior geologists[1] in unravelling the complex structures there, the exact structure may be determined. At present, however, only a few rather indefinite generalizations may be made from the data presented above. It was formerly thought by the writer[2] that the Leech River formation was involved in three or four large, nearly isoclinal folds so that the strata were repeated several times across the belt, and that one such fold was represented by the supposed infold of Malahat volcanics northwest of Jordan meadows on the divides between Jordan river and San Juan and Koksilah rivers. However, the detailed work of 1913 proves that there is no such infolding of the two formations. The writer's present interpretation is that the rocks are repeated by a great number of small isoclinal, similar folds produced largely in the zone of flow, and that they form one limb of a great composite fold involving both formations. Since the prevailing dip

[1] Notably C. R. Van Hise and C. K. Leith, see "Structural geology," 1913, by C. K. Leith, and "Principles of Pre-Cambrian geology," 16th Ann. Rept. U. S. Geol. Surv., pt. 1, 1896, pp. 571-874, by C. R. Van Hise.

[2] Geol. Surv., Can., Mem. 13, 1912, p. 40.

of the bedding and foliation is to the north, and since the northerly beds have in many places been thrust over the southerly beds, the inference[1] is that the exposed rocks form the southern limb of a great synclinorium. This inference is supported by the occurrence of the younger Vancouver volcanics to the north, although with but little question the Vancouver volcanics rest uncomformably upon the Leech River and Malahat formations. If this inference is true the Malahat volcanics are younger than and rest on the Leech River sediments.

It is clear that the Leech River and Malahat formations have suffered deformation during more than one period. Inasmuch as a part of the evidence upon which this conclusion rests is presented in the section dealing with structural relations with the younger formations, a discussion of the subject is delayed until all the evidence shall have been given.

Stratigraphy and Thickness.

Owing to the rapidity with which the varieties of rock succeed one another in the Leech River and Malahat formations, and owing to their great structural complexity, no attempt was made to measure any extensive detailed sections. Neither was it found possible to do more than roughly estimate their thickness. If, as supposed, the Malahat volcanics are the younger the general succession is as follows:

		Thickness in feet.
Malahat volcanics	Dacite tuff-breccias predominating, with meta-andesites, and numerous interbeds of tuffaceous argillites and cherts, the tuffaceous argillites being more numerous near the base of the formation..........................	2,500
Transitional zone	Interbedded chloritic feldspar schists, cherts, quartz-biotite schists, and tuffaceous argillites..	500
Leech River formations	Quartz-biotite schists and, where more metamorphosed, quartz-sericite and quartz-staurolite-sillimanite schists, resulting from the metamorphism of rapidly alternating shales and fine-grained sandstones, with interbedded quartz-hornblende and quartz-feldspar schists, more numerous near the top of the formation, resulting from the metamorphism of tuffaceous and possibly of calcareous sediments..........	5,000
	Total.........................	8,000

[1] Leith, C. K., "Structural geology," 1913, pp. 114–132.

EXTERNAL.

Relations to Younger Formations.

The Leech River sediments and Malahat volcanics are separated from the adjoining surface-formed rocks, the Vancouver volcanics to the north, and the Metchosin volcanics to the south, either by large irruptive masses, intrusive into the formations on both sides of the contact, or else by profound faults. The only possible exception to this statement is the contact between the Malahat and Vancouver volcanics north of Jordan meadows and east of Todd mountain. This contact is not exposed and hence its exact nature cannot be determined. Along the fork of the Koksilah river crossing the contact, the two formations are separated by a narrow intrusive mass of Wark gneiss, 1,500 feet wide. Although no exposures occur for a mile to the southeast, the writer feels little hesitation in concluding that the mass of Wark gneiss exposed in the fork is a narrow extension or large apophysis of the main batholith of Wark gneiss, which occurs a mile to the southeast; and this supposed extension or apophysis, like the main batholith and exposed portion of the Wark gneiss in the fork of the Koksilah, would separate the Malahat and Vancouver volcanics throughout its length. The western portion of the contact is presumably an extension of the profound fault which farther west separates the Leech River sediments from the Vancouver volcanics. The fault, which is described more fully in the section dealing with the structural relations of the Vancouver volcanics, has an almost east-west strike and vertical dip; and, since the Vancouver volcanics are presumably younger than the Leech River formation, the southern side, composed of the Leech River and Malahat formations, must be upthrown.

The boundary between the Leech River formation and the Metchosin volcanics is also a profound fault, and is described in detail in the section dealing with the structural geology of the Metchosin volcanics. It extends across the entire width of the map-areas and has a strike of north 70 degrees west in its eastern portion and a nearly east-west strike in its western portion. It dips to the north at as low angles as 36 degrees in places. The northern wall, consisting of the Leech River rocks, has been thrust over the Metchosin volcanics. Near the fault, the Leech River rocks have been greatly sheared by the major and accompanying minor faults (Plate VIII) and have been crumpled into small drag folds; hence the rocks strike nearly parallel to the major fault. However, considering the structure on a large scale, at least the eastern portion of the fault bevels across the Leech River formation at a small angle, so that the exposed width of the formation is much less in its eastern part.

Intrusive into the Malahat formation, and forming the greater part of its northern boundary is the large composite batholith of the Wark and Colquitz gneisses. Near the contact the Malahat volcanics are as a rule greatly metamorphosed. They are fractured, foliated parallel to the contacts, silicified, mineralized, and cut by numerous quartz and calcite veinlets, developing the metamorphic types described above. Apophyses and stringers, especially of the Colquitz quartz-diorite, extend into the volcanics, developing in places contact complexes and hybrid rocks.

The only subjacent rocks intrusive into the Leech River formation are two or three small stocks or bosses of the granite facies of the Colquitz gneiss, occurring in the southwestern part of the Duncan map-area and in the northeastern part of the Sooke map-area. Near the small stocks in the southwestern part of the Duncan map-area the Leech River schists have been converted into the highly foliated garnet-staurolite-sillimanite schists, and apophyses of the granite gneiss traverse the schists parallel to their foliation. As noted above the quartz veins in the Leech River rocks are exceptionally numerous in the vicinity of the stocks and bosses of granite gneiss and their close association indicates that perhaps most of the quartz veins traversing the Leech River rocks are among the metamorphic effects of the intrusion of the granite gneiss.

The Malahat volcanics and Leech River schists are cut also by two of the minor intrusives which have been tentatively correlated with the upper Jurassic irruptives. The Malahat volcanics are cut by two large dykes of gabbro, one crossing the Esquimalt and Nanaimo railway 200 yards north of 15-mile-post, and the other about 2 miles to the south and to the west of the railway. The Leech River schists are cut by two small dykes of quartz diorite porphyrite a quarter of a mile northeast of Goldstream post-office.

PERIODS OF DEFORMATION.

At no place are the Mesozoic rocks, chiefly the Vancouver volcanics, in direct unconformable contact with the Leech River or Malahat formations, but it is fairly certain that the Vancouver volcanics rest unconformably upon the Leech River and Malahat formations. Hence the Leech River and Malahat formations were deformed at least slightly before the accumulation of the Vancouver volcanics. Since the stocks and batholiths of Wark and Colquitz gneisses were clearly irrupted into the folded Vancouver volcanics as well as into the foliated Leech River and Malahat formations, it is quite clear that both the Vancouver volcanics and Leech River and Malahat formations had been greatly deformed before the irruption of the Wark and Colquitz gneisses. During this deformation the Vancouver volcanics presumably acted as a competent unit and appear to have been pushed southward, in the south limb of a composite synclinorium, across the Leech River and Malahat formations which, being incompetent, were greatly deformed and foliated. The Wark and Colquitz gneisses are themselves foliated, and in addition it appears from the position of certain quartz veins, from the contortion of a few of them, and from the relation of their joints to the cleavage of the schists, as if the formation of the quartz veins was followed by a large amount of deformation. Finally the schists were further contorted and deformed during the development of the great thrust fault which separates the Leech River formation from the Metchosin volcanics. Thus it is seen that the present complex structure of the Leech River and Malahat formations is the result of several periods of deformation.

MODE OF ORIGIN.

Most of the rocks of the Leech River formation were formed by normal sedimentary processes. They appear to have been originally shales and shaly and fine-grained sandstones composed largely of quartz. The great thickness of the formation, the lithological similarity of the rocks, and the absence of conglomerates indicate that the rocks were deposited in fairly quiet water under uniform conditions. In the absence of fossils or minor original structures, such as ripple-marks and mud cracks, which if ever present have been destroyed by the intense metamorphism that has affected the formation, it is impossible to state definitely whether the rocks are of marine or lacustrine origin. Their uniformity, fine-grained character, and prevailing quartzose composition suggest that they are marine.

These sedimentary rocks were dynamo-metamorphosed in the zone of anamorphism into quartz-biotite schists, and near the intrusive masses were also contact-metamorphosed into quartz-sericite and quartz-staurolite-sillimanite schists. It is possible that interbedded calcareous sediments were metamorphosed to form some of the quartz-hornblende schists.

The presence of the quartz-feldspar schists in the Leech River formation, containing essential amounts of feldspar and secondary mafic minerals, indicates that at times in certain places some volcanic detritus, presumably of explosive origin, was deposited with the sedimentary matter. This conclusion is further supported by the virtual restriction of the feldspathic rocks to the vicinity of the transitional zone between the Leech River formation and the Malahat volcanics. In the transitional zone, rocks of purely sedimentary material are interbedded with rocks that are partly or entirely of volcanic origin—such as chloritic feldspar schists, cherts, tuffaceous argillites, and even schistose andesites. Since the Malahat volcanics are supposed to overlie the Leech River sediments it appears that towards the close of the deposition of the Leech River formation vulcanism was initiated; and that some of the volcanic material, chiefly of pyroclastic origin, was deposited with the sedimentary material. With increased vulcanism the volcanic products greatly predominated over the sedimentary, resulting in the Malahat volcanics. Sedimentation does not seem to have ceased, however, since a large portion of the Malahat volcanics is mixed with considerable sedimentary matter, and since thin beds of sedimentary rocks occur throughout the Malahat formation.

Some of the Malahat volcanics are clearly flow rocks of the composition of andesite and possibly dacite. It seems probable that like the greater part of the other volcanics of Vancouver island, they were erupted under submarine conditions, since they are conformable with the Leech River sediments, almost certainly of marine origin, and since they are interbedded with stratified rocks which, like the Leech River sediments, are, as indicated below, doubtless of marine origin also. Other evidences of the conditions existing during the eruption of the Malahat andesitic lavas, such as pillow structure, flow breccias, and similar structures, if ever present, have been destroyed by the metamorphism that the andesites have undergone.

Accompanying the extrusions of the andesites were explosions during which fragmental ejecta were thrown out into the sea and deposited to form the well stratified but not well sorted dacite tuff-breccias. Indeed from the relative abundance of the fragmental rocks it appears as if the eruptions were largely explosive. The more salic or felsic character of the fragmental rocks, a characteristic of the Vancouver volcanics[1] as well, may be explained by gravitative differentiation in the vents of the volcanics,[2] where the upper solidified portion of the lava, that portion which was subsequently blown into fragments, would be more felsic than the lower unsolidified portion that was erupted as lava. The more felsic character of the tuff-breccias may also be explained as due in part to silicification and albitization during their deposition, or soon after, by thermal solutions escaping from the underlying cooling andesites, the alteration taking place in much the same manner as in the tuffs of the other volcanic formations of Vancouver island.[3] However, it must be borne in mind that a part, and presumably a large part of the silicification, and possibly of the albitization as well, was accompanied by mineralization, and was the result of the contact-metamorphic effects produced by the intrusion of the batholiths, stocks, and minor intrusives of upper Jurassic age.

---

[1] Geol. Surv., Can., Mem. 13, 1912, p. 53.
[2] Daly, R. A., "Igneous rocks and their origin." 1914, p. 228.
[3] See detailed description of the origin of the Metchosin cherty tuffs, p. 288, and also of the Sicker tuffs, by H. C. Cooke, p. 162.

Since the tuff-breccias contain thin interbeds of tuffaceous argillites, which are in part sedimentary, it appears as if fine silts and muds derived from neighbouring lands were being deposited in the sea in which the andesites and tuff-breccias were accumulating. During or immediately following periods of volcanic activity the volcanic material predominated over the terrestrial matter; but at times, during periods of volcanic quiet, the deposition of the fine silts and muds must have become dominant to form the thicker beds of tuffaceous argillites. As recorded by the rocks of the transitional zone, such periods of volcanic quiet were more numerous during the initiation of vulcanism.

The marine origin of the tuffaceous argillites cannot be positively proved, but their association with the Leech River sediments, and their similarity to them indicates almost certainly that the two were formed under like conditions which, as stated, appear to be marine. The conditions under which the other rocks of the Malahat volcanics were accumulated are even more uncertain, but an assumption that these rocks were likewise formed under submarine or at least subaqueous conditions is the most satisfactory. Therefore, although it may appear to be arguing in a circle to give as proof of the marine origin of each kind of rock, that it is closely associated with other rocks which appear to be of marine origin, the mere fact that all of the various kinds of rocks, including the cherts, are best explained as accumulating under the same conditions, gives cogent support to the conclusion that they were all marine.

That the cherts were deposited in quiet waters is evident from their persistent, and frequently thin, bedding. They differ from the tuffaceous argillites in their much finer grain, larger amount of quartz, and smaller amount of argillaceous and carbonaceous matter; and in places even their fragmental character is doubtful. Being so fine-grained they must have accumulated very slowly; hence the relative effect of the thermal solutions, which are believed to have silicified and albitized the tuff-breccias and tuffaceous argillites, would be much greater; hence a larger amount of quartz and ablite in the cherts than in the tuffaceous argillites is to be expected. It is even fairly certain that at times the deposition of volcanic ejecta virtually ceased, although it is possible that throughout their slow accumulation the deposition of very fine siliceous silt took place. During these times it seems as if there was also a direct precipitation of silica from the thermal solutions escaping from submarine flows. As is true of the other fragmental rocks, further silicification, accompanied by some mineralization, followed the intrusion of the upper Jurassic granitic rocks.

It is believed as already stated, that the chert-breccias associated with the cherts and tuffaceous argillites are autoclastic, although they appear in places to be agglomerates or tuff-breccias.[1] The chert-breccias form beds from 5 to 15 feet thick, conformable with their associated rocks, but they are everywhere highly sheared, much more so than the associated cherts and tuffaceous argillites; and since virtually all the strike shear zones of the Malahat volcanics are parallel to the bedding, the fact that the chert breccias are conformable to the bedding is not sufficient proof that they have been deposited in beds by either volcanic or sedimentary processes. Since the associated rocks were deposited in quiet water, presumably in the ocean at a considerable distance from any land mass, it is not at all probable that they are talus or purely sedimentary breccias of any kind. The absence of any fragments of quartz, feldspar, or andesite, such as are found in the tuff-breccias, and in fact the entire absence of any rocks or minerals which would lead one to believe that the chert-breccias are of volcanic origin, is good proof that they are not; especially as the chert fragments, although cut by quartz veinlets and partly replaced by a comparatively coarse-grained quartz, are clearly not the result, at least since the breccia was formed, of the complete replacement (silicification) of another rock. That any of the chert beds deposited with the volcanics were quickly enough indurated to be brecciated by neighbouring explosions of volcanic gases is also very doubtful.

In support of the conclusion that they are autoclastic or friction breccias formed by shearing or thrust faulting, we may apply two of the criteria proposed by Van Hise[2] and Leith[3] for distinguishing autoclastic rocks.

---

[1] Geol. Surv., Can., Mem. 13, 1912, p. 54.

[2] Van Hise, C. R., "Principles of North American Pre-Cambrian geology," 16th Ann. Rept., pt. I, U.S. Geol. Surv., 1896, pp. 680–681.

[3] Leith, C. K., "Structural geology," New York, 1913, pp. 64–65.

(1) The chert-breccias have evidently been derived largely if not entirely from the associated cherts and tuff-breccias; and the fragments of the breccia are composed of the more brittle of the two rocks; while the fine-grained matrix of the breccia appears to have been formed from the softer and more readily pulverized tuffaceous argillite.

(2) The fragments are chiefly angular and of such shape and in such intimate relation with the matrix that, even if the breccias were truly sedimentary, they must have been greatly foliated and their fragments further broken and stretched by shearing. Even in autoclastic breccias subrounded or even rounded fragments are to be expected since some of the fragments must have moved on one another during shearing.

AGE AND CORRELATION.

The Leech River slaty and quartzose schists and the Malahat volcanics closely resemble, both lithologically and structurally, similar rocks which occur throughout the Pacific Coast region of North America. These rocks contain in places interbedded limestones and argillites containing fossils, and have been determined to be of Carboniferous, chiefly Pennsylvanian, age. On the mainland in British Columbia the assemblage of rocks was first described in detail by Dawson under the name previously given by Selwyn, the Cache Creek group.[1] Recently the Cache Creek group has been subdivided in places into various series and formations. The correlation of these various series and formations with each other and with the other Carboniferous rocks of the Pacific Coast region has been recently discussed and tabulated with great care and in considerable detail by Daly,[2] so that a further discussion of the correlation need not be given here.

The chief difference to be noted between the Carboniferous formations of the mainland and the Leech River and Malahat for-

[1] Dawson, G. M., "Report on the area of the Kamloops map-sheet, B.C.", Geol. Surv., Can., Ann. Rept. vol. VII, 1896, pp. 373–493, B.

[2] Daly, R. A., "Geology of the North American Cordillera at the Forty-Ninth parallel," Geol. Surv., Can., Mem. 38, 1912, pp. 547–572; Twelfth Inter. Geol. Cong., Ottawa, Guide Book No. 8, 1913, p. 157; and Geological reconnaissance between Golden and Kamloops, B.C., along the Canadian Pacific railway," Geol. Surv., Can., Mem. 68, 1915, pp. 131–132.

mations of Vancouver island is the absence of limestones in the latter. It is possible, as was previously pointed out,[1] that the Nitinat limestones should be correlated with the Carboniferous limestones of the mainland; but in the absence of any further work on them they are still best considered as Mesozoic.[2] However, since the lithological and structural resemblance of the Leech River and Malahat formations to the Carboniferous rocks of the mainland is in every other way so close, since no such thickness of slaty rocks as occurs in the Leech River formation is definitely known in the Mesozoic of the Coast region,[3] and since it is fairly certain that the Leech River and Malahat formations are unconformable with the known Mesozoic rocks of Vancouver island, the Vancouver group, it is concluded with considerable surety that the Leech River and Malahat formations are correctly correlated with the Cache Creek group, and hence are Carboniferous.

Vancouver Group.

The great bulk of the pre-batholithic rocks of Vancouver island are of lower Mesozoic age—Triassic and Jurassic—and have been named by Dawson[4] the Vancouver group. The Vancouver group was previously subdivided[5] in southern Vancouver island on the bases of distribution, lithology, and structure, into the Nitinat formation, Vancouver volcanics, Sutton formation, Sicker series, and Metchosin volcanics. It was stated that the first and last were doubtfully included in the Vancouver group. It has since been found that the Metchosin volcanics are younger, of upper Eocene age. No further work has been done on the Nitinat formation and it does not occur in the Sooke and Duncan map-areas. The other three subdivisions

---

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 43–44.

[2] It may be interesting to note that the same conclusion was made in the writer's first report with regard to the Malahat volcanics, which have since been shown by detailed work to be conformable with the Leech River formation.

[3] The Cultus formation, described by Daly in Geol. Surv., Can., Mem. 38, 1912, pp. 516–517, consists largely of argillite with subordinate sandstone and is of Triassic age, but of doubtful thickness, given as 3,000 feet, and the Agassiz series described by Bowen in Guide Book No. 8, and Geol. Surv., Can., Sum. Rept., 1912, contains 3,000 to 4,000 feet of black shale containing poorly preserved fossils indicating a Lower Cretaceous or Jurassic age.

[4] Dawson, G. M., Geol. Surv., Can., Ann. Rept., 1886, p. 10 B.

[5] Geol. Surv., Can., Mem. 13, 1912, p. 44.

occur in the map-areas and their unity has been further established; yet the Sicker series has been further subdivided, and certain volcanics previously included with the Vancouver volcanics have been shown to be probably Palæozoic and, therefore, have been grouped separately as the Malahat volcanics. The Sicker series has been made the subject of special study by H. C. Cooke and his description of the series appears in this report. The Sutton formation consists of intercalated limestones in the Vancouver volcanics and is in general conformable; hence the structural relations, mode of origin, age, and correlation of the two formations are considered together.

VANCOUVER VOLCANICS.

DISTRIBUTION.

The Vancouver volcanics underlie a belt extending across the entire width of the Duncan map-area, immediately south of the Cowichan valley. The belt is 2 to 13 miles wide, and widens toward the west. Although broken in places by fairly large stocks of granitic rocks it is nowhere entirely interrupted. Two small areas, roof pendants, of Vancouver volcanics, occur, however, in the batholith of Wark and Colquitz gneisses, on the west shore of Finlayson arm, at the place called Squally reach. The outcrops within the belt are large and fairly numerous, and most of the contacts have been observed or fairly well determined. In places their location cannot be determined within a few hundred feet and north of Jordan meadows the location of their contact with the Malahat volcanics is uncertain.

LITHOLOGICAL CHARACTERS.

The Vancouver volcanics are basic, chiefly andesites, with some basalts or labradorite andesites. Flow, fragmental, and injected types are present and include amygdaloids, porphyries, pillow-lavas, tuff-breccias, slaty and cherty tuffs, and andesite porphyrites. All of the rocks have been metamorphosed and some of them recrystallized. They are also seamed with veins of quartz and feldspar and of quartz and epidote, and in places are impregnated with metallic sulphides, chiefly pyrite.

Flow Types.

Meta-andesite. The most common rock type of the Vancouver volcanics is a meta-andesite, in many places containing essential augite. The meta-andesites are fine-grained to aphanitic, and usually porphyritic rocks with phenocrysts of feldspar and altered hornblende. Their colour is usually dark olive or greyish green, but the finer grained and silicified varieties are lighter green, and some more altered varieties are reddish or purplish brown. On exposed, weathered surfaces the meta-andesites are commonly very dark, almost black, or dark brown. The groundmass, which usually greatly predominates over the phenocrysts, is aphanitic, except in a few rocks which are coarsely enough grained to exhibit tiny laths of feldspar. The phenocrysts are usually small, seldom over 2 or 3 mm. in diameter. In a few places, for example to the east of San Juan river, between Todd and Waterloo mountains, the hornblende phenocrysts attain diameters of 10 mm., and in some rocks they have a sub-radial to radial arrangement. The meta-andesites have been sheared and altered and their green colour is due largely to secondary chlorite. In some rocks irregular patches or nodules of light yellowish green epidote occur. The rocks are also cut by veinlets of quartz, feldspar, epidote, and calcite, and are commonly impregnated with pyrite.

The groundmass is seen, microscopically, to consist essentially of small, lath-shaped crystals or microlites of andesine (about $Ab_{55}An_{45}$) and rarely oligoclase (about $Ab_{85}An_{15}$) feldspar, and originally hornblende, and in some varieties augite. Both hornblende and augite are, however, largely altered to chlorite. Magnetite is the only accessory mineral which is virtually always present, and even it occurs only in fine grains and in small amount. Ilmenite and apatite have been detected in some rocks. The granularity of the groundmass varies from micro-aphanitic to decimillimetre grained. The original texture of the groundmass is usually obscured by alteration, but the feldspar laths have a diverse arrangement and hornblende and augite appear to have been largely interstitial. The phenocrysts are of andesine, altered hornblende, and augite. With the exception of hornblende they are small to medium sized, 1 to 3 mm. in diameter, and although fairly numerous in some rocks, dopatic to sempatic, the groundmass is always dominant. The degree of alteration is large, although in a few rocks the feldspars are fairly clear. Besides chlorite, mentioned above, the secondary minerals, calcite, epidote, zoisite, sericite, kaolin, quartz, pyrite, and limonite are common. Hematite, magnetite, and leucoxene are in some rocks apparently secondary; and in a few meta-andesites, which have apparently been altered under higher temperatures due to neighbouring intrusives, the original hornblende has altered to uralite or actinolite, and a part of the feldspar has been replaced by a secondary feldspar more sodic than the original.

Certain textural and structural varieties of the normal meta-andesites occur, chiefly amygdaloids. The amygdules are seldom large, although frequently numerous. However, 1½ miles west of Waterloo mountain, amygdules as large as 4 cm. in length were noted. The amygdules are composed chiefly of chlorite, calcite, and more rarely of quartz or of quartz and epidote. The quartz and quartz-epidote amygdules are usually left in slight relief on weathered surfaces. A well developed pillow structure was observed by Cooke in the lavas of Waterloo mountain, with pillows, 1 to 2 feet in diameter, of a fine-grained, green weathering andesite; and with the inter-pillow cavities filled with a black, fine-grained porphyritic material, which weathers reddish brown. Although pillow structure had been previously observed in the Vancouver volcanics[1] it is not at all common. Where it has been observed the volcanics are much less disturbed and metamorphosed than in most places, hence pillow lavas may have been common in the Vancouver volcanics; but, except in a few places, all traces of the structure, if originally present, have been destroyed by metamorphism. Taxitic, or eutaxitic varieties occur, which, although flow rocks, contain fragments of similar composition but of different texture. Flow lines and finely banded structures also occur in places, and are usually contorted and broken by very small faults. Flow structure is indicated also in one or two places by parallelly arranged phenocrysts and amygdules.

[1] Geol. Surv., Can., Mem. 51, 1914, p. 36.

Meta-basalt or Meta-labradorite Andesite. Some of the Vancouver volcanics, observed within the Duncan map-area only along the Canadian Northern Railway grade north of Koksilah river in Helmcken district, are more basic in composition than the normal meta-andesites and are classed as meta-basalts or meta-labradorite andesites. They are similar in macroscopic appearance to the meta-andesites, except that phenocrysts of the dark minerals are more numerous.

The groundmass consists essentially of labradorite feldspar, altered augite, and presumably altered hornblende. As in the meta-andesites, magnetite is the only important accessory. The granularity and texture of the groundmass is similar to that of the meta-andesites. The phenocrysts are small, and although numerous are subordinate to the groundmass. They consist of labradorite, about $Ab_{35}An_{65}$, augite, and possibly altered hornblende. The alteration of the meta-basalts is similar to that of the meta-andesites, the common secondary minerals being chlorite, uralite, calcite, and sericite.

Fragmental Varieties.

Associated with the flow rocks are numerous fragmental volcanics conspicuously exposed in the vicinity of Mt. Waterloo and Mt. Todd. They vary from very fine-grained, bedded tuffs, mixed with more or less purely sedimentary matter, to agglomerates consisting of angular fragments of volcanic rocks up to 1 or 2 feet in diameter. For purposes of description, they are subdivided into the coarser-grained agglomerates and breccias and the stratified, finer-grained rocks which include tuff-breccias and the so-called slaty and cherty tuffs.

Agglomerates and Breccias. The coarser-grained, fragmental volcanics usually consist of greenish to brown weathering angular fragments, in a fine-grained to dense, reddish to purplish weathering matrix. They are rarely stratified, although in places, as on the northeast slope of Mt. Todd, some of the elongated fragments are parallel. Furthermore, there is exposed in the bed of Koksilah river due west of the head of the west arm of Shawnigan lake a rudely stratified conglomerate composed entirely of volcanic detritus, with rounded, water-worn fragments.

The fragmental rocks, which are seen on microscopic examination to contain mineral as well as rock fragments, are similar mineralogically to the flow types, but are invariably more feldspathic. They are more altered, original dark minerals being very rare, while the secondary minerals include kaolin and hematite, frequently in large amounts, besides chlorite, epidote, calcite, and sericite, which are also characteristic and abundant secondary minerals in the flow rocks.

Stratified Tuff-breccias. The stratified fragmental volcanics occur in thin beds, seldom more than a few feet thick, interbedded with one another and, in several places, with the Sutton limestones. The coarser-grained varieties are composed almost entirely of volcanic detritus and contain angular fragments up to 2 cm. in diameter; hence they are called tuff-breccias. The fragments are chiefly greenish or brownish weathering, very dense meta-andesites similar in appearance to the normal flow rocks. They are usually embedded in very fine-grained, and in some rocks, even a slaty or cherty matrix, frequently of dark colour. Some of the finer-grained varieties resemble sandstones and about a mile southwest of Waterloo mountain is a coarse tuff apparently composed of small pieces of scoriaceous lava, similar to the lava fragments called lapilli. The tuff-breccias are cut by calcite veinlets, and where associated with limestones are in places replaced by calcite.

On microscopic examination the tuff-breccias are seen to be composed largely of fragments of finely porphyritic, feldspathic meta-andesites and of feldspar, in a very fine fragmental matrix apparently composed largely of feldspar, but containing considerable chlorite derived by the alteration of original ferromagnesian minerals. In some tuff-breccias the feldspathic matrix appears to contain some truly sedimentary, carbonaceous, and argillaceous material. The tuff-breccias are, as a rule, greatly altered. Calcite, as noted macroscopically, is a very abundant secondary mineral occurring in veinlets and replacements, and chlorite is also abundant. Other secondary minerals are limonite, sericite, and kaolin.

Slaty Tuffs. Associated with the tuff-breccias but also interbedded with the normal flow rocks are dark, finely fragmental, slaty rocks. They are usually laminated, different layers varying both in colour, due chiefly to a variation in the amount of carbonaceous matter present, and in grain. The coarser-grained layers consist invariably of angular feldspathic fragments, and differ only in grain from the tuff-breccias. Like the tuff-breccias they are cut and partly replaced by calcite.

Feldspar, chiefly plagioclase, and probably ranging from andesine to albite, appears to be the only essential mineral, although in the coarser-grained layers, as in the tuff-breccias, there are fragments of porphyritic meta-andesite. Quartz and argillaceous and carbonaceous matter are accessory. The rocks are clearly fragmental and stratified. The coarser-grained layers average about 0·2 mm. in diameter, with some fragments ten times as large, while the average grain of the finer-grained layers is less than 0·005 mm. As in the tuff-breccias, calcite and chlorite are abundant secondary minerals. Calcite has replaced certain feldspar fragments almost completely, and also portions of the fine-grained matrix, and occurs, in some rocks with quartz, as veinlets. Other secondary minerals are pyrite, limonite, kaolin, and in veinlets, epidote and zoisite.

Cherty Tuffs. Certain of the stratified, fragmental rocks associated with the Vancouver volcanics are siliceous looking, and so fine-grained that they appear to be ordinary cherts. They are usually light to dark greenish grey, and, in places, are banded or laminated. They are all greatly fractured and may be cut by numerous but tiny veinlets of quartz, or of quartz and epidote, and less commonly of calcite. In places they have been brecciated and angular fragments of the dark or laminated chert occur in an apparently finer-grained, lighter coloured, unbanded matrix.

Microscopically, the cherty rocks are very fine-grained and are partially unresolved even under high powers. They appear to be fragmental and to consist largely of quartz and feldspar, which appears to be chiefly albite. There are a few relatively large angular fragments of calcic feldspar and even of feldspathic, porphyritic meta-andesite. The secondary minerals, occurring both in veinlets and replacements, are quartz, epidote, zoisite, calcite, uralite, actinolite, and little pyrite and chalcopyrite.

The amount of total silica in one of the typical cherty tuffs from the San Juan river west of Waterloo mountain, was determined chemically to be 71·22 per cent. Allowing for 6 per cent of calcite, 0·5 per cent of pyrite, and 0·5 per cent of carbonaceous matter, the only other minerals present in the chert besides quartz and feldspar, and assuming that the feldspar contains 67 per cent of silica the theoretical amount in an albite-oligoclase of the composition $Ab_{94}An_{6}$, the amounts of quartz and feldspar present in the chert were calculated as 28 and 65 per cent respectively.

The brecciated cherts appear to be autoclastic, since in some of them, the fragments are only slightly separated from one another and are cemented largely by secondary quartz. In addition many of the adjoining fragments are of reciprocal outlines, projecting corners of some fragments corresponding to reentrant angles in adjoining ones. Even the brecciated cherts have been further fractured and cut and replaced by secondary minerals.

Injected Types.

Andesite and Basalt Porphyrites. Many dykes and sills occur in the Vancouver volcanics and are related to them in origin. The dykes cutting the flow rocks are readily overlooked as they resemble the flow rocks, but are conspicuous where they cut the fragmental varieties and intercalated limestones. The dykes are, as a rule, more basic than the flow rocks and include both augite andesite and basalt or labradorite andesite porphyrites. The porphyrites are dark green in colour, with an aphanitic to fine-grained groundmass consisting of lath-shaped feldspars and dark minerals, with medium sized phenocrysts of feldspar, augite, and hornblende. The dykes in the limestone are commonly impregnated with pyrite and are cut by calcite veinlets.

The mineral composition is seen on microscopic analysis to be similar to that of the flow rocks. The essential constituents of the groundmass are plagioclase ranging from labradorite (about $Ab_{40}An_{60}$) to andesine (about $Ab_{60}An_{40}$), augite, and hornblende. The accessory minerals are chiefly magnetic and ilmenite. The feldspars of the groundmass occur in irregularly arranged laths with interstitial and rarely poicilitic hornblende and augite. In some rocks hornblende occurs also in narrow laths or needles, but may be secondary. The phenocrysts are labradorite-andesine, augite, and hornblende. They are of medium size and subordinate in amount to the groundmass. With the exception of those that cut the limestone the porphyrites are less altered than the flow rocks, but the same secondary minerals are present, uralite, chlorite, epidote, sericite, and calcite.

Metamorphism.

As previously mentioned and as shown by the microscopic descriptions, the Vancouver volcani are all greatly metamorphosed, and, in places, have been greatly weathered, resulting in rocks containing large amounts of kaolin, limonite, and hematite. The meta phism that has resulted in the changes already described, the secondary minerals being chiefly uralite, chlorite, epidote, calcite, and sericite, is similar to that occurring at moderate to shallow depth and at moderate temperature; and in large part it has presumably taken place during the folding and shearing of the volcanics. Extreme metamorphism has taken place where the volcanics have been greatly sheared and foliated; and near the contacts with the intrusive granitic rocks the volcanics have been greatly contact-metamorphosed and pass into various metamorphic types.

Sheared and Foliated Meta-andesite. The highly sheared and foliated rocks differ from the normal meta-andesites in their fine-grained, crushed, and foliated texture, and in their larger amount of secondary minerals. Actinolite and uralite are the more common of these. The sheared rocks are cut by very numerous—in places by networks of—quartz, quartz-feldspar, and quartz-epidote veins, and the shear zones are impregnated and replaced by relatively large amounts of pyrite, pyrrhotite, and chalcopyrite. In places the mineralized shear zones form attractive prospects, but most of them are clearly too small and too low grade to be of commercial value.

Contact Metamorphosed Meta-andesites. The contact-metamorphosed meta-andesites vary from greatly fractured and sheared dense, silicified, and usually mineralized rocks with irregular veins of quartz and feldspar to completely recrystallized and hybrid varieties.

Silicified and Feldspathized Varieties. The most common type of the contact metamorphosed volcanics is characterized by quartz and sericitized feldspar. Microscopically this type is a green, usually a light green, very fine-grained to dense, siliceous appearing rock. In some varieties there are grains of altered feldspar having the appearance of original phenocrysts. The rock is commonly sheared and cut by veinlets of quartz. It is also partly replaced by quartz and other secondary minerals, feldspar, epidote, and calcite. Pyrite also impregnates the rock, and, altering to limonite, stains the weathered rocks deep brown.

Microscopically the rock is seen to consist largely of secondary minerals. Andesine feldspar, largely altered to sericite, is usually the only original mineral, and in some rocks it occurs as phenocrysts or fragments in a more altered groundmass and thus reveals the original texture. In many rocks indications of the original texture are entirely wanting, since they consist entirely of irregular, fine-grained aggregates of primary and secondary minerals. Besides quartz and secondary feldspar, presumably a sodic plagioclase, the secondary minerals include the usually predominating sericite, uralite, chlorite, epidote, and calcite, as well as pyrite and limonite.

Amphibolites. In places the contact metamorphosed volcanics have been converted into typical amphibolites. They are dark, finely crystalline and usually foliated rocks, cut by quartz veinlets, frequently parallel to and accentuating the foliation. In a few rocks larger feldspars are seen, which are apparently original phenocrysts. On microscopic examination the amphibolites are seen to consist essentially of parallelly arranged but anhedral grains of pale green hornblende and recrystallized feldspar, albite-oligoclase. Quartz and magnetite-ilmenite are accessory and epidote, chlorite, and sericite are secondary minerals, but none are present in large amount.

The following is a chemical and mineral analysis of a typical amphibolite from the Vancouver volcanics occurring in the Victoria map-area.[1]

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 34–35.

Chemical and Mineral Analysis of an Amphibolite from the Vancouver Volcanics.

SiO_2	51·60
Al_2O_3	15·00
Fe_2O_3	1·85
FeO	8·48
MgO	7·15
CaO	7·63
Na_2O	3·09
K_2O	0·70
H_2O	1·95
TiO_2	2·00
P_2O_5	0·18
MnO	0·24
	99·87
Specific gravity	2·95

Hornblende	60·5
Oligoclase ($Ab_{77}An_{23}$)	26
Quartz	9
Magnetite	1·2
Ilmenite	1·8
Apatite	0·1
Epidote	0·9
Sericite	1·0

Garnet-diopside-epidote Varieties. In a few places the volcanics have been metamorphosed into rocks characterized by the presence of garnet, diopside, and epidote, and in some instances the original rock has been completely replaced by these minerals. They are identical to similar rocks derived from the contact metamorphism of limestones. They are restricted in their occurrence to those localities where a relatively large amount of mineralization has taken place, which in the Duncan map-area are the Sterling and Glen Apa claims on the upper Koksilah river, in the southern part of Helmcken district, near the King Solomon mine about 4 miles west of south of Cowichan, and on Malahat ridge east of Shawnigan lake.

The principal type is a massive, fine-grained rock, light reddish brown to light green in colour, consisting of andradite garnet, diopside, epidote, and residual sericitized feldspar, and with quartz, calcite, and epidote veinlets. It is, furthermore, mineralized with pyrite, chalcopyrite, and magnetite. In some varieties garnet and diopside are absent, so that the rock consists chiefly of epidote with quartz and calcite, and, in some rocks, of chlorite.

The principal type is seen on microscopic examination to consist of andradite garnet in large irregular grains and diopside in small prismatic grains with interstitial and vein-like epidote. Quartz also occurs in the interstices and frequently includes poicilitically the older minerals, especially garnet. Garnet with quartz and epidote sometimes occurs in veinlets in the diopside, and diopside grains are occasionally included in the garnet. Later veinlets of calcite cut all the other minerals and the metamorphic silicates include and are replacing more or less of the original feldspar, now almost completely sericitized. The apparent order of crystallization of the metamorphic silicates is, therefore, diopside, garnet, epidote, quartz, and calcite, although the formation of the first three minerals is in general contemporaneous.

The following is a chemical and mineral analysis of a typical specimen from the Victoria map-area[1]

Chemical and Mineral Analysis of a Garnet-diopside-epidote Rock from the Vancouver Volcanics.

SiO_2	42·86		
Al_2O_3	7·19		
Fe_2O_3	14·24		
FeO	4·28	Andradite	45
MgO	2·96	Diopside	31
CaO	26·30	Epidote	19
Na_2O	0·27	Quartz	4·0
K_2O	0·33	Calcite	1·0
H_2O	1·00	Apatite	0·3
TiO_2	0·30	Chlorite	0·2
P_2O_5	0·21		
MnO	0·50		
	100·41		
Specific gravity	3·44		

Hybrid Rocks. At places along the contacts with the intrusive Wark and Colquitz gneisses, the normal contact-metamorphosed meta-andesite, the silicified and feldspathized variety, passes into a relatively coarse-grained rock consisting largely of plagioclase, quartz, and hornblende, with secondary minerals which cannot be clearly distinguished from certain fine-grained and foliated phases of the Colquitz gneiss. In places along contact with the Saanich granodiorite, largely confined to the contact shatter-breccias, the meta-andesites have been replaced and recrystallized to an even greater extent. Such rocks are dark greenish grey, fine to medium-grained, and composed of feldspar, hornblende, and biotite. Under the microscope they are seen to consist of diversely arranged stout

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 37–38.

laths of albite-oligoclase, with subhedral to anhedral grains of a sage green hornblende and a greenish brown biotite, similar to the hornblende and biotite of the Saanich granodiorite, and a small amount of interstitial quartz. Magnetite and apatite are accessory. The recrystallized rocks are only slightly altered, the feldspar to sericite and the hornblende and biotite to chlorite. The coarser-grained and more completely recrystallized portions of the inclusions of meta-andesites are indistinguishable from the dark segregations in the Saanich granodiorite, but their occurrence and gradation into the less completely metamorphosed meta-andesites, clearly reveal their metamorphic and hybrid character.

SUTTON FORMATION.

Intercalated with the Vancouver volcanics are numerous lentils of crystalline limestone or marble. It is probable that all of the limestone lentils of southern Vancouver island are of the same or nearly the same age, and they have been grouped into one formation, called the Sutton formation, from the type locality on the south shore of Cowichan lake 3 miles west of Sutton creek, where the limestone contains fossils of lower Jurassic age.[1]

DISTRIBUTION.

The limestone lentils constituting the Sutton formation have a wide distribution throughout the area underlain by the Vancouver volcanics, and occur also as isolated lentils in the intrusive granitic rocks. There are twenty-five lenses shown on the accompanying maps, ranging from 100 to nearly 1,000 feet wide and from 200 to 4,500 feet in length. The largest of these is associated with the Vancouver volcanics and occurs on the southeast slope of Eagle heights in ...mcken district. It is 4,500 feet long and nearly 1,000 feet wide. Other large lenses associated with the Vancouver volcanics occur on the west shore of Saanich inlet at Bamberton and in the extreme western part of the map-area south of Cowichan valley. In the northeastern part of the Sooke map-area in the southern part of Highland district, is a large lens of limestone in the Wark

[1] Geol. Surv., Can., Mem. 13, 1912, p. 68.

gneiss, 1,000 feet wide and over 3,000 feet long. Like all of the lenses in the intrusive rocks it is, however, broken by numerous apophyses and irregular intrusive masses. Other large lenses of limestone occur in the intrusive granitic rocks on Malahat ridge, on the west shore of Sooke lake, and to the west of 17-mile-post. Beside the mapped lenses there are great numbers of much smaller lenses or fragments of limestone, some of them only a few inches in diameter, in both the Vancouver volcanics and the intrusive granitic rocks.

LITHOLOGICAL CHARACTERS.

Unmetamorphosed Limestones.

The Sutton limestones are all crystalline. They are chiefly grey to greyish blue, less commonly white, and rarely, where carbonaceous, almost black. They vary from compact to medium-grained marbles, and in places are shaly. They weather characteristically, developing solution hollows with smooth surfaces and small knob-like protuberances. When banded they weather differentially, accentuating the banded texture. They are very frequently brecciated, and recemented by calcite veinlets. When not contact metamorphosed they are apparently very pure carbonates, although pyrite commonly occurs disseminated in minute cubical grains.

On microscopic examination the marbles are seen to consist essentially of calcite, or magnesian calcite, occurring in small grains, sometimes microscopic in size, that are firmly cemented together. Accessory or secondary constituents are, in many of the purer limestones, virtually absent. In others there are small amounts of argillaceous and carbonaceous matter; and as the metamorphic types of marble are approached a little quartz, diopside, and chlorite, as well as pyrite occur.

The following analysis is of one of the purer limestones of the Sutton formation occurring west of Raymond crossing, 1½ miles north of Shawnigan lake.

Calcium carbonate $CaCO_3$[1]	93·12
Magnesium carbonate $MgCO_3$[2]	0·96
Ferric oxide, Fe_2O_3, and alumina Al_2O_3	2·00
Insoluble mineral matter	1·80
	97·88

Sample from old quarry 1 mile west of Raymond crossing. H. A. Leverin, Mines Branch, Dept. of Mines, analyst.

Other available analyses of the purer Sutton limestones from southern Vancouver island are given in the following table.

Analyses of Sutton Limestones.

	1	2	3	4	5	6	7	8
$CaCO_3$	95·35	86·29	99·5	92·0	91·5	98·0	97·5	97·24
$MgCO_3$	2·85	0·42	none	none	none	trace	trace	trace
Fe_2O_3 } Al_2O_3 }	0·16	1·40	trace	trace	trace	0·2	0·8	1·60
Insoluble (silica)	1·95	11·88	0·4	7·8	8·0	1·5	1·1	0·80
Sulphur	trace	0·42	......	......	......	......	......	......
Phosphorus	trace	0·02	......	......	......	......	......	......
	100·31	100·43	99·9	99·8	99·5	99·7	99·4	99·64

1. Rosebank Lime Company's quarry. One-half mile west of Esquimalt harbour. F. G. Wait, analyst, Geol. Surv., Can., Mem. 13, p. 63.
2. South shore of Cowichan lake, interbedded with fossiliferous beds. F. G. Wait, analyst; Geol. Surv., Can., Mem. 13, p. 63.
3. Wriglesworth property, west of 17-mile-post. Saanich inlet. H. Carmichael, analyst; Rept. of Minister of Mines, B.C., 1911, p. k209.
4. Lorimer property, Saanich inlet. H. Carmichael, analyst; Rept. of Minister of Mines, B.C., 1911, p. k209.
5. Elford quarry (now Associated Cement Company), Saanich inlet. H. Carmichael, analyst; Rept. of Minister of Mines, B.C., 1911, p. k209.
6. Rosebank quarry, 1½ miles west of Esquimalt harbour. H. Carmichael, analyst; Rept. of Minister of Mines, B.C., 1911, p. k209.
7. Vancouver Portland Cement Company's quarry, Tod inlet; furnished by Mr. Adolph Neu formerly chemist with the company.
8. Associated Cement Company's quarry, Bamberton, Saanich inlet; furnished by the company.

Limestone-andesite Breccia.

At two places, in the north bank of Koksilah river at the crossing of the Canadian Northern railway, and in the bed of a large creek 3 miles south of Cowichan River falls, is a breccia

[1] Equivalent to CaO........52·15
[2] " " MgO....... 0·46

consisting of fragments of meta-andesite in a limestone matrix. The fragments are angular, average 2 or 3 cm. in diameter, and consist of a greenish, dense meta-andesite which is seen on microscopic examination to be fairly typical of the Vancouver meta-andesites, but which has been largely replaced by quartz, chlorite, and calcite. The matrix is a white to greenish weathering, fragmental limestone of compact to medium grain, averaging about 1·5 mm., composed partly of broken crinoid or coral stems and relatively few pieces of a ribbed mollusc. On microscopic examination it is seen that mixed with the calcite fragments is a considerable amount of very fine-grained volcanic matter largely feldspar and some quartz. A discussion of the origin of this breccia is given under the mode of origin of the Vancouver volcanics and Sutton limestones, but it is quite clear that the breccia has been the result of the deposition of volcanic ejecta with beds of contemporaneous marine organisms.

Metamorphism.

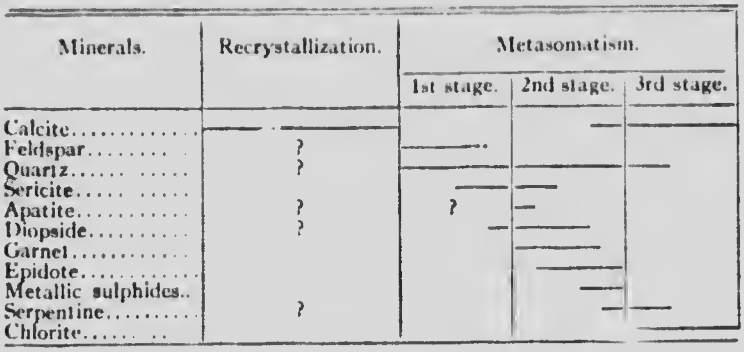
Diopside-bearing Marbles. Near the contacts with the intrusive granitic rocks the marbles are coarser grained and correspondingly lighter coloured, and are cut by a greater number of secondary calcite veinlets. Ordinarily calcite is the only essential mineral, but the accessory minerals are more numerous and occur in larger amounts. Diopside is the most common of the accessory minerals. It occurs in small irregular grains and in most rocks has been altered into a *white to dark* weathering, opaque serpentine. Hence the weathered marble is mottled, most conspicuously so on the weathered surface, since the altered diopside, being more resistant than the calcite, weathers out in slight relief. Where sheared, the diopside bearing or serpentinous marble is seamed with talcose and serpentinous material and in places, as on Malahat ridge, even with precious serpentine. At one locality in the southeastern corner of the Duncan map-area, in Highland district, the marble contains irregular lenses and masses of white weathering wollastonite which, also, being more resistant than calcite, is left in relief on the weathered surface. Original argillaceous matter has been recrystallized to sericite. Magnetite and pyrite are usually present.

Garnet-diopside-epidote Rocks. In several places, especially where considerable mineralization has taken place, as on Malahat ridge and to the south of Cowichan station, the Sutton limestones have been partly or completely replaced chiefly by garnet, diopside, and epidote, resulting in the so-called "garnetite" and "felsite." The principal type is a massive, rather fine-grained rock, light reddish brown to light green in colour, consisting of andradite garnet, diopside, and epidote, with quartz, calcite, and epidote veinlets. It is usually mineralized to a greater or less extent with pyrite, chalcopyrite, pyrrhotite, and magnetite. In some varieties garnet is absent or occurs only in veinlets, the rocks consisting of diopside and epidote, or of either one alone, with more or less sericite, quartz, and calcite. These varieties are dense and light green, and are called locally "felsite."

The principal type is seen on microscopic examination to consist chiefly of andradite garnet in large irregular grains, and diopside, in small prismatic grains, with interstitial and vein-like epidote and usually quartz. These minerals appear in certain rocks to be replacing a very fine-grained aggregate of quartz, sericitized feldspar, sericite, and residual calcite, with accessory apatite. In some rocks garnet with quartz and epidote occurs in veinlets in the diopside, and diopside grains are occasionally included in the garnet; and in turn the garnet may be surrounded and penetrated by the sulphide minerals. Serpentine and chlorite are present in places and apparently have resulted from the alteration of diopside. Late veinlets of calcite cut all of the other minerals.

A more complete discussion of the origin of the garnet-diopside-epidote rocks, which, as already stated, have been formed by the metamorphism of the Vancouver volcanics also, is given below under mode of origin, but the apparent paragenesis of the rock may be given here. The rock appears to have been the result of the recrystallization of the Sutton limestones, followed by a more or less complete metasomatic replacement of the rock. The replacement appears to have taken place in three rather indefinite and overlapping stages. The order of formation of the various minerals may be best illustrated by the following diagram which is in common use.

Diagram Illustrating the Paragenesis of the Garnet-diopside-epidote Rocks.



Quartzose and Feldspathic Varieties. Along many of the intrusive contacts the intruded limestones have been metamorphosed into siliceous appearing rocks which consist chiefly of quartz and feldspar and usually diopside, but in which garnet is conspicuously absent or confined to veinlets. They are greyish white to light green and dense and closely resemble the diopside or epidote rocks called "felsite," but they are characterized microscopically by essential feldspar. On microscopic examination they are seen to consist of very fine-grained and usually rather greatly altered, chiefly sericitized, crushed and sheared aggregates of plagioclase, probably albite-oligoclase, orthoclase, quartz, diopside, and calcite, with accessory actinolite, epidote, apatite, and titanite; and derived from these are abundant secondary minerals such as sericite, chlorite, and kaolin. The rocks are cut by veinlets of calcite, quartz, epidote, and in places garnet, and are impregnated and replaced by pyrite, chalcopyrite, and in some rocks magnetite.

Amphibolites. In places, especially where entirely enclosed in the intrusive granitic rocks, the limestones have been converted into amphibolites which are identical with those developed by the metamorphism of the Vancouver volcanics, and in most cases the two amphibolites cannot be distinguished even by their field relations.

Mineralization. Virtually all of the contact-metamorphosed limestones, especially those containing garnet, have been impregnated and more or less replaced by metallic minerals. These are chiefly magnetite, pyrrhotite, pyrite, and chalcopyrite. Pyrrhotite and magnetite occur in large replacements composed almost entirely of the massive metallic minerals. Sphalerite and galena are much less abundant than the other metallic minerals.

STRUCTURAL RELATIONS OF VANCOUVER VOLCANICS AND SUTTON LIMESTONES.

INTERNAL.

The various flow and fragmental rocks of the Vancouver volcanics are interbedded with one another and are apparently conformable; yet, in places, intrusive contacts between different volcanic rocks may be observed. The fragmental varieties, even the coarser-grained and unstratified agglomerates, appear to occur in beds between flows. The finer-grained, stratified tuff-breccias and cherty tuffs occur in thin beds seldom more than a few feet thick interstratified with one another, and, as a whole, form lenticular masses of no very great extent in the flow rocks. They were clearly deposited in water, and some of them during periods of at least local volcanic inactivity. Although the agglomerates and breccias indicate explosive eruptions, nothing resembling an ancient volcanic neck was observed. However, the dykes of andesite and basalt porphyrites probably represent old lava channels. Although only relatively few dykes were observed, for they are easily overlooked, they are probably numerous; since in places where the volcanics are exceptionally well exposed, as on Mt. Waterloo where the forest and brush have been largely burnt off, many dykes of varying sizes are visible. As already mentioned the dykes are also conspicuous where they cut the fragmental volcanics and Sutton limestones.

The Sutton limestones occur in the massive flow rocks of the Vancouver volcanics in much the same way as the slaty and cherty tuffs. Indeed, in many places, limestones are associated, and even interbedded with the slaty and cherty tuffs. The limestone lentils, many of them too small to map, are distributed throughout the entire thickness of the Vancouver volcanics. Many of the contacts of the limestones not only with the fragmental volcanics but with the flow rocks, are clearly conformable;[1] still, perhaps, most of the actual contacts, which in detail are usually extremely irregular, are intrusive, the volcanics forming irregular dykes and apophyses in the limestones, while the limestones frequently occur as inclusions in the volcanics.[2] It thus appears as if the limestones were deposited during periods of local inactivity throughout the period of Vancouver vulcanism, conformable with the flow rocks, which nevertheless were erupted through the limestones in places.

Deformation. On account of their massive and metamorphic character, the attitude of the Vancouver volcanics can seldom be determined by direct observation. This is true also of the interbedded Sutton limestones, although the general strike of the larger limestone lentils doubtlessly corresponds with the strike of the associated volcanics. The slaty and cherty tuffs are, however, well bedded and indicate clearly the attitude of the associated flow rocks. The volcanics and limestones have a general strike parallel to the belt which they underlie and to the general strike of Vancouver island, that is about north 65 degrees west. The dips are chiefly high, nearly vertical at several places, and apparently so at many others. Lower dips occur, however, one dip of only 18 degrees being observed to the south of Cowichan River falls. Southerly dips are more numerous than northerly ones, but do not greatly predominate. The strikes vary slightly from the general strike, but only in a few places by more than 25 degrees. In the exceptional places, however, north-south and northeast-southwest strikes occur. Small folds and crumplings are to be observed, especially in the slaty and cherty tuffs. Larger folds, such as the anticline 3 miles south of Cowichan River falls, are also recorded by the opposite dips in the two limbs. It is probable that the variations in

[1] Geol. Surv., Can., Mem. 13, 1912, p. 65.
[2] See Figure 2, Geol. Surv., Can., Mem. 36, 1913, p. 45.

strike and dip of the volcanics are due largely to minor and secondary folds. From the general north 65 degrees west strike and the steep dips it appears as if the major folds of the Vancouver volcanics and Sutton limestones were rather close with a general strike parallel to that of the island.

The volcanics and limestones are jointed and greatly sheared and faulted. In a very few places, as on Mt. Todd, the regularity of the jointing suggests that it was formed during the cooling of an old lava; but otherwise the jointing as well as the shearing and faulting is largely the result of deformation. The faults are marked by rather wide and conspicuous shear zones, but with the exception of the boundary faults, do not appear to be of large displacement, although the amount of displacement can be determined in only a few cases, because of the lithological similarity of the volcanics. Where the faults cross the Sutton limestones and the slaty and cherty tuffs, these rocks are not only sheared, but are frequently greatly brecciated; and they appear to have yielded, in part at least, by brecciation, under most of the deforming strains. The limestones have been recemented by secondary calcite veins, and many of the cherty breccias, which appear to be of autoclastic origin, have also been recemented with secondary silica. The faults are largely strike faults and presumably chiefly reversed, although normal faults were observed. The sheared rocks are commonly silicified and mineralized as described above, and are cut by veins of quartz, of quartz and epidote, of calcite, and rarely by veins of pyrite.

Since the detailed structure of the Vancouver volcanics and Sutton limestones is not known it is impossible to calculate their thickness. It must, however, be very great, as the maximum width of the belt underlain by the two formations is nearly 13 miles. As the dip of the volcanics is high their thickness may, therefore, be very conservatively estimated as 10,000 feet and is probably very much more. The thickness of any single occurrence of the Sutton limestones is probably not much more than 500 or 600 feet, but the total thickness of all the limestones occurring at different horizons would be much more than 1,000 feet.

EXTERNAL.

Relations to Older Formations. Only in the extreme western part of the Duncan map-area, to the west of Jordan Meadows valley, are the Vancouver volcanics in direct contact with the older formations of the map-area, the Leech River slaty schists and the Malahat volcanics. This contact is a fault. The fault outcrops on the steep slope north of the wide subsequent valley of the San Juan river and its eastern extension, Meadow creek. In the valley occur the Leech River slaty schists and, in its upper eastern end, the conformable Malahat volcanics; while the Vancouver volcanics form bold ledges overlooking the valley and surmounting it by 1,500 to over 2,000 feet. The fault on the side of the valley is heavily drift covered, but the Vancouver volcanics exposed in the outcrops nearest the contact are greatly sheared and broken along large distributive faults. In the narrow valley of the upper, southward flowing portion of San Juan river, nearly a mile above its junction with Meadow creek, and nearly a mile below Todd crevice, the main fault is actually exposed. It consists of a zone 10 feet wide of greatly sheared Vancouver meta-andesites converted almost entirely into serpentine, actinolite, asbestos, and other secondary minerals. The walls are highly slickensided and the fragments that were broken off the wall were crushed and worn by attrition into very small, polished fragments. The strike of the fault zone is nearly straight, bearing south 80 to 85 degrees west, and the dip is nearly vertical. To the south of the fault, the Leech River sediments have a north 83 degrees west strike and a vertical dip and are foliated parallel to the bedding. To the north of the fault, the Vancouver volcanics appear to strike north 60 degrees west, and dip about 80 degrees to the south. Thus the fault bevels across the formations at a slight angle. There is little or no direct evidence as to the direction of movement. The striæ of the fault zone strike and dip at varying angles, indicating a complex and shifting movement. There is, however, no reasonable doubt as to the relative ages of the Vancouver volcanics and Leech River and Malahat formations. The Vancouver volcanics are less deformed and much less metamorphosed and are of Triassic and Jurassic age, while the Leech River and Malahat formations are presumably Carboniferous. Hence it is virtually certain that the Vancouver volcanics are the younger, and unconformably overlie the Leech River and Malahat formations; so that the south side of the San Juan fault is the upthrown side.

Elsewhere the Vancouver volcanics are separated from the Leech River and Malahat formation by the granitic rocks intrusive into all three formations. However, in the Highland district, and west of 17-mile-post, lentils of Sutton limestone occur in the intrusive granitic rocks within 250 to 1,500 feet of the Malahat volcanics, but from 1½ to 3 miles distant from the nearest exposures of Vancouver volcanics. It seems, therefore, as if these limestone lentils were more closely associated with the Malahat volcanics than with the Vancouver volcanics. However, no limestones are known that are actually in contact or clearly conformable with the Malahat volcanics, while limestones, similar to those occurring near the Malahat volcanics, are clearly interbedded and conformable with the Vancouver volcanics; hence these limestones of doubtful relations are considered a portion of the Sutton formation, and may occur at the base of the combined Vancouver and Sutton formations.

Relations to the Sicker Series. The only member of the Vancouver group, other than the Vancouver ar[illegible]ton formations, occurring in the Sooke and Duncan [illegible], is the Sicker series. Cooke discusses in some detail ([illegible]) the relation between the Sicker series and the Vancouver volcanics. As he states, no conclusion of importance may be drawn from the inadequate data at hand concerning the relations of the two formations. Virtually no weight can be given to the occurrence of the porphyritic augite andesite dykes cutting the Vancouver volcanics on Mt. Waterloo, since similar dykes cut the Wark and Colquitz gneisses near the dam of the upper Goldstream reservoir, and since it is almost certain that the Wark and Colquitz gneisses were irrupted during the same general period as the Saanich granodiorite which is intrusive into the Sicker series. From the inadequate data it has been inferred that the Sicker series and the Vancouver volcanics are in general conformable, the Sicker series possibly being the younger.

Relations to Younger Formations. All of the principal batholithic rocks of the map-areas, as well as some of the minor intrusives, are clearly intrusive into the deformed Vancouver volcanics and Sutton limestones. The Wark and Colquitz gneisses form one large batholith and a few very small stocks intrusive into the Vancouver volcanics along their southern boundary, and the Saanich granodiorite forms two small batholiths and seven or eight small stocks intrusive into the northern portion of the Vancouver volcanics. At the contacts the volcanics and limestones are brecciated and cut by apophyses of the granitic rocks, and numerous inclusions of the volcanics and limestones occur in the granitic rocks, varying greatly in size from small fragments a few feet or inches in diameter to large roof pendants a few hundred to a thousand feet wide by a few thousand feet long. These inclusions are crowded near the main contacts, but, in places, occur 2 or 3 miles from them. Near the contacts and over large areas also, the volcanics and limestones have been greatly metamorphosed by contact agencies into the various contact-metamorphic and mineralized types described above.

The sedimentary rocks of the Nanaimo series rest unconformably upon the Vancouver volcanics and Sutton limestones. Coarse basal conglomerates occurring near the base of the series are made up largely of detritus from rocks of the Vancouver group, chiefly from the Vancouver volcanics and Sicker series. Only a few fragments of the Sutton limestones are known, but many of the lower sandy shales of the series are calcareous, suggesting that they may have been formed in part from the detritus from the Sutton limestones.

MODE OF ORIGIN OF VANCOUVER VOLCANICS AND SUTTON LIMESTONES.

At the type locality of the Sutton formation at Cowichan lake, the limestones were evidently formed by the accumulation of marine organisms. It is probable that the Sutton limestones of the Sooke and Duncan map-areas also are of a similar origin, and, indeed, in a few places, as in the north bank of Koksilah river at the Canadian Northern crossing, fragments of poorly preserved fossils have been found; but the larger part of the limestones has been recrystallized to such an extent that any fossils which they may have contained have been entirely destroyed.

Since the Sutton limestones are of marine origin and are intercalated in the Vancouver volcanics, it is to be presumed, therefore, that the volcanics were largely submarine. The comparative rarity of tuffs and breccias and of interbeds of terrestrial material adds weight to this conclusion. However, the occurrence of angular and unstratified tuffs suggests that some of the old vents were above sea-level and formed islands. Also there are found in the volcanics a few conglomerates composed of rounded volcanic fragments which imply that these volcanic rocks had been subjected to marine erosion on the shores of old volcanic islands. It was on these supposed volcanic islands that the organisms which built the Sutton limestones lived. Since the fauna is very provincial, and, since interbeds of sedimentary material other than limestone occur in the Vancouver volcanics but sparingly and consist only of the finest argillaceous matter mixed with tuffaceous matter, it is probable that the volcanic islands were far from the mainland to the east.

LIMESTONE-ANDESITE BRECCIA.

From the dykes of meta-volcanics in the limestones, and from the many intrusive contacts between the limestones and associated volcanics, it is quite clear that in places the volcanics were erupted through the limestones, while the limestones were apparently in the process of formation. The limestone-andesite breccias also indicate that certain of the island volcanoes, on the shores of which the organisms composing the Sutton formation lived, were active during the formation of the limestones, since it appears as if the breccias were formed by fragments of the volcanics that had been blown into the air in an eruption and fell into growing beds of marine organisms, chiefly corals or crinoids. A somewhat similar limestone-volcanic breccia, in the Triassic limestones of the Tyrol[1] was

[1] Grabau, A. W., "Principles of stratigraphy," New York, 1913, p. 437.

apparently formed by lava flowing over the submerged flanks of large coral reefs on which were limestone fragments derived by the destruction of the reefs. The predominance of the limestone matrix in the breccias of the Duncan map-area and the independent nature of the angular fragments of meta-andesite indicate that the andesite fragments fell rather than flowed into the coral or crinoid beds.

SLATY AND CHERTY TUFFS.

The association of slaty and cherty tuffs with flow and fragmental volcanic rocks is characteristic of all of the volcanic formations of Vancouver island, and doubtless they have all been formed in a similar manner.[1] The slaty and cherty tuffs are, however, less common in the Vancouver volcanics than in any other of the volcanic formations. The coarser-grained stratified tuff-breccias are clearly the result of the deposition in water of volcanic matter ejected from the old island volcanoes. Even the coarser fragments, clearly pieces of lava, are embedded in an extremely fine-grained matrix which is identical with the slaty and cherty tuffs. The slaty and cherty tuffs and the matrix of the coarser tuff-breccias are in places carbonaceous and contain a large amount of clayish matter, apparently in part of purely sedimentary origin. They are, however, more highly feldspathic than ordinary clays. It appears, therefore, as if fine clays, muds, and silts, possibly derived from the volcanic islands themselves or from more distant lands, were deposited at times in the neighbourhood of the volcanic islands. However, during periods of volcanic activity, along with the clays and silts, much greater quantities of volcanic ejecta were deposited to form the beds of tuff-breccia. During or immediately following their deposition the slaty tuffs and tuff-breccias, as in the other volcanic formations, were doubtless more or less replaced by quartz and albite through the action of thermal solutions escaping from the underlying cooling lavas. In this way the cherty tuffs and the cherty matrix of the tuff-breccias formed, the finer-grained matrix of the tuff-breccias being more

[1] See detailed discussion of the origin of the slaty and cherty tuffs of the Metchosin volcanics, p. 288, and of the Sicker series, by H. C. Cooke, p. 162.

easily replaced than the larger fragments. As shown by the presence of veinlets of quartz the rocks have also undergone further silicification after their consolidation as a result of the contact action of the intrusive granitic rocks. As already stated it appears as if the brecciated cherty tuffs are autoclastic, that is, they have been produced by folding and consequent slipping and shifting along the bedding planes.

METAMORPHIC VARIETIES.

The origin of most of the metamorphic phases of the Vancouver volcanics and Sutton limestones is clear. Undoubtedly the common alteration of the Vancouver volcanics and, in most cases, the crystallization of the Sutton limestones, took place under conditions of moderate to shallow depth and moderate temperature, largely during periods of dynamic metamorphism. Furthermore, the silicified and feldspathized phases of the Vancouver volcanics and the silicified and diopside and wollastonite-bearing phases of the Sutton limestones have certainly been the result of contact metamorphism. Unquestionably the amphibolites and garnet-diopside-epidote rocks are also the products of contact metamorphism; but the nature of the original rock and the character of the metamorphism is not always clear. The origin and mode of formation of these rocks were discussed in considerable detail in the description of the geology of the adjoining Victoria and Saanich map-areas.[1] It was concluded that the amphibolites and garnet-diopside-epidote rocks resulted from the contact metamorphism of both the limestones and associated volcanics and, except in those metamorphic rocks retaining some evidence of an original igneous texture, the character of the original rock could be determined only by field relations. The field relations are not everywhere clear, but it is believed that most of the amphibolites have resulted from the metamorphism of the volcanics, and most of the garnet-diopside-epidote rocks from the metamorphism of the limestones.

It is quite certain that most of the original limestones were of a high degree of purity. The range in composition of the

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 46–50.

Sutton limestones of Vancouver island, taking into consideration certain analyses of Sutton limestones from northern Vancouver island as well as those of Sutton limestones from southern Vancouver island, given above, is as follows:

$CaCO_3$	86·29 to 99·5
$MgCO_3$	trace " 9·83
$Fe_2O_3 + Al_2O_3$	trace " 2·00
Insoluble, chiefly SiO_2	none " 11·88

Assuming that during the metamorphism of the limestones all of the carbon dioxide CO_2 was driven off and no material added, the rocks resulting from the most impure of the limestones would contain about:

$CaO + MgO$	77 per cent.
$Al_2O_3 + Fe_2O_3$	3 per cent.
SiO_2	20 per cent.

It is obvious that the composition of the garnet-diopside-epidote rocks does not even approximate these percentages, but is more nearly like that of the garnet-diopside-epidote rock from the Victoria map-area, which was apparently derived by the metamorphism of the Vancouver meta-andesites, the composition of which was given above. That is, the composition of the garnet-diopside-epidote rocks derived by the metamorphism of the Sutton limestones approximates:

CaO MgO	28 per cent.
Al_2O_3 Fe_2O_3	27 per cent.
SiO_2	45 per cent.

However, it is quite certain that in contact metamorphism the limestones have lost some of their lime, part of which appears to have been transferred to the volcanics. It is seen on the other hand that the ratio of iron and alumina to silica changed from something like 1 to 7 in the original limestones to about 1 to 2 or less in the contact metamorphosed rocks, a change which necessitated an addition of at least iron and alumina. Furthermore, Lindgren[1] has shown that contact metamorphism has generally taken place without a great loss or change in the volume of the metamorphosed rock, a conclusion which is supported

[1] Lindgren, W., "Mineral deposits," 1913, pp. 669-671.

by the field relations exposed in Vancouver island. If this is true the loss in carbon dioxide and lime must have been compensated by additions of alumina, iron, and silica, doubtless through the agency of thermal solutions escaping from the crystallizing intrusives.

As noted above it appears as if the replacement of the Sutton limestones to form the garnet-diopside epidote rocks took place after a recrystallization of the limestone, in three rather indefinite and overlapping stages; the first characterized by feldspar and quartz, the second by garnet, diopside, and epidote, and somewhat later by metallic sulphides, and the third by calcite, serpentine, and chlorite. It also appears as if these stages were the result of corresponding changes, largely a decrease, in the temperature and pressure under which replacement occurred, and a change in the composition of the solutions causing replacement. The first two stages clearly took place at high temperatures and pressures, the solutions containing more iron and other metallic sulphides during the second than during the first stage. The origin of the feldspar characteristic of the first stage of metamorphism is in many rocks questionable inasmuch as the nature of the metamorphosed rock is doubtful. It is, therefore, difficult and perhaps impossible to determine whether or not the feldspar has been introduced into metamorphic limestones or remains after the nearly complete replacement of metamorphic volcanics. However, as is shown by the occurrence of the quartzose and feldspathic rocks also derived from the contact metamorphism of limestones, there is no question that both quartz and feldspar have been introduced into the limestones during metamorphism. The last stage of metamorphism took place under moderate to low temperatures and pressures partly through the agency of meteoric solutions.

A similar development of contact metamorphosed rocks with their accompanying mineral deposits, in more or less well-defined stages, has been recognized and described by several geologists.[1] Barrell and Leith conclude that the stages are the

[1] Barrell, J., Prof. Paper No. 57, U.S. Geol. Surv., 1907.
Leith, C. K., and Harder, E. C., Bull. No. 338, U.S. Geol. Surv., 1908.
Spurr, J. E., and Garrey, G. H., Econ. Geol., vol. 3, 1908, pp. 688–725.
Spurr, J. E., Garrey, G. H., and Fenner, C. N., Econ. Geol. vol. 7, 1912, pp. 444–484.

result: first of a period of recrystallization of the constituents already in the rocks undergoing metamorphism largely through the agency of heat from the intrusives, combined with the consequent expulsion of carbon dioxide from the usually prevalent limestone; and second, a period of metasomatism or replacement of the recrystallized rock by new materials brought to the metamorphic zone by emanations from the intrusive magma. On the other hand, Spurr and his associates conclude that the stages result largely from changes in the composition of the escaping solutions, due to corresponding changes in the crystallizing magma as a result of differentiation, and partly from decreasing temperature in the zone of metamorphism. It should be noted, however, that in common with most geologists, Spurr recognizes that metamorphism also takes place by [illegible]eneration or recrystallization.

It is seen that the writer's conclusion accords more fully with the views of Spurr; but the contact metamorphism on Vancouver island differs in many respects from that in Mexico described by Spurr. It appears to have taken place much more rapidly, in less well defined and fewer [illegible]ages, and not after the complete consolidation and fract[illegible]g of the intrusive rocks which do not ordinarily show alteration under such high temperatures and pressures as do the intruded rocks. It appears as if the differences were caused by corresponding variations in the conditions of metamorphism. The Vancouver Island deposits have clearly been formed in a deeper zone, adjoining much larger bodies of intrusive rocks than have the contact deposits of the southwestern part of North America. These conditions have resulted in a more general and complete silicification and feldspathization, during the early stages of metamorphism by emanations of silica, alumina, and alkalis, chiefly soda; and a less general and relatively far less effective metamorphism confined largely to shear zones in already silicified and feldspathized rocks by emanations presumably escaping from a lower zone in the intrusive body containing besides, silica and perhaps alumina, sulphur, iron, copper, and other metals.

AGE AND CORRELATION OF VANCOUVER VOLCANICS AND SUTTON LIMESTONES.

From purely structural evidence the age of the Vancouver volcanics and Sutton limestones may be approximately determined as lower Mesozoic, since they are pre-batholithic, that is, pre-upper Jurassic, and since they are almost certainly younger than the Leech River and Malahat formations, supposed to be Carboniferous. Also an interrupted belt of limestone lentils may be traced across the Duncan map-area south of Cowichan valley to Cowichan lake where one of the limestone lentils contains a lower Jurassic fauna[1], which has been called the Sutton Jurassic. The lithological characters and structural relations of all the limestones in the belt are similar, and the volcanic rocks with which they occur are continuous, so that the limestones and volcanics of the belt are doubtless of nearly the same age, that is lower Jurassic. With the exception of the isolated lentils of limestone in the granitic rocks, all the limestones and associated volcanics are related structurally and lithologically. It has also been shown that the isolated limestones in the granitic rocks are best considered as occurring near the base of the Sutton and Vancouver formations. Therefore, all of the limestones and associated volcanics of the Sooke and Duncan map-areas are considered to be of the same general age and are grouped into the same formations, the Sutton limestones and the Vancouver [illegible]nics, which are members of the Vancouver group.

In northern Vancouver island where the Vancouver group was first defined, Dawson found similar volcanic rocks with intercalated limestones and argillites which contain fossils referable to the Alpine Triassic.[2]. Therefore, the Vancouver group contains Triassic as well as lower Jurassic members. Hence it is probable, that although part of the limestones and associated volcanics of the Sooke and Duncan map-areas are of lower Jurassic age, some of them may be of Triassic, presumably upper Triassic, age.

[1] C. H. Clapp and H. W. Shimer, "The Sutton Jurassic of the Vancouver group, Vancouver island," Proc. Boston Soc. Nat. Hist., vol. 34, 1911, pp. 436-438. G. C. Martin has recently questioned the age determination of the Sutton fauna and tentatively considers it to be Upper Triassic; Geol. Soc. Am., Bull., vol. 27, 1916, pp. 709-710.

[2] G. M. Dawson, Geol. Surv., Can., Ann. Rept., 1886, pp. 7B-11B.

It has been previously supposed that the more metamorphosed of the volcanic rocks and intercalated limestones of southern Vancouver island, and indeed of the Coast region of British Columbia, might be of Palæozoic age, chiefly because poorly preserved fossils in some of the limestones resembled Palæozoic species. The Sutton fauna was first thought to be Palæozoic but is clearly of lower Mesozoic age, and almost certainly lower Jurassic. The Sutton fossils closely resemble the poorly preserved forms, thought to be Palæozoic, occurring in other limestones on Vancouver island and elsewhere in the Coast region of British Columbia. Therefore, since the structural relations and lithological character of most of the pre-batholithic volcanics and associated limestones of Vancouver island and of the Coast region are similar, and since all of the definitely determined fossils in them are either Jurassic or Triassic[1] most of them are best considered to be lower Mesozoic, Triassic, and Jurassic age, and consequently members of the Vancouver group as defined by Dawson[2]. If this correlation be true the great bulk of the pre-batholithic rocks of the Coast region are Mesozoic, although there are occasional infolds of Palæozoic sediments and associated volcanics, such as the Leech River and Malahat formations appear to be.

There seems to be little doubt but that the Vancouver group is correctly correlated with a similar group of volcanics and intercalated limestones and argillites known as the Nicola group occurring in the plateau region of British Columbia to the east of the Coast ranges. Indeed, as Dawson, who first described and named both groups, suggested several years ago[3], at the time of their deposition the rocks of the two groups may have been continuous. However, in southern British Columbia in the vicinity of the 49th parallel, the lower Mesozoic rocks are largely fine-grained sediments with very few or no volcanics.

---

[1] Kindle has recently determined the fossils in the Marble Bay limestone of Texada island to be Jurassic or Triassic, probably the former. McConnell, R. G., Geol. Surv., Can., Mem 58, 1914, pp. 19-20

[2] Dawson, G. M., "Northern Vancouver island and adjacent coasts." Geol. Surv., Can. Ann. Rept., 1886, pt. B.

[3] Dawson, G. M., "Rocky Mountain region in Canada," Bull. Geol. Soc. Am. vol. 12 1901, p. 73.

These Mesozoic rocks are represented by the Cultus formation of Daly,[1] and the Agassiz series of Bowen, which was first described as Palæozoic but which contains fossils that have been determined as indicating a Lower Cretaceous or Jurassic age.[2]

SICKER SERIES AND ASSOCIATED PORPHYRITES.

(H. C. Cooke.)

INTRODUCTION.

Underlying an area of approximately 120 square miles in the northern half of the Duncan map-area, is a group of rocks which include sediments, volcanics, and minor igneous intrusives. This group is pre-batholithic, i.e. pre-upper Jurassic, in age. It was first described by Clapp in 1908, and by him named the Mount Sicker series, because typically developed on Mount Sicker. Later, the name was abbreviated to Sicker series. In 1913, the term was restricted in its application to the volcanic and sedimentary members of the group,[3] although exposures of these rocks are of rare occurrence on Mount Sicker, the original, type locality. This restricted usage has been followed in the present report. The intrusive rocks consist of the Tyee quartz-feldspar porphyrite and the Sicker gabbro-diorite porphyrite.

DISTRIBUTION.

The Sicker series and its associated intrusives outcrop in three roughly parallel belts of which the northern is by far the largest, as it includes approximately two-thirds of the total area underlain by these rocks. The belts, which are synclinal in structure, are separated from the Vancouver volcanics to the south and from each other by bands of the Nanaimo (Cretaceous) sediments which occupy valleys developed in post-Jurassic time along the anticlines of the folded Sicker series and associated intrusives. Outcrops on the south side of Mt. Tzuhalem,

[1] Daly, R. A., "Geology of the North American Cordillera at the 49th parallel," Geol. Surv., Can., Mem. 38, 1912, pp. 516-517.

[2] Bowen, N. L., Geol. Surv., Can., Sum. Ret., 1912, pp. 112-113 and footnote.

[3] Clapp, C. H., "Geology of the Victoria and Saanich map-areas, Vancouver, B.C." Geol. Surv., Can., Mem. 36, p. 51, 1913.

at Separation point, and on southern Saltspring island, seem to represent an eastward extension of the middle belt of the Sicker series. The rocks of the series are well exposed in the eastern p[illegible] of the map-area, and especially well along the coast where the erosive action of the waves and tides is strong; so that in that district the formation boundaries are closely and accurately located. In the western part of the area exposures are very few, except in the creek bottoms and on the steepest hillsides; consequently, many of the formation boundaries there are indefinite or assumed.

TABLE OF FORMATIONS.

The following table shows the relationships of the formations of the series to each other and to the older and younger formations.

Cretaceous		Nanaimo series.
	Unconformity	
Upper Jurassic		Saanich granodiorite.
	Intrusive contact	
		Sicker gabbro-diorite porphyrite.
	Intrusive contact	
		Tyee quartz-feldspar porphyrite.
	Intrusive contact	
Middle Jurassic (?)		Sicker sediments.
		Black slates.
		Soft cherty tuffs.
		Hard cherty tuffs.
		Basal tuffs.
		Sicker porphyritic andesites.
Lower Jurassic and probably Triassic		Vancouver volcanics.

SUMMARY DESCRIPTION OF FORMATIONS.

The Sicker series, in the present restricted usage of the term, consists of volcanic and sedimentary members. These have been described by C. H. Clapp in some detail[1].

The volcanic rocks are fine to coarse-grained andesites, distinguished from the Vancouver andesites by the almost

[1] Clapp, C. H., "Southern Vancouver island." Geol. Surv., Can., Mem. 13, pp. 71-77, 1912.

"Geology of the Victoria and Saanich map-areas, Vancouver island, B.C.," Geol. Surv., Can., Mem. 36, pp. 51, 53, 1913.

universal presence of numerous conspicuous phenocrysts of hornblende, averaging 2·4 mm. in diameter. Fragmental and amygdaloidal varieties are fairly common. The lavas have been greatly altered, both by dynamic metamorphism and by percolating solutions, so that they now contain large amounts of epidote, calcite, chlorite, and other secondary products; and they have been converted locally into chloritic schists, the original character of which is sometimes so entirely lost that it can be determined only by the most careful study.

In Memoir 36, Clapp grouped some of these schists with the sedimentary rocks of the series under the comprehensive name "Sicker schists" since "in many cases the origin of the schists is doubtful, so that they have not been subdivided into sedimentary and volcanic members." In the work of the past summer, with larger areas of these rocks under observation, it became possible to find criteria by which the sedimentary schists could be differentiated from those of volcanic origin, with a high degree of certainty. Accordingly, the term "Sicker schists" has been discarded, and the series definitely subdivided into andesitic lavas and sediments.

Some of the sediments, viz., the basal tuffs, jaspers, and hard cherty tuffs, are closely related in origin to the extruded andesite; others, the black slates, are probably the result of normal sedimentation; while others, the soft cherty tuffs which are feldspathic clastics with the grains cemented by more or less kaolinic and calcareous material, were formed by the commingling of the two types of sediment. Metamorphism has affected the hard cherty members of the series very little, but has converted the soft cherty tuffs to sericitic schists and the upper, pelitic members to black fissile slates.

DETAILED DESCRIPTION OF FORMATIONS.

Porphyritic Andesites.

These are greyish-green, rather fine-grained, porphyritic rocks, containing phenocrysts of hornblende and feldspar embedded in an andesitic groundmass. They include a variety of phases, which will be described separately. They were probably extruded under submarine conditions (see "Mode of origin and history," page 157). Their eruptive origin is proved by the following facts: (1) The upper surfaces of the flows are amygdaloidal, in some cases highly so; in the Ladysmith flow the amygdaloidal stratum was at least 30 feet in thickness; the lower edge, observed in the Coronation Canyon flow only, is not amygdaloidal but is chilled. (2) Flow breccias are common; the fragments are all derived from the lava itself; most of them are porphyritic and many of them are amygdaloidal. (3) Flow textures are common; they are seen in the parallel arrangement of phenocrysts, in the parallel arrangement of dark and light bands, and, under the microscope, in the presence of flow lines passing around amygdules.

Ladysmith Type. The flow lying between the town of Ladysmith and Mt. Brenton has been only slightly tilted since its deposition, and very little disturbed by subsequent igneous intrusions. Consequently, its rocks are still comparatively fresh, and their composition, therefore, probably approaches more nearly to that of the original lavas than does that of any of the other flows. Four phases may be described: (1) the present surficial phase seen at the top of the flow on the northeast side of Mt. Brenton; (2) the older surficial phase represented now by amygdaloidal fragments in the volcanic breccia; (3) the massive phase which forms the matrix to the breccia (2); and (4) a coarsely crystalline phase which represents the deep zone of the flow.

The present surface of the flow on the northeast side of Mt. Brenton, is a black or greyish-black, microcrystalline, highly amygdaloidal rock. The amygdaloidal stratum is unusually thick, at least 30 feet and probably more, since the full thickness could not be observed on account of the paucity of outcrops. The amygdules are filled in the majority of cases with white or pink calcite, in a few cases with fine-grained feldspar. Under the microscope the rock is seen to have the composition of a mica basalt. Fine-grained feldspar, some of which was determined as andesine,[1] constitutes roughly 50 to 60 per cent of the rock.

[1] In classifying the plagioclases, in all the petrographic work, the index of refraction was first determined, against quartz if possible, or against Canada balsam when quartz was

biotite 20 to 25 per cent, augite about 5 per cent, and magnetite about 10 per cent. The magnetite seems to be concentrated, especially about the borders of the amygdules. A little glass is also present. Flow textures are pronounced.

The original surficial phase, represented by fragments in the volcanic breccia, is a greenish-grey, amygdaloidal, usually porphyritic rock. The phenocrysts are of white feldspar embedded in a microcrystalline groundmass. Under the microscope, the amygdules, which constitute 15 to 30 per cent of the rock mass, are seen to be filled only with feldspar, oligoclase-albite, and nearly pure albite. The porphyritic crystals consist of albite-oligoclase up to 1 mm. in length, and form about 20 per cent or less of the rock; hornblende phenocrysts are also present in some cases and form 2 to 3 per cent of the rock. The groundmass consists of about 70 per cent of needles of pale green hornblende forming an interlacing mat, and feldspar, with accessory titanite, pyrite, and ilmenite.

The massive phase which forms the matrix to the breccia just described is a dark grey, holocrystalline, porphyritic rock, composed of phenocrysts of albite-oligoclase feldspar, Ab_{85} An_{15}, and hornblende, embedded in a finer-grained groundmass. Under the microscope, the feldspar phenocrysts, up to 1 mm. in length, are observed to constitute roughly 20 per cent of the rock; those of hornblende, which are of about the same size, about 15 per cent; while in the groundmass the hornblende and the feldspar (also oligoclase-albite) are present in approximately equal proportions. Leucoxene is accessory.

The deep phase observed near Stocking lake is a rock much coarser in grain than those described, containing numerous phenocrysts of hornblende up to 5 mm. in diameter or even larger, and a few of andesine feldspar up to 2 mm., embedded in a rather basic groundmass. Under the microscope the ferro-magnesian mineral is seen to constitute about 70 per cent of the rock; most of it is a light green hornblende, which

absent, making all due allowance for variation in the index of the balsam, which, however, in the sections was rarely found to vary outside the limits 1·544 and 1·547. The optic sign was then determined. The combination of these data narrowed down the possibilities as a rule to one or two; then finally the statistical method of Michel Levy was used, whenever possible, for the final classification under the limits set by the previous determinations.

in the larger crystals is clearly seen to be the result of the paramorphism of augite which is still present as cores in the crystals. The feldspar, which constitutes most of the remainder of the rock, is of two types, an older, much altered oligoclase, $Ab_{70}An_{30}$, and a number of fresh, unaltered, granulated masses which were identified as oligoclase $Ab_{75}An_{25}$.

Common Type. The typical andesite of the series differs from those just described chiefly in its greater degree of metamorphism. It is a dark greenish rock, containing numerous conspicuous phenocrysts of hornblende, rendered more or less schistose by regional metamorphism, and containing large amounts of secondary epidote, quartz, and calcite. All of the andesites in the map-area, with the exception of the Ladysmith flow, are of this type, although some are less highly altered than others. Three phases may be distinguished.

(1) A massive, highly porphyritic, relatively non-schistose variety, containing numerous phenocrysts of hornblende up to 4 mm. diameter; (2) a more schistose variety which is non-porphyritic or nearly so, and contains large numbers of nodules of fine-grained quartz and epidote (the "epidote nodules") of all sizes up to 3 or 4 inches in diameter (Plate IV A); (3) a chloritic schist, which contains in some instances neither knots nor phenocrysts.

The massive variety under the microscope is seen to contain phenocrysts both of feldspar and hornblende, the former usually in excess, although not conspicuous on account of their smaller size and greenish-white colour. Varieties are also found in which the hornblende phenocrysts are absent or nearly so. The feldspar phenocrysts rarely exceed 1·5 mm. in length, and constitute 5 to 15 per cent of the rock mass. They were determined as andesine to oligoclase-andesine, usually the latter. The hornblende phenocrysts rarely amount to more than 5 per cent of the rock, but in size they may attain 10 mm. They are of the common green variety, and may be the result of the paramorphism of augite. The groundmass consists of a finely felted mass of feldspar and a light green, acicular hornblende, probably actinolite, with their alteration products, epidote, quartz, calcite, etc.

The phase just described may be traced through gradational intermediate phases into the nodular, non-porphyritic phase. The two are of similar composition, except that in the latter the phenocrysts of hornblende are absent, the grain finer, and the rock somewhat more schistose, presumably on account of its lesser competency. It is inferred, therefore, that this represents a more surficial portion of the flow. A curious and characteristic feature of this phase is the almost universal presence of nodules of all sizes up to 3 or 4 inches diameter, commonly composed of about 35 per cent quartz and 65 per cent epidote, with a little calcite (Plate IV A).

The origin of these epidote nodules has up to the present been obscure, but it is now proven fairly conclusively that they are the altered fragments of flow breccias. The evidence on which this conclusion is based is as folllows:

(1) The nodules are found almost exclusively within the fine-grained, presumably surficial portions of the lava flows, in which breccia fragments might be expected. As the fine-grained rock grades into coarser, presumably deeper portions of the flow, the nodules become fewer in number until they disappear altogether.

(2) A number of specimens taken from different localities display the course of the alteration. In the breccia fragments of the slightly altered Ladysmith flow, the feldspar that fills the amygdules was observed to be partly altered to epidote, while the remainder of the rock was unaltered. The amount of epidote present was about 10 per cent of the rock mass. In a nodule from the Coronation Canyon flow, the alteration has proceeded much further. In it the phenocrysts of hornblende and feldspar are still relatively unaltered, and constitute about 20 per cent of the rock mass; while, although the groundmass has gone over almost completely to calcite, quartz, and epidote, much of the original texture is still preserved, since the nodule has not been greatly sheared. Nodules from Mt. Richards display a still further degree of alteration, for all the original minerals have disappeared except the largest phenocrysts of feldspar and hornblende which together make up only about 10 per cent of the rock, the remainder being quartz and epidote. Pressure has

also obliterated the original textures. In the final stage, observed in a nodule from Maple bay, none of the original constituents or textures remain; the rock has become a chert-like mass of quartz and epidote, in proportions of about 2 to 3.

(3) The epidotization of these nodules is not due to causes affecting the nodules only, but it is a part of the general alteration of the whole rock mass. For some reason the alteration of the fragments has proceeded with greater rapidity than that of the matrix; and the dynamic metamorphism to which the rocks have been subjected has assisted in concealing the original nature of the nodules by moulding them into rounded forms and obliterating in large part their original textures.

The observed facts (1) that the amygdule fillings are the first to be attacked, and (2) that the phenocrysts are the last portion affected, suggest that the factors determining the difference in the rates of alteration of fragments and matrix are porosity and size of grain. If this is true, then it may be concluded that the breccia fragments were more liable to alteration than the massive matrix: (1) on account of their greater porosity, due to their amygdaloidal texture which allowed the reacting solutions freer access, and (2) on account of the finer grain of their groundmass, due to their being original surficial portions, by which a larger reacting surface was afforded to the attack of solutions.

The chloritic schist, the third common phase of the andesite, is a dark green, highly fissile schist formed by the regional metamorphism of both of the above phases. In some cases it is difficult to distinguish this chloritic schist from similar schists formed from the Sicker gabbro-diorite porphyrites by the action of shearing stresses. The gabbro-diorite schist, however, may generally be quickly traced into relatively unaltered gabbro-diorite, since the sheared portions of this rock rarely extend into the mass for more than a few feet from the edge. Wide areas of chloritic schist can be diagnosed with certainty as schistose andesite, since, except the gabbro-diorite referred to above, the andesite is the only rock found in the map-area in large amount, which yields such schists on metamorphism. This diagnosis may be confirmed in almost all cases by the discovery on careful examination of the rock, of rolled-out phenocrysts of hornblende or flattened epidote nodules.

Metamorphism. The porphyritic andesites have been extensively altered both by the action of dynamic forces and by percolating solutions. Dynamic action has produced more or less of a schistose texture in all the bodies in the area except the Ladysmith flow. Of the others, the Coronation Canyon flow is probably the least altered, while that which crosses southern Saltspring island and forms the summit of Mt. Bruce is so highly schistose that its nature was for some time in doubt.

There appear to have been two distinct periods at which these lavas suffered alteration through the action of solutions. The first, or period of minor action, is shown on various evidence to have taken place immediately after the extrusion of the lavas themselves[1] and resulted in the almost complete alteration of augite to hornblende, the partial rotting of the original andesine feldspar of the rock, and its replacement in part by more sodic feldspar—albite and oligoclase-albite. This alteration appears to have been very local and does not seem to have affected the great mass of the lavas. The second period of alteration was much more general, and converted portions of the rocks into granular masses of quartz, calcite, and epidote, the latter term including the minerals pistacite, clinozoisite, and zoisite. The amount of epidote present in some cases constitutes 50 per cent of the rock. Calcite rarely forms more than 5 per cent of the rock, although in one case it was observed to form 40 per cent. The extreme effect of this alteration is observable in the epidote nodules, already described. It is a notable fact that the Ladysmith flow is very little affected by this epidotization, and that it is the only flow not greatly folded or intruded by the Tyee quartz porphyry and Sicker gabbro-diorite. Epidote is a mineral found in contact metamorphic deposits and the deep vein zone; it is also characteristic of regionally metamorphosed rocks, and of weathering processes. These facts afford a considerable latitude for theorizing on the origin of the epidotizing solutions. The association of the epidotized rocks with the porphyrite intrusives may point to the intrusives as the source of the solu-

[1] See section on albitization, p. 162.

tions. Again, the restriction of epidotization to the more folded beds may mean that the epidote is the product of either magmatic or surface waters acting on the rocks during dynamometamorphism; or it may mean simply that after folding took place the sheared rocks proved more permeable to surface waters, and hence were more thoroughly altered, than those not converted into schist.

Dykes. An interesting dyke was found cutting the Ladysmith flow at the point where the logging railway crosses Miller creek about a mile to the west of Lake A[illegible]ew. In composition this dyke is almost identical with the lava which it cuts, *i.e.*, about 45 per cent hornblende and 50 per cent oligoclase-albite, with accessory pyrite and titanite. The presence of this dyke, with one or two others of a similar character, suggests that the Ladysmith flow may consist of two or more flows, of the upper of which these dykes are the feeders.

On Mt. Sicker, Mt. Richards, Maple mountain, and Saltspring island, the porphyritic andesites are cut by large numbers of dykes of the Tyee quartz porphyry, which are rarely more than 50 feet in width. The dykes are so numerous and so small that they are not represented on the map, except on the portion covering Maple mountain where, by exaggerating the size considerably, a few of them are shown. These dykes are characterized by great uniformity in strike, the great majority trending north 60 degrees west. This arrangement suggests that the dynamic forces which later folded the Sicker series must have commenced to act before the intrusion of the Tyee porphyrites, placing the andesites in a condition of strain which resulted in the formation of a set of parallel fractures.

Summary. The andesites of the Sicker series are porphyritic flow rocks, probably extruded under submarine conditions. The phenocrysts consist of hornblende and feldspar. The hornblende phenocrysts, in part at least, have been formed by the replacement of augite. In some parts of the mass they constitute 15 per cent of the rock, and in other parts they are altogether absent. The feldspar phenocrysts are smaller in size and more inconspicuous but are more numerous than the hornblende phenocrysts. They usually constitute about 15 to

20 per cent of the rock, even in portions quite close to the surface, and are andesine or oligoclase-andesine. The groundmass also consists of fine-grained hornblende which is possibly uralite and andesine feldspar, with accessory ilmenite, leucoxene, and pyrite.

The lavas display a considerable variety of phases, from rather coarse-grained forms which crystallized slowly, deep in the interior of the flows, through finer-grained varieties some of which contain numerous amygdaloidal fragments—flow breccias —to the microcrystalline, in part glassy, amygdaloidal surface phases. It should be noted that these surficial phases are not porphyritic; therefore the porphyritic texture of the flows was developed after their extrusion. This was proved by abundant evidence in the field which is further referred to on a later page.

The lavas have undergone metamorphism by the action of solutions at two periods. The first metamorphic action took place soon after the extrusion of the lavas, and the solutions probably originated as after effects of the extrusion. This metamorphism had only a very slight, local effect on the lavas themselves, though it affected notably the tuffs which were deposited immediately after. Its effect was to hornblendize the augite of the andesite and albitize the feldspar. This alteration will be described at greater length under the section devoted to "Albitization."

The second period of metamorphism probably occurred immediately after the intrusion of the Sicker gabbro-diorite porphyrite, or during the folding movements which followed it. Its effect was to convert the rocks into fine-grained admixtures of quartz, epidote, and calcite. All of the andesites were thus affected; in the case of the Ladysmith flow the alteration was very slight, owing to the fact that this flow was not intruded by the porphyrites; but, in the other flows, the replacement was great amounting in some cases to 50 per cent or more of the mass of the rock. In the flow breccias, the fragments were more highly altered than the matrix, probably on account of their greater porosity arising from amygdaloidal textures and their finer grain which offered a larger reacting surface to the solutions. The extreme effect of the metamorphism is seen in some of these fragments, which have been converted into rounded nodules composed only of fine-grained quartz and epidote.

The andesites have also undergone regional metamorphism, which has developed in all, except the Ladysmith flow, a schistose texture and in some of them has almost entirely obliterated the original textures and converted the rocks to chlorite schists. This folding probably took place after the intrusion of the Sicker gabbro-diorites and before the intrusion of the Saanich granodiorite.

Sedimentary Rocks.

Basal Tuffs. A dark greenish tuff lying directly on the surface of the lava flow on a small knob to the north of the Cowichan river 5 miles from the western boundary of the map-area, under the microscope proved to be fragmental and of much the same composition as the andesite. It originally consisted of 50 to 60 per cent of andesine feldspar, and 40 to 45 per cent of hornblende, now largely altered to chlorite. The bed is only about 6 feet thick, and grades upwards, by a gradual decrease in the size of the grain and a decrease in basicity, into the characteristic chert-like tuffs of the series, described below.

Although this is the only case in which a complete section was obtained across the strike of the rocks from the top of the lavas into the overlying tuffs it is believed that the sequence and gradation above described is the normal one. Facts which support this conclusion are:

(1) In the case of the Ladysmith flow, the contact of the lavas with the overlying sediments is drift-hidden; but, a short distance above the last outcrop of amygdaloidal lava, a bed of rather basic tuff outcrops and about 60 per cent of this tuff is made up of fragments of ferromagnesian minerals and about 40 per cent of oligoclase feldspar. Above this basic tuff the ordinary chert-like tuffs of the series appear.

(2) On the top of the Coronation Canyon flow, the sequence seems to be similar, although it preser certain differences. Lying directly on the amygdaloidal surface ... the flow is a 10-foot bed of red jasper, made up almost entirely of quartz, hematite, and magnetite. The composition of this jasper is shown in the

table of analyses on page 141. The critical contact between the jasper and the next overlying bed is hidden by drift; but the next outcrop, about 10 feet above, is of ferruginous slate which under the microscope is seen to be made up as follows: recrystallized quartz, about 20 per cent, sericite 60 per cent, iron oxides 10 per cent, and the remainder chiefly chlorite and calcite. The composition of this bed, excepting that it includes iron oxides, is very similar to some of the intermediate members of the gradational sequence first described; and, like them, this slate bed grades upwards into the ordinary, bedded, chert-like tuffs of the Sicker series.

The conclusion seems, therefore, justifiable, that a gradational relationship exists between the basal beds of the sedimentary series, which are undoubtedly of tuffaceous origin, and the overlying chert beds. Because of this gradation, and because the mineralogical and chemical composition of the cherty beds is rather unlike that of beds formed by the ordinary processes of clastic sedimentation, the cherty beds are concluded to be likewise of tuffaceous origin, hence the names "cherty tuffs" or "chert-like tuffs" applied to them.

Clastic beds, resembling in appearance basic sandstones or greywackes, are occasionally found interbedded with the cherty tuffs. These vary considerably in composition, and have suffered much secondary alteration and recrystallization, but in general they have a close resemblance to the basal tuffs already described. Hence they are probably clastic material thrown out by some vent at a distance, and carried to their present position by ocean currents. In one respect they differ from the true basal tuffs; their feldspar is not andesine but oligoclase-albite.

Hard Cherty Tuffs. These tuffs are very hard, microcrystalline rocks, characteristically light-coloured and translucent, though some of them are dark brown to black. They are well bedded, and the beds, though rarely over 4 inches in thickness, are very uniform and may be traced without change for considerable distances, indicating that they have been deposited in fairly deep, quiet water. Their composition is simple: the light-coloured varieties consist largely of feldspar which, when determinable, is oligoclase albite to oligoclase, and quartz. Some orthoclase is probably present, either free or dissolved in the plagioclase, as analysis shows the presence of some potash (K_2O). The relative amount of quartz and feldspar is almost impossible to estimate, on account of the fineness of the [illegible] ually 0·01 to 0·005 mm. If the analysis (page 141) [illegible] in terms of the minerals observed microscopically, [illegible] that about 20 per cent of this specimen is free quartz [illegible] nder is chiefly feldspars with some sericite; this [illegible] presents an average light-coloured, hard cherty tuff. [illegible] lly the tuffaceous nature of these rocks is emphasized [illegible] ence of larger, angular fragments of quartz, felds[illegible]. Chlorite, pyrite, and ilmenite are in some ca[illegible] sories. The dark coloured varieties are of [illegible] on, with the addition of varying amounts of biotite freque[illegible] to 40 per cent or 50 per cent of the rock. The minerals a[illegible] very fresh, and only slightly altered to secondary products.

Soft Cherty Tuffs. The soft cherty tuffs are usually light-coloured rocks, and are fine-grained though seldom equigranular. Their hardness is about that of slate. They are also thinly and uniformly bedded, a characteristic that can be observed on Mt. Tzuhalem, at Separation point, and at the southern end of Saltspring island (Plate IV B); in all other localities within the map-area the bedding has been obliterated by regional metamorphism. The composition of the different beds varies considerably; most of them contain calcium carbonate, and sometimes the amount of this is very large. One thin bed was observed to be a real limestone, as it contained about 95 per cent of calcite. Other beds are dark in colour, to almost black, and this colour is almost certainly due to the presence of carbon which was found on analysis to form over 6 per cent of the black slates into which these soft cherts grade upwards.

The least altered parts of the usual light coloured beds are made up of small fragments of oligoclase-albite up to 0·2 mm in diameter, a few fragments of quartz, and accessory pyrite, ilmenite, and leucoxene. These fragments are embedded in a very fine-grained groundmass, consisting of feldspar with, perhaps some quartz, and a large proportion of sericite and some chlorite. As mentioned, some calcite is also usually present.

In most cases the proportion of fragments to groundmass is about 1 to 3. The analysis of one of these light coloured beds, which happened also to be free from calcite, is given on page 141.

The differences in composition between these rocks and the hard cherts previously described are almost certainly due to original differences in sedimentation, and not to weathering or other influences acting on them long after deposition, as will presently be shown. These differences are, a less amount of free quartz in the soft cherts, and a much greater proportion of sericitic material which is probably the altered equivalent of clayey sediment or of clay and feldspar. Three alternative hypotheses may be advanced to account for the differences: (1) a decreasing rapidity of supply of material from volcanic sources, allowing longer time for the sea water to react on each bed before it was too deeply buried, may have resulted in the partial kaolinization of the feldspathic material; or (2) a decrease in the supply of volcanic material may have allowed clayey material, derived from a neighbouring shore, to form for the first time an appreciable proportion of the sediment deposited; or (3) the supply from volcanic sources may have remained unchanged, but an uplift of the near-by land, relative to sea level, may have so increased the amount of terrestrial sediment that the volcanic material became subordinate. The presence of calcium carbonate in considerable amount in some of the beds, and of carbon in others, would point to one of the two latter hypotheses being the correct one; and as these soft cherts grade upwards into black slates, which contain very little material definitely recognizable as volcanic, it would seem very probable that the change was due to decrease in the supply from volcanic sources, while the actual rate of deposition of the terrestrial sediment may or may not have increased.

However, under any of these hypotheses the soft cherty tuffs must be younger than the hard. The soft cherts were not seen anywhere in the field lying above the hard; but, as already stated, the hard cherts were observed in many instances lying directly on or close to the surfaces of the lava flows, and the soft cherts were nowhere seen in this position.

Black Slates. The basal tuffs and hard cherts of the Sicker series represent rocks laid down when volcanic sedimentation was dominant; during the deposition of the soft cherty tuffs, volcanic material and well-weathered, presumably terrestrial sediment, were thrown down in approximately equal proportions the black slate formation, the last member of the series of sediments, represents the period in which deposition of well-weathered material was predominant.

Not more than 10 per cent of the slates is made up of fragmental feldspar grains, and these are embedded in a fine-grained, kaolinic and sericitic groundmass. The origin of the black colour was determined qualitatively by Clapp[1] to be due to the presence of carbon, a determination that has since been verified by quantitative analysis. The carbon content in the specimen analysed was 6·14 per cent. The slates have entirely lost their original shaly character under regional metamorphism—only in one instance was any vestige of bedding observed—and have become massive and lustrous, with a perfect secondary cleavage.

Silicification. To explain the peculiar composition of the beds of hard chert already described, Clapp[2] offered the tentative hypothesis that they have resulted from the silicification of the slates of the series. The writer, however, is of the opinion that the composition of these rocks has remained unchanged, or nearly so, since their deposition, that they are composed of material almost wholly of volcanic origin, and that any alteration which this material has undergone took place before or at the time of its deposition. In support of this contention the following considerations are offered:

(1) The hard cherts occupy a definite position in the series, near its base, directly above the basal tuffs. No instance was noted of a hard chert bed interstratified with soft cherts or black slates. Were these cherts the result of silicification of the slates, they might be expected to occur at many horizons in the series.

(2) The hard cherts form definite beds of uniform composition. No unsilicified portions or cores of soft material were found in them.

[1] Geol. Surv., Can., Mem. 13, 1912, p. 74; Mem. 36, 1913, p. 53.
[2] Geol. Surv., Can., Mem. 13, 1912, pp. 75-76.

(3) No bed of hard chert was observed to pass into a bed of soft chert or slate along the strike, as might be expected had silicifying solutions acted on a bed of slate.

(4) The alteration of a highly kaolinic rock, like the slate, to a rock made up wholly of fresh feldspar and quartz, like the cherts, is a most unusual one, and it is extremely doubtful if it would take place under any conditions at the surface.

It is highly improbable, therefore, that silicification of clayey material, such as formed the slates, took place during deposition or at any subsequent time. Hence the conclusion appears inevitable that these beds are original depositions of sediment the character of which was originally unlike that of the slates. This conclusion does not bar the possibility that the sedimentary material forming the hard cherts, which is supposed to have been, in part, fresh volcanic ash, suffered certain alterations at the time of deposition. As will be shown, such alteration has certainly occurred.

Chemistry. The following analyses have been made of the red jasper bed referred to on page 136 the colourless hard cherty tuff, and the light coloured, soft cherty tuff, also of the black slate for carbonaceous matter only.

Rock Analyses.

	No. 1410	No. 1413	No. 1464
SiO_2	83·76	60·72	53·42
Al_2O_3	0·61	18·45	19·78
Fe_2O_3	10·73	0·14	0·57
FeO	4·48	5·63	8·96
CaO	0·04	2·44	1·94
MgO	0·34	2·90	2·96
Na_2O	....	2·35	4·44
K_2O	....	2·80	2·31
MnO	0·17	0·38	0·14
TiO_2	0·17	0·88	1·04
H_2O below 110° C	0·12 (both)	0·06	0·07
H_2O above 110° C		2·82	3·69
CO_2	....	trace ?	trace ?
	100·42	99·57	99·32

No. 1410—Red jasper from Coronation canyon.
No. 1413—Hard chert from Coronation canyon.
No. 1464—Soft chert from Sansum narrows.
No. 1469—Black slate from Sansum narrows. Analysed for its carbon content only. Contained 6·14 per cent of carbonaceous matter.
N. L. Turner, chemist.

The analyses confirm the conclusions previously drawn from field and microscopic study. The jasper bed, specimen 1,410, is simply a ferruginous chert, and it is interesting to observe, in connexion with Van Hise's and Leith's theories of the origin of such ferruginous cherts, that it lies directly on the amygdaloidal surface of an andesite flow, and that it was evidently deposited immediately after the flow came into place, as no detrital material is present between the chert and the lava. The hard and soft cherty tuffs, specimens 1,413 and 1,464, approach the composition of typical andesites, but they are proportionately rather low in lime and high in alumina, soda, and water, No. 1,464 being more conspicuous in these respects than No. 1,413. The large proportion of alumina and water would indicate that a considerable amount of kaolinic or chloritic material was present, and more in the soft than in the hard chert, thus confirming the theory of the admixture of clayey terrestrial sediment; while the relatively low proportion of lime to soda indicates the occurrence of an albitizing change which will be discussed later. If all the soda and lime of these analyses is assumed to be present in the form of feldspar, the plagioclase of No. 1,413 will have the composition $Ab_{70}An_{30}$, and that of No. 1,464 will be $Ab_{85}An_{15}$.

Metamorphism. The different members of the sedimentary series have been very differently affected by the orogenic movements which folded them. The very competent, hard, cherty tuffs have been somewhat fractured, but not rendered schistose. Occasionally strain shadows may be observed under the microscope in some of the larger fragments of quartz or feldspar, and some of the larger quartz grains have been partially granulated, but no schistosity has been developed or secondary micas formed. The soft cherty tuffs and the black slates, on the contrary, yielded by flowage under the stress of the folding movements, recrystallized, and formed highly fissile sericitic schists. Their alteration was the more extreme, since, as they were the softest formations of the region, nearly all the differential movement of the folding was concentrated in them; while the harder bodies of chert, gabbro-diorite, and to a less extent of andesite, moved as units and in consequence were much less sheared.

The sediments appear to have escaped almost entirely the action of the solutions which epidotized the lavas so highly. In only a few of the thin sections was any epidote observed, and in them it amounted only to a fraction of one per cent. But if this alteration has not taken place, the composition of the feldspar in the cherts suggests that the albite alteration, which affected the lavas only locally, was universal in the tuffs, and probably took place previous to or during deposition.

Summary. The sediments of the Sicker series consist of four formations. In ascending order they are, the basal tuffs, the hard cherty tuffs, the soft cherty tuffs, and the black slates. Two distinct types of sediment have combined to produce these: comparatively fresh, unweathered material, shown on good evidence to be probably of volcanic origin; and well-weathered, clayey material, probably of terrestrial origin. The basal tuffs and the hard cherty tuffs have been laid down when deposition of the first type was dominant; the soft cherty tuffs, when the factors were of about equal importance; and the black slates, when the principal deposition was of the clayey type.

The basal tuffs are a thin series of beds directly overlying the andesitic flows and of much the same composition. They grade upwards into the hard cherty tuffs which are very fine-grained rocks composed mainly of quartz and albite-oligoclase feldspar, with biotite in some varieties. The soft cherts and black slates are of similar composition, with the addition of constantly increasing amounts of kaolinic and sericitic material.

Dynamic metamorphism has affected the hard cherty tuffs very little; in the other members of the series, however, all original structures have been obliterated except in a few instances, and the rocks have been converted into sericitic schists. The sediments have not undergone any alteration to epidotes, but they appear to have been universally affected by solutions which altered their feldspars to albite, probably at the time of deposition.

STRUCTURAL RELATIONS.

Internal.

Stratigraphy. The oldest formations of the Sicerk series identified within the map-area are : (1) a north-dipping outcrop of porphyritic andesite about 5 miles from the western border of the map-area and a mile north of the Cowichan river; and (2) the Ladysmith flow which dips gently to the south. A study of the structure of the area leads to the conclusion that the position of the majority of the other andesite bodies in the series is also at or near the base, although some, like the Coronation Canyon flow, appear to hold a higher place and to be conformably interbedded with the sediments. The sediments lie conformably on the surface of the flows, and, so far as known, form the upper members of the series. No more definite statement of the relations than this can be made, since, as neither the base nor the top of the series has been identified within the map-area, its history may not be completely known.

Accurate estimates of the thickness of the series are difficult to make, since neither the top nor bottom has been identified, and since, on account of the faulting and intense folding which the series has undergone, the apparent thickness is almost certainly greater than the real thickness.

The thicknesses of the volcanic flows without doubt vary greatly. The Coronation Canyon flow is about 2,500 feet thick; this estimate is probably fairly accurate as the top and bottom of the flow were both observed, and its dip, 50 degrees north, is about the same at top and bottom. The flow crossing southern Saltspring island and the summit of Mt. Bruce, has about the same maximum thickness. On Maple mountain, where the lavas although crumpled are probably in general almost flat-lying, there is 1,700 feet of lava above sea-level as shown on the map. If the Ladysmith flow maintains throughout its entire width the dip of 20 degrees south that it has at its southern border, its thickness would amount to over 8,000 feet; it is more probable, however, that its structure is anticlinal, and that the Stocking Lake valley represents the summit of the anticline. If this is the case, the thickness of the flow would be approximately 3,700 feet.

In the sediments, the hard cherty tuffs are the only beds of which the thickness can be estimated with even an approach to accuracy; the softer beds have flowed under metamorphism and their bedding has been obliterated. The two beds seen on Mt. Brenton are of competent chert and their folding has been gentle. Their combined thickness is 2,050 feet. On Mt. Tzuhalem, where dips are very low, the maximum thickness of the beds exposed above sea-level is about 1,000 feet. On the south side of the Chemainus river, about a mile from the western border of the map-area, the hard cherts dip 60 degrees southwest, and the thickness of the rocks exposed is about 3,000 feet. The true thickness is probably greater, as the granodiorite intrusion there may have stoped away considerable thicknesses of the original beds.

The writer is of the opinion that, after making due allowances for the effects of folding and faulting, the thickness of the sediments in the eastern part of the map-area may be conservatively placed at 2,000 to 3,000 feet, and that in the western part of the map-area it is somewhat, probably considerably, greater; while the thickness of the lavas, which probably varies within wide limits, may amount to 3,700 feet as a maximum.

Folding. The Sicker series has been complexly folded. The axes of the major folds strike about north 55 degrees west and in the western part of the map-area plunge west at angles of from 10 degrees to 15 degrees. These major folds are represented by the three parallel belts of Sicker strata the structure of each of which is synclinal, whereas the separating belts of Cretaceous sediments occupy the position of the former anticlines from which the Sicker strata have been removed by erosion. The structure of each of these belts is similar, an unsymmetrical syncline whose axial plane dips toward the south. The southern syncline has been the most closely folded of the three, the northern syncline the least closely. The axial plane of the southern syncline dips south at an angle of approximately 75 degrees, that of the northern at an angle of about 45 degrees, while that of the central syncline is intermediate between the two. It is clear from these facts that these folds are secondary folds on the north limb of one of the great major folds of the region, and that this great major fold is either a normal anticlinorium or an abnormal synclinorium. As the folding was in the main of the normal type, except in the soft slates, it is concluded that this great major fold was a normal anticlinorium; its crest must have occupied the position of the present Cowichan valley.

The cross folding has been very gentle compared with the major folding, dips produced by it rarely amounting to over 10 degrees in the western or 25 degrees in the eastern part of the map-area. It is difficult to determine with absolute accuracy the large structure of the minor folding, but a close study of the areal relations of the various beds, as shown on the map, together with a considerable number of observations taken on secondary folds in the field, have made some of the features evident.

The increase in width of the two southern synclines toward the west, which is evidently not an apparent effect due to change in topography, suggests that these synclines plunge to the west. This was independently verified in the field by observations taken on the plunge of small secondary major folds which were found to plunge 10 degrees to 15 degrees to the west.

The structure of the sedimentary beds on Mt. Brenton and Coronation mountain, which, although greatly broken up by intrusions of the gabbro-diorite porphyrites, seem to retain their original relative positions is also that of a syncline with a gentle plunge to the west. In this case the plunge seems to decrease and flatten to the west of Coronation mountain.

The beds on Mt. Tzuhalem, Separation point, and southern Saltspring island are probably an eastward extension of the central syncline exposed on the west side of the map-area. As to their major structure, they form the northern limb of the syncline, while the southern limb has been faulted off. The minor or cross structure is more difficult to determine, as the beds on Saltspring island have been so greatly disturbed by igneous intrusion. The cross structure appears to be, however, synclinal in a large way, with several secondary minor folds: thus Mt. Tzuhalem is a secondary minor syncline, Genoa bay an anticline, Separation point a syncline, Sansum narrows probably an anticline. The dip of the axial plane of the Mt. Tzuhalem syncline, a gentle open cross fold, is steeply west, indicating that this minor fold has a small dip to the east. A number of similar observations on small secondary minor folds, and on the plunge of the axes of secondary major folds on Saltspring island, seem to indicate that the general dip of the minor folds there is to the west. These facts would seem to indicate that the minor structure of this group of rocks is that of a synclinorium with Sansum narrows as its bottom.

The minor structure of the Sicker series in the map-area, therefore, appears to be largely anticlinal; the two southern belts of sediments and the northern belt to the west of Mt. Sicker form the western limb of the anticline; Mt. Richards is approximately the crest and the rocks to the east of this, on Maple mountain and Mt. Tzuhalem, form the eastern limb.

Under these conditions, the strata on Mt. Richards and to the east and west of the mountain must have a major synclinal and a minor anticlinal structure; the strata, therefore, are probably at or near the base of the series, and probably should be flat-lying or as nearly so as is possible in a district so folded. As the map shows, the only rocks of the series that occur in this district are the andesitic lavas which have been shown on other grounds to lie at or near the base of the series in most cases (see page 144). Their wide areal development here over a belt 2 miles in width, while their maximum thickness elsewhere is only 3,700 feet, suggests strongly that they must be almost flat-lying, and this confirms the inference drawn from a study of the structure.

In the main the folding appears to have been of the normal type so far as the more competent beds, such as the hard cherty tuffs and gabbro-diorite intrusives, are concerned. The softer cherty tuffs and pelites, which yielded by flowage to the deforming forces, were probably abnormally folded, although the obliteration of the bedding makes the point impossible of field determination.

Metamorphic Effects of Folding. Folding has converted all of the softer rocks of the series, together with the more incompetent intrusives, into schists. All the porphyritic andesites, except the Ladysmith flow, have had developed in them a pronounced secondary cleavage. The hard cherts of the series are almost unaffected; but in all the other sedimentary rocks all primary bedded structures have been obliterated and slaty cleavage has been developed, except in the almost flat-lying deposits of Mt. Tzuhalem, Separation point, and of the southern shore of Saltspring island. Many of the sills of the Tyee quartz porphyrites, especially those in the neighbourhood of gabbro-diorite masses, have been converted into sericitic schists; and some of the thinner sills of gabbro-diorite porphyrite and the margins of larger masses have been converted to chlorite schists.

Shearing seems to have been unusually intense on the south limb of the northernmost syncline, as if all the differential movement between the strata when the syncline was formed had been concentrated there. The thick masses of quartz porphyrite have been completely converted into a highly schistose sericitic schist, the original character of which was determined only by the discovery of a few uncrushed phenocrysts of quartz and feldspar; even thick sill-like or dyke-like masses of gabbro-diorite porphyrite, which elsewhere would have been almost unaffected by the shearing stresses, are largely converted to chlorite schists. It is worthy of notice that all the valuable ore deposits have been found in this highly sheared zone.

Time of Folding. The folding took place toward the end of the Jurassic period, after the intrusion of the Tyee quartz-feldspar porphyrite, probably after that of the Sicker gabbro-diorite porphyrite, and before the intrusion of the batholiths of granodiorite. The granodiorite masses, even where small, are not schistose at their edges, although they were observed at some points in contact with very hard, competent, cherty tuffs; nor were the tuffs sheared at those points. Original gneissic textures are not conspicuous in the granodiorite masses; this may indicate that there was but little movement in the mass during consolidation. Hence the folding movements were evidently almost completed before the intrusion of these masses.

The Tyee quartz-feldspar porphyrites are very thoroughly converted into sericitic schists in many places, and in all other places they have been more or less affected by folding, as may be concluded from the granulation of quartz phenocrysts and the development of secondary sericite. Hence the main folding clearly took place after the intrusion of the Tyee porphyrite.

Most of the evidence seems to point to the conclusion that the main folding movement occurred after the intrusion of the Sicker gabbro-diorite porphyrite; nevertheless, there is some evidence from which it might be concluded that it took place before that intrusion.

It may be urged in favour of dating the folding in large part before the intrusion of the gabbro-diorite: that the gabbro-diorite masses are uniformly very fresh and non-schistose, except in places near their edges; that in many localities they cut across the folded strata of the Sicker series; and that the intrusive is frequently quite fresh and unaffected by shearing up to its edges. Against these considerations must be set the following: the porphyrites are coarse-grained, massive, and hard, easily the most competent rocks in the map-area to resist shearing stresses; therefore, they might be expected to be uniformly fresh and non-schistose. The points at which they are massive to their edges are invariably, so far as observed, points of contacts with soft slaty sediments which would form a cushion on which the more competent rock might slide without itself being deformed. While they cut across the folded Sicker strata, it is conceived that such cutting might have taken place as well before the folding as after, and the final phenomena in either case be very similar.

For dating the main folding movements after the gabbro-diorite intrusion the following evidence is presented:

(1) The porphyrite, when injected into well-bedded sediments, tends to form sills. These sills were observed to parallel the bedding of the sediments regardless of whether the beds lie almost flat or have been tilted even into a vertical position. It would seem from this most likely that the intrusion had preceded the folding, and the whole rock body had then been folded together.

(2) In one case a sill about 60 feet in thickness was observed, intruded into rather highly schistose rocks in which the bedding, on account of considerable colour differences, was still observable. This was in the bed of a small creek rising on Coronation mountain and flowing south to Chemainus river. In this case the strike of the sill was parallel to that of the bedding, not to that of the schistosity; hence intrusion probably occurred before the development of the schistosity, i.e., before the main folding.

(3) The gabbro-diorite masses themselves have been affected by the folding movements sometimes very greatly. Near relatively soft rock, such as the porphyritic andesites, the edges of the intrusive masses are usually considerably shattered, but as a rule not rendered schistose. Near masses of Tyee porphyrite or of the harder cherty tuffs the edges of the gabbro-diorite bodies are converted into chlorite schist for distances of 3 to 30 feet, or in exceptional cases even more, from the contact. Sills of gabbro-diorite porphyrite not over 30 feet in thickness have been observed to be converted entirely into schist. The most striking effect of this kind was observed on Mt. Sicker, where a large dyke of gabbro-diorite several hundred feet in width had developed a pronounced schistosity, though not sufficient to obscure its original character. In several other cases, sills of gabbro-diorite were observed to have thrown off dykes into the intruded sediments, cross-cutting the bedding. These dykes were schistose, and the planes of schistosity passed unbroken through them and the sediments alike. Also, where the edges of the gabbro-diorite masses are schistose as described, and the schistosity is not parallel to the contact, the planes of schistosity pass unbroken from the intrusive into the intruded rock. Apparently, therefore, the schistosity of both was developed at the same time.

(4) If the gabbro-diorite porphyrite was intruded before the main folding movements took place, and acting as a competent bed, moved as a unit, the portion of the older rock close to such a mass should be more schistose than that farther away. The determination of this is difficult, since the contacts in the eastern part of the area where exposures are good are mostly with the black slate, which in any case has been completely recrystallized during the shearing. That the intruded rocks are more sheared in the vicinity of gabbro-diorite masses was, however, observed in several places. The small mass of sediments on Saltspring island, to the south of the andesite band crossing Mt. Bruce, consist of bedded cherts, which become converted into sericitic schists as the contact with the gabbro-diorite is approached. On Saltspring island, in the andesite mass to the east of Mt. Erskine, a number of small unmapped masses of gabbro-diorite

porphyrite and quartz-feldspar porphyrite occur. The quartz porphyrites are very slightly affected by the folding movements when in contact only with the less competent porphyritic andesite. In one case, however, a dyke of Tyee porphyrite was in contact with a large dyke of gabbro-diorite porphyrite, and had been metamorphosed to a highly schistose sericite schist. But perhaps the best example of this action of the gabbro-diorite porphyrite was observed on the south side of Mt. Brenton where the thick mass of quartz-feldspar porphyrite is highly schistose close to the gabbro-diorite contact, and much less so at a distance from it.

To sum up this evidence: the gabbro-diorite has formed sills in the sediments, which appear to be parallel to the bedding and not to the schistosity, and seem to have been folded with the sediments rather than intruded after the folding: the gabbro-diorite masses have been rendered schistose to a greater or less extent, and the writer believes that the facts stated suffice to show that its general unmetamorphosed condition is due to its greater competency rather than to intrusion after the main deformation had taken place; and in several cases the gabbro-diorite masses appear to have acted as competent beds and moved as a unit, thus concentrating their differential movements in beds directly above or below them and rendering these beds more schistose than the same beds at a greater distance from the intrusive masses.

The time of the folding movements may perhaps be correlated with that of the intrusion of the Wark gabbro-diorite batholith to the south. The highly gneissic texture of this batholith, universal throughout its mass, which is probably an original gneissic texture,[1] implies great movement during consolidation, which may have been due to repeated injections of molten matter from below, or to regional folding movements, or to a combination of both causes. If due to either of the two latter causes, the folding movements are probably to be correlated with those that folded the Sicker series and its associated intrusives. The folding of both the Sicker and the Wark took place in later Jurassic time. It seems improbable that the

[1] Clapp, C. H., Geol. Surv., Can., Mem. 13, p. 96; Mem. 36, p. 57.

stresses affecting the Wark batholiths so strongly could have been so localized as not to affect the Sicker series. There is no evidence that the Sicker series has been affected by two great folding movements. Hence the assumption appears reasonable that both rocks were folded at the same period.

Faulting. The Sicker series has been much faulted, but most of the faults noted have displacements of only a few feet. While it is probable that much of this faulting was of pre-Cretaceous age, it is difficult to prove this, as most of the Sicker-Nanaimo contacts are drift-covered. All of the large faults noted in the district are of post-Cretaceous age, and will be described fully in connexion with the structural relations of the Nanaimo series (page 243).

It is suggested, though field proof is impossible, that a great pre-Cretaceous strike fault may follow the Cowichan valley. Such an assumption seems to be necessary to explain the absence of the thick series of Sicker sediments and lavas from the south side of the valley whose minimum width is 1¼ miles. Since the structure of the Sicker series is a normal anticlinorium, of which the Cowichan valley forms the crest, a development of the series might be expected on the south side of the valley similar to that on the north side. Faulting seems the most reasonable hypothesis by which to account for its absence.

External.

Relations to Other Members of the Vancouver Group. The Sicker series has been placed in the Vancouver group by Clapp and considered provisionally as conformable with the other members of the group[1]. From the work of the past summer, however, no definite statement can be made either as to the age of the series relative to that of the other members of the Vancouver group, or as to its conformability with them. Both the Sicker series and the remainder of the Vancouver group are pre-batholithic in age; the lavas of the two divisions are very similar in chemical and mineralogical composition; and both series have been subjected to approximately the same amount of metamorphism.

[1] Clapp, C. H., Geol. Surv., Can., Mem. 13, pp. 71, 83, Mem. 36, p. 55.

From these inadequate data, in the absence of better proof an identity in age and a conformability of deposition might tentatively be inferred.

Only at two points in the map-area were rocks resembling those of the Sicker series found in contact with the Vancouver andesites. On the summit of Mt. Waterloo several dykes of porphyritic augite andesite were found, cutting the Vancouver andesite flows. On account of their megascopic resemblance to the porphyritic andesite of the Sicker series, these dykes were correlated with it. Microscopic examination has added nothing to this determination, as there is no petrographic difference between the lavas of the two series except the almost universal presence of large phenocrysts of hornblende in the Sicker lavas, while in the Vancouver lavas such phenocrysts are rarely present, and, when present, are small. If the correlation is correct, the Sicker lavas are undoubtedly younger than those of the Vancouver group. Rocks of the Sicker series were also found in the bed of a small creek flowing north into the Cowichan river, about 3 miles from the western border of the map-area. These consist of well-bedded sediments dipping 50 degrees southwest, corresponding to their position on the south side of the Cowichan Valley anticline, of porphyritic hornblende andesites with a similar dip, of Tyee quartz-feldspar porphyrites, and of Sicker gabbro-diorite porphyrites. Unfortunately, in this critical area outcrops are poor, and in addition thick masses of the intrusive porphyrites have been injected between the contact of the Sicker series and the Vancouver lavas, so that the relations between the two were not determined.

From results obtained by workers in other areas, notably by J. D. Mackenzie in the Queen Charlotte islands where rocks very similar to these are found, it is believed that the Sicker series is conformable with the Vancouver volcanics and somewhat the younger. Fossils found by MacKenzie in the Maude argillites, which are tentatively correlated with the Sicker series by him and Clapp, have been determined by T. W. Stanton as lower to middle Jurassic forms[1]; whereas the Vancouver volcanics

[1] Geol. Surv., Can., Sum. Rept. 1913, p. 46.

have already been proved by Clapp to be of uppermost Triassic or lowermost Jurassic age.[1]

Relations to Younger Formations. The Sicker series has been intruded by two types of porphyrites, the Tyee quartz-feldspar porphyrite first, and the Sicker gabbro-diorite porphyrite later. The Tyee porphyrite forms sills in the sedimentary rocks and dykes in the volcanic rocks of the series; the Sicker porphyrite forms irregular masses and dykes in the volcanics, sills in the sediments where the bodies of intrusives are small, and irregular masses breaking across the bedding but with a tendency to elongation parallel to it where the bodies are large. The greatest development of these intrusive rocks is seen on Coronation mountain, Mt. Brenton, and Mt. Sicker; but they are almost universally present in small masses wherever the Sicker series is found. Many bodies occur which have not been mapped on account of their small size.

The Saanich granodiorite intrudes the Sicker series in irregular batholithic masses. Of these the largest is the Ladysmith batholith which has a length of 7 and a width of 3½ miles within the map-area. Smaller masses are fairly numerous as the accompanying map shows. It may be noted with reference to various theories that have been put forward concerning the mode of intrusion of batholiths, that in this area the batholithic masses do not seem to exhibit any decided preference for either anticlinal or synclinal structures in their upraising but break up into both indiscriminately.

The edges of the batholiths are never greatly chilled, but occasionally a thin chilled edge an inch or so in width may be noted. Dykes from the edge of the batholith penetrating the country rock are the exception rather than the rule, indicating that the intrusion was relatively quiet and did not greatly shatter the intruded formations. Contact breccias are, however, almost universal; the granodiorite is filled with fragments of the intruded rocks of all sizes up to 30 feet in diameter for distances of a mile or more from present contacts. These fragments, when of the Sicker series, have been usually metamorphosed to a considerable extent and recrystallized, but fragments of the

[1] Geol. Surv., Can., Mem. 13, pp. 68–71, 1912.

porphyrites intrusive into the Sicker have not been greatly affected. At the edges of the bathcliths, contact metamorphism is usually slight, but in one case, at the contact of the Ladysmith batholith with the Sicker andesite, feldspathic and quartzose matter from the intrusive has seeped into the andesite for a long distance from the contact, granitizing it and forming hybrid gneisses. The composition of the granodiorite also has been affected, in that the digestion of the stoped-off masses of andesite has rendered it more highly micaceous near the contact than farther away.

The Sicker series was intruded by the Tyee and Sicker porphyrites; it was folded, metamorphosed, intruded by the Saanich granodiorite, elevated above sea-level, eroded, and depressed to sea-level before the deposition of the Nanaimo (Cretaceous) sediments began. Consequently the Nanaimo overlies the Sicker series with great unconformity. As a rule, the Nanaimo series may be observed to lie almost flat upon the upturned edges of the Sicker, with great discordance in dip and strike, and always with a basal conglomerate of varying thickness containing rounded pebbles of many varieties of the underlying rocks. These pebbles frequently possess bedding or schistoisty which were clearly developed before they came into their present position, as the planes of schistosity in the various pebbles have no common orientation but lie at all angles to one another. As the map shows, the boundaries of the Nanaimo series bevel the Sicker formations, cutting indiscriminately across sediments, volcanics, Tyee porphyrites, Sicker porphyrites, and granodiorites. Proof of unconformity is, therefore, complete.

For some time, however, a gradational relationship was supposed to exist locally between the upper beds of the Sicker series and the lower beds of the Nanaimo series. This error arose through the observation of an apparent gradation between the metamorphosed Sicker series and the slightly metamorphosed overlying Nanaimo series at one point in the bed of the Chemainus river near Copper canyon[1]. On this occurrence was based the establishment of the Sansum formation[2] and the Cowichan group[3]

[1] Clapp, C. H., Geol. Surv., Can., Mem. 13, pp. 72, 84, 132, 1912; Mem. 36, p. 54, 1913.
[2] Allan, J. A., Geol. Surv., Can., Sum. Rept. 1909, p. 99.
[3] Clapp, C. H., Geol. Surv., Can., Mem. 13, pp. 72, 124, 1912.

to include such beds as did not fall with certainty into either the Sicker or Nanaimo groups. The evidence obtained at all contacts observed in the map-area, as well as that deduced from the areal relations, made it clear that the unconformity between the two is profound. The contact in Copper canyon was carefully studied, with the result that the unconformity was proved to exist there as in other localities, although not so easily determinable; for it was found that: both overlying and underlying formations have a similar strike and a steep dip: they are of very similar colour and grain; and the basal conglomerate is only a few inches thick, the pebbles are small and scattered, and most of them are of quartz. Moreover, during the folding movements which followed the deposition of the Cretaceous, the Nanaimo sediments were thrust against the buttress of Sicker rocks at this point, and somewhat more metamorphosed than usual—a metamorphism resulting in the stronger cementation of the pebbly sandstones, though not in the development of schistosity in them. The proofs of unconformity found at this point were as follows: (1) The overlying formation is a relatively unmetamorphosed, non-schistose, conglomeratic sandstone. The underlying formation is a phase of the Tyee quartz-feldspar porphyry still containing many feldspar phenocrysts in which deformation has produced a good secondary cleavage. In itself this determination affords complete proof of unconformity, since the Tyee porphyrite is an igneous rock intrusive into the Sicker series, and, therefore, the three time intervals of intrusion, deformation, and erosion must have passed before the Nanaimo series could be deposited in its present position. (2) Although similar in strike, the two formations differ in dip. The dip of the planes of schistosity of the Tyee porphyrite is 65 degrees northeast, implying that the dip of the "bedding" must be less than this. The Nanaimo beds dip 70 degrees to the southwest. (3) The base of the Nanaimo series here is a well-marked stratum of conglomerate, although the pebbles are small and scattered. The pebbles are rounded and, with the exception of the quartz pebbles, they possess either bedding or schistosity. The schistosity was evidently developed before the pebbles assumed their present position, as the planes of schistosity in the various fragments lie in all positions. The pebbles are of different kinds, all recognizable as originating in underlying formations. The following were noted, with rough estimates of their relative proportions in the conglomerate: milky quartz about 60 per cent, evidently from some large veins of exactly similar quartz immediately beneath; cherty tuffs of the Sicker series including black, white, and grey cherts, about 20 per cent; black slate with well developed slaty cleavage, 5 to 10 per cent; sericitic schists similar to those formed by metamorphism of the Tyee porphyrites, about 10 per cent. (4) Two quartz veins were observed, each about 4 inches in width, penetrating the underlying rock almost at right angles to its plane of contact with the conglomerate and cut off squarely by it.

It is clear, therefore, that, although somewhat obscured, the unconformity between the two series exists here as in other localities. The function of the terms Sansum formation and Cowichan group thus disappears, and the use of these terms hereafter is discouraged.

MODE OF ORIGIN AND HISTORY.

The Sicker epoch appears to have opened with a great outpouring of andesitic lavas, which was probably the last paroxysm of the mighty volcanic outbursts of the Vancouver period. The Vancouver lavas, as has elsewhere been shown, were largely or wholly ejected under submarine conditions (page 116). It is certain that these conditions still remained unchanged when the Sicker andesites were poured out, since they also are characterized by flow breccias in large amounts, and since well-bedded sediments and jaspers are laid down directly on the surface of the earlier flows and interbedded with the later ones. The lavas must have been poured out in a sea of considerable depth, since the overlying and interstratified sediments are thin-bedded and the beds persistent, implying water undisturbed by winds, tides, or currents; and far from any shore, or at least from any but a very low-lying shore, as the overlying sediments are free from admixture of any but the finest clayey material. After the first great period of ejection there was apparently a period of quiescence, followed here and there by a few lesser explosions, until finally all became quiet and the volcanic activity was at an end.

Accompanying and perhaps also following the extrusions of lava, volumes of volcanic ash were thrown out into the sea, together with juvenile waters carrying dissolved silica, soda, and locally iron. As a result, the amygdaloidal surfaces of the flows were filled with albite-oligoclase, calcite, and jasper. The albite-oligoclase seems to have filled the first-formed amygdules, that is those found now in the fragments of volcanic breccias, while the latest formed amygdules are filled with calcite or jasper plus very little feldspar. This probably indicates some change in the character of the solutions, probably due to dilution or cooling. While these processes were going on, the volcanic ash was settling on the surfaces of the lava flows, the coarsest first, followed by that of finer and finer grain. With this decrease in grain the ash became more and more susceptible to alteration by the solutions with which it was bathed (see page 162) and which tended to convert the ash into mixtures of quartz and albite. In the very fine-grained ash the alteration was almost complete, and thus the hard cherty tuffs were formed. Gradually the supply of ash grew less, either by a decrease of the activity of the volcanoes, or because settling had become very slow on account of the increasing smallness of the particles, and weathered material began to be deposited along with the altered ash, thus forming the soft cherty tuffs. This weathered material may have been ash altered by the sea water, or terrestrial sediment carried in from the nearest shore, more probably the latter. The proportion of the weathered material increased until, becoming dominant, it formed the pelites which on being regionally metamorphosed became the black slates of the Sicker series.

It is almost certain that this cycle of deposition was repeated during the Sicker epoch, and perhaps repeated more than once. The records of the Duncan map-area are too incomplete, or have not been studied with sufficient care, to make as yet a final statement in this regard.

After the deposition of the slates had been completed and the sedimentary series had become well indurated, very gentle folding movements began, accompanied by the intrusion first of the Tyee quartz-feldspar porphyrites then of the Sicker gabbro-diorite porphyrites. After the latter event, the folding movements continued, resulting in the profound dynamic metamorphism of all the more incompetent rock members. This period of folding may perhaps be correlated with the intrusion to the south of the Wark batholith. Emergence from the sea may have occurred during the folding or may have been deferred until after the intrusion of the Saanich granodiorite, which took place a little later. Erosion began after emergence, cut valleys in the Sicker series 1,000 to 2,000 feet deep, in many cases along the anticlines, and unroofed many of the batholiths of granodiorite. Then followed a gradual submergence and the deposition of the Nanaimo series.

THEORETICAL CONSIDERATIONS.

Porphyritic Textures.

A number of interesting observations were made during the course of the summer's work on the development of porphyritic textures in the rocks of Vancouver island, which may be briefly summarized in the statement that in all cases observed the development of phenocrysts took place in situ and not previous to intrusion or extrusion.

The method used to determine these facts was in all cases the same, that of examination of chilled contact edges. When such an edge was observed in a porphyritic rock, it was closely examined for changes in the size of the phenocrysts as the edge was approached, as well as for the change in the grain of the groundmass. In every case studied, the glassy selvage of the igneous rock contained no trace of phenocrysts; an inch or two from the edge, minute porphyritic crystals, barely visible, began to appear, and they increased rapidly in size as the distance from the edge grew greater, until in most cases the phenocrysts attained their full size 1 to 2 feet from it.

Thus, the porphyritic andesites of the Sicker series, which were lavas ejected from submarine vents, contain phenocrysts of augite, now changed to hornblende, and of andesine feldspar. From examination made as described both at the upper and lower surfaces of these flows, it is clear that both the feldspar and the augite phenocrysts were developed after extrusion. The same is true of dykes of porphyritic andesite of very similar composition which cut the Vancouver andesites on the summit of Mt. Waterloo.

The Tyee quartz-feldspar porphyrites which form dykes and sills in the Sicker series, contain phenocrysts of quartz and albite-oligoclase feldspar. Data on this rock were more difficult to obtain, as the phenocrysts in it do not develop rapidly, probably because so highly siliceous a rock can be highly supercooled before crystallization begins, and, once begun, the greater part of it would crystallize with great rapidity and without formation of large phenocrysts. Whatever the reason, there are many masses of this rock 100 feet or more in width whose porphyritic texture is visible only under the microscope. In one or two cases where some of the less siliceous varieties were under examination, however, it was evident that the phenocrysts both of quartz and of feldspar were developed in place and not before intrusion.

The Sicker gabbro-diorite porphyrite is characterized by the presence in it of feldspar phenocrysts which at times grow to sizes of half an inch or more. Application of the criterion described shows that these phenocrysts were developed after the intrusion of the rock into the Sicker series.

The rapidity with which these phenocrysts develop is notable. As above mentioned, in the more basic rock they usually attain their full size within 1 foot or at most 2 feet from the edge of the igneous mass. This is not the case only in large masses which cool slowly and thus afford plenty of time for the processes of crystallization to go on, but even in the submarine flows which must have been cooled with great rapidity, and also in dykes not more than 6 feet in width. In some small basaltic dykes, 4 to 6 feet in width, to the south of the Duncan map-area, feldspar phenocrysts were observed, developed in situ, nearly half an inch in diameter. Since the glassy selvage in these dykes was over a foot in width, they must have been intruded into cold rocks and have solidified very rapidly, but yet these large feldspars had had time to complete their growth.

Relative Speeds of Crystallization of the Constituents of Basic Rocks.

In the petrographic study of the Ladysmith flow it was observed that the relative proportions of the ferromagnesian mineral to the feldspar were approximately the same in the fragments of the volcanic breccia as in the matrix of lava in which they were embedded. The fragments were evidently more surficial phases which had become later broken up by the movements of the flow, as they were amygdaloidal and of somewhat finer grain than the matrix. But a marked difference exists; in the fragments in the breccia the feldspar phenocrysts constitute about 20 per cent of the rock and the hornblende phenocrysts only 2 to 3 per cent; in the lava matrix the feldspar phenocrysts constitute about 20 per cent and those of hornblende about 15 per cent of the rock mass. The groundmass in the fragments is correspondingly more basic in the fragments than in the lava matrix.

Hence, although the feldspars in this rock may not have initiated their crystallization before the hornblendes, it is evident that their rate of growth was by far the greater, although the ferromagnesian mineral is present in sufficient amount to produce finally about the same proportional quantity of porphyritic crystals. A similar observation was made by W. H. Collins in his study of the Gowganda diabase[1]. In those rocks, which form non-porphyritic sills in the Huronian sedimentary series of northern Ontario, the feldspars and hornblendes both initiate their crystallization at approximately the same time; but the feldspars, which form only about 40 per cent of the rock, increased in size with much greater rapidity than the ferromagnesian minerals which form nearly 60 per cent. As a result the coarse-grained diabase has an ophitic texture.

The relative speed with which the feldspars in these basic rocks complete their crystallization is notable as being opposite to what occurs in the granitic rocks; in the granitic rocks the ferromagnesian mineral, concentration of which may not be more than 10 per cent instead of 50 to 60 per cent, except in rare

[1] Collins, W. H., "Geology of the Gowganda mining division," Geol. Surv., Can., Mem. 33, p. 85, 1913.

instances, completes its crystallization long before the feldspar. The results described are, however, in accord with the experimental results obtained by Doelter who determined that in a slag from which labradorite, augite, and olivine crystallized, the labradorite grew more rapidly than the augite.

If the course of magmatic differentiation at times proceeds as is suggested by Harker[1], by partial crystallization of a fluid magma and subsequent expulsion of the still fluid portion by crustal movement, it seems very possible that this rapidity of crystallization on the part of the feldspar in these basic rocks might result in a course of differentiation opposite to that supposed usually to take place, so that the material first to solidify would be the more feldspathic, while the liquid residue would be the more basic.

Albitization of the Rocks of the Sicker Series.

The formation of albite in lavas and other rocks at the expense of more basic feldspars has already been described and discussed by Termier[2], Cathrein[3], Duparc and Pearce[4], Bailey and Grabham[5], Dewey and Flett[6], and others. Cathrein in 1883, showed that saussurite consisted of a fine-grained aggregate of albite, epidote, zoisite, and garnet, and that the bulk composition of the aggregate was approximately that of the feldspar from which it had been derived, so that the processes involved in the change had led to little more than a chemical rearrangement of the constituents. Termier demonstrated that formation of albite may take place under conditions of weathering, through the removal from the feldspars of their lime by leaching meteoric waters; so that the albite still remaining is merely a residue derived from the original feldspars. Duparc

[1] Harker, Alfred, "The natural history of igneous rocks" pp. 323-7, 1909.

[2] Termier, P., "Sur l'élimination de la chaux par metasomatose dans les roches éruptives basiques de la région du Pelvoux." Bull. Soc. Geol., France, tome 26, pp. 165-192, 1898

[3] Cathrein, Zeit. Krist., 1883, Band 7, p. 234.

[4] Duparc and Pearce, "Sur les andésites et les basaltites albitisées du Cap Marsa," Comptes Rendus, 1900, vol. 130, p. 96.

[5] Bailey and Grabham, "Albitization of basic plagioclase feldspars," Geol. Mag. 6, pp. 250-256, 1909.

[6] Dewey and Flett, "On some British pillow lavas and the rocks associated with them" Geol. Mag. 8, pp. 241-8, 202-9, 1911.

and Pearce merely describe instances of albitization observed by them, without entering into a discussion of the processes involved.

Bailey and Grabham, in the paper quoted above, introduce a new conception of the causes of this change in the lavas examined by them, ascribing it to the influence of juvenile soda-bearing waters which were residual from the crystallization of the lavas themselves. In support of their contention they point to the following facts: (1) The most basic feldspars are those which are first albitized in every case where reaction has occurred, but many highly basic, basal portions of the lavas have escaped alteration entirely. Hence the albitization in these lavas cannot be due to weathering, as in the cases Termier describes, because, if so, the basic varieties, which contain the most basic feldspars, would be the most highly albitized.

(2) There is an actual introduction of soda in the albitized portions, and, as the basic feldspars are the first to be albitized, there is no source from which the soda could have been supplied except from magmatic waters.

(3) In the most albitized portions of the lava the amygdules are also lined with albite, while their centres are filled with delessite and calcite. This fact, coupled with that observed that it is the upper portions of the lava flows which have been most albitized, points to the origin of the albitizing solutions in the lavas themselves.

Dewey and Flett, in the case of the Devonian pillow lavas of the west of England, have adduced more definite evidence to show that their albitization, which is great, took place very soon after extrusion. The highest lavas of the series are embedded in the lower Carboniferous. At the close of the Carboniferous the Armorican earth-movements began, resulting in the crushing of the rocks and of their constituent minerals. The evidence of the thin sections shows that albitization was complete before these movements began, since the broken albites are not healed nor their surfaces united by a new deposit. Immediately after the close of the movements granitic intrusions took place, resulting in the alteration of the albite to andesine and labradorite near the granite contacts. Every stage in the alteration can be traced.

After a very complete description of the albitized rocks of Great Britain, these authors summarize as follows:

(1) "The pillow lavas are members of a great natural family of igneous rocks, the spilitic suite.................This family comprises a great variety of types, picrites, diabase, minverite, quartz diabase, spilite (i.e., pillow lava), keratophyre, quartz keratophyre, soda-felsite and albite granite, ranging from ultra-basic to acid in composition.

(2) "Their essential characteristics are the abundance of soda feldspar, and the remarkable frequency with which they have been albitized.

(3) "The albitization is not characteristic of the whole suite, but is especially frequent in certain members of it, such as the spilites and diabases, while others like the quartz diabases are less liable to this change It is not due to weathering nor shearing. Good evidence exists to show that the albitization took place soon after the rocks had solidified, and consequently it may be grouped among the post-volcanic or juvenile changes of rock masses.

(4) "The constant association of adinoles (albitized shales) with the albite diabases, and of radiolarian cherts with the pillow lavas, finds a simple explanation in this hypothesis, and at the same time affords the strongest confirmation of it.

(5) "The composition of the pneumatolytic solutions cannot be exactly defined, but it is certain that they consisted of water with soda and silica in solution; probably also carbon dioxide was abundant, and many other substances may have been present.

(6) "In the British Isles spilitic eruptions have appeared in great numbers in all the Palæozoic formations (with the exception of the upper Silurian and the Permian), and in the Tayvallich volcanic series they have an important development among the metamorphic schists of the Scottish highlands.

(7) "They have an intimate connexion with certain types of geographical conditions. They are essentially rocks of districts

that have undergone a long continued and gentle subsidence, with few or slight upward movements and no important folding."

The striking similarity of the characteristics of the lavas described by the British investigators to those of the lavas of the Sicker series is apparent: the submarine origin of the lavas, the occasional replacement of andesine by albite and albite-oligoclase; the local nature of this alteration and its confinement to the upper zones of flows; the filling of amygdules with albite-oligoclase, with jasper containing feldspar, and with calcite and feldspar; and the intimate association with cherty and albitic sediments; in all these points the Sicker andesites are similar to the British lavas described by Bailey and Grabham and by Dewey and Flett. That albitization has occurred is undoubted, and by applying to this case the same criteria as Bailey and Grabham applied to determine the age of the albitization, the same proofs are obtained that the albitization was caused by juvenile solutions given off by the cooling lava itself. In addition to the criteria developed by Bailey and Grabham, we have in this case one which they lacked, the albitization of the lower strata of tuffs which overlie the flows.

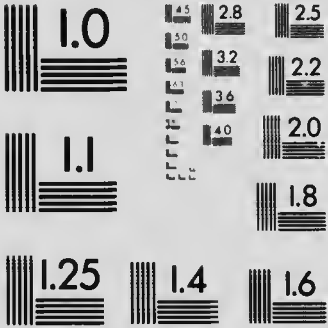
The occurrence of overlying tuffs of the composition of those of the Sicker series is one which the writer has never seen described in the literature. No such occurrence is mentioned by Dewey and Flett, although they do refer to the occurrence of radiolarian cherts on the surface of flows. Van Hise and Leith[1] also are of the opinion that the jaspers and cherts of the Lake Superior region are chemical precipitates from juvenile waters accompanying the extrusion of lava flows; but no mention is made of the presence of albite in these cherts. The writer would advance the following hypothesis for the origin of the cherty tuffs of the Sicker series:

(1) At the time that the lavas were poured out of the volcanic vents great quantities of ash were also ejected. This ashy material settled rapidly on the surfaces of the flows, the coarsest settling with the greatest rapidity, followed by finer and finer material.

[1]Van Hise and Leith, U. S. Geol. Surv., Mon. 52, pp. 506-516.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc

1653 East Main Street
Rochester, New York 14609 USA
(716) 482-0300 - Phone
(716) 288-5989 - Fax

(2) As the lavas cooled, juvenile waters were given off from their surfaces, charged with silica, soda, carbon dioxide, and locally with iron. These solutions permeated the lavas themselves locally, albitized their surficial zones in part, and filled their vesicles with albite, albitic jasper, and calcite.

(3) The greater part of these solutions must have escaped from the surface of the cooling lavas, however, to become entangled in the thick beds of ashy mud which covered them. Here they found plenty of easily altered material, loose-textured and porous, fine-grained, and offering large reacting surface. The solutions readily converted the ashy mud into mixtures of albite and silica, and at the same time much fine-grained silica was probably precipitated chemically from the solutions, filling the interstices of the muds and cementing them.

(4) With the dying away of volcanic activity the supply of the solutions probably decreased also. In addition, a large amount of kaolinic material, probably terrestrial sediment, was becoming mixed with the volcanic ash, and this was probably not so readily affected and albitized by the weakening solutions as the fresh ash had been. Hence the second type of sediments, the soft cherty tuffs, was formed.

(5) The black slates represent the final stage in this cycle, deposited after volcanic activity had completely died away, or almost so. In them there is little evidence of albitization, with the exception of the presence of a few fragments of feldspar which appear to be albite; the major part of the rock is made up of kaolinic and sericitic material.

In this connexion there may be mentioned an albitization which appears to be the result of a second, local attack of albitizing solutions. In many of the black chert beds on Mt. Brenton, which have been intruded by the Sicker gabbro-diorite, a spotted texture has been developed, similar to the formation of adinole in slates. These black cherts are composed of quartz and oligoclase-albite, with 40 to 50 per cent of fine-grained biotite. The spots are seen under the microscope to be segregations of feldspar not very sharply defined from the groundmass, as if the feldspar had been introduced and displaced the ferromagnesian mineral in part. The centre of the spot is usually pure feldspar; biotite begins to appear towards the periphery, and may amount to 25 per cent of the rock at the edge. Whether this spotted texture has developed through the action of solutions emanating from the gabbro-diorite, or from a second injection of solutions from the andesite lava, there appears to be no means of determining.

ASSOCIATED INTRUSIVE PORPHYRITES.

Tyee Quartz-Feldspar Porphyrite.

Relations to Older and Younger Formations. The Tyee quartz-feldspar porphyrites which have already been well described by Clapp[1], are intrusive into the Sicker series, forming dykes and irregular masses in the andesites and sills in the sedimentary formations. Facts that clearly prove that these porphyrites are truly intrusive masses and not extrusive rocks are difficult to obtain; the grain is uniformly fine, making the determination of chilled edges doubtful; nearly all the masses parallel the bedding very closely; and deformation has usually altered them near the edges sufficiently to obliterate chilled edges and amygdaloidal textures if they ever existed. But during the course of the field work the porphyrites were definitely observed in two or three instances to cut across the bedding of the sediments with which they were in contact; in several others the edges of the porphyrite masses were clearly chilled for a width of an inch or so; in three localities intrusive breccias had formed at contacts with the sediments; and in one case the sediments were silicified for a short distance from the contact. As no evidence of any kind was obtained indicating that they might have been flow types, the porphyrites were concluded to be intrusive.

The Tyee porphyrites are intruded by the Sicker gabbro-diorite porphyrites and by the Saanich granodiorite, and are overlain unconformably by the Nanaimo series of sediments. These relations are discussed more fully in the sections devoted to these formations.

Petrography. The quartz-feldspar porphyrites are characterized by a fine-grained groundmass which in the smaller

[1] Clapp, C. H., Geol. Surv., Can., Mem. 13, p. 105; Mem. 36, p. 77.

bodies is almost glassy, and by a varying number of phenocrysts of quartz and feldspar. The feldspar phenocrysts are always in excess, at least as 5 to 1, but those of quartz are the more conspicuous as they are usually larger and in colour do not blend so nearly with the groundmass. From acid varieties in which quartz forms approximately 20 to 25 per cent of the phenocrysts and 30 per cent of the groundmass, all gradations may be observed to basic types in which quartz phenocrysts are few or lacking and not more than 5 per cent of free quartz is present in the groundmass. The feldspar, which constitutes nearly all of the remainder of these rocks, is albite-oligoclase to oligoclase, while biotite, hornblende, pyrite, and ilmenite are accessory. Usually more or less secondary epidote is present. Clapp states that orthoclase is found in the groundmass, and it is probable that this is the case, as analysis of the Saanich granodiorite, to which these porphyrites are closely related, shows the presence of 2·14 per cent of K_2O[1]; but no orthoclase could be identified by the writer in the thin sections at his disposal. It is possible that the potash probably present in these rocks does not form orthoclase, but is dissolved in the lime-soda feldspars as frequently is the case.

North of Maple mountain and on Saltspring island Tyee porphyrite occurs in larger masses and is much more granitic than elsewhere, resembling the more altered and foliated, feldspathic facies of the Saanich granodiorite. It is very fine to medium-grained and foliated, and is composed almost entirely of quartz and feldspar which is largely albite-oligoclase, although a little microperthite, consisting of an irregular intergrowth of orthoclase and albite, is present. Even in the medium-grained varieties quartz forms rounded phenocrysts up to a centimetre in greatest diameter. The accessory minerals are chiefly hornblende, and some biotite, muscovite, and magnetite. Since foliation, which has strained and even granulated the quartz phenocrysts, the rock has been moderately altered to chlorite, epidote, sericite, and calcite and has been impregnated with pyrite which has altered near the surface to limonite. On the

[1]Geol. Surv., Can., Mem. 36, p. 73, 1913.

shore of Saltspring island due west of Mt. Belcher, the granitic phase of the Tyee porphyrite brecciates and includes the more normal porphyritic type (Plate V).

Metamorphism. The Tyee porphyrites have suffered very little alteration by solutions of any kind. As mentioned previously, they have been epidotized to a small extent.

They have, however, been very considerably affected by the later Jurassic folding movements. In the eastern part of the map area, on Mt. Richards and Maple mountain, the alteration is not great as a rule. A certain amount of schistosity is always observable in the outcrop, but rarely in the hand specimen; thin sections show partial granulation of the quartz phenocrysts and development of small quantities of sericite or paragonite. Deformation has been much more extreme near contacts with the more competent Sicker gabbro-diorite porphyrite, as on Mt. Sicker, on the south side of Mt. Brenton, on Coronation mountain, and at one point on Saltspring island. The gabbro-diorite masses acted as a unit during the folding movements and thus concentrated the differential movement in the less competent quartz-feldspar porphyrites, with the result that in these localities the latter have been converted very completely into sericite (or paragonite) schists. It is in places difficult to differentiate such schists from the similar ones formed by the shearing of the soft cherty tuffs; but a few uncrushed phenocrysts of quartz or feldspar can usually be found on weathered surfaces and they indicate its origin.

Sicker Gabbro-Diorite Porphyrite.

Relations to Older and Younger Formations. The Sicker gabbro-diorite porphyrites intrude the Sicker series and the Tyee quartz-feldspar porphyrites, forming dykes and irregular masses in the Sicker andesites and Tyee porphyites, and tending to form sills in the sediments. However, they break through the bedding of th[illegible]ments with much greater frequency than do the Tyee porph[illegible]ites, with the result that masses of irregular shape are common. Their intrusive nature is much more easily demonstrated than is that of the Tyee porphyrites. Chilled edges, often several feet in width, may be frequently observed at both contacts of a sill or dyke. The intrusive masses crosscut the structures of the older rocks, such as bedding in the sediments and the epidote nodules in the andesites. Occasionally the sills are seen to send off dyke-like tongues into the sediments at right angles to the bedding. Intrusive breccias are seen here and there along contacts, and occasionally a slight baking of the intruded rocks may be observed.

The Sicker gabbro-diorite porphyrite is probably intruded by the Saanich granodiorite and is overlain unconformably by the Nanaimo series. Its relations with the Nanaimo series are similar to those of the Sicker series with the Nanaimo, and have been discussed on page 155. The proofs of its relation to the Saanich granodiorite are not very satisfactory, as all contacts between the two, so far as observed, are covered with drift The evidence obtained is as follows:

(1) Three inclusions were found at as many places in the granodiorite of rock petrographically similar to the gabbro-diorite. There is no similar rock in the area which might yield such inclusions. One of these inclusions, which was small, contained phenocrysts of feldspar arranged in a partial rosette, a highly characteristic feature of the gabbro-diorite porphyrite. Microscopic examination of another revealed the presence in it of graphically intergrown quartz and feldspar, a second earmark of the gabbro-diorite.[1]

(2) The masses of granodiorite are not at all deformed, even where they are in contact with hard competent cherts, while the gabbro-diorite bodies although of equal if not greater competence to resist deformation, are frequently schistose at their edges.

(3) The mass of granodiorite on the summit of Mt. Brenton cuts directly across the strike of the intruded rocks, and interrupts both the gabbro-diorite and an intercalated band of cherty tuffs. The areal relations of this mass seem to prove that it was intruded after the intrusion of the gabbro-diorite into the cherts.

Petrography. Although the average Sicker porphyrite is a rather coarse-grained, equigranular rock, it is nevertheless a true

[1] Geol. Surv., Can., Mem. 13, p. 79, 1912; Mem. 36, p. 82, 1913.

porphyrite, as a first generation of feldspar crystals is always present. These phenocrysts may be observed in the fine-grained chilled edges of masses, or in the finer-grained diorite porphyrites. When the grain grows coarser, the phenocrysts are usually obscured by the second generation of feldspars and hornblendes which attain approximately the same size as the phenocrysts, and the rock resembles an ordinary gabbro. Occasionally this does not take place, and in such cases the phenocrysts usually group themselves with their long axes radial to a common centre, forming the "rosette gabbro" described by Clapp.[1]

The gabbro-diorite porphyrites vary widely in composition, from rather acid quartz diorites to fairly basic gabbros. The more acid varieties consist of albite-oligoclase, about 50 to 60 per cent, with small quantities of more acid and more basic varieties; common green hornblende, 30 to 40 per cent; quartz, 2 to 5 per cent, graphically intergrown with albite feldspar; and ilmenite, about 1 per cent. From this type all gradations in composition may be found, to a basic type which consists approximately of basic feldspar, 40 to 45 per cent; andesine to labradorite; no quartz; and hornblende, 50 to 55 per cent, which is certainly in part and may be altogether replac' augite. The percentage of accessory ilmenite is also higher, 2 to 3 per cent, occasionally even more.

From the descriptions given it will be seen that the gabbro-diorite porphyrite sequence and the Tyee porphyrite sequence of rock phases form, taken together, an almost complete series from acid to basic, with only a short gap between the acid end of the one and the basic end of the other. A close magmatic relationship probably exists between the two. A detailed study, microscopic and chemical, of the relationships of these rocks, with a consequent determination of the course taken by the magmatic differentiation, of the order in which they were expelled from the magma reservoir, and of the relationships of the differentiations to the orogenic movements in the district, would be of great lithologic interest and significance.

[1] Geol. Surv., Can., Mem. 13, p. 80, 1912.

Metamorphism. These rocks have been less altered by the various forces of metamorphism than any other in the district. They are almost unaffected by the action of solutions; augite has been partially converted to hornblende, hornblende to chlorite and epidote, feldspars to epidote and kaolin; but the total alteration of this kind is rarely over 5 per cent.

Almost as little has been the effect of the dynamic metamorphism. Where the porphyrites are in contact with the soft slates of the Sicker series, their edges are not usually schistose, but more or less fractured and broken. In contact with harder rocks, such as the harder cherts or the Tyee porphyrite, the edges of the gabbro-diorite porphyrite have been converted into schists, for distances depending on the competency of the rock with which it is in contact and the intensity of the shearing movement at that point. Thus on Saltspring island a schistose edge more than 6 feet in width will rarely be observed in a Sicker porphyrite, though on the west slope of Mt. Sicker, thicknesses of 300 feet or even more of chlorite schists traceable into gabbro-diorite have been observed.

Batholithic and Closely Associated Minor Intrusives.

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. Most of the smaller masses of injected rocks, or, as they are called, the minor intrusives, were irrupted during the same general period as well. They consist of dykes and small injected bodies of porphyrites, of two principal types, granodiorite or quartz-feldspar porphyrites, and gabbro-diorite porphyrites. They are largely restricted in their occurrence to the Sicker series, and have been given respectively the distinctive names of Tyee quartz-feldspar porphyrites, and Sicker gabbro-diorite porphyrites. The distribution, lithological characters, and structural relations of these two rocks are only briefly considered in this section, since the rocks are more fully described by Cooke in the section on the Sicker series. Three of the minor intrusives: a gabbro, a quartz-diorite porphyrite, and a hornblende-augite andesite porphyrite are not clearly associated with the batholithic rocks and hence have been described separately. In this section the distribution and lithological characters of each of the principal batholithic rocks and closely associated minor intrusives are described separately and then the structural relations, mode of origin, and correlation of all the closely associated types are considered together.

WARK GNEISS.

DISTRIBUTION.

The Wark and Colquitz gneisses are very intimately involved and form virtually a single batholith. The batholith extends, with a general north 60 degrees west trend, across the northeastern part of the Sooke map-area and the southern part of the Duncan map-area, from the Highland district on the east side of Finlayson arm for nearly 20 miles to the headwaters of Koksilah river, north of Jordan meadows. It has a maximum width of 9 miles near Sooke and Shawnigan lakes, but narrows to an apex toward the northwest.

The Wark gneiss is the predominating rock of the batholith, especially in the northwestern portion, but in the central and southeastern p[illegible] large masses of Colquitz gneiss occur. Although the[illegible] areas of the typical Wark gneiss, it is intersected tl[illegible] the batholith by apophyses of the Colquitz gneiss [illegible] in several places, a complex of the two gneisses has resulted, where the two types cannot be mapped separately. The Wark gneiss forms also several small bosses in the Vancouver volcanics to the north of the main batholith but within a mile or two of it.

The Wark and Colquitz gneisses are very resistant and form large and numerous outcrops. There are, however, large areas, especially in the north-central and northwestern portions, where the gneisses are heavily drift covered. Excellent exposures of the Wark gneiss are to be had along the Esquimalt and

Nanaimo railway for a distance of 6 miles from Malahat (20-mile-post) nearly to Strathcona. Both the Wark and Colquitz gneisses are well exposed along the shores of Sooke lake. In spite of the fact that the gneisses are as a whole well exposed, their actual contacts seldom are, as small valleys have been cut in the rocks, altered and weakened near the contacts. Thus, although the general outlines of the batholith have been well determined, the actual positions of the contacts, both the outer boundaries of the batholith and the contacts of the Wark and Colquitz gneisses, are in error in many places by several hundred feet.

LITHOLOGICAL CHARACTERS.

Gabbro-diorite Gneiss, Normal Phase.

The principal rock type of the Wark gneiss is a gabbro-diorite. It is a dark greenish rock of medium to coarse grain, and of gneissic texture. It consists essentially of light greenish to white weathering feldspar and hornblende. In some varieties, found east of Sooke lake and on Malahat ridge east of Shawnigan lake, it also contains some pink weathering feldspar. The feldspar usually predominates, but the relative proportion of feldspar and hornblende varies, and some varieties contain a large excess of hornblende and grade into certain hornblendic facies. With the essential minerals are varying amounts of quartz and biotite. The gneiss is commonly cut by quartz and calcite veinlets and impregnated slightly with pyrite.

In most instances the essential minerals are seen microscopically to be only plagioclase feldspar and hornblende. The feldspar varies from labradorite about $Ab_{45}An_{55}$ in a few rocks to oligoclase-andesine, about $Ab_{75}An_{25}$, in others, the principal feldspar being andesine about $Ab_{60}An_{40}$; but in the individual grains of any single facies there is very little tendency to a zonal change of composition. Orthoclase or cryptoperthite and some microperthite are present in many varieties and are essential in these varieties which, as described above, contain some pink weathering feldspar which is doubtless orthoclase or microperthite. The microperthite consists largely of orthoclase irregularly intergrown with a little plagioclase. The hornblende is a rather pale green, common hornblende with a moderately strong pleochroism, ranging from light yellowish green to bluish green. Some of the grains cont ain a small nucleus of augite, partly and irregularly replaced by hornblende. This fact suggests that part of the hornblende may be secondary after augite which is, however, entirely absent in most of the rocks. In a few rocks, however, notably from the northeast of Jordan meadows, augite is an essential mineral, but is associated with essential and apparently primary hornblende. The accessory constituents are quartz, biotite, magnetite, ilmenite, titanite, and apatite. The amount of quartz varies greatly, in some facies being as high as 15 per cent, though in many others it is absent. It always occurs in the interstices of the other minerals and may be largely secondary, having been formed during the contact metamorphism of the Wark gneiss by the intrusive Colquitz gneiss. The original texture of the rock has been partially destroyed by foliation, but euhedral plagioclases still remain and where orthoclase is present it is intersertal, enclosing poicilitically plagioclase and some hornblende. Most of the primary minerals are now fractured and crushed, partly recrystallized, and more or less elongated in the direction of foliation. Since foliation the rock has been altered moderately to considerably, developing the following secondary minerals: uralite, biotite, chlorite, epidote, serpentine, muscovite, sericite, [illegible]lin, and limonite. In addition, veinlets and partial replacements of quartz, actinolite, epidote and zoisite, sericite, and calcite are common.

The following is a chemical and m[illegible]l analysis of a typical quartz-free facies of the Wark gneiss f[illegible] the Victoria map-area[1], which with the exception of its rather calcic plagioclase, is also fairly typical of the normal Wark gneiss of the Sooke and Duncan map-areas.

---

[1] Geol. Surv., Can., Mem. 36, 1913, p. 59.

Chemical and Mineral Composition of the Normal Wark Gabbro-diorite Gneiss.

Chemical composition	
SiO_2	48·68
Al_2O_3	18·05
Fe_2O_3	3·41
FeO	6·44
MgO	2·82
CaO	10·00
Na_2O	3·18
K_2O	1·60
$H_2O\pm$	2·40
TiO_2	0·80
P_2O_5	2·01
MnO	0·20
	99·59
Specific gravity	2·91

Mineral composition.	
Orthoclase	7·3
Labradorite, Ab[illegible] An[illegible]	53·4
Hornblende	31·8
Biotite	4·1
Magnetite	2·3
Apatite	1·2

It is seen from the above analysis and petrographic description that the Wark gneiss is rather more mafic than a typical diorite and it has, therefore, been classified as a gabbro-diorite,[1] although many of the facies in the Sooke and Duncan map-areas are true diorites. Also in those places where the rock contains essential orthoclase or microperthite it is approaching a monzonite and hence might be called a monzonitic diorite.

Fine-grained Phases.

Fine-grained phases of the Wark gneiss occur associated with the normal gabbro-diorite gneiss, especially near the contacts with the intrusive Colquitz gneiss, and in places near the intruded Malahat and Vancouver volcanics. In the vicinity of the middle (No. 2) Goldstream lake, the fine-grained rocks form a large part of the Wark gneiss, but ordinarily they form segregations or inclusions, up to several yards in width, in the normal rock. In places they form bands parallel to the foliation, but more commonly they form irregularly shaped masses which frequently are elongated in a direction transverse to the foliation. In a few places, best exposed around Shawnigan lake, small dyke-like masses of the fine-grained rock occur in the normal coarser-grained gneiss.

The fine-grained phases of the Wark gneiss are usually darker in colour, as well as finer-grained than the normal gneiss. They

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 60–61.

are commonly more foliated and pass into a hornblende schist or amphibolite. Most of them contain a small amount of pyrite and are cut by veinlets of quartz and other light-coloured minerals, both parallel to and at angle to the foliation. In places, as in the vicinity of Shawnigan lake, they contain small phenocrysts of hornblende and feldspar; and in the vicinity of the middle (No. 2) Goldstream lake a large portion of the fine-grained gneiss, which as seen microscopically owes in part its fine-grained texture to foliation, retains small phenocryst-like patches of the primary feldspar, so that the rock has a conspicuously porphyritic appearance. Portions of the fine-grained rock in the vicinity of the middle (No. 2) Goldstream lake are much more feldspathic than the typical fine-grained rock, and these are light greyish green in colour, since they are composed largely of greenish weathering feldspar with thin streaks of hornblende.

On microscopic examination the fine-grained phases are seen to consist of the same minerals as the normal gneiss with the addition of the following secondary minerals: pale green hornblende, fibrous amphiboles, and feldspar; while the other secondary minerals, with the exception of biotite and muscovite, are not so abundant. In some varieties the fine-grained texture appears to be primary, and these varieties may contain euhedral grains of primary feldspar and hornblende, the primary andesine having in some rocks rims of a clear, unaltered, more sodic feldspar. In most of the fine-grained rocks the original texture has been partly obliterated by foliation, and in many, especially those occurring in the vicinity of the middle (No. 2) Goldstream lake, the fine-grained texture might have been formed by the granulation, attendant upon the foliation of coarse-grained rocks. Accordingly most of the fine-grained gneisses consist of streaks of hornblende, composed of small flakes with a sub-parallel orientation, interleaved with streaks of very fine-grained and altered feldspathic material which appears to have been formed by the granulation of the primary feldspars. In those rocks having a porphyritic appearance either certain grains of feldspar escaped granulation or else the granulated material retains the shape of the original grain. The lighter coloured, more feldspathic varieties are similar in their mineral composition to the other fine-grained gneisses; but, besides a larger amount of the feldspathic material, they contain small clear grains of unaltered feldspar and quartz, both of which appear to be largely secondary.

Gabbro-diorite with Recrystallized Hornblendes.

Due to the contact metamorphism produced by the intrusion of the Colquitz gneiss, the Wark gneiss appears to have been more or less recrystallized, developing certain characteristic varieties. One of the most common of these contains large recrystallized hornblendes varying from rectangular grains 1 cm. square to bladed crystals, 2 or 3 cm. long and 6 to 7 mm. wide. The interstitial matter consists largely of relatively coarse-grained, light greenish weathering feldspar with some quartz and flakes of light-coloured mica. Pyrite is common and may be more or less altered to limonite.

The mineral composition is similar to that of the normal gabbro-diorite gneiss, but the texture is different, owing to the large crystals of light green hornblende which may include small grains of altered feldspar. Although clearly secondary the hornblende is itself broken and altered to some extent.

Poicilitic Phases.

A peculiar phase of the gabbro-diorite with recrystallized hornblendes is fairly common in the Highland district near contacts with the Colquitz gneiss. In this phase the hornblende forms very large rectangular crystals up to 6 or 8 cm. in diameter, which include the older minerals, especially altered feldspar, thus developing a conspicuous poicilitic texture.

Mafic (Femic) Facies (Hornblendites).

Near contacts with the intrusive Colquitz gneiss are fine to coarse-grained hornblende-rich facies of the gabbro-diorite gneiss. The coarse-grained varieties are largely recrystallized, and are virtually identical with the coarse-grained hornblendites of the Colquitz gneiss. They differ from the normal gabbro-diorite gneisses chiefly in their large amount of hornblende.

On microscopic examination the hornblende-rich facies are seen to consist, as would be expected from their macroscopic appearance, chiefly of recrystallized hornblende and altered feldspar. The hornblendes are not, as might be expected, all the same: they vary from light green, slightly pleochroic varieties of negative character to dark brownish green, rather strongly pleochroic varieties of positive character, probably pargasite. The alteration products are similar to those of the normal gabbro-diorite gneiss, although epidote is more abundant and characteristic. The recrystallized hornblendes are only slightly altered, although they are frequently crushed into aggregates of diversely orientated, small fragments.

Metamorphism.

The normal Wark gabbro-diorite gneiss is everywhere moderately to considerably altered, and in places has been metamorphosed by dynamic and contact action into the fine-grained and recrystallized types described above. In places the character of the original rock has been almost completely obscured through foliation and concomitant or subsequent replacement. At several places the primary feldspars have been completely clouded with an opaque, finely granular to dense mixture of sericite, presumably kaolin, and saussurite, composed chiefly of zoisite and epidote; and the hornblendes have been entirely altered to actinolite. More rarely more coarsely granular mixtures of these same secondary minerals are found with virtually no traces of the primary minerals.

Another metamorphic type is found in the vicinity of Survey mountain, along a greatly foliated contact with the Malahat volcanics. It is a greenish grey, fine-grained schistose rock, evidently composed of altered feldspar and hornblende. The feldspar is seen microscopically to have been crushed and altered to a fine saussuritic aggregate containing some quartz, although a few rounded and broken grains of residual, but greatly altered, feldspar may remain. The hornblende has been completely altered to a pale brownish green to almost colourless hornblende, the variety pargasite, which forms foliated aggregates of small and a few much larger flakes.

Hybrid Types.

There are virtually no true hybrid types developed at the contacts of the Wark gneiss, although the restriction of monzonitic diorites to the vicinity of the large roof pendants of Sutton limestones suggests that the monzonitic diorites owe their existence in some way to the included and perhaps partially assimilated limestones. As additional evidence in support of this conclusion is the occurrence (noted in two places—at the old Aldemere quarry, Mill Stream road, Highland district, and on the east slope of Malahat ridge) of apophyses in the limestone that are apparently related to the Wark gneiss. The apophyses are light greenish grey, medium-grained rocks, evidently composed largely of feldspar and a light green pyroxene with disseminated small grains of pyrite. On microscopic examination they are seen to consist essentially of orthoclase which is microperthitically intergrown with a little albite, oligoclase, and diopside, some of which is intergrown with a little actinolite. The accessory minerals are titanite, magnetite or ilmenite, quartz, and pyrite. The diopside and oligoclase are euhedral, while the orthoclase is interstitial and even includes the other minerals. The rocks are moderately to considerably altered to uralite, chlorite, zoisite and epidote, sericite, calcite, and quartz.

COLQUITZ GNEISS.

DISTRIBUTION.

As already described the Colquitz gneiss is so intimately involved with the Wark gneiss that the two gneisses together form virtually a single batholith extending across the northeastern part of the Sooke map-area and the southern part of the Duncan map-area, the Colquitz gneiss being confined chiefly to the southeastern and central portions of the batholith. In these portions the Colquitz gneiss forms in general, lenticular masses up to 5 or 6 miles long and 1 to 1½ miles wide, elongate in the same direction as the main batholith, that is about north 60 degrees west. Although the rocks as a whole are well exposed, their boundaries seldom are, and consequently are in places located with a possible error of several hundred feet. Furthermore, the location of the boundaries is rendered difficult by their indefinite character, as the contacts in many places are marked by wide zones of a complex of the two gneisses. As mentioned, apophyses of the Colquitz gneiss are found throughout the Wark-Colquitz batholith, and a few small apophysal masses are found to the south of the main batholith in the Malahat volcanics. In addition a granite gneiss, considered to be a facies of the Colquitz gneiss, forms small bosses and stocks, intrusive into the Leech River formation, in the northeastern part of the Sooke map-area from one-half mile to nearly 3 miles west of Goldstream, and in the extreme southwestern portion of the Duncan map-area near Jordan river. Most of these bosses, which are elongate in the direction of the foliation of the Leech River rocks, are only a few feet in width and 100 or 200 feet in length. By far the largest occurs half a mile to the north of the Jordan river in the southwestern corner of the Duncan map-area, and is over a mile long (extending beyond the western boundary of the map-area) and nearly half a mile wide.

LITHOLOGICAL CHARACTERS.

Quartz Diorite Gneiss (Normal Type).

The principal rock type of the Colquitz gneiss is a quartz diorite gneiss. It is a light to dark grey rock, of medium to rather coarse grain and usually of gneissic to schistose texture. In some varieties the foliation is not shown conspicuously in the hand specimen. It is seen to be composed of altered, white to light greenish weathering feldspar, which in some rocks occurs in rectangular crystals, quartz, hornblende, and usually biotite, and in some varieties, muscovite. In the more altered varieties hornblende is replaced by chlorite and epidote. The gneiss is frequently cut by veinlets of quartz and sericite, and in places contains disseminated small grains of pyrite which has weathered to limonite, colouring the rock brown.

The essential minerals of the quartz diorite gneiss are plagioclase, chiefly a sodic andesine about $Ab_{70}An_{30}$ which in many varieties is greatly in excess, quartz, and pale green hornblende. Orthoclase is also present but cannot always be distinguished from the plagioclase feldspar. Biotite is a common mineral, and, although in part secondary, it appears to have been an original essential mineral in some varieties. The accessory minerals are magnetite, apatite, and more rarely titanite. The original texture was subhedral, with euhedral andesine and hornblende with interstitial quartz, orthoclase, and some plagioclase. In places primary euhedral feldspars are included poicilitically in hornblende, which may, however, be secondary. The original texture has been largely destroyed during foliation and the feldspar and quartz grains have been distorted and broken, so that now the grains are chiefly anhedral and elongate in the direction of the foliation, with interstitial flakes and irregular streaks of the dark and secondary minerals. The quartz diorite gneiss is also moderately to greatly altered to uralite, biotite, chlorite, muscovite, sericite, epidote, and zoisite, and is frequently cut by veinlets of quartz, sericite, epidote, and calcite, and is in places impregnated with pyrite.

The normal quartz diorite gneiss of the Sooke and Duncan map-areas is virtually identical with that of the Victoria and Saanich map-areas, and the chemical and mineral composition of a typical specimen from Smith hill in the Victoria map-area[1] is fairly representative of the quartz diorite gneiss of the Sooke and Duncan map-areas.

Chemical and Mineral Composition of the Colquitz Quartz Diorite Gneiss.

Chemical composition.		*Mineral composition.*	
SiO_2	64·04	Quartz	30
Al_2O_3	15·83	Orthoclase	6
Fe_2O_3	2·16	Andesine $Ab_{70}An_{30}$	46
FeO	2·40	Hornblende	8
MgO	2·72	Biotite	7
CaO	3·60	Magnetite	2
Na_2O	3·52	Apatite	1
K_2O	1·43		
H_2O	1·60		
TiO_2	0·30		
P_2O_5	1·56		
MnO	0·15		
	99·31		
Specific gravity	2·74		

[1] "Geology of the Victoria and Saanich map-areas." Geol. Surv., Can., Mem. 36, 1913 pp. 64–65.

As previously noted,[1] the Colquitz gneiss differs from the average quartz diorite in its high silica and phosphoric acid content, in its low ferrous oxide, magnesia, and lime, and slightly lower potash; differences which are due chiefly to its large amount of quartz. With the exception of its large amount of quartz the normal Colquitz gneiss is, however, a fairly typical quartz diorite; and it appears from the laboratory study of the rocks that the average Colquitz gneiss from the Sooke and Duncan map-areas contains rather less quartz, and much less biotite, than the gneiss from Smith hill.

Banded Gneiss.

One of the most striking features of the Colquitz gneiss is its banded character, although this feature is not so conspicuous as it is to the east in the Victoria and Saanich map-areas. The light and the dark minerals occur in separate bands, which vary in width from a fraction of an inch to 4 or 5 feet; however, most of the darker bands are seldom more than a few inches wide. There are also irregular dark masses in the light coloured gneiss, but many of these appear to be inclusions.

Light Coloured or Felsic Bands.

The light coloured or felsic[2] bands are light greenish grey to white, fine to medium-grained, and gneissic to schistose. They consist chiefly of quartz and feldspar, but there are narrow streaks of altered dark minerals that accentuate the foliation. In some varieties dark minerals are virtually absent, and then the rock, although foliated, has a uniform appearance and resembles quartzite. The felsic bands are cut by veinlets of quartz, sericite, epidote, and calcite. Pyrite frequently occurs in disseminated grains, and in the sheared varieties may be present in places in considerable amounts, such rocks being heavily stained with iron oxides on weathered surfaces.

The essential minerals are oligoclase about $Ab_{75}An_{16}$, orthoclase and albite or microperthite, and quartz. The

[1] Loc. cit.

[2] Improperly called salic bands in the writer's previous reports. See misuse of the terms salic and femic. W. Cross, J. P. Iddings, L. V. Pirsson, and H. S. Washington. Jour. Geol. vol. 20, 1912, pp. 559–560.

microperthite is an irregular intergrowth of orthoclase and albite, the former greatly predominating. The accessory minerals are very small in amount and in places are almost absent. They consist of hornblende, biotite, magnetite, titanite, and apatite. The minerals are apparently of two formations. The older, chiefly feldspar, occurs in relatively large, irregular to lens-shaped grains that are fractured, strained, and altered. The younger minerals occur in smaller interlocking anhedral grains that are unaltered but foliated, and have apparently been derived through the crushing and recrystallizing of the original minerals. The degree of alteration varies from moderate to large, and the following secondary minerals have been formed; actinolite, epidote and zoisite, chlorite, sericite, and kaolin, as well as pyrite and limonite and veinlets of quartz, sericite, epidote, and calcite.

The following chemical and mineral analyses of a specimen from the Saanich map-area,[1] appear to be representative of the felsic bands of the Colquitz gneiss in the Sooke and Duncan map-areas.

Chemical and Mineral Composition of the Felsic Bands of the Colquitz Gneiss.

Chemical composition.[2]		*Mineral composition.*	
SiO_2	75·02	Quartz	36
Al_2O_3	13·90	Orthoclase	31·5
Fe_2O_3	0·45	Oligoclase $Ab_{85}An_{15}$	30·5
FeO	0·40	Hornblende	0·5
MgO	0·10	Biotite	0·5
CaO	1·16	Magnetite	0·7
Na_2O	3·06	Apatite	0·3
K_2O	5·37		
H_2O	0·95		
TiO_2	0·04		
P_2O_5	0·15		
MnO	0·10		
	100·70		
Specific gravity	2·63		

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 67–68.

[2] The writer takes this opportunity to correct his former classification of the rock according to the quantitative system as given in Mem. No. 36, p. 68. The rock falls in rang 2 instead of rang 1, although it is transitional to rang 1, and is thus a toscanose. More specifically it is an extremely quaric liparose-toscanose, its symbol being 1. (3) 4. (1) 2. 3.

Dark Coloured or Mafic Bands.

Interlaminated with the light coloured, felsic bands are the complementary, dark coloured, mafic bands.[1] They are composed of dark green, foliated rocks, of fine to medium grain. They are of coarse grain in only a very few places in the Sooke and Duncan map-areas as near the southern part of Sooke lake, and in the vicinity of Goldstream lakes. They consist essentially of hornblende and rarely of biotite, with more or less feldspar, which may be absent in the very coarse-grained rocks. Those coarser-grained rocks that contain feldspar are virtually identical with the Wark gneiss.

Microscopically the rocks of the mafic bands consist essentially of pale green, common hornblende and altered andesine, with accessory magnetite, apatite, titanite, and even quartz; in a few places biotite also is an essential mineral. As in the Victoria and Saanich map-areas[2] it is probable that in the very coarse-grained varieties feldspar is absent and augite is present. The secondary minerals are numerous, although as a rule the mafic bands have suffered only slight alteration since foliation. The secondary minerals are albite, occurring in small clear grains, quartz, biotite, uralite, epidote, zoisite, sericite, and calcite. Foliation is usually conspicuous: in some rocks the hornblende leaves have a parallel to sub-parallel orientation, with interstitial quartz and secondary feldspar, and interlaminated with the hornblende are irregular streaks of feldspar and secondary minerals.

Apophysal Phases. Aplites.

Cutting both the Wark and Colquitz gneisses and the invaded Malahat and Vancouver meta-volcanics are numerous aplitic and pegmatitic apophyses that are related to the Colquitz gneiss. The aplites are light coloured, in places white, fine to medium-grained, foliated rocks. They consist almost entirely of quartz and feldspar and some of the fine-grained varieties closely resemble quartzites.

[1] Improperly called femic bands in the writer's previous reports.
[2] Geol. Surv., Can., Mem. 36, 1913, p. 69.

The feldspar of the aplites, which predominates over the quartz, consists of plagioclase, probably albite-oligoclase, and a microperthite composed chiefly of orthoclase which is irregularly intergrown with albite. The accessory minerals are hornblende, muscovite, magnetite, titanite, and apatite. They are never present in large amounts, and in some varieties are virtually absent. The original texture was probably anhedral and traces of a microscopic intergrowth of quartz and feldspar may be detected, but the original grains have been, for the greater part, crushed into a fine matrix, which in the finer-grained aplites averages about 0·005 mm. in diameter. In the fine-grained matrix are larger, sub-rounded, residual grains of the primary minerals. The aplites are commonly greatly fractured, seamed with veinlets of secondary minerals, and in places are even considerably altered to sericite, chlorite, epidote, and zoisite. Pyrite and limonite also are common secondary minerals.

Pegmatites.

Pegmatites are scarce and not at all conspicuous. They are nearly white, coarsely crystalline, and unfoliated. They consist chiefly of white weathering feldspar, orthoclase and albite, muscovite, and a relatively small amount of quartz.

Granite Gneiss.

Most of the masses of gneiss intrusive into Leech River formation differ from the normal Colquitz gneiss or any of its closely allied facies in that they have the composition of a granite, with mica instead of hornblende as the major accessory mineral, and, although as greatly foliated, are less altered. There are, however, transitional types that are intrusive into the Leech River formation and certain facies are virtually identical with the biotite granite gneiss occurring in the Saanich map-area to the southwest of Saanich hill[1]; this gneiss appears to be transitional into the normal Colquitz quartz diorite gneiss and to be a facies of the Colquitz gneiss. The granite gneiss intrusive into the Leech River formation is, therefore, correlated with the

[1] Geol. Surv., Can., Mem. 36, 1913, p. 66.

Colquitz gneiss, although it is shown on the accompanying geological maps in a different colour.

The granite gneiss varies from a light to dark grey, rather fine-grained rock to a nearly white, coarse-grained, foliated, and in places banded rock, consisting largely of quartz and clear feldspar with white and brown mica. Some varieties, chiefly near the contacts, contain no biotite, but they contain large flakes of glistening, silvery white mica. On the other hand, in the darker fine-grained varieties biotite is the only mica. In the lighter coloured and rather coarser-grained varieties small, pinkish to light reddish brown garnet, averaging about 2 mm. in diameter, is a prominent accessory mineral.

The various types of gneiss, binary granite (muscovite-biotite), muscovite granite, and biotite granite, occur inter-banded with one another, although the muscovite granite gneiss is largely confined to the contacts of the intrusive masses.

The individual bands are from a fraction of an inch to several yards wide, the contacts of the various types being, as a rule, fairly sharp and definite. The banding is parallel to the foliation and the foliation is also parallel to that of the intruded Leech River schists.

Microscopically the typical granite gneiss consists essentially of albite-oligoclase about $Ab_{90}An_{10}$, orthoclase which is usually irregularly intergrown with a little albite, and quartz, with both muscovite and greenish brown biotite as major accessory minerals, and with garnet, magnetite, and titanite as minor accessories. Magnetite and titanite are more abundant in the biotite granite gneiss and garnet is virtually restricted to the muscovite granite gneiss. In the coarser-grained, less foliated rocks the albite-oligoclase has a tendency to be euhedral, and orthoclase and quartz are interstitial. In some rocks these minerals form a rude microscopic intergrowth. The micas occur as flakes elongate in the direction of foliation. During foliation the feldspars and quartz have been rotated, broken, and distorted, and the finer-grained rocks appear to be largely the result of foliation. The original grains appear to have been crushed to fine anhedra with an average diameter of 0·05 mm., in which are large, irregular, residual grains of feldspar and quartz, and knots and streaks of mica. The typical rocks are only slightly altered, sericite being almost the only secondary mineral.

Transitional Types.

The types mentioned as being transitional between the granite gneiss and the normal Colquitz gneiss, all occur in the northeastern part of the Sooke map-area to the west of Goldstream. They are similar in appearance to the granite gneiss but more altered, containing greenish weathering feldspar and chorite. On microscopic examination the feldspar is seen to be largely if not entirely oligoclase-andesine, and in the less altered rocks the only major accessory is light greenish brown biotite of the same variety as that in the typical granite gneiss. The biotite is altering to chlorite and in the more altered rocks chlorite is the only ferromagnesian mineral. It is not clear that the chlorite has not resulted from the alteration of hornblende since these more altered rocks are virtually identical with the altered, rather felsic facies of the normal Colquitz gneiss. In one of these altered transitional types found in Goldstream creek half a mile west of Goldstream post-office a single grain of staurolite 3 mm. in diameter was detected in the thin section.

SAANICH GRANODIORITE.

DISTRIBUTION.

The Saanich granodiorite forms numerous small stocks, many of which are too small to map, and several small batholiths, more than a mile in diameter, which are intrusive into the Vancouver volcanics and the Sicker series. The stocks and batholiths intrusive into the Vancouver volcanics are grouped along an axis nearly parallel to and just south of Cowichan valley. There are two batholiths. The eastern is about 3 miles wide and 6 miles long, and extends from south of Mill bay on Saanich inlet to north of Cobble Hill station. The western is 2 miles wide and 7 miles long and underlies the northern slope of Koksilah ridge. Between the two batholiths are several small stocks, the largest of which is exposed for 2½ miles in the bed of the lower portion of Koksilah river. Other stocks occur in the vicinity and to the west of the Koksilah Ridge batholith. The batholiths are elongate in a direction parallel to the strike of the intruded Vancouver volcanics, about north 65 degrees west. The eastern batholith forms the western portion of the Saanich batholith[1], which is about 15 miles in total length. Furthermore it appears as if the small stocks were protuberances of a much larger batholith that underlies the Vancouver volcanics at no great depth and connects the two exposed batholiths. Evidence of this is given by the occurrence of granodiorite in the stream bottoms, notably along the Koksilah river, while the upland on either side is capped with Vancouver volcanics. The stocks of Saanich granodiorite intrusive into the southern greatly deformed portion of the Sicker series, are conspicuously elongate in the direction of folding, north 65 degrees west, and are from 2 to 4 miles long and average less than a mile wide. They occur only near the western boundary of the map-area on the ridge north of Cowichan valley and north of the upper portion of Chemainus river. A few small stocks, the largest of which occurs on Mt. Brenton, and the largest batholith of granodiorite in the map-area, are intrusive into the northern, less deformed portion of the Sicker series, and are circular rather than elongate in outline. The batholith occurs to the west of Ladysmith in the northwestern part of the map-area: it is over 7 miles long and, even within the limits of the map-area, is nearly 4 miles wide.

The granodiorite is well exposed along the shores of Saanich inlet, and inland the less fractured portions of the granodiorite form large outcrops and ledges. The greater portion of most of the stocks and batholiths is, however, covered by drift, but there are enough exposures to indicate their general outline, so that their boundaries are, for the greater part, fairly well located on the accompanying map.

---

[1] Geol. Surv., Can., Mem. 36, 1913, p. 71.

LITHOLOGICAL CHARACTERS.

Normal Granodiorite.

The Saanich granodiorite is a light-coloured, medium-grained rock, with a characteristic granitic, and frequently somewhat gneissic texture which, except near contacts, is rarely pronounced. The weathered surface is in general much lighter coloured than the freshly broken surface. The rock consists of feldspar and quartz, with essential hornblende and in some rocks biotite, and accessory magnetite. Pyrite is also a common constituent and may be original. The feldspar in some varieties weathers both pink and greenish white, the latter occurring in rec[illegible]alar crystals. The hornblende frequently occurs, especially near contacts, in large euhedral crystals that give the rocks a characteristic porphyritic appearance. The granodiorite usually contains, especially near its contacts, numerous, small rounded segregations or inclusions of a darker colour and of more femic composition.

Microscopically the essential minerals are plagioclase, orthoclase, frequently microperthitically intergrown with a little albite, quartz, common green hornblende, and in some varieties greenish brown biotite which is always present at least as an accessory or secondary mineral. The accessory minerals are magnetite, pyrite, titanite, and apatite. The plagioclase, which is the chief feldspar, is largely andesine, about $Ab_{65}An_{35}$, but varies in composition from $Ab_{55}An_{45}$ to $Ab_{90}An_{10}$, and is frequently zonal. The texture of the rock is subhedral, with euhedral grains of hornblende and andesine, and interstitial quartz, some plagioclase, orthoclase, and microperthite. The quartz and potash feldspars are in a few varieties graphically intergrown. The original minerals have been fractured, strained, and even distorted. They are also moderately altered, the hornblende to biotite, chlorite, and epidote, and the biotite to chlorite. The feldspars are partly replaced by sericite, kaolin, and calcite. Quartz, sericite, and calcite also occur in veinlets.

The following is a chemical and mineral analysis of a rather basic phase of the Saanich granodiorite from the Saanich map-area.[1]

[1] Geol. Surv., Can., Mem. 36, 1913, p. 36.

Chemical and Mineral Composition of the Saanich Granodiorite.

Chemical composition.		*Mineral composition.*	
SiO_2	62·64	Quartz	21
Al_2O_3	17·75	Orthoclase	10
Fe_2O_3	1·64	Andesine $Ab_{65}An_{35}$	44
FeO	3·44	Hornblende	10
MgO	2·53	Biotite	9
CaO	4·44	Magnetite	1·5
Na_2O	3·53	Titanite	0·4
K_2O	2·14	Apatite	0·6
H_2O	1·65		
TiO_2	0·60		
P_2O_5	0·25		
MnO	0·14		
	100·75		
Specific gravity	2·74		

The Saanich granodiorite as previously described[1] is somewhat more basic than the average granodiorite, leaning towards a quartz diorite, and some facies of the granodiorite, such as commonly occur near basic segregations and inclusions, are true quartz diorites, with little or no orthoclase or microperthite.

Ladysmith Phase. The granodiorite of the circular stocks and batholith intrusive into the northern, less deformed portion of the Sicker series, differs slightly from the normal Saanich granodiorite, and has been designated from the large batholith west of Ladysmith, the Ladysmith phase.[2] The Ladysmith phase is less fractured, somewhat coarser grained, and possibly more gneissic than the normal Saanich granodiorite. It contains more microperthite and microcline and less andesine feldspar which in some varieties is slightly more sodic. The dark minerals, more particularly biotite which appears conspicuously in the hand specimen, occur in larger amounts. The segregations of dark minerals are also more numerous, and near them the granodiorite passes into a quartz diorite, with little or no orthoclase or microperthite, a smaller amount of quartz, and a larger amount of dark minerals. In the Nanaimo map-area the Ladysmith granodiorite is associated with a gabbro-diorite which appears to be a marginal differentiate.[3] While these

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 74–75.

[2] See detailed lithological description of this phase from the Nanaimo map-area, Geol. Surv., Can., Mem. 51, 1914, pp. 40–42.

[3] Geol. Surv., Can., Mem. 51, 1914, pp. 39-44.

differences are fairly characteristic it is not believed that in themselves they are sufficient to warrant the conclusion that the Ladysmith granodiorite is anything more than a phase of the Saanich granodiorite.

Contact and Hybrid Phases.

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 texture of these rocks is more porphyritic than that of the normal granodiorites, hornblende and some of the feldspar occurring in large euhedral crystals; while the quartz and the rest of the feldspar is usually interstitial. In a few places quartz also occurs in large phenocrysts. The feldspar-rich varieties are similar in texture to the quartz diorites, but contain a smaller amount of quartz and femic minerals. In contact with some of the limestones, better developed to the west of the map-area, but occurring to the southeast of Cowichan station near the King Solomon mine, the feldspathic or monzonitic diorites contain pyroxene, chiefly diopside but some augite. The pyroxene has apparently been formed by the recrystallization of material derived from assimilation of the limestone, so that the pyroxene-bearing rocks are considered to be true hybrid or mixed rocks. All of the contact phases are as a rule more altered than the normal granodiorite, and epidote is an especially characteristic alteration product.

Quartz Gabbro. A peculiar type of the contact phase, classified as a quartz gabbro, is found to the east of the King Solomon mine, associated with the granodiorite in small bosses, near small lentils of intruded limestone. It is a rather dark, medium-grained porphyritic rock, consisting largely of feldspar and hornblende, the hornblende forming phenocrysts slightly larger than the average grain It also contains relatively large amounts of disseminated pyrite.

The feldspar is seen on microscopic examination to be chiefly labradorite about $Ab_{25}An_{75}$ but has a pronounced zonal structure, so that the outer rims grade to andesine $Ab_{60}An_{40}$. It occurs in lath-shaped crystals, which with interstitial quartz, form a groundmass for the larger, euhedral hornblendes. Besides quartz the other accessory minerals are magnetite and pyrite. The rock is only slightly to moderately altered to biotite, chlorite, and sericite, and has not been foliated to any appreciable extent. Its relatively slight alteration and lack of foliation, as well as its geological associations, connects the quartz gabbro with the Saanich granodiorite rather than with the older, but more basic Wark gabbro-diorite gneiss. The minerals composing the quartz gabbro, although present in different proportion, are the same as those composing the Saanich granodiorite, although, of course, the feldspar is more calcic. Although the diopside-bearing, feldspathic diorites are developed apparently by assimilation, along most of the limestone-granodiorite contacts, it appears from the occurrence of the quartz gabbro as if the granodiorite had assimilated enough lime from the intruded limestone to form the more calcic feldspar, the most distinctive characteristic of the quartz gabbro.

Segregations.

Throughout virtually all the phases of the granodiorite and more abundantly near the contacts, are numerous, small rounded segregations which are composed of a fine-grained, dark groundmass with a few small phenocrysts of feldspar and hornblende. Their contacts with the granodiorite are well marked, but crystals of the one penetrate into the other. Furthermore, since their mineral composition is related to the granodiorite they are considered to be segregations and not inclusions.

Microscopically the essential minerals of the segregations are andesine-oligoclase, $Ab_{60}\,An_{40}$ to $Ab_{80}\,An_{20}$, and hornblende, with biotite and in places quartz. Magnetite is the chief accessory and in some segregations is present in relatively large amount. The groundmass of the segregations has a rather characteristic texture, since it is composed of lath-shaped feldspars and prismatic hornblendes, with poicilitic biotite and interstitial quartz. The alteration products are similar to those of the granodiorite, chiefly chlorite, epidote, and sericite.

Apophysal Phases.

Apophysal phases of the Saanich granodiorite, chiefly aplites, cut the various types and phases of the granodiorite, and also the intruded rocks. They are light coloured, fine-grained rocks consisting essentially of albite, microcline, orthoclase or microperthite, and quartz, with accessory biotite, muscovite, hornblende, magnetite, and titanite. They are fine-grained and anhedral, as a rule unfoliated, and only slightly altered to chlorite, epidote, biotite, sericite, and kaolin. They closely resemble the aplites of the Colquitz gneiss, but may usually be distinguished by their lack of foliation and less degree of alteration. In places, however, their geological occurrence is their only distinctive characteristic.

STRUCTURAL RELATIONS AND METAMORPHISM OF THE BATHOLITHIC AND MINOR INTRUSIVES.

INTERNAL.

Foliation.

All of the intrusive igneous rocks have been more or less foliated, some of them slightly; but the Wark and Colquitz gneisses and Tyee quartz-feldspar porphyrites have been foliated to such an extent that the Wark and Colquitz gneisses have been contorted in places, and the Tyee porphyrites have been converted into schists. The general strike of the foliation of the Wark and Colquitz gneisses is about north 65 degrees west, which corresponds with the greatest length of the batholith and with the strike of the intruded Vancouver volcanics. In detail, as shown on the accompanying maps, the strike of the foliation varies greatly, usually following the contacts of the Wark and Colquitz gneisses with each other and with the invaded rocks. The Saanich granodiorite, especially the Ladysmith phase, is gneissic in many places, especially near its contacts, to which the foliation is usually parallel.

Jointing and Shearing.

All of the intrusive rocks are rather greatly jointed and fractured. The joints and fractures although numerous, are usually small and irregular, only the Saanich granodiorite and particularly the Ladysmith phase, having in places regular and large joints. All of the batholithic rocks are broken by joints which throughout the map-area have a general north-south strike. This feature has apparently determined the strike of many of the valleys that traverse the batholithic rocks. The rocks have also been sheared, in places extensively, developing wide shear zones. These usually correspond in strike with the foliation, and have, therefore, a general northwest-southeast strike. Transverse fractures also occur, along which more or less movement has taken place. The fracturing and shearing have been so great as to render the granitic rocks, with the possible exception of portions of the Ladysmith batholith, unfit for building purposes. Along the shear zones the granitic rocks are more or less mineralized and cut by small and irregular quartz and quartz-epidote veins which are of no commercial value.

Relations of Types To Each Other.

Wark and Colquitz Gneisses. The Wark and Colquitz gneisses form virtually a single batholith, but the Colquitz gneiss is clearly intrusive into the Wark gneiss. The Wark gneiss is cut by masess of the Colquitz gneiss, usually the salic facies, some of which are several hundred feet in width. These masses are usually parallel to the foliation, but many of them are crosscutting. Furthermore, the contacts of the Colquitz gneiss with the Wark gneiss are marked by extremely wide zones of contact shatter breccias and by numerous apophyses of the quartz diorite. Some of the contact zones are so wide that they are shown on the accompanying maps as "contact complexes". The contact zones are frequently sheared and foliated and the angular inclusion or xenoliths of gabbro-diorite gneiss in the quartz diorite gneiss have been pulled out into long, dark, femic streaks which resemble the femic bands of the banded Colquitz gneiss; but, in part perhaps, they differ from them by being occasionally broken or by being cut across the foliation by the quartz diorite. Both the Wark and Colquitz gneisses are cut by veins or dykes, from a fraction of an inch up to several hundred feet in width, of the apophysal phases of the Colquitz gneiss. These are, of course, most prominent in the dark coloured gabbro-diorite gneiss and are in no place absent over large areas of Wark gneiss. Although crosscutting apophyses occur, they are usually injected parallel to the foliation, and are themselves foliated parallel to their walls. In some places the apophyses parallel to the foliation are so numerous as to convert the gabbro-diorite gneiss into a banded gneiss, not always distinguishable from the banded Colquitz gneiss. It is also probable that some of the quartz in the Wark gneiss, which is virtually always confined to the interstices between the apparently older minerals, is secondary, having infiltrated into the Wark gneiss during the intrusion of the quartz diorite gneiss. The relatively few dykes of pegmatite that have been noted are unfoliated, and, while usually parallel to the foliation, are in places crosscutting.

Banded Colquitz Gneiss. The banded Colquitz gneiss, in particular that type with the wide, coarse-grained, mafic bands or masses, is more or less restricted in its occurrence to the contacts with the intruded Wark gneiss. Its felsic and mafic bands vary in width from a fraction of an inch to 4 or 5 feet. The length of the individual bands in proportion to their width varies from 10 to 1 to almost 50 to 1, averaging about 20 to 1. Some of the bands, especially the narrower and finer grained, gradually pinch out; but others, notably the wider, coarse-grained, end abruptly and irregularly. The sides of the bands are usually straight or broadly curved. Rather frequently, however, they are irregular, and in places the bands are contorted and offset by minor faults. The contacts between the bands, while usually well marked and persistent, that is without minor irregularities except those due to foliation, are not sharp in detail, but the crystals of one band are intergrown with those of the contiguous bands. In places the banded gneiss is cut by felsic apophyses of the Colquitz gneiss which, although usually parallel to the banding, are also crosscutting.

Saanich Granodiorite and Wark and Colquitz Gneisses. The Saanich granodiorite does not occur in contact with the Wark and Colquitz gneisses within the Sooke or Duncan map-areas, but to the east, near Victoria, it is clearly intrusive into the Wark gneiss, and is quite certainly younger than the Colquitz gneiss.[1] Since the three rocks have the same characteristics in the Sooke and Duncan map-areas as they have near Victoria, it is virtually certain that they have the same structural relations to each other in the Sooke and Duncan map-areas.

Saanich Granodiorite and Tyee and Granodiorite Porphyrites. Associated with the Saanich granodiorite in the Victoria and Saanich map-areas and confined for the greater part to the periphery of the Saanich batholith, are dyke-like and irregular intrusive bodies of quartz and feldspar porphyrites which have been called, in order to indicate their close connexion with the granodiorite, granodiorite porphyrites.[2] Many of the masses of granodiorite porphyrite are not only intrusive into the rocks of the Vancouver group but into the Saanich granodiorite itself. Other masses are, however, distinctly older than the Saanich granodiorite, having been intruded by it. Within the Duncan map-area porphyrite masses similar to the granodiorite porphyrites of the Victoria and Saanich map-areas are almost entirely confined to the Sicker series. Apparently all these porphyrite masses are older than the Saanich granodiorite, and have been called by Cooke, the Tyee porphyrites. Within the Duncan map-area only a few dykes of the granodiorite or quartz-feldspar porphyrite have been observed unassociated with the Sicker series. These are intrusive into the Vancouver volcanics south of Cowichan valley, and are well exposed on the west shore of Saanich inlet. However, it cannot be determined whether they are older or younger than the Saanich granodiorite The granodiorite porphyrites intrusive into the Vancouver volcanics may be distinguished from the typical Tyee porphyrites, intrusive into the Sicker series, in that the latter are everywhere foliated to a greater or less degree, while the former are not; otherwise the porphyrites are virtually identical. It

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 84–85.
[2] Geol. Surv., Can., Mem. 36, 1913, pp. 77–79.

is probable that dykes of granodiorite porphyrite which are younger than the Saanich granodiorite occur at least in the Vancouver volcanics of the Duncan map-area, for dykes of that age are found in the Victoria and Saanich map-areas, as well as elsewhere on Vancouver island, near Cowichan lake, Nitinat river, Barkley sound, and Alberni canal.[1] However, they have not been determined, and indeed with one exception, the dykes of granodiorite porphyrite have not been located sufficiently well to be shown on the accompanying map.

Saanich Granodiorite, Sicker Gabbro-diorite Porphyrite, and Diorite Porphyrite. Dykes of diorite porphyrite cut the Saanich granodiorite and associated rocks in the Victoria and Saanich map-areas,[2] and elsewhere on Vancouver island,[3] but in the Duncan map-area they have not been recognized although they probably exist there also. Some dykes of diorite porphyrite may have been seen, but the diorite porphyrite has not been distinguished from the Sicker gabbro-diorite porphyrite which it closely resembles. However, Cooke[4] has shown that the Sicker gabbro-diorite porphyrite has almost certainly been intruded by the Ladysmith phase of the Saanich granodiorite; hence, it is older than the Saanich granodiorite whereas the diorite porphyrite is younger. Unlike the Sicker porphyrite the diorite porphyrite has a wide distribution throughout Vancouver island.

EXTERNAL.

Relations to Older Formations. The batholithic rocks and accompanying porphyrites are as a whole intrusive into the Leech river and Malahat formations and into all of the formations of the Vancouver group. There are, however, certain associations between the intruded and intruding rocks. The Leech River formation is intruded only by relatively small stocks of granite gneiss, supposed to be a facies of the Colquitz gneiss; and the Malahat volcanics are intruded only by the Wark and Colquitz batholith and closely connected satellitic

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 105–106.
[2] Geol Surv., Can., Mem. 36, 1913, pp. 79–80.
[3] Geol. Surv., Can., Mem. 13, 1912, pp. 100–107. Called in this memoir andesite porphyrite.
[4] Section on the Sicker series, p. 170.

stocks. The Vancouver volcanics and Sutton limestones are intruded by all the irruptive rocks with the exception of the Tyee and Sicker porphyrites which are strictly confined to the Sicker series; and the Sicker series are not intruded by the Wark and Colquitz gneisses although farther west and north they are intruded by gabbro-diorites of batholithic or subjacent character.[1] It is possible that these associations are nothing more than accidental. For example, there is, so far as known, only one large batholith, the one described, of the Wark and Colquitz gneisses, and hence these rocks are intrusive only into the "surface formed" rocks of the extreme southeastern portion of the island. Large scale irruptions may have been confined to the axes of the major folds, and hence the limbs of the folds would have escaped intrusion by large masses of the irruptive rocks. Such an explanation may account for the absence of large bodies of irruptive rocks in the Leech River schists which appear to form the limb of one of the major folds of the region. It would further explain the felsic, apophysal-like character of the intrusive stocks in the Leech River schists. The restriction of the Sicker gabbro diorite porphyrite to the Sicker series, like the restriction of the Oligocene Sooke gabbro to the Eocene Metchosin volcanics, seems, however, to be more than accidental; and the close lithological similarity between the Sicker volcanics and the Sicker porphyrites suggests that both rocks have been derived from the same deep-seated reservoir of magma.

The intrusive character of the batholithic and minor intrusives is seldom in doubt. Most of the minor intrusives have fine-grained or "chilled" contacts and although as a rule they are parallel to the bedding or foliation planes of the rocks into which they are intrusive, all of the minor intrusives are crosscutting in places. Although most of the stocks and batholiths are elongate in a direction parallel to the axes of folding of the intruded rocks they are, of course, distinctly crosscutting and have quite certainly replaced large volumes of the intruded rocks. Since it appears to the writer, as discussed below, that the batholiths and stocks were intruded into rocks which, at the time of

[1] Geol. Surv., Can., Mem. 13, 1912, p. 97, and No. 51, 1914, pp. 39–40.

intrusion, had been already deformed, it is difficult to discover whether or not the intrusion of the batholiths and stocks caused further deformation; especially, since, with few exceptions, the larger features of deformation cannot be accurately determined. It appears, however, as if the irruption of the batholiths occurred in a relatively quiet manner, in such a way as not to disturb greatly the attitude of the invaded rocks. This is more especially true of the larger stocks and batholiths of normal Saanich granodiorite and of the Ladysmith phase of the granodiorite. In many places the Malahat volcanics are foliated parallel to the contacts with the Wark and Colquitz gneisses, but, since the gneisses themselves are also foliated parallel to their contacts, it appears that such foliation might have been produced by late dynamic forces thrusting the Malahat volcanics against the more competent intrusive masses. That folding has taken place after the intrusion of the stocks of granite gneiss into the Leech River formation seems clear.[1]

Along most of the main batholithic contacts, the intruded rocks are usually brecciated, especially by the Colquitz gneiss and Saanich granodiorite and are cut by numerous apophyses which are chiefly aplitic. The shatter zones thus developed are seldom very wide, 50 to 150 feet, and should not be confused with wide zones of shatter breccias and "contact complex" produced by the intrusion of the Colquitz gneiss into the Wark gneiss. In addition, numerous inclusions of the intruded rocks occur in the granitic rocks. They vary in size from small fragments a few feet or inches in diameter, to large roof pendants. They are clustered chiefly near the main contacts, in the shatter zones, but in places occur 2 or 3 miles from the main contacts. The intruded rocks have been contact-metamorphosed and mineralized to form the metamorphic types already described. Moreover, many of the batholithic rocks and their apophyses have been changed near their contacts, chiefly with the Sutton limestones, apparently by assimilation, to form hybrid rocks, many of which are monzonitic in character.

For further details concerning the relation of the batholithic and minor intrusives the reader is referred to the sections

[1] See periods of deformation of the Leech River and Malahat formations, page 87.

dealing with the structural relations of the various older formations.

Relations to Younger Formations. The Saanich granodiorite, and the minor intrusives are all unconformably overlain by the sediments of the Nanaimo series. The unconformity, described in the section dealing with the Nanaimo series, is well exposed and is marked in most places by a coarse basal conglomerate composed partly of fragments of the granodiorite and porphyrites. The Nanaimo sediments are not in contact with the Wark and Colquitz gneisses, but are, of course, much younger and unconformable.

The batholithic rocks and their closely associated minor intrusives are not in contact with the Metchosin volcanics and the Sooke intrusives. Since the Metchosin volcanics are, however, of Eocene age, and since the Upper Cretaceous sediments rest unconformably upon the batholithic and minor intrusives, the Metchosin volcanics and Sooke intrusives are, of course, much younger than the batho ithic and minor intrusives.

SEQUENCE AND TIME OF IRRUPTION.

The general sequence of irruption of the batholithic and minor intrusives as determined by the structural relations given above, is fairly definite; the irruption of the Wark gneiss was evidently closely followed by the irruption of the Colquitz gneiss, and that, after a longer interval, by the Saanich granodiorite and its various phases and associated minor intrusives. The Sicker and Tyee porphyrites are clearly older than the Saanich granodiorite, but whether they are older or younger than the Wark and Colquitz gneisses cannot be determined. If the Tyee and Sicker porphyrites were both intrusive into virtually undeformed rocks, as Cooke believes, they are probably older than the Wark and Colquitz gneisses which were intruded into deformed rocks, although deformation continued after their irruption. However, the Sicker gabbrodiorite porphyrite appears to be younger than the Wark gabbrodiorite gneiss, since it is less foliated and altered. Therefore, the sequence is considered provisionally to be as follows:

Diorite porphyrite (dykes).
Granodiorite porphyrites (dykes).
Saanich granodiorite and its various phases (stocks and batholiths).
Sicker gabbro-diorite porphyrite (dykes, sills, and masses).
Tyee quartz-feldspar porphyrite (dykes, sills, and masses).
Colquitz quartz diorite gneiss.
Wark gabbro-diorite gneiss.

It seems clear that the batholithic rocks were irrupted during two main periods, which have been called the Wark and Saanich periods[1]. During the first period the Wark and Colquitz gneisses were irrupted independently. Thus the Wark period is divided into two sub-periods, the second sub-period being characterized by the irruption of a more acid or salic magma than that first irrupted. A similar division into two sub-periods is made of the Saanich irruptive period. The first sub-period, during which the basic or mafic rock, the Beale diorite[2], 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. A few miles to the north of the map-area, however, there is associated with the Ladysmith phase of the granodiorite a gabbro-diorite, similar in its lithology and structural relations to the typical Beale diorite.[3] As a whole the batholithic rocks irrupted during the Saanich period are more acid or felsic than those of the Wark period. There is, therefore, a general sequence of from basic to acid among the batholithic rocks, a phenomenon which is very characteristic of complex batholithic irruptions.

In general the minor intrusives have followed the irruption of the batholithic rocks and the latter in turn have followed the eruption of the Malahat, Vancouver, and Sicker lavas. The irruptive cycle represented by the pre-Upper Cretaceous igneous rocks of the Sooke and Duncan map-areas, therefore, conforms to the general eruptive cycle announced by Harker,[4] which consists of three phases of igneous activity which follow one another in the following sequence: the volcanic phase, the batholithic phase, and the phase of minor intrusives.

[1] Geol. Surv., Can., Mem. 13, 1912, p. 110, and Mem. 36, 1913, pp. 87–88
[2] Geol. Surv., Can., Mem. 13, 1912, p. 99.
[3] Geol. Surv., Can., Mem. 51, 1914, pp. 39–44.
[4] Harker, A., "The natural history of igneous rocks," Macmillan, 1909, pp. 23–29.

In more detail, it appears from the sequence of irruption, as given in the table on page 202, as if the irruption of the minor intrusives was also divided into two periods. During the first of these the Tyee and Sicker porphyrites were injected, and during the second, which followed the irruption of the Saanich granodiorite, the granodiorite and diorite porphyrites were injected, in each sub-period the more mafic rock following the more felsic.

It is quite obvious that the batholithic and minor intrusives were irrupted into the surface formed rocks during and following the period during which the surface formed rocks were most intensely folded, that is the upper Jurassic or Lower Cretaceous mountain building or organic period. Whether or not they were irrupted during the first or last part of the period is not, however, certain. All of the rocks are rather greatly jointed and fractured and more or less foliated; the Wark and Colquitz gneisses are greatly folded. The jointing and fracturing may well have been caused by crustal movements much later than those which accompanied or preceded the intrusion of the irruptive rocks. However, since Cooke[1] has shown that there is no transition between the schistose beds of the Sicker series and the basal beds of the Nanaimo series, and that the Nanaimo series were folded during the next great period of deformation, and that they were folded almost entirely in the zone of fracture under relatively low temperatures and pressures, it is improbable, although a contrary opinion has been previously expressed by the writer[2] that any of the exposed irruptives were deep enough at the time of the folding of the Nanaimo series to have been foliated. Hence it seems certain, since all of the irruptives are at least somewhat foliated in places, chiefly parallel to their contacts, that at least slight orogenic movements accompanied or followed, as well as preceded the intrusion of all the irruptives. It has been concluded[3] that the Wark and Colquitz gneisses are primary gneisses, that is they have been foliated before their complete solidification. It is also probable that the relatively

[1] See page 156.
[2] Geol. Surv., Can., Mem. 36, 1913, p. 89 and p. 93.
[3] See the following section dealing with the mode of origin.

slight amount of foliation in the Saanich granodiorite, more especially in the Ladysmith phase, is also a primary texture, although produced largely by local movements which were perhaps caused by the intrusion of the granodiorite magma.

Strong orogenic movements not only accompanied or immediately followed the irruption of the Wark and Colquitz gneisses, but occurred after the gneisses had been crystallized. This is proved by the intense foliation of both the Wark gneiss and Malahat volcanics along some of their contacts, by the occurrence of cross folds in the Malahat volcanics such as that exposed along the Esquimalt and Nanaimo railway south of 17-mile-post, which are nearly parallel to dykes of Colquitz gneiss, and by the relations of the dyke-like stocks of Colquitz granite gneiss to the intruded Leech River schists. Nevertheless the main batholith of the Wark and Colquitz gneisses in many places cuts sharply across the foliation of the Malahat volcanics; and while the Malahat volcanics retain their normal northwest-southeast foliation, the Wark and Colquitz gneisses may be foliated parallel to the contact that bevels across the foliation of the Malahat volcanics. Whereas the stocks of Colquitz granite gneiss in the Leech River schists, being smaller, were more affected by late orogenic movements so that the foliation in the stocks is nearly everywhere parallel to the schistosity of the intruded rocks, there are in places apophyses from the stocks which break across the schistosity. Not only do the Wark and Colquitz gneisses bevel across the foliation of the Leech River and Malahat formations, but the main batholith almost completely intercepts the Malahat volcanics, as it does their contact with the Vancouver volcanics. Hence it is assured that the Wark and Colquitz gneisses were irrupted into the Malahat and Leech River formations after they had undergone considerable deformation. Moreover, for virtually identical reasons it is also assured that the Wark and Colquitz gneisses were irrupted into the deformed Vancouver volcanics and Sutton limestones.

As the Saanich granodiorite is younger than the Wark and Colquitz gneisses, it too must have been irrupted into the deformed Vancouver volcanics and Sutton limestones. This conclusion is in perfect accord with the field facts; and indeed since there is a complete absence of secondary folds parallel to the periphery of the Saanich granodiorite masses, and since the Saanich granodiorite does not seem to have been greatly foliated or sheared after crystallization it is further concluded that at the time of irruption of the Saanich granodiorite the orogenic movements had almost entirely ceased.

Nevertheless the Tyee quartz-feldspar porphyrites were obviously, as has been shown by Cooke, greatly deformed by intense orogenic movements. Indeed, as Cooke concludes, it appears as if the Tyee porphyrites were intruded into the virtually undeformed Sicker series, and have been deformed with them. A similar conclusion is reached by Cooke, from much less convincing evidence, with respect to the Sicker gabbro-diorite porphyrites. Cooke has presented his reasons for considerin the Sicker porphyrites to have been injected into the Sick. series before their deformation in considerable detail[1], but it does not appear to the writer that Cooke's conclusion harmonizes completely with the crosscutting structures observed by the writer between the Sicker series and the Sicker porphyrite to the east of the Duncan map-area in southern Saltspring island and on Moresby and Portland islands[2]; and it is believed by the writer that at least some, and perhaps most of the larger masses of Sicker porphyrite were intruded into deformed rocks of the Sicker series. That extensive deformation, chiefly faulting and shearing, followed the injection of the Sicker porphyrite is, however, entirely clear.

MODE OF ORIGIN.

INTRUSION.

The batholithic and minor intrusives have crystallized from a molten state under deep-seated conditions. They were irrupted into the rocks of the Leech River and Malahat formations and of the Vancouver group, and have replaced them, apparently in a relatively quiet manner, without disturbing them greatly. The invading batholiths, even during their last

[1] See section on the Sicker series, page 149.

[2] See geological map of the Saanich map-area; Geol. Surv., Can., Mem. 36, 1913.

active stages, shattered the invaded rocks along their contacts into angular fragments. Near the present contacts great numbers of these fragments occur in the intrusive rocks, but they disappear within a few yards. They may have been further shattered to smaller fragments which were assimilated by the intrusive magmas to form hybrid rocks, for hybrid rocks are found in certain localities, but in relatively small amounts; or else the fragments have sunk in the intrusive magmas to abysmal depths.[1] It is by this last method that Daly supposes that batholiths have replaced large volumes of the rocks into which they were intrusive.

DIFFERENTIATION.

The batholithic rocks were irrupted during two main periods, called the Wark and Saanich periods, each of which is further divided into two sub-periods. The younger sub-period in both instances is characterized by the irruption of a more salic magma, the Colquitz quartz diorite and the Saanich granodiorite, than that irrupted during the earlier sub-period, the Wark gabbro-diorite and the Beale diorite. Furthermore, the younger Saanich magma was more salic than the older Wark magma. The intimate lithological and structural relations of all the batholithic rocks, most intimate between the rocks irrupted during the same period, indicate that all the batholithic rocks are derivatives of the same parent magma. Since the principal batholithic rocks have been separately and more or less independently intruded in large masses, the differentiation of the parent magma must have been, at least relative to the present position of the batholiths, deep-seated. Since both the Wark and Saanich magmas, the first derivatives of the parent magma, underwent further differentiation, also under deep-seated conditions, it looks as if the Wark and Saanich magmas, after differentiation from their parent magma, were irrupted into separate magma chambers where each underwent its further differentiation, producing the sub-types which were themselves irrupted independently into their present positions. The principal types thus

[1] Daly, R. A., "Igneous rocks and their origin," McGraw-Hill, 1914, pp. 194–208.

formed, underwent further differentiation, but relatively in place, thus giving rise to most of the various phases of the principal rock types. As noted, some of the phases of small extent and of restricted occurrence, are due to the interaction of the invaded and invading rocks producing [illegible] hybrid types.

The cause or manner of the differentiation is not clearly indicated by the occurrence or lithological characters of the batholithic rocks. Assimilation appears to have played only a small and an entirely local part in the production of the various rock types. There is no direct evidence that the differentiation, which produced the principal types of batholithic rocks finally irrupted nearly into their present positions, took place by a separation or splitting of the parent magma into immiscible portions. Neither is it necessary to assume that the Wark and Saanich magmas, the first derivatives of the parent magma, were necessarily of very different composition; for as Bowen[1] has shown, if differentiation is caused by fractional crystallization and a draining off of the residual liquid, the composition of the residual liquid, that portion which undergoes further irruption, depends upon the stage of crystallization reached by the parent magma at the time the residual liquid was drained off. The stage of crystallization reached at any time is, of course, the direct result of the rate of cooling which is largely controlled by the size of the magma chambers. Bowen has further shown that if, as it appears, differentiation takes place under gravitative control, the upper portion of a large magma chamber will be more salic than the upper portion of a smaller chamber. Hence the difference between the rocks resulting from the Wark and Saanich magmas may be due to the fact that the Saanich chamber was larger than the Wark. Although the exposed Wark batholith is larger than any known single batholith of the Saanich granodiorite and Beale diorite, the Saanich granodiorite is much more abundant, and it seems fairly certain that the exposed portions of the Saanich granodiorite are merely the protuberances of an immense batholith which may underlie a large part of Vancouver island at no very great depth. What is fairly clear is that the

[1] Bowen, N. L., "The later stages of the evolution of the igneous rocks." Jour. Geol., supplement to vol. XXIII, 1915, p. 10 and following pages.

Wark and Saanich magmas were further independently differentiated in separate chambers and that the resulting sub-types were irrupted nearly into their present positions independently.

Not only have the Wark and Saanich rocks been derived from separate magma chambers, but it is quite certain that some of the minor intrusives have been derived from independent magma chambers. From some of these chambers, local in their extent, apparently both volcanic and intrusive rocks have been erupted. The clearest example of such a case is that of the Tertiary Metchosin volcanics and the intrusive Sooke gabbro confined to the southern end of Vancouver island. However, the Sicker volcanics, chiefly andesites, and the Sicker gabbro-diorite porphyrite appear to have similar relations. The chief reasons for considering that these two rocks have been derived from the same magma chamber, largely independent of the other large magma chambers of Mesozoic age, are their close lithological resemblance and their virtual restriction (absolute with respect to the Sicker porphyrites) to a comparatively narrow belt, in which they predominate, while the other Mesozoic igneous rocks, with the possible exception of the Wark and Colquitz gneisses that appear to be confined to southeast Vancouver island, are found throughout the island.

As stated, the relations of the dykes of granodiorite and diorite porphyrites are not exposed within the Duncan map-area; but it has been shown that in the Victoria and Saanich map-areas[1] the granodiorite and diorite porphyrites are very closely related to each other, in fact are transitional, and are also closely related to the Saanich granodiorite. The injection of the granodiorite porphyrites may have preceded in places, but usually followed closely the final irruption of the Saanich granodiorite; hence in most places the granodiorite porphyrites were injected into slowly cooling, but still hot, granodiorite. Consequently the relations of the two rocks, even where their contact is well exposed, are frequently indefinite. The diorite porphyrite, on the other hand, forms well-defined dykes with chilled contact portions against the granodiorite and usually against the grano-

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 92-93.

diorite porphyrite; hence it was injected into these rocks after they had become relatively cold. Further, since the granodiorite porphyrites are composed almost entirely of quartz and alkali feldspar, the last minerals of the granodiorite magma to crystallize, it appears as if the granodiorite porphyrites have resulted from the squeezing out of the residual liquid remaining after the main portion of the Saanich granodiorite magma had been crystallized, and the injection of the residual liquid into the still warm granodiorite and into the invaded country rocks as well. With continued solidification of the magma to form the Saanich stocks and batholiths the residual liquid would be injected from deeper and deeper portions of the magma chamber and consequently[1] would become more and more basic. Thus the change and succession from quartz-feldspar porphyrites through feldspar porphyrites to diorite porphyrites is explained, an order of succession from acid to basic, just the reverse of the normal order of batholithic intrusion, from basic to acid.

As stated above there appear to have been two periods during which the minor intrusives were injected: the Tyee and Sicker porphyrites were injected during the earlier period which, like the later period, was characterized by a succession from acid to basic, the Sicker porphyrite being younger and intrusive into the Tyee porphyrite. It [illegible] however, clear to what batholithic rocks, if any, the [illegible] minor intrusives are related. Cooke has suggested that, [illegible]e both the Tyee and Sicker porphyrites are greatly deformed, they were injected during or immediately following the irruption of the Wark and Colquitz gneisses, a period which was clearly one of great deformation. However, no exposures of the typical Wark and Colquitz gneisses are known in the vicinity of the Tyee and Sicker porphyrites. Nevertheless, as mentioned several times, a gabbro-diorite, gneissic in places, occurs in the Nanaimo map-area a few miles to the north of the Sicker porphyrites; but, since it occurs in closest association with the Ladysmith phase of the Saanich granodiorite, it has been considered to be the equivalent of the

[1] See Bowen, N. L., Op. cit.

Beale diorite; and less than a mile to the west of the map-area and north of Cowichan valley, intrusive into the Sicker series, but also in close association with the Saanich granodiorite, is another diorite gneiss[1] which cannot be distinguished from certain facies of the Wark gneiss. Thus there is some slight support to Cooke's suggestion.

It appears as if the Sicker volcanics and the Sicker porphyrites were derived from the same rather restricted magma chamber. This chamber has not yet been revealed by erosion, hence it is not to be expected that the batholithic rocks, if any exist, most closely related to the Sicker porphyrite, would be exposed; it is possible that the granitic phase of the Tyee porphyrite occurring on Saltspring island is really the upper portion of an otherwise, unexposed batholith. Differentiation in this chamber would doubtless proceed in much the same way as it did in the other chambers, and would produce a quartz-feldspar (Tyee) porphyrite similar but clearly older than the quartz-feldspar (granodiorite) porphyrite derived from the Saanich magma.

As already noted the Mesozoic rocks of Vancouver island conform to the general eruptive cycle, viz., (1) the volcanic phase, (2) the batholithic phase, and (3) the phase of minor intrusives. The volcanics are composed almost entirely of basalts and andesites of a remarkably uniform composition. The batholiths are made up of a number of rocks irrupted in a general sequence, basic to acid. The minor intrusives consist of a few rocks irrupted in a general sequence of from acid to basic. The phenomena may be quite simply explained by the application of the theory recently elaborated by Bowen[2] of a primary basaltic magma differentiated by fractional crystallization under gravitative contact. Applying this theory, the volcanic rocks have resulted from the solidification of the undifferentiated or only slightly differentiated magma brought to the surface through deep vents. The composite batholiths have been the result of the more complete differentiation of the primary magma in chambers of various sizes; the older, smaller,

[1] Geol. Surv., Can., Mem. 13, 1912, p. 97.
[2] Bowen, N. L., op. cit.

and more quickly crystallized, and hence less completely differentiated portions of the primary magma formed more basic rocks than those portions crystallizing more slowly in the upper, exposed parts of the later developed and larger chambers. The minor intrusives, in turn, have been formed by the injection of the residual liquids which were drawn successively from lower and lower levels as the crystallization of the batholithic rocks progressed downwards in the larger magma chambers, and which for that reason became more and more basic.

METAMORPHISM.

The development of the metamorphic and foliated and banded phases of the batholithic rocks was discussed in considerable detail in the report on the adjacent Victoria and Saanich map-areas[1] and it is not necessary to repeat the discussion here. It was concluded that the coarse-grained, recrystallized phases of the Wark gneiss, especially the variety with the poicilitic hornblendes, were due to the metamorphic action of the intrusive Colquitz gneiss. It was further concluded that the Wark and Colquitz gneisses were primary gneisses, formed largely by dynamic movements during their consolidation. The banded texture, especially characteristic of the Colquitz gneiss, was shown to be formed in different ways, by the injection of Colquitz gneiss along the foliation planes of the Wark gneiss, by the stretching and flowage of xenoliths of Wark gneiss enclosed in the viscous Colquitz magma, and by movement during consolidation, caused largely by regional folding. It has already been stated that it is believed that the gneissic texture of portions of the Saanich granodiorite, especially the Ladysmith phase, is also original, although the movements causing foliation, since the foliation is usually parallel to the contacts of the granodiorite masses, may have been due to the irruption or repeated irruptions of the Saanich magma.

The foliation of the Tyee and Sicker porphyrites, as fully described by Cooke, seems to have been due largely to regional folding after the injection and consolidation of the two rocks.

[1] Geol. Surv., Can., Mem. 36, 1913, pp.88–92.

AGE AND CORRELATION.

The batholiths are intrusive into lower Jurassic rocks (portions of the Vancouver group) while Upper Cretaceous (Nanaimo) sediments rest unconformably upon them. They are, therefore, correlated with entire certainty with the other, virtually identical batholiths of Vancouver island and with the Coast Range batholith of the mainland of British Columbia. All of these batholiths are considered to have been irrupted chiefly during the upper Jurassic. Similar composite batholiths, with associated minor intrusives of porphyries or porphyrites similar to those of Vancouver island, and doubtless having the same general relations, occur all along the Pacific coast of North America; and most of them were irrupted during the same period of batholithic intrusion. This period, however, apparently occurred at an earlier date in Alaska (middle Jurassic) and at a later date (lowermost Cretaceous) in California.[1] The succession of separate intrusions, the older irruptions having been foliated and completely crystallized before the irruption of younger rocks (a conclusion drawn from the occurrence of extensive shatter breccias) indicates, however, that even in one locality the period of batholithic intrusion was one of long duration. Nevertheless, in the Sooke and Duncan map-areas it was doubtless confined to the upper Jurassic and possibly lowermost Cretaceous.

The Vancouver Island batholiths differ from the Coast Range batholith in that instead of outcropping in one large mass they appear as several relatively small masses. The lithological and structural similarity of all of the stocks and batholiths, their elongate outlines, their occurrence in deep valleys such as that of Koksilah river with the upland on either side directly underlain by the invaded rocks, and their predominance in the southeastern lowland of Vancouver island indicate that the granitic rocks form only a few or possibly only one large composite batholith not yet completely unroofed, of which the exposed stocks and batholiths are mere protuberances or cupolas. The true differ-

---

[1] Lindgren, Waldemar, "Igneous geology of the Cordilleras, problems of American geology," New Haven, 1915, pp. 254–258.

ence between the Coast Range and the Vancouver Island batholiths may be, therefore, merely a matter of erosion.

Minor Intrusives not Clearly Associated with the Batholithic Intrusives.

GABBRO.

DISTRIBUTION AND STRUCTURAL RELATIONS.

Near the southern boundary of the Duncan map-area to the west of Finlayson arm, crossing the Esquimalt and Nanaimo railway 200 yards north of 15-mile-post, is a small mass of gabbro intrusive into the Malahat volcanics. The gabbro mass strikes about north 75 degrees west, and is about 2,000 feet long with a maximum width of 250 feet. It is clearly intrusive into the Malahat volcanics as it has a pronounced fine-grained and somewhat porphyritic contact zone; although elongate in the general direction of the foliation of the Malahat volcanics, in detail it is seen to cut across the foliation at a considerable angle. Neither is the gabbro so greatly sheared or altered as the Malahat volcanics. Not far to the west of the gabbro are the Wark and Colquitz gneisses which also are intrusive into the Malahat volcanics; but there does not appear to be any definite structural relation between the gneisses and the gabbro. Another much smaller mass of similar gabbro cuts the Malahat volcanics about 2 miles to the south. It is 50 to 60 feet wide and strikes north 20 degrees west and crosses a small hill west of the Esquimalt and Nanaimo railway, a mile northwest of Goldstream post-office.

LITHOLOGICAL CHARACTERS.

The gabbro is a greenish, medium-grained rock consisting of greenish weathering feldspar and dark green ferromagnesian minerals. As mentioned, the contact zone is finer grained with a somewhat porphyritic texture.

Microscopically the essential minerals of the gabbro are labradorite about $Ab_{45}An_{55}$, and augite, present in about equal amounts. Magnetite, or more probably ilmenite, since it is altering to leucoxene, is the only accessory mineral. The labradorite forms euhedral, lath-shaped grains, while the augite, although in part euhedral, is in general interstitial to the labradorite and of somewhat finer grain. The feldspars and augite are both fractured and moderately altered to epidote, zoisite, and chlorite. The ilmenite or magnetite has altered to leucoxene and limonite, and a little quartz occurs in small shear zones.

RESEMBLANCES, AND AGE AND CORRELATION.

The gabbro is almost identical with the gabbro occurring in the Victoria map-area in the southeastern part of the Highland district,[1] which has been correlated with the Wark gneiss. The gabbro of the Victoria map-area appears to grade into the Wark gneiss,[2] but, as noted, the relations of the two rocks are not definitely known. The gabbro under consideration is also very similar to the Sooke gabbro, but the feldspar is slightly more sodic, the chief accessory mineral appears to be ilmenite rather than magnetite, and the rock is more altered than the typical Sooke gabbro. The gabbro differs from the Sicker gabbro-diorite porphyrite, which it also resembles, in that it contains no hornblende nor original quartz, nor micrographic intergrowth of quartz and feldspar. Neither is there any suggestion of the so-called rosette texture,[3] a feature which is characteristic of the Sicker gabbro-diorite porphyrite. Since the gabbro is not so greatly foliated nor metamorphosed as the Wark gneiss and since it so closely resembles the Sooke gabbro, the writer is inclined to believe that it is younger than the Wark gneiss and should be correlated with the Sooke gabbro. If so, its age is, of course, lower Oligocene. Owing, however, to the apparent gradation which exists between the virtually identical gabbro and the Wark gneiss in Victoria map-area, and to the occurrence of the Wark gneiss in the vicinity of the gabbro under consideration, and to the remoteness of any stocks of Sooke gabbro, the gabbro is correlated tentatively with the Wark gneiss and is provisionally considered to be of upper Jurassic age.

[1] "Geology of the Victoria and Saanich map-areas," Geol. Surv., Can., Mem. 36, 1913, p. 62.
[2] Op. cit., p. 84.
[3] See page 171 and Geol. Surv., Can., Mem. 13, 1912, p. 89.

QUARTZ DIORITE PORPHYRITE.

DISTRIBUTION AND STRUCTURAL RELATIONS.

A quarter of a mile northeast of Goldstream post-office, the Leech River schists are cut by a dyke, 6 to 7 feet wide, of quartz diorite porphyrite. The dyke strikes north 55 degrees west, parallel to the strike of the schists, but crosscuts them; for, near the dyke, doubtless owing to its injection, they are slightly contorted and dip to the north at angles varying from 35 to 90 degrees. The dyke may be traced for over a thousand feet, and 200 feet to the north is a similar but much smaller dyke, not shown on the accompanying map. There may be other similar dykes cutting the Leech River schists or Malahat volcanics, but no others have been discovered.

LITHOLOGICAL CHARACTERS.

The dyke-rock is greyish green, medium to fine-grained, and porphyritic. It consists chiefly of small, rectangular to lath-shaped, altered, hornblende phenocrysts which compose nearly half the rock and occur in a feldspathic matrix which contains a little quartz. The edges of the dyke are chilled, that is, they are much finer-grained and contain fewer and smaller phenocrysts of hornblende. The feldspathic groundmass is also greatly altered, and is replaced by epidote, which as seen microscopically forms with zoisite nearly 50 per cent of the groundmass.

Microscopically the rock is composed essentially of hornblende, oligoclase about Ab_{75} An_{25}, albite, orthoclase, and quartz, with accessory apatite, titanite, and magnetite, the magnetite being confined to the chilled, contact portions of the dyke. The phenocrysts form almost one-half the rock and are not much coarser grained than the groundmass but are distinguished rather by their euhedral character. They consist chiefly of hornblende and oligoclase, the former greatly predominating, and some albite. The groundmass, which is composed of albite, orthoclase, and quartz, is anhedral and much of the quartz is micrographically intergrown with the albite and orthoclase. Since the rock contains such a large amount of hornblende and predominating plagioclase feldspar, it is classed with the diorites, and more specifically, since it contains essential quartz, with the quartz diorites. The feldspar is, however, more alkaline than that of typical diorites and is more characteristic of quartz monzonites. The rock has been sheared somewhat and has been moderately to greatly altered, especially the contact portions, to epidote, zoisite, and chlorite.

AGE AND CORRELATION.

Since the dyke rock is not identical with any of the other dyke or subjacent rocks of Vancouver island, although similar in mineral composition to most of the granitic and dioritic rocks, and as it is rather isolated in its occurrence, it cannot be definitely correlated with any of the major intrusives. It occurs only 300 feet from one of the small bosses of Colquitz gneiss intrusive into the Leech River schists and is, of course, not far from the large batholith of the Wark and Colquitz gneisses. However, since the dyke rock, although sheared slightly, does not exhibit evidence of profound foliation as the Wark and Colquitz gneisses do, it is unlikely that it should be correlated with either of them. Of the other rocks in the Sooke and Duncan map-areas, the dyke rock is most like the granite facies of the Sooke intrusives and, although classed as a quartz diorite, differs from a typical quartz diorite in the alkalinity of its feldspar; this suggests that the rock is a differentiate of a quartz monzonite or granite rather than of a quartz diorite or even a granodiorite. The writer is strongly inclined to correlate the so-called quartz diorite porphyrite with the Sooke intrusives and to consider it as of lower Oligocene age. In the absence of definite information, and on account of the relative insignificance of the two known dykes, they are described at this place with the other minor intrusives most probably of upper Jurassic age, that appear to have accompanied or followed the irruption of the main batholithic rocks.

HORNBLENDE-AUGITE ANDESITE PORPHYRITE.

DISTRIBUTION AND STRUCTURAL RELATIONS.

Near the dam of the upper Goldstream reservoir small irregular dykes which resemble the Sicker volcanics cut a complex of the Wark and Colquitz gneisses. Similar dykes have been noted by Cooke cutting the Vancouver volcanics of Mt. Waterloo.

LITHOLOGICAL CHARACTERS.

The dyke rock is greyish green with an aphanitic groundmass and numerous phenocrysts of hornblende which are in large part pseudomorphs after augite, and more numerous but smaller phenocrysts of white weathering feldspar.

Microscopically the essential minerals of the groundmass were originally augite, hornblende, and plagioclase feldspar, apparently andesine, with accessory magnetite. The original minerals have been greatly altered and are now largely replaced by uralite, chlorite, epidote, and zoisite. In the altered groundmass are the distinguishing hornblende phenocrysts that are pseudomorphs after augite. They average about 0·5 cm. in diameter, but some attain a diameter of nearly 1 centimetre. Although the phenocrysts are numerous the groundmass greatly predominates. The rock is classed as a hornblende-augite andesite porphyrite.

RESEMBLANCES, AND AGE AND CORRELATION.

The hornblende-augite andesite porphyrite is almost identical with the Sicker andesite flows and is similar to the Sicker gabbro-diorite porphyrite, although, of course, much finer-grained. It cannot, however, be definitely correlated, merely on the basis of lithology, with the Sicker andesites. On the other hand, since the Sicker andesites are best considered to be in general comparable with the Vancouver volcanics into which the Wark and Colquitz gneisses are intrusive, and since the dykes of hornblende-augite andesite porphyrite are injected into the Wark and Colquitz gneisses, it seems fairly certain that the two rocks are not contemporaneous. The dykes cannot be even tentatively correlated with the Sicker gabbro-diorite porphyrites, which are presumably younger than the Wark and Colquitz gneisses and yet are related to the Sicker andesites. They are probably, however, one of the minor intrusives that accompanied or followed the irruption of the upper Jurassic batholiths.

Nanaimo Series.

GENERAL DESCRIPTION AND STRATIGRAPHY.

All of the unmetamorphosed sedimentary rocks of southern Vancouver island supposed to be of Mesozoic (largely Upper Cretaceous, Nanaimo) age and possibly of lower Cenozoic (Eocene) age were previously grouped together by the writer because the sediments could not be definitely subdivided and were supposed to consist of two or more unconformable formations. They were called[1] the Cowichan group[1]. It was found, however, during the detailed work of 1910 and 1911 in the Saanich and Nanaimo map-areas, that all the sediments of the so-called Cowichan group rested unconformably upon the metamorphic and granitic rocks of the island, were conformable with each other, and were largely, if not entirely, of Upper Cretaceous age and members of the Nanaimo series or formation, so named and described by Richardson[2], Whiteaves[3], and Dawson[4]. Since the probability of there being any Eocene members in the conformable series of sediments is very slight,[5] the name Nanaimo was extended to embrace the entire conformable series which in the Nanaimo map-area was definitely subdivided into various members or formations. It has been found by Cooke[6], that the transition supposed by the writer to occur along the Chemainus river[7] between the unmetamorphosed rocks of the Cowichan group and the metamorphic rocks of the Sicker series does not exist; but that there is instead a transition between somewhat metamorphosed conglomerates and sandstones and conformably overlying unmetamorphosed sandstones and shales and that the metamorphosed conglomerates rest unconformably upon the schistose Tyee quartz-feldspar porphyrites (sericitic schists) intrusive into the Sicker series. It was supposed als

[1] Geol. Surv., Can., Mem. 13, 1912, p. 121 and pp. 134–136.

[2] Richardson, James, "Report on the coal fields of Nanaimo, Comox, Cowichan, Barclay Inlet, and Sooke, B.C.," Geol. Surv., Can., Rept. of Prog., 1876–77, pp. 160–192.

[3] Whiteaves, J. F., Geol. Surv., Can., "Mesozoic fossils," vol. I, part II, 1879, pp. 93–99.

[4] Dawson, G. M., "The Nanaimo group." Am. Jour. Sc., vol. 39, 1890, pp. 180–183.

[5] Geol. Surv., Can., Mem. 51, 1911, pp. 44–45 and 79–80.

[6] See p. 157.

[7] Geol. Surv., Can., Mem. 13, 1912, pp. 84–85.

that the steeply dippling sandstones and shales forming the base of Mt. Prevost were unconformably overlain by the gently dipping conglomerates forming the top of Mt. Prevost.[1] The discordance of dip is now explained more satisfactorily in another way since the lower (Haslam) shales and sandstones are in most places clearly conformably overlain by the conglomerates (Extension formation). The discordance is probably due to the crumpling and nearly isoclinal folding of the weak shales beneath the more competent conglomerates which were deformed only into broad open folds. Also some thrust faulting has probably occurred along the contact of the shales and conglomerates. It is thus fairly certain that all of the sediments previously mapped as the Cowichan group are conformable and, since they contain in places fossils of Nanaimo age, are all members of the Nanaimo series. The term, Cowichan group, therefore, will no longer be used.

The rocks of the Nanaimo series occur in two principal areas or basins; one the southeastward extension of the Nanaimo basin, and the other, the Cowichan basin. The portion of the Nanaimo basin within the Duncan map-area fringes the east coast of Vancouver island from Ladysmith to Crofton and its rocks form the northern part of Saltspring island and all of the smaller islands of the northeastern part of the map-area. The Cowichan basin is separated from the Nanaimo basin by a narrow axis of the crystalline rocks of the Sicker series and their intrusive porphyrites occurring to the south of Crofton, and extends from the east coast of Vancouver island entirely across the map-area. It has a maximum width of nearly 10 miles, but in its eastern portion it is broken by a narrow axis of crystalline rocks of the Sicker series and in its western part it is divided into three elongate basins, which partly fill anticlinal valleys in the Sicker series. The southern and largest of the three basins between the Sicker series on the north and the Vancouver volcanics on the south underlies the Cowichan valley. A very small outlier of the Nanaimo series occurs near the first forks of the Koksilah river.

---

[1] Geol. Surv., Can. Mem. 13, 1912, pp. 131-132.

The rocks of the Nanaimo series consist of conglomerates, sandstones, and shales, with, in places, thin, coaly streaks and lenses associated with carbonaceous shales and sandstones. The total of the average thicknesses of the formations of the Nanaimo series within the Duncan map-area is 10,100 feet. Only the lower formations of the series are found in the Cowichan basin, although it is probable that the upper formations once occurred there and have been eroded, so that the total average thickness of the sediments in the Cowichan basin is only 4,950 feet. The totals of the minimum and maximum thicknesses of each formation are 7,950 feet and 13,200 feet in the Nanaimo basin, and 3,400 feet and 7,400 feet in the Cowichan basin; but no complete section along any single line is as thin or as thick as these totals, in fact it is very doubtful if any complete section differs greatly from the total average thicknesses given above.

Within the Nanaimo map-area, as has been already mentioned, the Nanaimo series was subdivided on a lithological and stratigraphical basis into eleven formations.[1] The recognition of these formations within the Duncan map-area has been difficult, owing to the change in the lithological character of some of the formations, the rapid vertical and lateral gradation of the sediments, the absence of distinct horizon markers, the deformed character of the rocks, and the poor and scattered exposures which in many places are separated by wide stretches of water, whereas in other places the rocks are hidden by a thick mantle of drift. However, it has been found possible to distinguish most of the formations by their continuity with the formations of the Nanaimo map-area, or by their lithological similarity, or by their stratigraphical position. One of the formations of the Nanaimo map-area, however, the East Wellington sandstone, the floor of the Wellington coal seam, is not developed in the Duncan map-area, nor are the three principal coal seams of the Nanaimo map-area, the Wellington, the New-

---

[1] Geol. Surv., Can., Mem. 51, 1914. As noted in the memoir, page 45, strictly speaking the subdivisions should perhaps be called "members," since they contain identical fauna; but since most of the subdivisions, while more or less characteristic and well defined, consist of several kinds of strata and are of considerable thickness, the term "member" is not so satisfactory as the term "formation."

castle, and the Douglas. Two of the formations of the Nanaimo map-area, the Cranberry and the Newcastle, are similar in lithology but are separated by the Newcastle coal seam. As the seam is not developed in the Duncan map-area the two formations cannot be differentiated there and hence are mapped together as the Ganges formation. In the Cowichan basin it has been impossible to separate the rocks of the Ganges formation from those of the Cedar District formation, since the intermediate formation, the Protection sandstones, can be recognized only in one place. Hence in the Cowichan basin the Ganges, Protection, and Cedar District formations are all mapped together as the Duncan formation. The formations with their principal lithological character and thickness are enumerated in the following table.

Table of Formations of the Nanaimo Series.

Name.	Lithological character.	Thickness.		
		Minimum.	Maximum.	Average.
Gabriola formation. (In the Nanaimo basin only)	Chiefly thick-bedded, but many medium to thin-bedded, yellowish grey, fine to coarse-grained, and in places concretionary sandstones, with some shaly sandstones and sandy shales	2,200	2,400	2,300
Northumberland formation. (In the Nanaimo basin only)	Sandy shales with thin interbeds of sandstone at the top, unexposed in the Duncan map-area; an upper middle portion of coarse - grained, thick-bedded sandstones with thick lens-like beds of coarse conglomerates of predominating, well rounded fragments of granitic, porphyritic, and quartzose rocks; a lower middle portion of thick-bedded to shaly sandstones and sandy shales; and sandy shales with thin sandstone interbeds and dykes at the bottom	1,700?	2,300	2,250

Table of Formations of the Nanaimo Series. (Continued.)

Name.	Lithological character.	Thickness.		
		Minimum.	Maximum.	Average.
DeCourcey formation. (In the Nanaimo basin only)	Chiefly thick-bedded, greenish grey, fine to coarse-grained, gritty and even pebbly sandstones, in places cross stratified and concretionary, and some thin-bedded to shaly sandstones and sandy shales	800	1,400	900
Cedar District formation. (In the Nanaimo basin only)	Chiefly dark grey, carbonaceous and ferruginous sandy shales, with numerous thin interbeds of brownish grey, fine-grained sandstone, and some thicker beds of yellowish grey, coarser-grained sandstone......................	750	900	800
Protection formation. (In the Nanaimo basin only)	Chiefly thick to thin-bedded, greyish white, fine to medium-grained sandstone, in places coarse-grained and pebbly, and thin interbeds of shaly sandstone and sandy shale......................	600 ?	700 ?	650
Ganges formation. (In the Nanaimo basin only)	Chiefly dark greenish, thin-bedded shaly sandstones and sandy shales................	700 ?	800 ?	750
Duncan formation. (In the Cowichan basin only the equivalent of the Cedar District, Protection, and Ganges formations)	Chiefly dark greenish, sandy shales and shaly sandstones, with numerous thin layers of sandstones, and at least one horizon of thick-bedded, greyish white, fine to medium-grained sandstone ..	2,200 ?	2,700 ?	2,500
Extension formation	Chiefly conglomerate of subrounded pebbles of a great variety of rocks in a predominating sandstone matrix, with thick interbeds of coarse-grained sandstone and thin layers of shaly sandstone and sandy shales. Near Ladysmith composed largely of greyish white, medium-grained sandstone...............	600	1,500 ?	800

Table of Formations of the Nanaimo Series. (Continued.)

Name.	Lithological character.	Thickness. Mini-mum.	Maxi-mum.	Aver-age.
Haslam formation	Chiefly thin-bedded, light to dark grey, sandy and carbonaceous, calcareous, and in places concretionary shales and fine-grained shaly sandstones. Toward the base predominating sandstones and arkoses..................	600	2,500 ?	1,500
Benson formation	Basal conglomerates and arkose....................	0	700	150
	Total in Nanaimo basin......	7,950 ?	13,200 ?	10,100
	Total in Cowichan basin.....	3,400	7,400	4,950

DETAILED DESCRIPTION OF FORMATIONS.

BENSON CONGLOMERATE.

Distribution and Thickness. The basal conglomerate of the Nanaimo series, called the Benson conglomerate, is developed only locally along the eastern base of Mt. Brenton, east of Crofton, and on Maxwell mountain and near Maxwell lake on Saltspring island, in the Nanaimo basin; and on and near Mt. Tzuhalem, overlapping upon Mt. Sicker, in places along the Chemainus river and in the narrow extensions to the west of the river, and on the south slope of the western part of the Cowichan valley, in the Cowichan basin. Elsewhere the arkosic but shaly sandstones of the lower part of the Haslam formation rest directly upon the underlying crystalline rocks. The basal conglomerate is well exposed in most of the localities mentioned, but especially well on Mt. Maxwell and Mt. Tzuhalem where it attains its maximum thickness of 700 feet. The conglomerate thins out rapidly, so that within 2 miles to the northwest of Mt. Maxwell the overlying sandstones and shales rest upon the crystalline rocks. Owing to its rapid variation its average thickness can only be estimated approximately, as about 150 feet.

Lithological Characters. The Benson conglomerate varies from a typical coarse basal conglomerate, composed of angular or subangular fragments of the immediately underlying rocks to a fine breccia-conglomerate, and in places even to an arkose which, although it rests upon the crystalline rocks, is interbedded with dark carbonaceous, sandy shales characteristic of the Haslam formation. Where the conglomerate is thick, as on Mt. Tzuhalem and Mt. Maxwell, the fragments of the lower portion are distinctly angular and unsorted, while those of the upper portion are fairly well rounded, sorted, and arranged in layers. Some of the larger fragments are 3 or 4 feet in diameter, but the average size is not more than an inch. They are composed of all of the older metamorphic and granitic rocks, but fragments of chert, vein quartz, fine-grained meta-andesite, and granodiorite predominate. Near the small outlier in the Koskilah river, are boulders of a basal conglomerate with rounded pebbles of limestone. The fragments are contained in an abundant matrix of coarse, arkosic sandstone or fine breccia which, as mentioned, forms in places the entire rock. The arkose is of a prevailing greenish colour and contains large amounts of feldspar, largely albite, as well as quartz and considerable biotite, chlorite, epidote, magnetite, ilmenite, muscovite, and calcite. Small, angular grains of undecomposed rock fragments, notably Sicker andesite and gabbro-diorite porphyrite, are also numerous. The conglomerate is cemented partly by calcite and ferruginous minerals and largely by argillaceous and carbonaceous matter. In places it contains disseminated pyrite and in the south end of Copper canyon is somewhat foliated and schistose.

HASLAM FORMATION (MARINE SHALES).

Distribution and Thickness. Overlying the Benson conglomerate, but in many places resting directly upon the underlying crystalline rocks, is the Haslam formation which is locally called the "marine shales" on account of the marine fossils which are found in the sandy shales composing the larger part of the formation. The Haslam formation extends along the inner, southwestern border of the Nanaimo basin in an unbroken belt, one-eighth of a mile to over 3 miles in width, from Ladysmith to south of Crofton. It also extends across the central part of Saltspring island, underlying the valley between Mt. Maxwell and Mt. Erskine. In the Cowichan basin, the Haslam formation outcrops along the southern boundary, in a belt from half a mile to over a mile wide; it also directly underlies the greater portion of the northern part of the Cowichan basin, being overlain only by the Extension conglomerates of Mt. Prevost and of the ridge extending westward from Mt. Prevost. In the three arm-like, westward extensions of the Cowichan basin the only remaining rocks are those of the Haslam formation and underlying Benson conglomerate. Although they are unexposed within the Duncan map-area it is quite certain that the Haslam shales underlie the broad, low valley on Saltspring island extending southeast from Burgoyne bay on the west coast of the island to Fulford harbour on the east coast. The rocks are exposed on the southwestern shore of Fulford harbour and a deep shaft near the head of the harbour penetrates the thick drift mantle into the Haslam shales. In addition, the sandy shales of the small outlier in the upper part of the Koksilah river doubtless belong to the Haslam formation.

The rocks of the Haslam formation are usually heavily drift covered, but many streams have cut through the drift cover and into the Haslam rocks. The larger streams, especially the Chemainus river and the middle portion of Cowichan river, have cut deeply into the rocks to form narrow canyons or gorges, 100 to 200 feet deep, which afford excellent exposures of considerable thickness of the Haslam rocks.

The Haslam formation is much thicker in the Duncan map-area than in the Nanaimo map-area; in the latter it has an average thickness of about 600 feet. Although its thickness in the northern part of the Duncan map-area is not much more than 600 feet, along the Chemainus river, well over 1,500 feet of rocks belonging to the Haslam formation are exposed. At the base and resting upon the basal conglomerates are 300 feet of massive, grey, arkosic sandstones, on which are 350 feet of shaly concentric-weathering sandstones, which are overlain in turn by nearly

1,000 feet of black sandy shales with thin sandstone beds. Within the Cowichan basin the thickness of the Haslam formation appears to be over 2,000 feet, and in places, as between Mt. Tzuhalem and Maple bay, where the Haslam formation rests upon the thick portions of the Benson conglomerate, there is nearly 1,000 feet of sandstones at the base of the Haslam formation, which are overlain by about 1,500 feet of sandy shales. The thickness of the formation varies, therefore, from 600 feet to nearly 2,500 feet, and averages about 1,500 feet.

Lithological Characters. The Haslam formation as in the Nanaimo map-area, is composed chiefly of thin-bedded, light to almost black, sandy, and usually carbonaceous shales. Some of the shales are ferruginous, and may contain pyrite, and weather to a reddish brown colour. Virtually all of the shales weather concentrically into rounded masses varying in size up to a foot in greatest diameter, and thus appear to have a concretionary structure. In places the shales contain hard sandy and flint-like concretions, with a calcareous cement. The concretions may vary from large ellipsoidal masses 3 to 5 feet in diameter and about 1 foot thick to small, irregular, grotesque forms 1 to 3 inches in diameter. On microscopic examination the shales are seen to be composed largely of fine, usually calcareous, silt in which are small angular grains of quartz and feldspar, chiefly albite, and more or less chlorite, epidote, muscovite, biotite, and calcite. Many of the shales are decidedly calcareous, and those exposed in the upper Koksilah are virtually consolidated marls, and in the lower part of the Chemainus river, some of the shales are crowded with calcareous shells. Several of the shales are cut by calcite veinlets, and the shales in the southern end of Copper canyon are somewhat schistose and are cut not only by calcite but by quartz veinlets.

The shales grade into fine-grained, shaly or argillaceous sandstone and throughout their entire thickness they are interbedded with thin beds of light grey, fine-grained, and often fairly siliceous sandstones. The sandstones average less than a foot in thickness and occur in great numbers from 1 to 10 feet apart. Toward the base of the formation the sandstone layers are thicker and of coarser grain; where the Haslam formation rests upon the thick portions of the Benson conglomerate, as on Mt. Tzuhalem and Mt. Maxwell, yellow, grey, and greenish, coarse and even pebbly sandstones form nearly 1,000 feet of sediments at the base of the formation. Elsewhere the formation rests upon the thin Benson conglomerate or directly upon the crystalline rocks. The sandstones grade into arkose or arkosic sandstones. The arkoses vary in lithological character, some being composed largely of the detritus from the metamorphic volcanic and sedimentary rocks of the Vancouver group and others being composed largely of the detritus of the Saanich granodiorite. The latter resemble more or less closely the granodiorite. They are greyish green, medium-grained rocks, composed of angular grains of quartz and feldspar, with flakes of biotite, in a greenish matrix. Under the microscope they are seen to contain the primary and secondary minerals of the granodiorite, and even the accessories, titanite and magnetite. The former are dark green, fine-grained rocks and they contain, in addition to quartz and feldspar, fragments of the dark, slaty and cherty rocks of the Sicker series and a large amount of chlorite, serpentine, and calcite. Some of the arkoses are carbonaceous, containing small carbonaceous and even bright coaly fragments. In places, especially in the lower sandstones, as exposed in the southern part of Maple bay, there are small lenses and seams of impure coal a few inches to a few feet thick and a few feet in extent.

EXTENSION FORMATION.

Distribution and Thickness. The Extension formation, which consists chiefly of conglomerates, occurs within the Nanaimo basin in three places; to the west of Ladysmith in a narrow belt less than 1,000 feet wide, fringing the coast between Chemainus and Crofton, and extending across the central portion of Saltspring island in a belt 1,000 to 2,000 feet wide. In the Cowichan basin the Extension formation outcrops in a belt 1,500 to 2,000 feet wide; it extends from the coast westward for 15 miles along the base of the southern slope of the Cowichan valley and then turns and crosses the valley; the belt also caps the ridge between Chemainus and Cowichan valleys, that culminates at its eastern end in Mt. Prevost. Along the coast between Chemainus and Crofton, the Extension conglomerates are well exposed, and on Saltspring island they form a well-defined cuesta-like ridge culminating in Mts. Erskine and Belcher; and in the southern steep slope of the two mountains, cut at right angles to their bedding, the conglomerates are very well exposed. Elsewhere the conglomerates are not well exposed and are largely drift covered, although they form in places as in Mt. Prevost, large outcrops which, however, do not extend for any great distance in the direction of the strike.

The thickness of the Extension formation varies ordinarily from 600 to 1,000 feet, averaging about 800 feet. On Mt. Prevost, however, the thickness appears to be at least 1,500 feet but some of the beds may be repeated by unrecognized faults. Over a large portion of the map-area the thickness of the formation does not vary significantly from its average thickness of 800 feet.

Lithological Characters. The Extension formation, as in the Nanaimo map-area, is composed largely of conglomerate. Within the Nanaimo map-area the fragments are almost entirely of quartz or quartzose rocks, but, within the Duncan map-area, they consist of a great variety of rocks: quartz and quartzose, slaty, and cherty rocks of the Sicker series; granodiorite, and granodiorite and gabbro-diorite porphyrites; and even metavolcanics. The fragments are angular to rounded, chiefly subrounded, and are somewhat larger than in the Extension conglomerates of the Nanaimo map-area. The largest fragments are over a foot in diameter and the average diameter is more than an inch. The fragments occur in a coarse-grained, predominating sandstone matrix, and in many places the conglomerates are interbedded with thick beds of coarse-grained sandstones, yellowish to olive grey in colour, and composed largely of angular grains of quartz and feldspar. The sandstone interbeds increase in number and thickness in the upper part of the formation and may be interbedded with thin layers of shaly sandstones and sandy shales, similar to those of the overlying formations. In the vicinity of Ladysmith, where it is poorly exposed, the Extension formation appears to be composed largely, as in the southern part of the Nanaimo map-area, of greyish white, medium-grained, siliceous sandstones. At places within the formation, the conglomerates and sandstones are cross bedded and exhibit contemporaneous erosion and deposition, structures which indicate that the formation was deposited in shallow waters.

GANGES FORMATION.

Distribution and Thickness. Overlying the Extension formation in the Nanaimo basin is a very poorly exposed formation composed largely of sandy shales. This is the equivalent of the Cranberry and Newcastle formations of the Nanaimo map-area. The Cranberry and Newcastle formations differ slightly in lithology but are separated by the Newcastle coal seam. As already noted the Newcastle seam is not developed within the Duncan map-area, nor can the Newcastle and Cranberry formations be distinguished. Hence the two formations are replaced by a single formation which is called the Ganges formation, since it is best exposed in the shores of Ganges harbour. The formation should outcrop in a narrow zone, 800 to 900 feet wide, extending through the town of Ladysmith, but the only exposure is on the shore south of the Ladysmith ferry wharf. It should outcrop to the north of Crofton between the Extension conglomerates and the Shoal islands built of Protection sandstones but is unexposed. The formation extends across Saltspring island beneath the valley between Booth bay on the west coast and Ganges harbour on the east coast. The width of the outcrop of the formation is about a mile; for, although the dips are high, certain beds are repeated by folding. The rocks of the formation are exposed along the southern and inner shores of both Booth bay and Ganges harbour. but, although the exposures are numerous, they are not continuous; hence it is impossible to do more than estimate roughly the thickness of the formation. The thickness of the formation is estimated to be about 750 feet and it does not appear to vary greatly in the different portions of the map-area.

Lithological Characters. The Ganges formation is composed of alternating thin-bedded, concentric-weathering, shaly sandstones and sandy shales. They are usually carbonaceous and hence dark in colour, and greenish from chlorite, biotite, and epidote derived from the underlying metamorphic volcanics. In the dark greenish, silty matrix are small angular fragments (predominating in the sandstones) of quartz and feldspar and of slaty, cherty, and volcanic rocks. Although the equivalent formations within the Nanaimo map-area contain the Newcastle and Douglas coal seams, no coal seams or even lenses are known in the Ganges formation of the Duncan map-area; and even the so-called "coal markings," impressions of leaves and bark, and coaly fragments are uncommon in the poorly exposed rocks of the Ganges formation.

PROTECTION FORMATION.

Distribution and Thickness. The Protection sandstone, which in the Nanaimo map-area is the best horizon marker in the Nanaimo series, extends into the Duncan map-area and is readily recognized among the rocks of the Nanaimo basin. A similar and presumably equivalent sandstone occurs at one place in the Cowichan basin; but since it cannot be traced away from the single exposure, within the Duncan map-area the formation is mapped only in the Nanaimo basin. The formation extends southeastward through the city of Ladysmith in a narrow belt less than 1,000 feet wide, and is well exposed along the shore and on the point southwest of Coffin point at the entrance to Ladysmith harbour. Farther to the southeast the rocks of the formation outcrop along the southwestern shore of Wil.. island, and form those islands of the Shoal Islands group that are nearest the main island. The formation extends across Saltspring island to the north of the Ganges formation, outcropping in a belt almost 1,000 feet wide. The rocks are well exposed on the point and ridge between Booth bay and Vesuvius bay and again on the north shore of Ganges harbour, and to the east of the map-area they form the Chain islands extending southeastward in Ganges harbour.

The thickness of the formation, as in the Nanaimo map-area, varies less than that of any other formation of the Nanaimo series, and is everywhere about 650 feet.

Lithological Characters. The formation consists chiefly of a greyish white, fine to medium and uniformly grained sandstone, consisting of subangular grains of quartz or of quartzose rocks and clear or white weathered feldspar, shreds of biotite and some white mica, and a few green and red grains of other minerals. Under the microscope the rock is seen to consist largely of granodiorite detritus, both orthoclase and plagioclase feldspar being present. The accessory and secondary minerals, besides those already mentioned, are epidote, chlorite, magnetite, titanite, zircon, and kaolin. The cement is chiefly secondary silica, and is not always sufficient to bind the rock firmly. The sandstone is thick to thin-bedded and in places is even flaggy, but thick beds are the most common. Some beds are cross stratified and even concretionary, and weather to a concentric or honeycomb structure. Although usually greyish white, weathering to a dirty or brownish grey, some beds are slightly ferruginous and have a yellowish grey colour on fresh fracture, and a brownish weathered surface. In places the sandstones are coarse-grained and pebbly and pass into fine conglomerates with well rounded fragments of quartz and quartzose rocks. Interbedded with the sandstones are fairly numerous, rather thin beds of olive grey, shaly sandstones, and of darker, carbonaceous, siliceous, sandy shales. These beds are more numerous and thicker in the upper part of the formation and are transitional into the shales of the overlying Cedar District formation.

CEDAR DISTRICT FORMATION.

Distribution and Thickness. In the Nanaimo map-area the Protection formation is overlain by the Cedar District formation, which consists largely of sandy shales. Identical, and doubtless equivalent shales, and hence correlated with the Cedar District formation, overlie the Protection sandstones of the Duncan map-area. They are not, however, exposed near the boundary of the Nanaimo and Duncan map-area where they come to the surface. On Willy island they are well exposed, and are seen to overlie the Protection sandstones and they also form the outer islands of the Shoal Islands group. On Saltspring island the shales of the formation are ex[illegible]d on the shore of Vesuvius bay, at a few places betw[illegible]ins bay and Ganges harbour, and to the east of t[illegible]ong the northern portion of the inner shore of Ganges [illegible]

Like t[illegible]rotection formation, the thickness of this formation, [illegible]ot be well determined since continuous cross sectio[illegible] ha[illegible], seems to be fairly uniform and nearly the [illegible]e Na[illegible] map-area, varying but little from 800 fe[illegible]

Lithol[illegible] The formation consists chiefly of dark gr[illegible]thering, carbonaceous, ferruginous, and in places [illegible]careo[illegible] sandy shales, with a great number of thin (1 t[illegible] inch[illegible]eds of brownish grey, rather fine-grained sandstones. In the upper part of the formation on Saltspring island are small, rather thick (1 to 20 feet) beds of yellowish grey, medium to coarse-grained sandstones, similar to those which compose the larger part of the overlying DeCourcy formation.

DUNCAN FORMATION.

Distribution and Thickness. As already mentioned, the Protection sandstone can be recognized in the Cowichan basin only at one place, in the vicinity of the quarry to the east of the Esquimalt and Nanaimo railway nearly a mile northwest of Cowichan station. At that place the sandstones overlie shales which doubtless correspond with the shales of the Ganges formation. The overlying rocks are not exposed and neither may the sandstones be traced to the east or to the west. It is, therefore, impossible to separate in the Cowichan basin the sandstones and predominating shales, which overlie the Extension conglomerates, into the Ganges, Protection, and Cedar District formations; hence they are all mapped together as an equivalent formation, and called, after the principal town in the Cowichan valley, the Duncan formation.

The Duncan formation is the uppermost of the formations of the Cowichan basin, although it is probable that the upper formations of the Nanaimo series were once present but have been stripped away by erosion. The formation underlies most of the eastern and widest portion of the Cowichan valley. The rocks of the formation are repeated many times by complex folding and probably by faulting, so that the width of the area immediately underlain by the formation averages about 4 miles. The formation extends up the valley from Cowichan valley for more than 10 miles, and extends southeast to Saanich inlet. The rocks of the formation are very poorly exposed. Fairly long sections are afforded by the gorges of the Cowichan and Koksilah rivers. Other exposures occur at places in the shallow gorges of some of the smaller streams, in a few cuts along the Esquimalt and Nanaimo railway especially along the Cowichan branch, and at one or two places along the shore south of Cowichan bay. One or two small outcrops of sandstone occur in other portions of the valley, but elsewhere the formation is covered by a thick mantle of drift.

Since the formation is so poorly exposed as well as being complexly folded, its thickness cannot be determined. It must be fairly great, since in places, as along the Koksilah river, nearly 2,000 feet of sediments are exposed. If the formation was exactly the equivalent of the Ganges, Protection, and Cedar District formations, it would average about 2,200 feet thick; but it appears to be even thicker and 2,500 feet is doubtless a very moderate estimate.

Lithological Characters. The rocks of the formation are predominantly dark, carbonaceous, and in places greenish, sandy shales, similar to those of the Ganges and Cedar District formations. They grade into fine-grained shaly sandstones and are interbedded with numerous sandstones. Most of the sandstone layers are thin but some of them are thick bedded. The sandstones in and near the quarry northwest of Cowichan, like those of the Protection formation, are thick-bedded, greyish white, and fine to medium-grained.

DECOURCY FORMATION.

Distribution and Thickness. Overlying the Cedar District shales in the Nanaimo basin and continuing southeastward from the Nanaimo map-area, is a thick and fairly uniform formation, consisting chiefly of sandstones, called the DeCourcy formation.

The DeCourcy formation outcrops in the limbs and along the axes of four major folds in the northeastern portion of the map-area. The formation occurs chiefly on the point northeast of Ladysmith harbour, on Thetis, Kuper, and northern Saltspring islands, and on Reid and Hall islands. Other small islands and reefs between the larger islands are also composed of the DeCourcy sandstones. The rocks of the formation are well exposed in the shores of the islands, the best sections being found along the northwest shore of Saltspring island. Inland the rocks form a few rather small cuesta ridges, but are largely drift covered.

The thickness of the formation on Saltspring island and the smaller islands of the northeastern part of the map-area varies from 800 to 1,000 feet, averaging, as in the Nanaimo map-area, about 900 feet. To the northeast of Ladysmith harbour as in the adjoining portion of the Nanaimo map-area, the thickness increases to 1,400 feet.

Lithological Characters. The formation has the same lithological characters as in the Nanaimo map-area. The prevailing rock is a greenish grey, yellowish brown weathering, fine to coarse-grained, gritty, and even pebbly sandstone, composed of angular grains of quartz, feldspar, and meta-andesite, and shreds of muscovite and biotite, in a greenish matrix composed chiefly of chlorite. Also it is seen microscopically to contain magnetite, titanite, and epidote. Its cement is siliceous and ferruginous. It is chiefly thick-bedded, but there are many thin-bedded and even flaggy or shaly bedded portions. The sandstone is frequently cross-bedded and concretionary. Some of the concretions are very large, having a maximum diameter of 10 feet. They are frequently fissured and filled with indurated mud or fine sand, but in many places, the fissure filling has weathered out. The concretions themselves frequently weather out, leaving round holes in the sandstone. The sandstones also weather into "galleries" with honeycombed surfaces (Plate III A). In places, as in the northeast shore of Ladysmith harbour and in Reid and Hall islands, the sandstones are chiefly very coarse, and pass into conglomerates with large subangular to well rounded fragments, averaging over an inch in diameter, of quartz, meta-volcanics, granodiorite, and granodiorite porphyrites, in a predominating sandstone matrix. Interbedded with the sandstones are relatively thin beds, a few inches to 2 or 4 feet in thickness, of darker, carbonaceous sandy shales and shaly sandstones. These shaly interbeds are more numerous in the lower and upper portions of the formation which is transitional into the Cedar District shales below and the lower shales of the Northumberland formation above. The transitional zones, 100 to 200 feet thick, consist of interbedded shaly sandstones or sandy shales and thick-bedded sandstones in about equal amount. The first bed of coarse sandstone, 20 feet or more in thickness, is considered as the bottom or top of the DeCourcy formation.

NORTHUMBERLAND FORMATION.

Distribution and Thickness. Overlying the DeCourcy formation is the Northumberland, a formation consisting of shale, sandstone, and conglomerate, but limited at the top and bottom by persistent beds of sandy shale. Within the Duncan map-area the upper shale is not exposed, but it occurs at no great distance both to the northwest on Valdes island, and to the southeast in the southern part of Galiano island. The Northumberland formation outcrops with the DeCourcy formation in the limbs and along the axes of the four major folds in the northeastern part of the map-area. The formation occurs chiefly on Thetis, Kuper, and northern Saltspring islands, and on Norway, Secretary, and Wallace islands. On the map a small area is shown overlying the DeCourcy formation on the peninsula northeast of Ladysmith harbour, but the formation is not exposed on account of the thick drift mantle. However, considering the thickness and structure of the underlying DeCourcy formation, the Northumberland formation must outcrop below the drift, and was so shown on the map of the adjoining Nanaimo map-area. Elsewhere the rocks of the formation are well exposed, and excellent and fairly extensive sections are displayed along the shores of Thetis, Kuper, and Saltspring islands.

The Northumberland formation varies greatly in thickness. In the Nanaimo map-area the thickness varies from 1,100 to 1,200 feet, and to the southeast, in the southern part of Galiano island, it is over 2,500 feet. In the Duncan map-area the entire thickness of the formation is not exposed, yet a section 1,670 feet thick is exposed along the north shore of Thetis island about a mile north of the map-area, and one 1,560 feet thick is exposed along the northwest shore of Saltspring island. The upper shales of the Northumberland, unexposed within the Duncan map-area, average nearly 500 feet thick, so that the thickness of the Northumberland formation in the Duncan map-area is in most places doubtless more than 2,000 feet, and is probably nearly 2,250 feet, although it appears to be considerably less in the northeastern part of the map-area where it is perhaps not more than 1,700 feet.

Lithological Characters. The Northumberland formation consists of shales, sandstones, and conglomerates, with the shales occurring chiefly at the top and bottom of the formation. The generalized section of the formation is as follows:

	Thickness in feet.
Sandy shales and thin layers of sandstone. (Unexposed in the Duncan map-area.)	500
Coarse-grained sandstone and conglomerates	800
Interbedded sandstones and sandy shales	600
Sandy shales with thin layers of sandstone	350
Total	2,250

The relation of the generalized to the actual sections is shown by the two following sections of the formation, which are the most complete and best exposed in the map-area.

Sections of the Northumberland Formation.

Southwestward dipping rocks on the northwest shore of Saltspring island, fron 2 to 3 miles north of Vesuvius bay.

	Thickness in feet.
Sandstone, chiefly coarse-grained and medium to thick-bedded	550
Unexposed, probably thin-bedded and shaly sandstones	70
Sandstone, chiefly coarse-grained and thick-bedded	100
Unexposed, probably sandy shales and shaly sandstones	50
Sandstone, chiefly coarse-grained and thick-bedded, but numerous beds of fine-grained sandstones which are medium and thin-bedded and even shaly	250
Sandy shales with thin beds of sandstone	100
Sandstone, medium to coarse-grained and thick-bedded	70
Sandy shales with a few thin beds of sandstone and sandstone dykes	370
Total	1,560

Southwestward dipping rocks, north shore of Thetis island.

Chiefly coarse-grained thick-bedded sandstone, some fine to coarse conglomerate, and a few thin beds of shaly, fine-grained sandstones	800
Thin-bedded and shaly sandstone	80
Unexposed, probably sandstone	100
Sandy shales with numerous sandstone layers 1 to 6 feet thick	140
Unexposed, probably sandstone	40
Coarse-grained thick-bedded sandstone	170
Unexposed, probably sandy shales	340
Total	1,670

The shales are grey, somewhat carbonaceous, thin-bedded and sandy, and are interbedded with numerous layers, 2 to 6 inches thick, of yellowish grey, fine to medium-grained sandstone, and with a few beds, up to 10 feet thick, of coarse-grained sandstone. As in the Nanaimo map-area, the shales are cut by sandstone dykes which are especially well exposed in the northwest shore of Saltspring island 3 miles north of Vesuvius bay, and on the small islet called Idol island nearly half a mile off shore. Many of the dykes, some of which are 3 feet thick, are regular but others are irregular and branching. In the shale at the southern extremity of the Secretary islands is a lens of conglomerate, 3 feet thick and 10 feet wide, which evidently fills an old channel eroded in the shale during its deposition.

The sandstones are chiefly yellowish to olive grey, brownish weathering, and thick-bedded, and are similar to the sandstones of the DeCourcy and overlying Gabriola formations. Like the DeCourcy and Gabriola sandstones, they are commonly concretionary and weather into "galleries" with honeycombed surfaces. The conglomerates occur as rather lens-like interbeds in the sandstones and measure as much as 15 feet thick; but to the southeast of the map-area and in the southern part of Galiano island the Northumberland conglomerates are nearly 1,000 feet thick. The conglomerates consist of fragments of virtually all the crystalline and metamorphic rocks of Vancouver island: vein quartz, cherty and schistose rocks of the Sicker series, granodiorite and diorite, porphyrites, meta-andesites, and even limestones and sandstones. The fragments are well rounded, some are several inches in diameter, and they average over an inch in diameter, and in most of the conglomerates they greatly predominate over the sandstone matrix.

GABRIOLA FORMATION.

Distribution and Thickness. In the Duncan map-area the Gabriola formation, the highest of the Nanaimo series, occurs only on Galiano island, the outermost of the island group. The rocks of the formation, mostly sandstones, are very well exposed along both shores of the island and in the interior of the island they form long cuesta ridges with steep, bare slopes on the southwest, perpendicular to the bedding, but with wooded, drift or talus covered slopes on the northeast, nearly parallel to the bedding. The exposed thickness of the formation in the Duncan map-area varies from 2,200 to 2,400 feet, but in the southern part of Galiano island, to the southeast of the map-area, the thickness increases to 3,000 feet.

Lithological Characters. The Gabriola formation consists largely of sandstones. These are chiefly thick-bedded, but many are medium to thin-bedded, yellowish grey, brownish weathering, fine to coarse-grained, concretionary, and in places inconspicuously cross-bedded. The concretions, which average 1 to 3 feet in diameter, weather out leaving holes, and, where the sandstones are subject to wind and to some extent to wave erosion, especially along the shores where the calcareous cement has been partially dissolved by salt-water spray, the sandstones have been carved into hemispherical and hemicylindrical caves, or as they are locally called, galleries. In places the walls of the galleries are smooth, but in other places the sandstone is of unequal resistance and has been carved into fantastic shapes with lacework and honeycomb patterned surfaces. The sandstones are composed chiefly of angular grains, 0·1 to 2 mm. in diameter, of quartz, feldspar, and meta-volcanics, and flakes of biotite in a greenish matrix composed of chlorite, serpentine, epidote, and magnetite, cemented largely by calcite. Interbedded with the medium and thick-bedded sandstones are numerous, relatively thin layers of thin-bedded and shaly sandstones, and in places sandy shales. The shaly beds are exposed at a few places along the shores which are nearly parallel to the strike of the rocks; but in the interior of the island they are exposed at only one or two places in the steep southwestern cliffs of the cuestas, beneath massive resistant sandstones. It is probable, however, that the narrow valleys between the cuestas are directly underlain largely by shaly sandstones and sandy shales.

STRUCTURAL RELATIONS OF THE NANAIMO SERIES.

INTERNAL.

Nanaimo Basin.

Folding. The rocks of the Nanaimo basin have a general northwest-southeast strike and a prevailing dip to the northeast. The angle of dip is chiefly from 15 to 30 degrees, but angles of 50 to 60 degrees are common, and near Ladysmith the dip is nearly vertical. The rocks are, however, involved in a few large folds and several smaller ones. Virtually all the folds are longitudinal, and hence have northwest-southeast axes. Only a few of the folds have a decided pitch, but folds pitching and flattening out to northwest and others pitching and flattening out to southeast occur. The larger folds extend across the Duncan map-area, beginning in the adjacent Nanaimo map-area. These are the Kulleet syncline to the southwest and the Trincomali anticline to the northeast. Between these two are an anticline and a syncline which, although they begin in the Nanaimo map-area, are there of little importance and have not been previously named. These may be called the Thetis anticline and the Channel syncline.

The Kulleet syncline is a rather sharp crested syncline involving chiefly the Northumberland and DeCourcy formations. Its axis extends from Kulleet bay in the Nanaimo district southeast beneath Stuart channel and between Kuper and Tent islands to and nearly across Saltspring island. The trend varies from north 35 degrees west to north 60 degrees west, and averages north 50 degrees west. The limbs dip at angles varying from 5 to 80 degrees. The southwestern, northeasterly dipping limb is the steeper, its dip averaging about 55 degrees; the dip of the rocks on Saltspring island varies from 40 to 75 degrees, while that at Coffin point is 80 degrees. The dip of the northeastern, southwesterly dipping limb averages only about 17 degrees. The southeastern end of the fold near Saltspring postoffice pitches to the northwest at a low angle. The fold near this place is virtually offset to the northeast for somewhat more than a mile, by a transverse anticline, so that the northwesterly end of the offset portion of the syncline which extends many miles to the southeast, pitches at a low angle to the southeast. Between the broken ends of the folds are three well-defined smaller folds, two anticlines and a syncline, and numerous wrinkles or contortions.

The Thetis anticline is an open but fairly sharp crested anticline which extends southeastward from Yellow point in the Nanaimo map-area, crosses the eastern portion of Thetis and Kuper islands, and continues across Saltspring island, parallel to and not far from the northeasterly shore of the island. It varies very little from its average trend of north 45 degrees west. The crest of the fold is best exposed in the north shore of Thetis island, less than a mile north of the map-area, and the character of the fold is well shown in the shores of the little cove at the northern extremity of Saltspring island, although the crest of the fold at the latter locality has been destroyed by erosion. The limbs of the anticline, consisting largely of the DeCourcy sandstones, dip at angles varying from 10 to 45 degrees, and averaging about 25 degrees; the northeastern limb is somewhat the steeper.

The Trincomali anticline with its eroded axis beneath Trincomali channel extends southeastward from the Nanaimo map-area with a trend of south 45 degrees east. Across the Duncan map-area the axis extends between Reid, Hall, and Galiano islands on the northeast and Norway, Secretary, and Wallace islands on the southwest. However, a few hundred feet north of the map-area, on a small reef off the northwestern point of Reid island the crest is actually exposed. The northeastern limb of the fold, in which the DeCourcy and Gabriola sandstones are the only exposed rocks, dips at angles varying from 12 to 30 degrees and averages about 20 degrees. The southwestern limb is unexposed in the Duncan map-area, but its dip is probably steeper than that of the northeastern limb.

Between the Thetis anticline on the southwest and the Trincomali anticline on the northeast there must be a syncline. This syncline which is called the Channel syncline, since it extends southeast beneath Trincomali channel, is doubtless a continuation of the syncline south of Boat harbour in the Nanaimo map-area. Across the Duncan map-area its axis must be nearly parallel to the axis of Trincomali anticline and cannot occur more than half a mile from it. The southwestern limb is, of course, the only one exposed and this, which is composed of both the Northumberland and DeCourcy formations, dips northeastward at angles varying from 35 to 65 degrees and averaging about 45 degrees.

Besides the larger folds just described there are many smaller folds, the larger and better exposed of which are shown on the accompanying maps. The smaller folds are largely of the nature of secondary folds produced by the slipping of the competent beds over each other during folding. The smaller folds are, therefore, longitudinal; and as already mentioned, cross folding is nowhere conspicuous. Along the coast of Vancouver island, between Crofton and Ladysmith, are two small basins. The southern and larger of the two basins drained by the Chemainus river is nearly 4 miles in width, and, separated from it by an axis of the underlying crystalline rocks, is a smaller basin about 2 miles wide. These basins are largely underlain by the Haslam shales which are wrinkled into small, open, longitudinal folds, of no very great extent, with gently dipping limbs, the southwestern limbs of the anticlines being shorter and steeper. To the north of the probable fault contact with the Sicker series on Saltspring island and south of Booth bay, the Haslam shales are somewhat crumpled into small open folds; farther north the Ganges formation also is involved in two well-defined folds; a longitudinal syncline and anticline, and a few smaller wrinkles with accompanying faults of small displacement. These folds are not exposed in the Duncan map-area but are exposed a short distance to the east in the south shore of Ganges harbour, and must extend westward into the Duncan map-area.

The steeply dipping DeCourcy sandstones to the northeast of Ladysmith harbour are contorted slightly and are broken by small faults. In central Saltspring island in the vicinity of St. Mary lake near the break in the Kulleet syncline, the rocks of the DeCourcy and Northumberland formations are greatly crumpled into three relatively large folds, already mentioned; two anticlines and a corresponding syncline, and several smaller folds. Movement in the limbs of the larger folds is also recorded by the insignificant strike faulting in the Cedar District shales of Vesuvius bay, and by the crumpling, slight faulting, and sandstone dykes in the lower shales of the Northumberland formation on the northwest shore of Saltspring island 3 miles north of Vesuvius bay.

The most pronounced zone of folding occurs along the northeast shore of Saltspring island where the weaker rocks of the Northumberland and DeCourcy formations are involved in rather sharp crested longitudinal folds, two of which at least, an anticline and corresponding syncline, extend along the whole length of the shore.

Faulting. As already mentioned, the weaker rocks in the Nanaimo basin, where crumpled by the sliding of the strong, competent beds over one another as a result of folding, are slightly faulted. These faults are usually strike faults of nearly vertical dip, and are of no great displacement, the slip being seldom more than 2 or 3 feet; many of the faults are little more than abrupt, sharp angled rolls or wrinkles. Cross or dip faulting has been noted in places, especially in the Ganges formation to the east of the map-area, but is not common and the slip of the cross faults is only a few feet. Large strike faults such as those of the Nanaimo map-area do not occur in the Nanaimo basin of the Duncan map-area, although more or less strike faulting has taken place along the contacts with the underlying metamorphic rocks. The amount of displacement along these faults, which have been noted southwest of Ladysmith, southeast of Crofton, and on Saltspring island south of Booth bay, is probably slight, perhaps not more than a few feet.

Jointing. The jointing of the rocks in the Nanaimo basin is usually irregular, although in a few places parallel sheet jointing is to be observed. Along the axes of the folds and in the weaker rocks the jointing is extreme, but in most places in the thick-bedded sandstones and conglomerates the joints are few and small.

Cowichan Basin.

Major Folding and Faulting. The rocks of the Cowichan basin have a general north 60 to 70 degrees west strike and steep dips of 30 to 80 degrees to the north. The structure of the basin is in general synclinal, but the major synclinorium consists of two rather closely folded synclines slightly overturned to the southwest. The northern limb of each syncline is broken by a fault, and in each case the northern hanging-wall has been shoved up over the southern foot-wall. Along the northern fault the underlying crystalline rocks have been brought against the Haslam shales, but, along the southern fault, the crystalline rocks have been brought to the present surface only in the eastern and western portions of the basin. Although the fault is not actually exposed, its existence and location in the eastern portion of the map-area are reasonably certain. It extends from the Saanich map-area across the southern end of Saltspring island, where the Sicker series on the north are thrust against the basal (Benson) conglomerates and Haslam shales which are folded against the fault into a small, closed syncline. The fault extends northwest beneath the waters of Satellite channel and Cowichan bay, still separating the crystalline rocks of the Sicker series on the north from the Nanaimo sediments on the south. Northwest of Cowichan bay it is not clear whether the sediments which are in fault contact with the Sicker series and which are folded into a small syncline like that on Saltspring island, are members of the Duncan formation, or whether they are the basal rocks of the series and members of the Haslam, Benson, or even Extension formations. The sediments have been mapped with the Duncan formation and this interpretation seems the best. Somewhat farther northwest the northward dipping shales, more certainly of the Duncan formation, are in fault contact with the basal rocks, also northward dipping, the Benson conglomerates and lower sandstones of the Haslam formation. Owing to the lack of outcrops, and to the lack of distinguishing features between the shales of the Duncan and Haslam formations the extension of the fault across the map-area is questionable. However, to the west of the map-area, in the vicinity of Cowichan lake, a faulted syncline, similar to that at the eastern end of the valley, is observed. A similar structure best explains the relations of the rocks in the western portion of the Cowichan valley in the Duncan map-area, where the generally northward dipping rocks of the Haslam formation dip against the rocks of the Sicker series which form the ridge that steeply surmounts the valley on the north. That the fault extends northward from Cowichan bay for at least 2½ miles to beyond Quamichan lake, is proved by a small outcrop of the Sicker schists to the southwest of the lake. Farther west there are no outcrops of the Sicker rocks for 8 miles, but throughout the valley are scattered outcrops of the Nanaimo sediments, chiefly shale. However, as is shown by the relations of the Haslam shale and the overlying Extension conglomerates on the Mt. Prevost ridge, the northern of the two closed synclines extends west completely across the basin, and it is fairly certain that the southern syncline does also. But the Extension conglomerates, well developed in the southern limb of the southern syncline, and again developed in the northern syncline are missing in what would be the north limb of the southern syncline. Thus all the evidence available goes to prove that the fault breaking across the northern limb of the southern syncline does extend entirely across the basin, with insufficient throw in its middle portion to bring the underlying Sicker series to the surface; so that in its middle portion the fault separates the Haslam shales on the north from the Duncan shales on the south.

The character of the fault has already been indicated. The rocks on the north have been thrust up against, and apparently over, the rocks on the south. The dip of the fault cannot be ascertained, but, where it crosses the southern end of Saltspring island, it appears to be nearly vertical, or has a steep dip to the north. For the greater part it probably has a northward dip which is everywhere fairly steep and approaches the vertical. The fault trace is fairly straight and is nearly parallel to the strike of the rocks but, in its west central portion, it appears to turn to the southwest for 3 miles and to bevel across the Duncan and Extension formations. The actual slip or throw of the fault cannot be accurately determined. The throw appears to be greatest near Cowichan bay where if the sedimentary rocks on the south are correctly mapped as members of the Duncan formation, the stratigraphic separation of the fault is at least 4,000 feet. The throw is doubtless least in the middle portion of the fault to the south of Mt. Prevost where the stratigraphic separation appears to be less than 3,000 feet. Owing to the steep northward dip of the beds the throw and the slip of the fault must be considerably greater than the stratigraphic separation, presumably from about 4,500 to 6,000 feet.

The fault which breaks across the northern syncline is actually exposed only in its extreme western portion, in the Copper canyon of the Chemainus river where it has but very little if any actual displacement; for, as Cooke[1] describes, at that place the sheared basal conglomerate rests directly upon the eroded Sicker schists. Between Copper canyon and Maple bay the fault is well located at several places and southeast of Maple bay it extends beneath Sansum narrows to and across Saltspring island where it separates the Haslam shales underlying the valley between Burgoyne bay and Fulford harbour from the igneous rocks that occur to the north. At Maple bay the fault separates the upper portion of the Haslam shales, which dip steeply to the north, from the Sicker series; so that there the stratigraphic diplacement must be at least 1,500 feet and the throw and slip at least 2,200 feet. Across Mt. Sicker the lower portion of the Haslam shales, and at one place in the valley between Little and Big Sicker, the basal conglomerates are in contact with the Sicker rocks. Furthermore, as is indicated by the outliers of basal conglomerate on the southern flank of Mt. Sicker, the upthrow of the northern wall has been slight, perhaps not more than 700 to 800 feet. Although nearly parallel to the syncline the fault bevels across it at a slight angle; for,

[1] See page 156.

at Maple bay it cuts across the northward dipping, southern limb of the fold, whereas on Mt. Sicker the axis of the syncline occurs in Mt. Prevost over a mile to the south of the fault.

The northern syncline, only the eastern end of which is broken by the fault described above, consists chiefly of rather weak and incompetent rocks, shales, and shaly sandstones of the Haslam formation. These have been closely compressed and the northern limb of the syncline has been slightly overturned in places, so that now on the lower flanks of Mt. Prevost the rocks are virtually isoclinal and have a general north 70 degrees west strike and nearly vertical dip. Along the axis of the syncline, on Mt. Prevost and on the ridge extending west from Mt. Prevost, the Haslam shales are overlain by the Extension conglomerates. These rocks are folded into a small open synclinorium consisting of three or four short folds the limbs of which dip at angles varying only from 15 to 40 degrees. The conglomerates on Mt. Prevost, therefore, appear to bevel across the nearly vertical dipping shales outcropping on the flanks of Mt. Prevost. The contact between the shales and the conglomerates is not exposed on Mt. Prevost, but may be located within 100 or 200 feet, and both the shales and conglomerates retain their characteristic attitude near the contact. The disconformity in structure was formerly explained by the writer[1] as due to unconformity; but it has been shown by Cooke that the shales are not conformable with the underlying Sicker series as was formerly supposed, and that farther west on the Mt. Prevost ridge the conglomerates clearly conformably overlie the shales, as has been found to be true throughout the Nanaimo and Cowichan basins. The writer, therefore, fully concurs with Cooke's conclusions that the disconformity in structure is due largely to the fact that the conglomerate beds, being thick and competent, were not so greatly affected as the more incompetent shales beneath. In addition, as the folding took place in the zone of fracture, the folds were of the parallel type, and as Van Hise[2] and Leith[3] have shown, such folds rapidly die

[1] Geol. Surv., Can.,Mem. 13, 1912, pp. 131–132.
[2] Van Hise, C. R., "Principles of North American Pre-Cambrian geology." 17th Ann. Rept., U.S. Geol. Surv., part 1, 1896, pp. 598–601.
[3] Leith, C. K., "Structural geology," 1913, pp. 106–107.

out upward. The dying out of the folds downward is quite clearly shown by the more open folding in the Haslam shales, exposed along the railway track to the south of Tyee station. Furthermore, parallel folding is necessarily accompanied by a slipping between the competent and incompetent beds and hence it appears as if some slipping or faulting had taken place between the conglomerates and underlying shales. West of Mt. Prevost the syncline is poorly exposed but it appears to be more open and less complex. Although somewhat offset the syncline apparently extends still farther west to form the long narrow basin striking north 65 degrees west, which is followed by the Chemainus river. A similar but smaller basin extends north 55 degrees west across the southern slope of Coronation mountain. The two narrow basins appear to be rather closely folded synclines, but their rocks vary greatly and irregularly in dip and considerable minor faulting has taken place along the contacts with the underlying Sicker series.

Subordinate Folding and Faulting. Most of the subordinate folding in the Cowichan basin is secondary or longitudinal in character, and incidental to the major folding; it is, however, abundant. The weaker rocks, the shales and shaly sandstones of the Haslam and Duncan formations which directly underlie the greater part of the Cowichan basin, wherever exposed for several hundred feet, are seen to be warped into small, rather closely compressed to open folds. The larger of these folds are shown on the accompanying maps. Owing to the lack of outcrops the folds cannot be traced for more than a few yards, and hence their longitudinal extent cannot be determined. Most of the folds dip to the north, at low angles, that is their axial planes dip to the south at steep angles, and many of the folds pitch to the northwest.

Where the rocks are greatly crumpled they are also broken by strike faults of a reverse character. The rocks are in places, for example to the west of Duncan, broken by dip faults also. These are usually of small throw and to the west of Duncan the northwest side of the faults is the downthrown side.

Koksilah Basin.

The Haslam shales exposed in the single outcrop of the Nanaimo series in the Koksilah valley are greatly deformed. They have a general strike of north 75 degrees east and a dip of 50 to 80 degrees to the north. The rocks are not only contorted but are broken by a nearly horizontal thrust fault of small displacement, the upper wall having been pushed to the southwest over the lower wall.

EXTERNAL.

Relations to Older Formations.

The Nanaimo series rest unconformably upon the metamorphic sedimentary and volcanic rocks of the Vancouver group and upon the granitic rocks and porphyrites of upper Jurassic age that are intrusive into the metamorphic rocks. The unconformable contact is exposed and the structural relations are clearly revealed at several places. It was formerly supposed by the writer that the shales and basal conglomerates in Copper canyon of the Chemainus river, there somewhat metamorphosed and sheared, were transitional into the Sicker schists; but Cooke has clearly demonstrated that the somewhat metamorphosed sediments rest unconformably upon the schistose Tyee quartz-feldspar porphyrites. The basal sediments of the Nanaimo series consist of coarse basal conglomerates composed of fragments of the underlying metamorphic and crystalline rocks or arkoses composed largely of mechanically formed debris derived from the underlying rocks. These rocks rest upon an erosion surface cut indiscriminately across the deformed sedimentary and volcanic rocks and granitic and porphyritic rocks. The erosion surface is not, however, smooth, but is of considerable relief. Small irregularities are directly observable in exposed unconformities, best displayed around the southern flanks of Mt. Maxwell and of Mt. Tzuhalem. In addition it has been described how the basal (Benson) conglomerates thin out completely in places, while in other places they are 700 feet thick. The thick, somewhat lens-shaped masses of conglomerate were doubtless deposited in local basins, channels, lakes, or estuaries, in the old erosion surface. It was formerly thought[1] that the basal sediments in portions of the Nanaimo basin should be correlated with formations considerably above the base in other deeper parts of the basin. Thus it was supposed that the thick basal conglomerates of Mt. Tzuhalem and Mt. Maxwell were the equivalent of the Extension formation; but this conclusion has not been supported by the recent work within the Duncan map-area nor by the revision of the structure and correlation of the formations necessitated by the recent detailed field work. It seems quite certain, on the other hand, that within the Duncan map-area, as within the Nanaimo map-area, only the Benson conglomerates and lower rocks of the Haslam formation are in contact with the underlying crystalline rocks.

It has, however, been shown[2], although not clearly exhibited in the Duncan map-area[3] that the contacts of the Nanaimo series with the underlying rocks, where not disturbed by such intense folding and faulting as has been general along the contacts within the Duncan map-area, follow very closely the contours of present elevations which must have been elevations at the time of deposition also. It appears that the sediments were deposited in bays, while resistant rocks formed headlands which now project into the basins underlain by the Nanaimo series. It is believed that the crystalline rock ridge west of Blainey and the ridge northwest of Chemainus, the latter being a spur of Mt. Brenton, were such headlands. Although the three narrow western extensions of the Cowichan basin are synclinal, it is not at all clear that the crystalline rock ridges between them were once covered by the Nanaimo sediments. Instead, it appears as if sedimentation, at least during the deposition of the rocks now found in the extensions, was more or less confined to anticlinal valleys in the Sicker series, for at several places, where no significant faulting has occurred, the Nanaimo sedi-

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 132-133.
Geol. Surv. Can., Mem. 51, 1914, pp. 76-77.
Geol. Surv., Can., Sum. Rept. 1913, p. 100.

[2] Geol. Surv., Can., Mem. 51, 1914, pp. 76-77, and accompanying maps of the Nanaimo map-area.

[3] The mapping of the contact of the Nanaimo series with the underlying Sicker series west of Crofton, as illustrated by the figure on page 133 of Mem. 13, Geol. Surv., Can., 1912, is incorrect.

ments appear to abut directly against the Sicker series. The outlier of the Haslam shales in the Koksilah valley is apparently a remnant of sediments that were deposited in a similar pre-Nanaimo valley, rather than a remnant of sediments that were deeply downwarped or downfaulted between the crystalline rocks that form the upland on either side of Koksilah valley. If the sediments were *once* continuous between the present basins it is to be expected that small outliers would be found in places on the upland between the basins; but no such outliers have been found on the upland, although there are many in the larger valleys which appear to have been eroded first in pre-Nanaimo times. From the evidence given above, it seems fairly certain that the surface upon which the Nanaimo series rests was one of great variety and considerable relief; and it is possible that the differences in elevation were as great as 2,000 feet or more.

In places near the underlying crystallines the Nanaimo series have been folded against them, so that the strikes of the lower beds of the Nanaimo series are parallel to the contacts and the dips are steep, usually away from the contact. In many other places southwest of Ladysmith, southeast of Crofton, on Saltspring island south of Booth bay, and in places along the contacts of the two northern of the narrow westward extensions of the Cowichan basin, faulting has taken place along the contacts. Most of the faults are probably small and of slight displacement but they are marked by rather conspicuous shear zones, with quartz and calcite veins and veinlets.

Relations to Younger Formations.

In the Duncan map-area the Nanaimo series are not in contact with any younger rocks except the superficial deposits which, of, course rest unconformably upon the eroded Nanaimo rocks. However, a quarter of a mile north of the northwestern corner of the map-area in Haslam Creek canyon, the Benson conglomerate is cut by a dacite porphyrite dyke.

MODE OF ORIGIN.

The Nanaimo series, as shown by its fauna, is partly of marine origin, doubtless estuarine, since it was deposited on a surface of considerable relief and under varying conditions shown by the rapid vertical and lateral gradations of the sediments. The series also contains land plants and coal most probably of freshwater accumulation. Hence conditions of fresh or at least brackish water, that is terrestrial conditions, alternated with marine conditions. The upper part of the Nanaimo series, the Gabriola formation, however, contains few or no marine organisms, the only fossils being a few obscure plants. Therefore, it is possible that the alternating conditions recorded in the lower part of the Nanaimo series were finally replaced entirely by terrestrial conditions. The lithological character of the sediments, the sandstones being composed chiefly of angular to subangular fragments and of a large percentage of easily decomposed minerals, such as feldspar, indicates a very rapid accumulation and deposition in relatively small basins where the detritus, largely the result of mechanical decay, was not subject to [illegible] wave action.

AGE AND CORRELATION.

Based on the determination by Whiteaves of the fossils from the Nanaimo series, collected in great numbers by Richardson and others the series has been correlated with the Chico (Upper Cretaceous) of the California Cretaceous and approximately with the Pierre of the Great Plains. Identical species have been collected throughout the series, from the Haslam shales to the upper shales of the Northumberland formation. The Gabriola formation, as already stated, is virtually unfossiliferous.

Few fossils have been collected and determined from the Duncan map-area either during the recent investigation under the supervision of the writer or by earlier workers in the region. However, sufficient fossils have been collected to prove the Nanaimo (Upper Cretaceous) age of the sediments in the Duncan map-area even if there were no other means of correlation or of age determination. From the Duncan map-area, James Richardson collected in 1875 only the following fossils, determined by Whiteaves.[1]

---

[1] Whiteaves, J. F., "Mesozoic Fossils," vol. I, Geol. Surv., Can., part II, 1879; and part V, 1903.

Haslam formation, Maple bay:
Heteroceras elongatum Whiteaves.
Cedar District formation, Vesuvius bay, Saltspring island:
Haminea horni? (Gabb).
Tellina sp.
Inoceramus vancouverensis Shumard.

The writer previous to 1913 collected and identified the following fossils:

Haslam formation, Chemainus river, west of Fuller lake:
Ostrea sp.
Ostrea congesta Conrad.
Rhynchonella sp.
Haslam formation Mt. Tzuhalem:
Trigonia tryoniana Gabb.
Duncan (?) formation, head of Cowichan bay:
Axinea veatchii Gabb.
Protection formation, quarry, north shore of Booth bay:
Inoceramus sagensis Owen.

The following fossils were collected by Cooke during 1913, and have been identified by L. D. Burling:

Haslam formation, Cowichan river, south of Cowichan River falls:
Anomia vancouverensis (Gabb).
Lima multiradiata (Gabb).
Ostrea sp.
Astarte sp.
Haslam formation, Chemainus river, western part of map-area:
Anomia vancouverensis (Gabb).
Ostrea sp.
Rhynchonella cf. *suciensis* Whiteaves.

The correlation of the formations in the Duncan map-area with the formations of the Nanaimo map-area have been already discussed sufficiently under the general description and stratigraphy of the Nanaimo series.

All of the other indurated sedimentary rocks of Vancouver island that rest unconformably upon the upper Jurassic granitic rocks, with the exception of the Tertiary rocks of the west coast, are also of Upper Cretaceous age, and are the equivalent of, and indeed are at present mapped as the Nanaimo series. They are confined chiefly to the east coast of Vancouver island, and are most widely developed near Comox and Suquash. It was formerly supposed[1] that the similar sediments on Queen Cha

[1] Dawson, G. M., Geol. Surv., Can. Rept. of Prog., 1878–79, pp. 633–843, and Bul. Geol. Soc. Am., vol. 12, 1901, p. 75.

lotte island were older than the Nanaimo and were largely of Lower Cretaceous age. However, it has been shown[1] that the post-batholithic sediments of Queen Charlotte islands are of Upper Cretaceous age and contain a fauna similar to although not identical with the Nanaimo series. It is, therefore, with considerable assurance that the Nanaimo and Queen Charlotte series are correlated with each other.

Upper Cretaceous sediments are apparently wanting over the greater portion of the interior of British Columbia, although the upper portion of the Pasayten series, found on the eastern flank of the Cascades, near the 49th parallel, is Upper Cretaceous[2] and presumably the equivalent of the Nanaimo series which the Pasayten series resembles lithologically. Covering a large part of the western portion of the Interior plateaus of British Columbia is a thick series of shale, conglomerate, and sandstone, which closely resembles the Nanaimo series. This series was first described by Selwyn[3] and was called by him the Jackass Mountain group from the locality on the Fraser river a few miles below the mouth of the Thompson where he first encountered the rocks. Later Dawson[4] found that the Jackass Mountain rocks had a wide distribution throughout the western portion of the Interior plateaus and he correlated them with the supposed Lower Cretaceous rocks of Queen Charlotte islands, mapping them as the Queen Charlotte Islands formation. He demonstrated, with the aid of fossils found at several localities, the Lower Cretaceous age of most of the rocks of the series[5] but also noted that some of the upper beds of the series were probably Upper Cretaceous. Recent workers in the southwestern portion of the Interior plateaus[6] have, however, failed to discover any

[1] Dowling, D. B., Bull. Geol. Soc. Am., vol. 17, 1906; pp. 289–292.
Clapp, C. H., Geol. Surv., Can., Sum. Rept., 1912, pp. 24–25.
MacKenzie, J. D., Geol. Surv., Can., Sum. Rept. 1913, pp. 42–47.

[2] Daly, R. A., Geol. Surv., Can., Mem. 38, 1912, pp. 479–489.

[3] Selwyn, A. E. C., Geol. Surv., Can., Rept. of Prog., 1871–72, p. 60.

[4] Dawson, G. M., Geol. Surv. Can., Rept. of Prog., 1875–76, pp. 253–254; Rept. of Prog., 1877–78, pp. 108–109 B; Ann. Rep. 1891, pp. 62–66 B.

[5] This correlation has recently been confirmed by Stanton, who, however, correlated the fauna with the Horsetown of California instead of with the lower Knoxville. Prof. Paper 71, U. S. Geol. Surv., 1912, footnote p. 626.

[6] Bowen, N. L., Geol. Surv., Can., Sum. Rept., 1912, pp. 108–114.
Drysdale, C. W., Geol. Surv., Can., Sum. Rept. 1912, pp. 115–150.
Bateman, A. M., Geol. Surv., Can., Sum. Rept., 1912, pp. 177–210.

distinctly Upper Cretaceous rocks, but have found Lower Cretaceous or Jurassic rocks. It seems, therefore, as if the deposition of the Upper Cretaceous Nanaimo sediments was largely confined to the Coast region, although this deposition was preceded by a similar type of sedimentation in Lower Cretaceous time in the interior of British Columbia.

TIME OF FOLDING.

The Nanaimo series was deformed by forces acting from the northeast, probably having their origin below the downfold between Vancouver island and the mainland, since the folds have been overturned and overthrust to the southwest. The deformation probably took place at or near the close of the Eocene period, at the same time that the upper Eocene, Metchosin volcanics of the Sooke map-area were deformed. There seems to have been no widespread deformation on the Pacific coast at the close of the Cretaceous corresponding with the Laramide revolution of the interior; for, as Arnold[1] points out, with one exception at San Diego, California, the unconformity between the Eocene and the Chico (equivalent to the Nanaimo) is not angular but, as far as the stratigraphic evidence goes, the two formations represent an apparently uninterrupted period of sedimentation. This conclusion has been confirmed in general by the writer's work on Vancouver island; for, although there were local movements throughout the deposition of the Nanaimo sediments, and doubtless there was an uplift without much folding at the close of the Cretaceous since definitely lower Eocene sediments are not known in the region, the first pronounced deformation after the late Jurassic or early Cretaceous took place after the close of Eocene sedimentation and vulcanism.

The folding evidently followed close upon the cessation of Eocene vulcanism; for, before the deposition of the Sooke and Carmanah formations of lower Miocene or possibly upper Oligocene age[2] erosion had worn down the deformed Metchosin volcanics deeply enough to expose the Sooke gabbro stocks irrup-

[1] Arnold, Ralph, "Tertiary faunas of the Pacific coast," Jour. Geol., vol. 17, 1909, p. 512
[2] See page 335.

tive into them and to obliterate the scarp that must have formed along the profound Leech River fault, separating the Metchosin volcanics and the Leech River formation. The deformation is, therefore, quite certainly of early Oligocene age.

The post-Eocene or early Oligocene deformation was of the first order and in general was widespread, being noted by Smith[1] in central Washington, by Arnold[2] in Oregon and California, and by Drysdale[3] in the interior of British Columbia. Although the deformation was intense in places, as in southern Vancouver island, the intense deformation as noted by Arnold in California was extremely localized. Even in the Puget Sound region in the vicinity of Tacoma, sedimentation appears to have taken place continuously from the Eocene to the Neocene[4] although Weaver[5] notes that the time interval following the Eocene is characterized by a marked evolution of the marine faunas. Also the Eocene sediments of the Fraser delta region and even the Nanaimo sediments of Texada island[6] are comparatively undisturbed and only partially consolidated.

Metchosin Volcanics.

DISTRIBUTION.

The Metchosin volcanics underlie a broad belt, 5 to 7 miles wide, which extends across the southern end of Vancouver island with a somewhat north of westerly trend. Thus the volcanics, although interrupted in places by stocks of Sooke intrusives, extend across and underlie the greater part of the Sooke map-area; and, toward the west, they extend north for a short distance into the Duncan map-area. Except in the western portion, the volcanics are unusually well exposed, especially along the shores, and an excellent and almost continuous section across them is afforded by the rock-cuttings

[1] Smith, G. O., "Geology and physiography of western Washington," Prof. Paper 19, U.S. Geol. Surv., 1908, p. 22.

[2] Arnold, Ralph, "Tertiary faunas of the Pacific coast," Jour. Geol. vol. 17, 1909, pp. 518–519.

[3] Drysdale, C. W., Geol. Surv., Can., Sum. Rept., 1912, p. 150.

[4] Willis, Bailey, Tacoma Folio, No. 54, U.S. Geol. Surv., 1899, p. 3.

[5] Weaver, C. E., Bull. 15, Wash. Geol. Surv., 1912, p. 25.

[6] McConnell, R. G., Geol. Surv., Can., Mem. 58, 1914, pp. 31–39.

along the grade of the Canadian Northern railway. The northern boundary of the Metchosin volcanics, the profound fault that separates them from the Leech River formation, has been located with considerable accuracy. Except for the boundaries of the stocks in the western part of the Sooke map-area, the boundaries between the Sooke intrusives and the Metchosin volcanics have also been well located. The boundaries with the Sooke formation, which overlaps the Metchosin volcanics, are, however, very irregular, indefinite, and poorly exposed, and hence are poorly located.

LITHOLOGICAL CHARACTERS.

The Metchosin volcanics are all basic or mafic, chiefly basalts, and to a large extent probably olivine-free basalts or labradorite andesites, and diabase. Texturally and structurally they vary widely from coarsely porphyritic and ophitic basalts to pillow lavas and amygdaloids, from fine cherty tuffs to breccias and coarse agglomerates, and from flows and bedded fragmental rocks to dykes, pipes, and irregular injected masses.

FLOW TYPES.

Normal Basalts.

The principal flow rocks or the normal basalts are dark greyish green, aphanitic to fine-grained, and in a few places even medium-grained rocks which are more or less porphyritic. Although similar in character to the non-porphyritic or inconspicuously porphyritic rocks, the porphyritic varieties are described separately. The normal basalts are rarely or never glassy, but the matrix of the pillow lavas is conspicuously so and fragments of a basic glass or tachylyte, found in the unconformably overlying Sooke sandstones, were doubtless derived from the Metchosin volcanics. Where more affected by surface alteration and oxidation, the basalts have a pronounced purplish tint and they usually weather to a deep or reddish brown. In the aphanitic and fine-grained varieties the component minerals, except for a few inconspicuous phenocrysts of feldspar, are not readily recognized in the hand specimen although occasional flashes of light from the cleavage surfaces of the plagioclase needles in the dark matrix are seen. In the matrix are dark green patches of chlorite, and less conspicuous lighter green masses of epidote or serpentine, and in addition disseminated pyrite and, in a few places, chalcopyrite and pyrrhotite. In the coarser-grained varieties, especially on smooth, glacially polished, and slightly weathered surfaces, the lath-shaped plagioclases are seen conspicuously in the dark matrix. The rocks are fractured, in places greatly, and are frequently cut by calcite and epidote veinlets.

Microscopically the basalts consist essentially of labrodorite, ranging from $Ab_{30}An_{70}$ to $Ab_{40}An_{60}$, and colourless to pinkish augite, with accessory magnetite, probably ilmenite, and apatite. As described below, the arrangement of some of the secondary minerals suggests that olivine was one of the primary minerals, but no definite evidence of its occurrence has been found in the normal basalts. The granularity varies from relatively coarse, decimillimetre grain to microcryptocrystalline; in only a few instances are the normal basalts partly glassy. In the coarser-grained varieties the texture is conspicuously ophitic or diabasic, the lath-shaped crystals of plagioclase having a diverse to subradial arrangement. In the fine-grained varieties the augite is interstitial to the lath-shaped feldspars but does not enclose them. Many of the normal basalts have no well-defined phenocrysts, although certain grains of labradorite and fewer grains of augite are somewhat larger than the rest. Other basalts have hiatal phenocrysts of both labradorite and augite; but these are small, and in most of the normal basalts are few in number, so that the groundmass greatly predominates.

Some of the rocks have been sheared and foliated, distorting, fracturing, and even granulating the feldspars and augites. As a whole, the basalts are only slightly to moderately altered, although in places they are greatly altered. The feldspar is, as a rule, comparatively fresh, while the augite is altered to various types of chlorite and probably to serpentine as well, since the chlorites and serpentines are not readily distinguishable. Other secondary minerals, present in the more altered basalts, are leucoxene after ilmenite, actinolite, epidote, calcite, kaolin, and pyrite and limonite. In places chlorite is clearly seen to be the result of the alteration of augite, but in many of the basalts there are comparatively large rounded to irregular masses (0·2 to 1·0 mm. in diameter) of a light yellowish or brownish green, pleochroic, fibrous to scaly, serpentine or a moderately birefringent chlorite, such as delessite. The augite, in the same rocks, is comparatively fresh or is altering to a pale bluish green weakly birefringent chlorite. Thus, as there are no transitional stages between the augite and these masses of chlorite or serpentine, they may have resulted from the alteration of olivine. But as no other evidences of olivine are found in the normal basalts, they may have been formed by the complete replacement of augite phenocrysts.

Porphyritic Basalts.

The porphyritic basalts are found at several places throughout the Metchosin volcanics. They are similar to the normal basalts except for their more numerous and larger phenocrysts of white or greenish weathering feldspar and augite, and finer-grained groundmass which in some of the more altered varieties is reddish. The phenocrysts are fairly numerous in most of the porphyritic basalts, although the groundmass is in all varieties predominant. The phenocrysts are usually of medium size, averaging 2 or 3 mm. in diameter, although some are much smaller, while a few are 1 cm. in diameter. The feldspar phenocrysts are more numerous and larger than the augite phenocrysts. They usually form stout laths, and in some rocks have a subradial to radial arrangement. In one very characteristic porphyritic basalt found, however, only as fragments in the agglomerates south of the Leech River fault west of Goldstream station, the phenocrysts are tabular and appear on the exposed surfaces as narrow laths, which have a diverse to subradial arrangement. Dark patches of chlorite or serpentine, like those occurring in the normal basalts, are common, and as they are associated in some rocks with a reddish, micaceous mineral, probably iddingsite, the probability is strong that at least some of the porphyritic basalts, contained originally phenocrysts of olivine. Neither the grain nor the component minerals of the groundmass, which is frequently amygdaloidal, can ordinarily be detected in the hand specimen and in some varieties the groundmass is almost glassy.

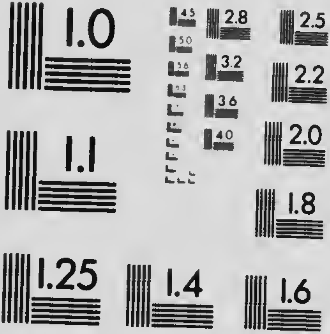
Microscopically the phenocrysts are of labradorite, $Ab_{35}An_{65}$ to $Ab_{40}An_{60}$, augite, and as mentioned, possibly olivine. The feldspar phenocrysts are usually fresh, although in some rocks they are clouded with sericite and saussurite. On the other hand, the augite phenocrysts are usually altered, almost completely, to chlorite or serpentine, while the supposed olivine phenocrysts are entirely replaced by chlorite or serpentine and iddingsite. The groundmass in many of the porphyritic basalts consists of diversely arranged, small, needle-shaped labradorites in an extremely fine-grained matrix now largely composed of secondary mafic minerals and small grains of magnetite. Where more coarsely crystalline, the groundmass is identical with the normal basalts, although very commonly amygdaloidal, with amygdules of quartz, calcite, epidote, and chlorite. Like the normal basalts the alteration and shearing are usually slight to moderate, but in some rocks are considerable. The character of the alteration is virtually identical to that of the normal basalts, although, as mentioned, red weathering rocks are more common, the red colour being due to hematite or turgite.

Gabbro-like Facies.

In a few places throughout the Metchosin volcanics, but best developed to the north of the Sooke basin in the vicinity of Sooke river, and on Trap mountain are coarse-grained, gabbro-like rocks which are clearly facies of the Metchosin basalts and are gradational into them. The feldspars form diversely arranged tables up to 1 cm. square and are associated with interstitial or enclosing augite which in a few rocks occurs in large, black platy grains up to 2 cm. square. Under the microscope the augite is seen to contain dust-like inclusions of magnetite or ilmenite arranged in parallel lines nearly perpendicular to the prismatic cleavage which is well developed.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



Pillow Basalts.

At several places throughout the Metchosin volcanics, notably in the vicinity of the small point on the south shore of Albert head to the north of Parry bay, and at another locality within 2 miles to the north and northeast of Sooke basin, are basalts with an exceptionally well developed ellipsoidal or "pillow" structure (Plate VI). Mr. Uglow reports that a 5-foot dyke exposed along the shore one mile east of Glacier point, also exhibits pillow structure.

The pillow structure of the Metchosin volcanics is virtually identical with the same structure developed in similar volcanics of widely different ages, varying from Pre-Cambrian to the present time, and occurring in many parts of the world.[1] They are found on the Pacific coast in California[2] and Alaska[3] and also in the Vancouver volcanics of Vancouver island[4] although they are not so well or so extensively developed in the Vancouver volcanics as in the Metchosin volcanics. The Metchosin pillow-lavas consist of small, well rounded, ball-shaped masses a few inches in diameter, to much larger ellipsoids. The larger ellipsoids are more irregular than the smaller masses, but are smooth and rounded, pillow or bolster-like masses, varying from 1 foot to 7 feet[5] in diameter. As is common, the individual masses are separated from one another and are sharply outlined on weathered surfaces, owing to the more rapid weathering of the interstitial material (Plate VI). Where the lavas are more deeply weathered, the masses have been weathered out completely; and in places a talus of the rounded masses has been formed at the base of the larger ledges of pillow basalt. The weathering out of the pillows is facilitated by the concentric

---

[1] See list and summary description of occurrences by J. Volney Lewis. "Origin of pillow lavas," Bull. Geol. Soc. Am., vol. 25, 1914, pp. 595–633.

[2] Ransome, F. L., "The eruptive rocks of Point Bonita, California," Bull. Dept. Geol., Univ. Cal., vol. 1, 1893, p. 112.

Lawson, A. C., San Francisco folio, No. 193, U.S. Geol. Surv., 1914.

[3] Grant, U. S., and Higgins, D. F., "Geology and mineral resources of Prince William sound, Alaska," Bull. No. 443, U.S. Geol. Surv., 1910, pp. 21, 26, 51, 52.

Capps, S. R., "Some ellipsoidal lavas on Prince William sound, Alaska," Jour. Geol. vol. 23, 1915, pp. 45–51.

[4] "Geology of the Nanaimo Map-area," Geol. Surv., Can., Mem. 51, 1914, pp. 36–37.

[5] This seems to be about the maximum size reached by the individual masses in any of the pillow-lavas that have been described.

jointing which many of the pillows possess, and even in the fairly fresh lavas, where they are exposed in the railway cuttings along the Canadian Northern Railway grade, the smaller spherical and ellipsoidal masses separate readily from the interstitial matter. In a number of places the masses, both those weathered out and broken out by blasting, since they are of a size to be easily and economically handled, have been used for railway ballast. As mentioned, the smaller masses are fairly regular in shape but the larger masses are irregular. They are usually elongate in the direction of flow and parallel to the bedding. Surfaces of adjoining masses are concordant, protuberances of one fitting nicely, in a ball and socket fashion, into indentations in the other. In other lavas the pillows have been observed to be flattened on their under side,[1] but in the Metchosin volcanics the underside of the pillows is notably concave with large indentations fitting around the convex upper surfaces of the pillows beneath, and with pendants, between the indentations, fitting into the triangular spaces between adjacent underlying pillows (Plate VI).

The pillows as seen macroscopically, and confirmed microscopically, vary from very fine-grained or aphanitic and coarsely amygdaloidal basalts to fairly coarse-grained, ophitic and even porphyritic basalts. The amygdaloidal pillows are more amygdaloidal near their periphery and in many of them the amygdules have a rudely radial arrangement with the long axes of the amygdules perpendicular to the surface of the pillow. The interstitial material between the pillows is virtually identical with the pillows, although it is usually finer-grained, in some places glassy, and is much more fractured and altered. It has been replaced and cut by irregular veinlets of quartz, calcite, and zeolites (chiefly laumontite, heulandite, and chabazite) to such an extent that in places a breccia composed of angular fragments of basalt in a matrix of quartz, calcite, and zeolites has been formed. It is also commonly amygdaloidal and where replaced by zeolites contains irregular gas cavities, resembling miarolitic cavities, which are lined with chabazite. Neither

[1] Cf. Wilson, M. E., "Kewagama Lake map-area," Geol. Surv., Can., Mem. 39, 1913, pp. 50–54.

the pillow nor interstitial rock is variolitic as are many of the pillow lavas of other regions,[1] but the interstitial rock contains numerous spheroids, from 2 to 20 mm. in diameter, which have a conspicuous, concentric, onion-like structure, some of them having also a nucleus that has been replaced by calcite, quartz, and zeolites. These resemble lithophysæ rather than variolites but, as has been pointed out,[2] lithophysæ are at least partly variolitic or spherulitic in character, a conclusion that is confirmed in the case of the Metchosin volcanics by microscopic examination.

Microscopically the pillows present no special or characteristic microscopic features, but are identical with the other basalts, chiefly the fine to medium-grained, ophitic basalts. As noted macroscopically they are in places porphyritic and in other places amygdaloidal. They differ from most other pillow lavas in their comparative freshness, the degree of alteration seldom being more than slight to moderate. The mafic minerals, chiefly augite, have been altered to the greater extent. Most of the feldspar, which is labradorite, about $Ab_{30}An_{70}$, occurs in clear, unchanged or unreplaced, primary crystals. In this respect the Metchosin basalts differ greatly from the pillow-lavas of Great Britain, that are characterized by albite or albite-oligoclase feldspar which has been considered to be the result of the albitization of the original feldspar soon after the solidification of the lavas.[3]

In places, as noted macroscopically, the interstitial matter is virtually identical with the pillows, but it is usually finer grained and more altered, and is in many places glassy. In the glassy rock the only recognizable essential mineral is feldspar which occurs in poorly developed spherulitic groups some of which are not definitely resolved under high powers. In other groups the structure is irregular and the feldspar appears to be secondary. Owing to its fineness and its indefiniteness, the feldspar cannot be definitely determined, but its index of refraction

---

[1] See table of occurrences of pillow-lava. Daly, R. A., "Variolitic pillow-lava from Newfoundland," Am. Geol., vol. 32, 1903, p. 75.

[2] Iddings, J. P., "Igneous rocks," vol. 1, 1909, p. 236.

[3] Dewey, H. and Flett, J. S., "British pillow-lavas," Geol. Mag., vol. 8, 1911, pp. 202-209, 241-248.

is less than that of Canada balsam and hence the feldspar is doubtless albite or albite-oligoclase. The rude spheroidal groups, which form the lithophysæ seen macroscopically, are set in a greenish to colourless glass, and some include irregular areas of glass. The alteration in the glassy rocks has been considerable, the secondary minerals, other than feldspar, being epidote, chlorite, and sericite. As noted macroscopically, they are fractured and also replaced by quartz, calcite, presumably siderite, and zeolites. It is thus seen that in places the interstitial matter is much more altered than the accompanying pillows, the character of the alteration, partly albitization, resembling that characteristic of other pillow-lavas.[1]

Amygdaloidal Basalts.

As described above, both the porphyritic and pillow basalts are amygdaloidal in places and besides these there are many flows of typical amygdaloid. Except for their structure the amygdaloids are similar to the normal basalts in all of their characters, although more commonly reddish or purplish weathering. The amygdules are of chlorite, and less commonly of serpentine, calcite, epidote, and quartz, and far less commonly of actinolite which occurs in radiating needles, and of feldspar which has, however, never been definitely identified. Chlorite and calcite also occur in radial groups, seen only upon microscopic examination, and in some rocks calcite and less frequently chlorite show concentric growth lines. The amygdules are both almond-shaped and irregular. They are seldom large, averaging 1 or 2 mm. in length, although some are over 4 cm. long. In number they vary greatly, although in no rocks do they predominate. As mentioned, in some of the amygdaloidal pillow-lavas, the amygdules have a rudely radial arrangement, the long axis of the amygdules being perpendicular to the outer surface of the individual pillows. A similar arrangement of amygdules has been seen in the fragments of some of the agglor[illegible]es. In most cases, however, the amygdules have a rud[illegible] parallel arrangement and are presumably elongate in the

[1] The cause of the alteration and the origin of the pillow-lavas are discussed in a later section on the origin of the Metchosin volcanics, pp. 282-288.

direction of flow, clearly so in the comparatively few cases where individual flows and definite bedding could be distinguished. As would be expected in such cases the amygdules are best developed near the contact of the flows, the upper portion of an individual flow being, as a rule, more amygdaloidal than the lower portion.

Taxitic Varieties.

At not a few places flow-breccias and banded basalts are found, and they are particularly abundant near Buck hill and Ragged mountain in Goldstream district, and to the south and west of Trap and Muir mountains in Malahat district. On fresh surfaces the banding or brecciation is seldom noticeable, but on weathered surfaces it is most conspicuous since certain minerals, fragments, or bands, due largely to difference in texture, weather to a different colour, and less readily than adjoining bands or matrix, and hence are left in slight relief. In a few places the difference in texture between adjoining bands is extreme, one being very fine-grained and even amygdaloidal, while the other may be much coarser-grained or porphyritic. The brecciated basalts or flow breccias usually consist of numerous, small, angular, and in places block-shaped fragments, seldom more than 1 cm. square, in a fine-grained to aphanitic basalt. On microscopic examination the fragments are seen to be identical with the matrix, and, although they may be ophitic, are usually amygdaloidal and microaphanitic, or even glassy. They are, as a rule, more greatly altered than the more massive basalts.

FRAGMENTAL VARIETIES.

Associated with the flow rocks are fragmental volcanics which are found at several places, notably on the south shore of Albert head, at William head, and in the short range of hills north of Mt. Blinkhorn in Metchosir district; at two or more places near Sooke river, and on the south slope of Trap mountain in Malahat district; and along the northern boundary of the Metchosin volcanics in Goldstream district. With the exception of the agglomerates at the last named locality, the fragmental volcanics do not form extensive beds which can be traced for more than half a mile; but at the last named locality, a fairly uniform, coarse agglomerate underlies a strip about 2,000 feet wide, that follows the northern fault-contact of the Metchosin volcanics from near Langford lake to Jack lake, a distance of 5 miles.

The fragmental volcanics are of two main types; those which are entirely or largely the result of volcanic or explosive, activity and those which have resulted largely, if not entirely, by ordinary erosive processes, although composed entirely of volcanic material. The former include agglomerates, breccias, that is tuff-breccias, and tuffs; the latter include basaltic conglomerates and sandstones, and slaty or cherty tuffs. The slaty or cherty tuffs cannot be distinguished sharply from laminated tuffs which, although clearly of explosive origin, have been deposited in water and admixed with some purely sedimentary material; hence all of the tuffs are described together.

Agglomerates.

The agglomerates are alike in consisting of basalt fragments in a basaltic detritus, and seldom or never show evidence of stratification. The fragments a· clearly related in most instances to the neighbouring flow rocks, varying in texture from amygdaloidal to porphyritic. In the agglomerates along the northern boundary of the Metchosin volcanics in Goldstream district there are, however, numerous fragments of the basalt with tabular feldspar phenocrysts. which was not found as a flow rock. In most places the fragments are from 6 inches to 2 feet in diameter, and subangular to angular. They are usually dense, reddish weathering, and in places are more resistant to weathering than the more porous and more frequently greenish weathering matrix. At Albert head and at one or two other places, the agglomerates contain fragments as large as 6 feet in diameter. At these places, which appear to be volcanic centres, some of the fragments are subrounded to rounded and resemble volcanic bombs. Some of the fragments, at Albert head, chiefly the smaller ones, are clearly water worn, and these agglomerates are associated with and related to the basaltic conglomerates.

The agglomerates present no special microscopic features; the fragments are identical with the various flow rocks already described, although, as a rule, they are more altered. The matrix is fragmental, usually unsorted, considerably altered, and identical with the closely associated tuffs and breccias.

Tuff-breccias and Tuffs.

The tuffs and tuff-breccias are chiefly dark greenish rocks consisting of angular and irregular, red or greenish weathering fragments (up to an inch in diameter), of dense and amygdaloidal basalt in a finely fragmental matrix. They are altered largely to chlorite and are frequently cut by quartz or calcite veinlets and impregnated with a little finely disseminated pyrite and chalcopyrite.

Like the agglomerates the tuffs and tuff-breccias present, upon microscopic examination, no features of special interest. They are clearly composed of basalt detritus chiefly labradorite and augite with accessory magnetite. The grains are angular to subrounded, of widely varying size, and in most places have not been deposited in thin layers or otherwise sorted, even though the beds as a whole are clearly stratified. As noted, the tuffs and tuff-breccias are very greatly altered, chiefly to chlorite, epidote, calcite, and limonite, with quartz and calcite veinlets.

Laminated and Slaty or Cherty Tuffs.

Certain of the very fine-grained and even dense tuffs are laminated and clearly deposited in fairly quiet water. They are lighter coloured and more greyish on fresh fracture than the ordinary tuffs, the lamination being shown by slight differences in the colour of adjoining layers (Plate VII). Certain layers, usually the coarser-grained, in some of which small angular fragments may be seen, are also more resistant to weathering.

The laminated tuffs, as shown by microscopic examination, contain angular fragments, averaging about 2 mm. in diameter, not only of calcic feldspar and augite, but also of albite-oligoclase, quartz, and even of micrographic intergrowths of quartz and feldspar. In most of the fine-grained, bedded tuffs the more sodic feldspar greatly predominates and the fine-grained but granular matrix, the grain of which averages less than 0·01 mm., appears to be composed largely of the sodic feldspar. With the primary minerals are associated moderate amounts of such secondary minerals as epidote, chlorite, and limonite.

The bedded tuffs of the type described are transitional into and interbedded with certain very dense and cherty-like rocks which, although they are composed partly and perhaps largely of sedimentary material and were deposited in quiet water, clearly contain a large amount of volcanic detritus, and hence have been called slaty or cherty tuffs, a term which has been applied to the similar and in places virtually identical rocks occurring in the Malahat, Vancouver, and Sicker volcanics. The slaty or cherty tuffs form thin, but fairly persistent beds of hard, dense, usually banded or laminated rocks that are red, green, or nearly black on weathered surfaces, but usually greyish green on fresh fractures. They are fairly homogeneous but certain layers are of slightly finer or coarser grain than others, indicating that the rocks were deposited slowly in quiet water.

They are composed of small angular fragments (averaging about 0·02 mm. in diameter, 0·05 mm. being the maximum diameter), of feldspar which appears to be chiefly albite-oligoclase. although small laths of andesine-labradorite are present, and augite and quartz. These are embedded in a very fine-grained matrix, the grain of which is about 0·001 mm. Although it [illegible]rly resolved by the microscope, the matrix appears t[illegible]osed largely of feldspar, mixed with quartzose and p[illegible]ilaceous matter, and partly replaced by carbonates wh[illegible]e shown by chemical analysis to be chiefly the iron carbonate, siderite, although some calcite is present. Epidote, chlorite, sericite, and limonite occur in small amounts and may be largely secondary.

A partial analysis of one of the typical and least altered cherty tuffs from William head, by Dr. Brinton, professor of analytical chemistry in the University of Arizona, gave the following results:

SiO_2	68·75
Al_2O_3	12·25
Na_2O	5·16
K_2O	0·09

The igneous nature of the rock and the sodic character of the feldspar are indicated by the high soda and the very low potash. From the partial chemical analysis, aided by a microscopic, Rosiwal analysis, and by a determination of the amount of soluble minerals, chiefly siderite, 10·5 per cent, the mineral composition of the rock has been calculated as follows:

Quartz	33
Oligoclase $Ab_{85}An_{15}$	53
Augite	1·5
Epidote	1·2
Chlorite	0·7
Sericite	0·1
Siderite	8·5
Calcite	1·0
Magnetite and limonite	1·0

Conglomerates and Sandstones.

In a few places, notably on the south shore of Albert head, coarser-grained sedimentary rocks, varying from fine-grained sandstones to conglomerates with pebbles 5 to 6 inches in diameter, occur with the other fragmental rocks of the Metchosin volcanics. They are dark green and composed entirely of angular to well rounded water worn fragments of the associated basaltic rocks, from the debris of which they have been derived by transportation and deposition in water. One bed of basaltic sandstone on the south shore of Albert head only a few yards west of the eastern boundary of the map-area contains a large number of fossil gastropods and fragments of the shells of other animals which lived on the shores of the sea in which the basaltic sandstones and conglomerates were deposited.

INJECTED TYPES.

Diabase Dykes.

Intrusive into the flow and some of the coarser-grained fragmental rocks are numerous dykes of diabase which are clearly related to the effusive types, and which are virtually identical with many of the ophitic basalts. They are fine to medium-grained, and in places porphyritic with a conspicuous ophitic or intersertal texture, dark green on fresh fracture, but weathering into rounded masses of a brown colour. The essential minerals are labradorite and augite, with accessory magnetite and pyrite. The larger grains are fairly fresh, but the groundmass is altering to chlorite, epidote, uralite, and calcite, and the feldspar laths are slightly clouded.

Augite Andesite.

On Sheringham point, west of Kirby (Coal) creek, is, as previously described,[1] a dyke of dense purplish augite andesite with small phenocrysts of altered feldspar. The feldspar on microscopic examination is shown to be andesine about $Ab_{65}An_{35}$, although it is associated with a few augite phenocrysts. Microlites of a similar feldspar form the greater part of the groundmass which probably contained some augite and considerable magnetite. The groundmass is now greatly altered to calcite, epidote, hematite, and limonite. No other similar or such feldspathic rock has been found in the Metchosin volcanics.

METAMORPHISM.

Except locally, the Metchosin volcanics have not suffered such great metamorphism as at first might be thought; for, although they have the appearance of typical greenstones they are only slightly to moderately altered. The mafic minerals have been replaced to a greater or less extent by chlorite and serpentine, but the feldspars, except in the more decomposed surface rocks, are usually unaltered. The alteration of this type has doubtless been caused by ground waters circulating at moderate to shallow depths and at low temperatures.

Except in the pillow lavas, there is little evidence that the Metchosin volcanics have been altered by hot waters or gases while cooling; but in the pillow lavas as described, the matrix or interpillow material has been cut and replaced by irregular veinlets of quartz, zeolites, and calcite; and the original feldspar

[1] Geol. Surv., Can., Mem. 13, 1912, p. 90.

has been partly replaced by secondary albite or albite-oligoclase. Like changes in similar lavas have recently been considered as taking place during the cooling of the volcanics, through the agency of either juvenile or resurgent waters, or in some instances of surface waters, especially of a saline composition, into which the volcanics were erupted. Since in the Metchosin volcanics zeolitization and albitization are virtually confined to the pillow lavas, the conditions producing the pillow lavas must have been responsible also for their peculiar alteration. It is believed, as discussed under mode of origin, that the pillow lavas are of shallow, submarine origin, and that they were altered by the hot sea water mingled with emanations from the cooling volcanics.

Although generally only slightly altered, the Metchosin volcanics have been profoundly metamorphosed where they have been invaded by the Sooke intrusives, and also where they have been greatly sheared by faulting. Near the Sooke intrusives they have been contact-metamorphosed into rather fine-grained massive rocks consisting largely of feldspar and hornblende. Where sheared the basalts have been converted into schistose rocks composed largely of quartz, feldspar, chlorite, and epidote. Both the contact-metamorphosed and the sheared rocks have been cut by quartz and quartz-epidote veins and in many places are rather richly impregnated and replaced by metallic sulphides, chiefly pyrite, pyrrhotite, and chalcopyrite.

Contact Metamorphosed Type

The contact-metamorphosed type is abundantly and almost universally developed around the stocks of Sooke intrusives. The contact zones are, however, seldom more than 200 to 300 feet in width, and are frequently narrower, although in a few places, especially along sheared zones, the contact-metamorphosed and mineralized rocks are found at distances of a mile from any outcrop of the intrusives. Where less metamorphosed the original texture of the basalt is partially preserved, since the feldspars remain unaltered, and form diversely to subradially arranged laths, set in a fine-grained, lustrous groundmass which is clearly seen, even upon microscopic examination, to consist largely of hornblende. On microscopic examination the original ophitic texture is conspicuous, but the augite is in most rocks entirely replaced by a light sage to brownish green, weakly pleochroic, fibrous to almost compact hornblende. The brownish and more compact hornblende is very similar to that developed in the Sooke gabbro itself, and in a few places forms large poicilitic crystals. In the more metamorphosed rocks the original ophitic texture is less conspicuous and irregular areas of actinolite and chlorite, as well as of uralite, have been developed, and veinlets and replacements of epidote and zoisite are common. The feldspars, however, remain almost unchanged. The more metamorphosed rocks have in most places been impregnated with finely crystalline pyrite, pyrrhotite, and chalcopyrite, and also replaced and cut by veinlets of these minerals. These metallic minerals are seldom abundant except in sheared zones in the contact-metamorphosed rocks. Some of the shear zones are, however, highly mineralized and in them are numerous prospects. The sheared and mineralized rocks consist largely of aggregates of secondary minerals, chiefly hornblende, actinolite, epidote, chlorite, quartz, and secondary feldspar, cut by veinlets of quartz and epidote. The metallic minerals have developed late in the metamorphism of the rocks; and occur disseminated through the earlier secondary minerals, and in veinlets and irregular replacements, usually associated with quartz, cutting the earlier quartz-epidote veinlets.

The first changes in the development of the metamorphic rocks, that is the replacement of augite by fibrous to compact hornblende, evidently took place under fairly high temperatures and pressures. Since these changes were confined to the contact zones of the Sooke intrusives, they doubtless took place through the agency of thermal solutions which presumably emanated from the intrusive itself. The later changes, the development of actinolite, chlorite, epidote, zoisite, quartz, and secondary feldspar, were clearly related to dynamic movements, chiefly shearing; and presumably took place at somewhat lower temperatures. The introduction of the metallic minerals appears to have taken place after shearing, but the presence of pyrrhotite indicates that the mineralization took place under at least moderate and presumably under fairly high temperatures. These conditions only prevailed within a short time after the invasion of the Sooke intrusives, and must be considered as a part of the contact metamorphism of the Metchosin volcanics, which was doubtless a continuous process with apparently three well-defined, although probably overlapping, stages.

Sheared Type.

The highly sheared, dynamo-metamorphosed rocks are virtually confined to the immediate vicinity of the great Leech River fault, and form a zone 200 to 300 feet wide (Plate VIII). They consist of greyish or greenish, but dark red or purplish weathering, fine-grained, soft slaty to schistose rocks cut by numerous quartz, quartz-epidote, and calcite veinlets, and in many places they are rather highly mineralized. They reveal their highly metamorphic character only upon microscopic examination which shows them to consist of greatly sheared aggregates of actinolite, chlorite, epidote, occasionally biotite, quartz, secondary feldspar, and sericite with, in some rocks—in particular those which were originally porphyritic—a little residual labradorite. The change was clearly accomplished during the shearing of the volcanics under high pressure, but presumably at moderate temperatures. The shearing and accompanying changes were closely followed by the formation of the quartz and quartz-epidote veins, which are themselves foliated, and by the mineralization. The development of the calcite veinlets and replacements, which are rather abundant, took place at a much later time; they are presumably due to cold ground water circulation in the zone of cementation. The sheared rocks have recently been subject to rapid weathering which has resulted in large amounts of kaolin and limonite.

STRUCTURAL RELATIONS.

INTERNAL.

The various rocks composing the Metchosin volcanics are to a large extent conformably interbedded with one another.

The ophitic, porphyritic pillow, and amygdaloidal basalts form flows varying from 1 or 2 feet to possibly 300 feet or more in thickness. The individual flows are not readily distinguished because of their irregular, and in places indefinite contacts with one another, their lithological similarity, and in places metamorphic character. However, where the flows are thin and not greatly disturbed, as in the vicinity and to the south of Mt. McDonald in Goldstream district, and where the flows are separated from one another by interbeds of fragmental rocks, the individual flows may be readily distinguished. All types of flow rocks occur interbedded with one another, coarse-grained ophitic or porphyritic basalt in contact with amygdaloids or pillow basalts. The contacts although irregular, are in places fairly well defined and amygdaloidal, with the amygdules elongate parallel to the contacts, and with the upper portion of some of the flows more amygdaloidal than their lower portion. The various types of basalt occur in places in the same flow and are transitional. Porphyritic and ophitic basalts commonly grade into one another and the thicker flows contain in places the coarser-grained gabbro-like facies. To the north of Sooke basin porphyritic basalt apparently grades into an amygdaloidal basalt with a pronounced pillow structure. At this place the relations of the rocks are obscure; for a mass of porphyritic basalt which appears in places to be conformable with the associated flow and fragmental rocks in other places clearly cross-cuts them. It seems plain, however, that most of the massive basalts are flow rocks, although doubtless there are in places, sheet-like or laccolithic masses that have been injected into the associated surface formed rocks.[1]

Most of the finer-grained fragmental rocks, the tuff-breccias, tuffs, and laminated, slaty, and cherty tuffs form thin beds, 1 to 30 feet thick, of no very great extent, interlayered with one another and with the massive flow rocks and on the south slope

[1] Similar injected masses are known to occur in other volcanic formations. R. A. Daly in the "Nature of volcanic action," Proc. Am. Acad. Arts and Sc., vol. 47, 1911, pp. 108–119, notes the occurrence of a small laccolith which is exposed in the wall of the Kilauean sink, and cites other apparent or possible examples. A lantern slide, No. 25088, issued by the Institute Pestalozzi, Paris, from a photograph by Platania, of the volcanic island Aci Frezza, shows a thick laccolith which has been injected into flow rocks.

of Bluff mountain, 2 miles west of Sooke river, in the southern part of Malahat district, thin beds of cherty tuff occur in an agglomerate. Extending for 5 miles along the northern boundary of the formation, there is, as already mentioned, an extensive bed of coarse agglomerate which, since its average dip is about 18 degrees and its exposed width 2,000 feet, must be 600 to 700 feet thick.

The coarser-grained agglomerates do not usually occur in distinct beds, but in a few places, near Albert head in Esquimalt district, 2 miles south of Mt. McDonald in Goldstream district, near the south end of Ragged (Saddle) mountain in Goldstream and Otter districts, and along the shore south of Kemp lake in Otter district, they form large, irregular to roughly circular areas. They are associated with flow rocks and the coarser-grained tuffs and breccias. The various types occur intermingled with each other in a most complex manner and are invariably cut by great numbers of diabase dykes. It looks as if these areas of agglomerates represent centres of volcanic irruption, active during the accumulation of the Metchosin volcanics. A detailed examination of the exposures along the south shore of Albert head strengthens the conclusion although the relations and origin of the various rocks has not been definitely proved. There is a central mass of coarse agglomerate roughly 100 yards in diameter which is at least partly surrounded by fine-grained, bedded tuffs which in places dip towards the agglomerate. Beyond and dipping away from the agglomerate, are coarse-grained tuffs and breccias, containing what are apparently volcanic "bombs," interbedded with flows and with conglomerates and sandstones. As elsewhere, all of the rocks are cut by irregular dykes of diabase. It appears as if the central mass of agglomerate is the filled pipe of a small volcano surrounded by inward dipping ash beds and by outward dipping flow and fragmental rocks irrupted from the volcano. The volcano was doubtless built above sea-level and was subject to wave attack along its shores, resulting in the conglomerate and sandstones composed of basaltic detritus.

Although explosive eruptions of the central type occurred during the accumulation of the Metchosin volcanics, it is concluded from the relative scarcity of the agglomerates and the abundance of diabase dykes that the eruptions were largely of a quiet nature and from fissures. The dykes are, as a rule, rather short, and though fairly well defined where well exposed, with chilled contacts, yet are of greatly varying width and strike, and in places begin and end abruptly.

Folding. The volcanics have been moderately deformed and now have a general north 60 degrees to 70 degrees west strike and northeasterly dip. The dip is as a whole only from 15 to 30 degrees, but locally approaches the vertical. Broad northeasterly plunging undulations occur, as is recorded by the varying strikes and dips in the southern part of Goldstream district. In places, clearly seen, however, only in the thin flows and laminated, fine-grained, and cherty tuffs, closed, overturned, and broken folds occur, and it is probable that these secondary folds and crumplings are confined to the weaker rocks. They usually strike parallel to the major axes, their axial planes dip to the north, and where decipherable their northern limbs appear to have been pushed to the south over the southern limbs (Plate VII). In general the northern portion of the formation dips continually to the north, whereas in the southern portion the dips are more variable and in several places are towards the south.

Faulting. Traversing the more massive rocks are numerous shear zones, with slickensided walls, frequently several feet wide. Brecciated fault zones are not absent, although they are uncommon. The largest shear zones occur along and in connexion with the large Leech River fault which forms the northern boundary of the formation,[1] but other large shear zones occur throughout the volcanics. Most of them are rudely parallel to the general strike of the formation, with steep, nearly vertical dips, and doubtless are the result of strike thrust faulting which took place during folding. Small thrust faults are observed breaking the secondary folds in the weaker rocks, but it is probable that massive, more competent flows did not bend readily but yielded to the compressive forces causing deformation, by faulting and

[1] A description of the fault is given on page 277 under the relations of the Metchosin volcanics with the Leech River formation.

shearing. Owing to the uniformity of the formation and the great alteration of the sheared rocks, it is virtually impossible to tell the amount and direction of displacement. In places a thrusting of the northern walls over the southern may be inferred from the character of the resulting slickensides, drag folds, and fracture cleavage.

Cross shear zones were observed in many places, especially near the stocks of Sooke intrusives. Not enough data were collected to determine their relations with the general forces of deformation.

Jointing. The volcanics are everywhere broken by a highly complex and seemingly irregular system of jointing. In places, however, closely spaced, sheet jointing standing at high angles, occurs. In a few of the massive flows columnar jointing has been developed and is particularly conspicuous on smooth glaciated surfaces. The rock near the joint weathers to a darker colour than elsewhere, so that on the smooth, glaciated surface a more or less regular hexagonal or pentagonal pattern is developed.

Stratigraphy and Thickness. There is no regular succession of different types of flows; all types occur interbedded with one another, no one type appearing to predominate at certain horizons over others. A possible exception is the 600 or 700-foot bed of agglomerate occurring along the northern boundary of the formation in Goldstream district. Since the general dip is to the northeast, this bed would occur, if it is in place, at the top of the formation. The base of the formation is not exposed.

Since the structure cannot be definitely determined throughout any continuous section across the volcanics, the thickness of the Metchosin volcanics cannot be accurately determined. If, however, the rocks, without being broken by faults, dip continually northward at angles of from 15 to 20 degrees along the Sooke-Goldstream road, as they appear to do for at least 4 miles to the south of Goldstream, the thickness must be at least 6,000 feet. Farther south the structure becomes more complex and southerly dips and faults occur, but there is no evidence that at 4 miles south of Goldstream the rocks are near the base of the formation which, as mentioned, is nowhere exposed. Hence it is possible that the thickness may be considerably more than 6,000 feet, and 7,500 feet seems to the writer to be a very moderate estimate.[1]

EXTERNAL.

Relations to Older Formations.

To the north of the Metchosin volcanics, except in the extreme eastern part, is the Leech River formation. In the eastern part the relation of the volcanics to the crystalline rocks to the north is obscured by the thick deposit of sand and gravel of the Colwood delta. The contact between the Leech River formation and the Metchosin volcanics is a profound and extensive fault, called the Leech River fault; it is probable that the fault extends to the east beneath the sands and gravels of the Colwood delta.

The Leech River fault follows the conspicuous Leech River valley which extends west from Goldstream to the west coast of Vancouver island, 13 to 14 miles beyond the western boundary of the Sooke and Duncan map-areas. The fault is actually exposed only in a few places; for, except in the upper part of Wolf creek and near the junction of Jordan river and Y creek, the rocks exposed in the various streams of the Leech River valley are the slaty schists of the Leech River formation. On the steep southern slope of the valley the slaty schists are more or less continuously exposed to an elevation of 50 to 300 feet above the streams; and separated from them by a drift covered slope 300 to 400 feet wide, of low grade and no exposures, are high bold ledges of the Metchosin volcanics. In the deep valleys which cross the fault zone, and in the railway cuttings northwest of Goldstream station, the drift covered slope is seen to be underlain by highly sheared and schistose volcanics that form a sheared zone 300 feet or more in width (Plate VIII). From this main shear zone branching shear zones extend into the volcanics for several hundred feet. The branching shear zones strike northwest, but at a much smaller angle than the main zone which in its eastern part strikes north 60 degrees west and in its western part almost due east and west. The actual fault is exposed in the

[1] The thickness was previously estimated by the writer, after his first reconnaissance, as 5,000 feet. Geol. Surv., Can., Mem. 13, 1912, p. 92.

railway cuttings northwest of Goldstream station, and is best exposed in a small drainage tunnel under the railway track about a mile northwest of the station. Where crossed by the tunnel the main fault zone is about 30 to 40 feet wide, highly slickensided, and dips to the northeast, exactly north 15 degrees east, at an angle of 36 degrees. The striæ, drag folds, and cleavage clearly indicate that the northern wall has been upthrown, and that the movement was not exactly parallel to the dip of the fault, as the strike of the striæ is north 22 degrees east, showing that the hanging-wall has moved with respect to the foot-wall from the east towards the west. As seen in the railway cuts, the fault surfaces are not plains, but are gently undulating, with sharp crested ridges in the foot-wall only. The dip in places is as high as 70 degrees and averages about 45 degrees.

In the western part of the map-areas, and even more conspicuously west of them, the fault bends at a small angle across the northwesterly striking Metchosin volcanics. The strike of the adjoining Leech River rocks is, however, more nearly parallel to the fault, although as described, at least the eastern portion of the fault bevels across the Leech River formation at a very small angle.

Even if we had no direct evidence of the upward movement of the northern wall, it would be readily concluded from the fact that the Leech River formation is much older than the Metchosin volcanics, and has, therefore, been upthrown against the volcanics. The amount of slip cannot be accurately determined, but apparently it is the upper beds of the Metchosin volcanics, which have been estimated as 7,500 feet thick, that are in contact with the Leech River rocks considered to be the oldest rocks of the island; hence the slip has evidently been large. Before the accumulation of the Metchosin volcanics the deformed Mesozoic and Palæozoic rocks had evidently been bevelled by erosion and the Metchosin volcanics may, in fact very probably do, rest directly upon the Leech River rocks; but in any case the stratigraphic separation is at least 7,500 feet. The fault not only extends across Vancouver island, a distance of 40 miles, but appears to extend beneath Puget sound, 50 miles farther to the mainland, and as far again across western Washington[1]. Throughout its length the fault separates pre-Tertiary metamorphic and crystalline rocks from the Tertiary rocks which occur to the south of the fault. Since the Metchosin volcanics dipping northward 15 to 20 degrees have been broken and shifted by the fault so that the severed portions were separated stratigraphically from each other by at least 7,500 feet, and considering the fault to have an average dip of 45 degrees, the shift of the fault is at least 16,000 feet; and considering among other things, the great length of the fault, we may safely assume even a much greater maximum shift. To summarize: the Leech River fault is a reverse or overthrust, nearly a strike and nearly a dip-slip fault, it is of great length, at least 40 miles and possibly 140 miles long; throughout its known and assumed length it separates the comparatively unmetamorphosed Tertiary rocks from the pre-Tertiary metamorphic and plutonic rocks which lie to the north and have been pushed up over the Tertiary rocks.

Relations to Younger Formations.

The Metchosin volcanics have been intruded by several stocks of Sooke intrusives. These are grouped, as described later, along two principal axes which may correspond with axes of folding, and the stocks themselves are elongate in the same direction. Near the stocks the Metchosin volcanics have been greatly fractured, contact-metamorphosed, and cut and replaced by veinlets and masses of quartz, epidote, and metallic sulphides. They are also cut by apophyses of gabbro and granite, and in a few places along the contacts are shatter breccias, like that on the northwest slope of Ragged mountain.

At several places along the southern coast of the island, from the east Sooke peninsula west, the Metchosin volcanics are unconformably overlain by relatively small basins of clastic sediments constituting the Sooke formation. At the base of the Sooke formation is a coarse basal conglomerate, composed chiefly of cobbles and boulders of the Metchosin basalt, and it is exposed at several places resting directly upon an eroded surface

[1] See preliminary geological map of western Washington by C. E. Weaver Plate A, Bull. 15, Wash. Geol. Surv., 1912.

of the volcanic rocks (Plate X). It should be noted also that west of the map-areas near the mouth of Sombrio river, similar sediments but possibly belonging to the Carmanah rather than to the Sooke formation, have been deposited on top of the eroded Leech River fault. Hence before the deposition of these rocks in lower Miocene or upper Oligocene time, any fault scarp that may have been produced by the Leech River fault had been planed off by erosion.

DEFORMATION.

From the data given above it is quite clear that the Metchosin volcanics have been deformed by forces acting in a northeast-southwest direction, so that the resulting structures, both folds and faults, have a general northwest trend. Since the prevailing dip of the volcanics is to the north it appears as if they form either the southern limb of a geosyncline or the northern limb of a geoanticline. The northern part of the formation as already mentioned, appears to dip continuously to the north, but varying dips are recorded in the southern part, so that the southern, more greatly disturbed portion may be an anticlinal axis. It was along this supposed anticlinal axis that the larger stocks of Sooke intrusives were irrupted. From this occurrence it might be supposed that the northern stocks of Sooke intrusives were also irrupted along an axis of disturbance, but there is little or no direct evidence that such was the case. As noted, the dip of the axial plane of the secondary folds or crumplings is to the north, as is also the dip of the Leech River fault, the only fault carefully studied. The secondary folds and strike faults all indicate a relative upward and southward movement of the northern limbs or walls; hence it appears as if the forces of deformation acted from the north or northeast toward the south or southwest. This fact partly substantiates the conclusion that the volcanics form the southern limb of a geosyncline.

All of the larger structures are co-ordinate so that it is almost certain that they were produced during the same period of deformation. Since the lower Miocene or upper Oliogocene sediments of the Sooke formation rest upon the eroded deformed volcanics, the deformation must have taken place soon after the formation of the volcanics in upper Eocene time, and, therefore, presumably in lower Oligocene time.

MODE OF ORIGIN.

The Metchosin formation was formed largely by the accumulation of successive basaltic flows. The eruptions were probably for the greater part of a quiet nature, from numerous fissures. Actual vents are doubtless represented in many cases by the diabase dykes which cut the basalt. That the eruptions were in part explosive is fully substantiated by the occurrence of agglomerates and tuffs, and it is possible that the irregular masses of coarse agglomerate, associated with the tuffs flows, and dykes, represent the pipes or necks of old volcanic cones. In addition it appears as if certain of the massive basalts, especially the porphyritic basalts, were injected into their present positions as laccoliths, sheets, or more irregular, in places, crosscutting bodies. Daly[1] has recorded the occurrence of similar injected masses which he believed to be satellitic to the main volcanic abyssal injections and to be the reservoirs feeding the smaller, satellitic volcanoes.

The base of the formation is not exposed so that it is impossible to tell upon what sort of surface the volcanics were accumulated. The entire absence of terrestrial sediments of either subaerial or subaqueous deposition in the Metchosin volcanics suggests that they were built up in deep water far removed from any continental mass. But the occurrence of waterworn fragments in the agglomerates and of marine organisms in the interbedded sandstones indicates that enough lava was erupted to form a platform which reached nearly to the surface of the water and on which were built the cones which actually projected above sea-level. The probable conditions existing at the time of formation were, therefore, similar to those existing during the formation of the Vancouver volcanics.

---

[1] Daly, R. A., "Nature of volcanic action," Proc. Am. Acad. Arts and Sc., vol. 47, 1911 pp. 108-119.

The flow and dyke rocks and presumably the coarser-grained fragmental rocks are of surprisingly uniform composition and hence very little differentiation took place. That slight differentiation took place is evidenced, however, by the feldspathic, augite, andesite dyke in Sheringham point. The differences between the various types are largely differences in texture or structure, caused clearly in most instances by corresponding differences in the physical conditions under which the rocks solidified. Doubtless differences, now largely impossible to determine, in the amount and character of the volatile constituents of the original lavas, were also significant. Of especial interest are the origin and conditions existing during the formation of the pillow lavas and laminated tuffs, in particular those which are virtually cherts.

ORIGIN OF THE PILLOW LAVAS.

Many hypotheses have been advanced to explain the formation of the pillow lavas[1]; from some of these and especially from the direct observations by Dutton,[2] Green,[3] and Anderson[4] the hypothesis most completely and carefully stated and elaborated by Lewis[5] under the name "The theory of bulbous budding," has been developed[6]. The essential conditions for the development of pillow lavas are, according to the hypothesis, quoting Lewis to a great extent; (1) a highly fluid lava which is viscous only within a limited range of temperature as it approaches rigidity, (2) a small but continuous flow of lava, and (3)

[1] See summary by Lewis, J. V., "Origin of pillow-lavas," Bull. Geol. Soc. Am., vol. 25, 1914, pp. 637–645.

[2] Dutton, C. E., "Hawaiian volcanoes." 4th Ann. Rept. U.S. Geol. Surv., 1884, p. 96.

[3] Green, W. L., "Vestiges of the molten globe," pt. 2, Honolulu, 1887, pp. 172, 173, and p. 277.

[4] Anderson, Tempest, "The volcano of Matavanu in Savaii." Quart. Jour. Geol. Soc., vol. 66, 1910, pp. 631–633.

[5] Op. cit. pp. 646–653.

[6] The essential features of the theory are to be found in Anderson's description of the pillow-lavas of the volcano Matavanu; the theory was based on observations of the pillow-lavas in the process of formation. M. E. Wilson in his discussion of the origin of the pillow-lavas of the Kewagama Lake region of Quebec, Geol. Surv., Can., Mem. 39, 1913, pp. 50 to 54, emphasises the two important features of the theory, although restricting it to subaqueous flows. The writer also had written out a theory of "budding" (the word being suggested by Anderson's use of it) for this report before either Lewis' or Wilson's theories had been published.

comparatively rapid cooling. These conditions may vary within certain limits, but as Lewis points out, a variation in one condition necessarily demands a complementary change in the other conditions. Basalt or other related highly fluid basic lavas are the only ones that meet the first condition. The third condition appears from most of the recent descriptions of pillow lavas to be brought about by the chilling action of water on subaqueous (usually submarine) flows or those flowing into water. As may be seen from the following summary statement of the hypothesis, the second condition is also necessary, although greatly affected by the other two conditions.

Briefly the theory is that pillow structure is produced by a sort of hydroid-like budding or "bulbous budding" due to the extrusion of lava through numerous small vents in the rapidly formed crust of a flow, or of other "buds" or "bulbs," by movements in the still fluid lava beneath the crust. Some of the buds while still in communication with their parent or source of supply, although surrounded by the tough, viscous crust that forms immediately upon extrusion, increase rapidly in size, heat, and mobility, and from them other buds may form. This process may continue indefinitely as long as the lava is supplied in suitable amount and at favourable temperatures, the lava flowing through a succession of pillows connected by short necks. After the source of supply is cut off the slight connexion is readily severed by contraction while cooling and the "buds" completely solidify in the form (to judge from the shape of the masses in the Metchosin and other pillow lavas) of fairly regular spheroids or ellipsoids if small (up to 12 or 18 inches in diameter); or if large, irregular or bolster-like masses which are drawn out in the direction of flow. The masses conform more or less perfectly with the upper surfaces of the pillows beneath; and the under surfaces of the lower layer of pillows, which form the bottom of the flow, conform to the surface upon which the pillow-lava rests.[1]

The chief difference of opinion among recent writers upon pillow structure is that many, indeed most geologists insist that

[1] See Capps, S. R., op. cit.

the presence of water is essential; while others[1] have described pillow structure in clearly injected rocks, which appear, however, to have been intruded at very shallow depths into unconsolidated sediments; and still other geologists[2] have described pillow lavas which are unquestionably subaerial. Hence pillow lavas clearly do form under other conditions than subaqueous, a fact which is in accord with the theory of "bulbous budding." Lewis[3] states that:

"Contact with water may....... have the effect of either hindering or promoting the formation of pillow structure. Conditions of temperature and flow that are favourable to the production of extensive pillow lava on land........may become so modified by flow into water that the extent of the structure will be much restricted. On the other hand........a flow of such volume and fluidity as would spread rapidly into a continuous sheet on land might be checked and largely transformed into pillow lava on entering a body of water. Hence it seems safe to conclude that neither the presence nor the absence of water *per se*, can be predicated as particularly favourable to the formation of this structure."

From evidence already given it is quite certain that the Metchosin volcanics are largely of submarine origin, although certain cones may have been built above sea-level to form islands. Hence it seems fairly certain that the pillow lavas of the Metchosin volcanics were either erupted beneath the ocean or flowed from the sides of volcanic islands into the ocean. As already stated, it appears from the numerous descriptions that most pillow lavas are of subaqueous origin and hence it seems as if the proper relation between the three essential conditions in the production of pillow lavas is most commonly met with in subaqueous (chiefly submarine) flows. Since the formation of pillow structure may be terminated at any time that the proper

[1] Platania, G., "Geological notes of Acircale. The South Italian volcanoes," ed. by H. T. Johnston-Lavis. Naples 1891, pp. 37–44.

Ransome, F. L., "Geology of Angel island," Bull. Univ., Cal., Dept. of Geol., vol. 1, 1894, pp. 200–262.

Lawson, A. C., San Francisco, Folio No. 193, U.S. Geol. Surv., 1914, pp. 6–7.

[2] Notably Lewis, J. V., op. cit. pp. 624–629. Lewis also cites A. L. Day on p. 645, who has seen pillows forming in the crater of Kilauea.

[3] Op. cit. p. 652.

relation of the three conditions is not maintained, pillow structure may be developed only in portions of a flow, as is seen to be the case in some of the Metchosin flows.

There are also a few places in the Metchosin volcanics, notably in the mass of porphyritic basalt north of Sooke basin, and in the 5-foot dyke exposed along the shore one mile east of Glacier point, where pillow structure has been developed in rock bodies which have certainly been injected into their present position. They, like the other injected pillow basalts, have doubtless been injected under very little pressure, as is clearly shown by the large amygdules in the porphyritic basalt north of Sooke basin, and, as shown by the glassy interpillow matter, they have cooled rapidly.

As noted, the masses or ellipsoids of the pillow lavas are only slightly to moderately altered, no more nor differently altered than the normal flow rocks. The interspheroidal matter of the pillows is, however, much more altered and the labradorite, characteristic of all the other Metchosin lavas, in this one instance has been albitized. It has also been replaced and cut by veinlets, not only of calcite and quartz, both of which are found in the other Metchosin basalts, but of zeolites as well. It is probable that some of the supposed calcite is really siderite which occurs so abundantly in the associated cherty tuffs. It should also be borne in mind that where the zeolites have been developed, the interspheroidal matter is very fine-grained or glassy, amygdaloidal, and contains large irregular gas cavities lined with chabazite, and in places has been brecciated.

Elsewhere than in the Metchosin volcanics the alteration of pillow lavas is usually great, the character of the alteration being similar to that of the interspheroidal matter of the Metchosin volcanics. Even in the other pillow lavas, the alteration, although not by any means confined to the interspheroidal matter, is greatest there. The origin of the altered interspheroidal matter of pillow lavas is excellently summarized by Lewis[1] as follows:

"The spalling off of glass fragments (from the outer crusts of the pillows), which may be expected to occur in most cases—

[1] Lewis, J. V., op. cit., pp. 649–650.

perhaps most actively in water—partially fills the interspheroidal spaces with breccia, when such openings persist, owing to the failure of the pillows to fit together perfectly.......Occasionally a growing pillow may crack during its expansion, in such a manner as to spill a portion of its liquid contents into the spaces between underlying or adjacent pillows. (As seen in the Metchosin volcanics, the interspheroidal spaces are filled with a basalt almost identical with that of the pillows although no hollow pillows were noted in the Metchosin volcanics.)...... Where conditions suitable to their production exist, the spaces still remaining unfilled offer favourable places for the wonderful variety of beautifully crystallized minerals for which some of the pillow lavas are noted. These include quartz, calcite, the zeolites, datolite, prehnite, pectolite, epidote, and many other less abundant species. Secondary processes, especially in lavas that become deeply buried, have transformed the glassy crusts and interstitial fragments in many flows into green chloritic mixtures, and in many regions corresponding changes have taken place within the crystalline lava as well."

It remains to discover the suitable conditions necessary to produce the alteration. These conditions many geologists, including Lewis,[1] have discussed. Perhaps the most characteristic of the secondary minerals, referring especially to the Metchosin volcanics, are albite and the zeolites. The formation of zeolites and secondary albite in basic volcanics has been recently summarized by Lindgren[2] who quotes rather fully the conclusions of Fenner,[3] Lewis,[4] and Dewey and Flett[5]. There are two principal hypotheses of origin: (1) that they are formed by percolating ground waters possibly in the zone of weathering but chiefly in the zone of cementation; (2) that their formation

---

[1] Lewis, J. V., "Origin of the secondary minerals of the Triassic trap rocks." Bull. 16, Geol. Surv., New Jersey, 1915, pp. 45–49.

[2] Lindgren, Waldemar, "Mineral deposits," 1913, pp. 394–399.

[3] Fenner, C. N., "Features indicative of physiographic conditions prevailing at the time of the trap extrusions in New Jersey." Jour. Geol., vol. 16, 1908, pp. 299–327, and

"The Watching basalt and the paragenesis of its zeolites and other secondary minerals" Annals N.Y. Acad. Sc., vol. 20, 1910, pp. 97–187.

[4] Op. cit.

[5] Dewey, H. and Flett, J. S., "On some British pillow-lavas and the rocks associated with them," Geol. Mag., vol. 8, 1911, pp 202–209, 241–247.

follows closely upon eruption and is distinctly connected with the cooling processes, their deposition taking place in the still hot rocks by the aid of thermal solutions.

The restriction of zeolites and secondary albite to certain volcanic, usually basaltic rocks, their still further restriction to certain portions of these rocks, well illustrated by their occurrence in the Metchosin volcanics, and the difficulty of concentrating elements, such as copper, silver, fluorine, and boron, occurring in minerals associated with zeolites and albite in other lavas, clearly dispose of any general application of the first hypothesis.

Under the second hypothesis varying ideas as to the source of the thermal solutions prevail. Some regard them as: (1) magmatic emanations, aqueous or gaseous, from the cooling lavas, either of juvenile or possibly resurgent origin; (2) others regard them as meteoric waters which are heated by contact with the lavas, and which may be contained either in the ocean or lake into which the lavas are erupted, or in associated sedimentary rocks; (3) still others regard them as mingled magmatic and meteoric waters. As Lindgren[1] has stated, there are no definite physical or chemical criteria by which the origin of a given water can be determined. When, as in the present instance, waters of supposedly different origin have acted under the same physical conditions it becomes almost if not entirely impossible to distinguish the different waters. However, the presence of such elements as copper, silver, fluorine, and boron, common in minerals associated with zeolites and albite in other lavas, and uncommon except in the altered portions of basic lavas, is usually taken by most geologists as valid evidence of magmatic solutions. But since altered pillow and other basic lavas are believed by nearly all geologists to have been formed under conditions that must have included abundant meteoric waters it seems clear that when the waters were heated by contact with the lavas they too must have been active. Thus the conclusion held by many, that the thermal solutions are mingled magmatic and meteoric waters is by the writer the most favoured. This conclusion is further substantiated by the

[1] Lindgren, Waldemar. "Mineral deposits," 1913, p. 82.

restriction of the zeolites and albite in the Metchosin volcanics, to the pillow lavas; for, although nearly all the Metchosin lavas are believed to be of submarine origin, yet water played a significant part in the cooling only of those flows which were neither too large nor too small or neither too hot nor too cold to form pillow lavas.

ORIGIN OF LAMINATED AND CHERTY TUFFS.

In many places, for example California[1], Alaska[2], Lake Superior region[3], and Great Britain[4], basic lavas like those of Vancouver island, especially those containing pillow lavas such as the Metchosin volcanics, are associated with cherty and jaspery rocks such as are found with the volcanics of Vancouver island. In California, Alaska, and at many places in Great Britain, the cherts and jaspers are clearly of organic origin, composed largely of radiolarian remains. In the Lake Superior region[5] where, as in the Metchosin volcanics, the cherty rocks contain large amounts of iron carbonate, and at places in Great Britain[6], the chert has been considered to be largely a chemical precipitate; and Dewey and Flett[7] conclude that the abundance of radiolarian cherts with pillow lavas is due to the exhalations of magmatic vapours or solutions, rich in dissolved silicates of soda and other bases, into the sea, thus providing very favourable conditions for the rapid multiplication of silica secreting organisms. Lawson[8] regarded the radiolarian cherts

---

[1] Ransome, F. L., "Geology of Angel island," Bull. Univ. of Cal., Dept. of Geol., 1894, pp. 193–240, and

Lawson, A. C., San Fransisco Folio No. 193, U.S. Geol. Surv., 1914.

[2] Martin, G. C., "Geology and mineral resources of Kenai peninsula, Alaska." Bull 587, U.S. Geol. Surv., 1915, pp. 60–61.

[3] Van Hise, C. R. and Leith, C. K., "Geology of the Lake Superior region," Mon. 52, U.S. Geol. Surv., 1911.

[4] Dewey, H. and Flett, J. S., On some British pillow-lavas and the rocks associated with them. Geol. Mag., vol. 8, 1911, pp. 244–245.

[5] Van Hise, C. R. and Leith, C. K., op. cit., see especially pp. 500–518.

[6] Cole, G. A. J., "The radiolite of Ceryg Gwladys, Anglesey," Sc. Proc. Roy. Dublin Soc., vol. 7, 1891–92, pp. 112–120; and

Gardiner, C. I. and Reynolds, S. H., "Palæozoic rocks of the Kilbride peninsula," Quart. Jour. Geol. Soc., vol. 68, 1912, pp. 80–81.

[7] Dewey, H. and Flett, J. S., Loc. cit.

[8] Lawson, A. C., "Geology of the San Francisco peninsula," 15th Ann. Rept., U.S. Geol. Surv., 1895, pp. 425–426.

of California as of similar origin, concluding that they were formed by precipitations of colloidal silica from submarine springs, which produced a sort of ooze in which the radiolaria became embedded. However, there is little suggestion in the description of the cherts given in the San Fransisco folio that Lawson still retains his earlier opinion.

The cherty rocks of the Metchosin volcanics while found interbedded with the pillow lavas are found also with basalt flows showing no pillow structure. In all cases, however, they are closely associated with fragmental volcanics, chiefly the fine-grained, laminated tuffs. The laminated tuffs differ from the ordinary tuffs not only in texture, but, in that they contain besides calcic feldspar and augite (the essential original constituents of the flow rocks and coarse-grained tuffs) albite-oligoclase which predominates over the calcic feldspar, quartz, micrographic intergrowths of quartz and feldspar, and siderite. These minerals are not found elsewhere in the Metchosin volcanics as original constituents, and, therefore, it is fairly certain that the feldspar in the tuffs that contain quartz, albite, and siderite has been altered. As these minerals which are only slightly to moderately altered to such minerals as epidote, chlorite, and limonite appear from their textural relations to be original in the laminated tuffs, apparently the laminated tuffs were altered at the time of their formation. Since the agents of alteration were able to form albite-oligoclase, quartz, and micrographic intergrowths of the two, they were doubtless thermal solutions. To conclude, it appears as if these tuffs, which on account of their fine grain were deposited very slowly in quiet water, were altered at the time of their deposition by alkaline thermal solutions carrying silicates and carbonates of soda and iron.

If the rate of deposition of the tuff decreased or if the thermal solutions became more active through an increase in concentration, volume, or temperature, the original feldspar would be more completely converted to albite-oligoclase, and a direct precipitation of silica and siderite would doubtless occur. This seems to have been true at times and to have resulted in the formation of the cherty tuffs associated with the laminated tuffs. The cherty tuffs accumulated so slowly in quiet water, that they may have been mixed with a little truly sedimentary, but very fine-grained material.

A similar conclusion as to the origin of the cherty rocks of the Sicker series has been deduced by Cooke[1] from somewhat different data.

As already stated, Dewey and Flett have considered that similar thermal solutions furnished the necessary silica for the rapid multiplication of silica secreting organisms which formed the radiolarian cherts associated with the pillow lavas of Great Britain; while other geologists believe that such solutions have deposited silica directly. It is also believed that these same solutions, as stated in the previous section, caused the albitization and zeolitization of the associated lavas. The source of the thermal solutions has already been discussed in the previous section and it has been concluded that they are either direct magmatic emanations or magmatic emanations mingled with meteoric waters heated by contact with the hot lavas, the writer preferring the second conclusion. Although the lavas which are albitized and zeolitized are frequently, as in the case of the Metchosin volcanics, pillow lavas, they are not so everywhere. The greater alteration of the pillow lavas is presumably due to their porosity and rate of cooling rather than to any chemical cause. Hence it is not to be expected, for theoretical reasons as well as from their occurrence in the Metchosin volcanics, that cherts will be found in more frequent or in closer association with submarine pillow lavas than with any other submarine lava of the same composition.

AGE AND CORRELATION.

The Metchosin volcanics, which were previously considered to be doubtfully Jurassic or Triassic,[2] are now known to be of upper Eocene age. Interbedded with the normal basalts on the south shore of Albert head, a few yards west of the eastern boundary of the Sooke map-area, and well exposed only at low tide, is a 3-foot bed of sandstone of basaltic detritus, that is crowded with shells of gasteropods and pelecypods. The

[1] See section on the Sicker series.

[2] Geol. Surv., Can., Mem. 13, 1912, pp. 94-95.

conformability of the basaltic sandstone with the flow and fragmental rocks of the Metchosin volcanics is unquestionable.

Dr. Charles E. Weaver, professor of geology at the University of Washington, in Seattle, who has been working for several years on the Tertiary rocks and fauna of Washington, reports on the fossils from Albert head as follows:

Venericardia planicosta.
Cardium breweri.
Modiolus ornatus.
Meretrix uvasana.
Turritella uvasana. (By far the most abundant.)

"The species are all characteristic of the Tejon formation or upper Eocene of California. A similar fauna embedded in a similar rock matrix occurs in the south side of the strait of Juan de Fuca at Port Crescent in Clallam county, Washington.[1]"

Owing to the fact that Dr. Weaver's determinations were called into question some of the fossils from Albert head were submitted to the United States Geological Survey also and were reported on by Dr. Wm. H. Dall as follows:

"The specimens......are Tejon Eocene as Weaver claimed. The material examined did not show any *Venericardia*, but *Turritella uvasana*, Conrad, is present; and fragments of a '*Meretrix*' which is probably a *Paradione*."

Since two independent palæontologists have identified fossils in the Metchosin basalts that are identical with fossils in the basalts of the Olympic peninsula, called by Arnold the Crescent formation[2] there can be no question that the two volcanic formations, which appear to be lithologically identical as well, are the same. Weaver[3] believes the Crescent basalts

---

[1] For a description of the Port Crescent volcanics and associated fossiliferous tuffs or basaltic sandstones and list of fossils contained in them, see

Arnold, Ralph, "Reconnaissance of the Olympic peninsula," Bull. Geol. Soc. Am., vol. 17, 1906, pp. 460–461; and in addition,

Weaver, Charles E., "Preliminary report on the Tertiary palæontology of western Washington," Bull. 15, Wash. Geol. Surv., 1912, pp. 12–14; and

Arnold Ralph, and Hannibal, Harold, "Marine Tertiary stratigraphy of the North Pacific coast of America," Am. Phil. Soc., vol. 52, 1913, p. 566.

[2] Arnold, Ralph, "Reconnaissance of the Olympic peninsula," Bull. Geol. Soc. Am., vol. 17, 1906, pp. 460–461.

[3] Weaver, Charles E., "Preliminary report on the Tertiary palæontology of western Washington," Bull. 15, Wash. Geol. Surv., 1912, p. 13.

to have a thickness of only 1,500 feet to 2,000 feet, but there are exposed single sections of the Metchosin basalts that are over 2,000 feet, and they have been conservatively estimated as 7,500 feet thick.

Weaver[1] considers nearly all of the Tertiary volcanics of the Olympic peninsula as of upper Eocene age. These are presumably correlated with the Eocene Teanaway basalts of central Washington[2], but have no correlatives among the Tertiary volcanics of the mainland of British Columbia, which are all of Oligocene and Miocene age[3].

Sooke Intrusives.

Intrusive into the Metchosin volcanics are several small masses and stocks composed chiefly of gabbro. This gabbro has been called the Sooke gabbro[4] from its principal occurrence in the East Sooke peninsula; but as the intrusive masses have a considerable range in composition, their name has been changed to the Sooke intrusives. In mapping, a granitic and an anorthositic differentiate have been distinguished from the normal gabbro and its more closely allied facies.

DISTRIBUTION.

The Sooke intrusives are found throughout the area underlain by the Metchosin volcanics which, with the exception of a narrow strip along the western half of the southern boundary of the Duncan map-area, are confined to the Sooke map-area. The intrusive masses are grouped along two principal axes, which have a general north 70 degrees west strike, corresponding with the strike of the Metchosin volcanics, one axis occurring in the northern part of the belt underlain by the Metchosin volcanics, and the other occurring in the southern part of the belt. By far the largest stock, about 5 miles long, $2\frac{1}{2}$ miles wide,

[1] Op. cit. p. 13 and Plate A.

[2] See Mt. Stuart folio, No. 106, 1904, and Snoqualmie Folio, No. 139, 1906; U.S. Geol. Surv.

[3] Daly, R. A., "North American cordillera, Forty-ninth parallel," part II, 1912, tables xxxv and xxxvi, pp. 557-563

[4] Geol. Surv., Can., Mem. 13, 1912, p. 113.

and 11 square miles in area, forms almost the entire East Sooke peninsula. A similar, but much smaller stock occurs in the Rocky Point peninsula. These two stocks, the only ones known previous to the present survey, have been the subject of special study by Cooke and are described separately by him. The East Sooke stock has been mapped on a scale of 1:24,000. There are four other large but irregular stocks from over 3 to nearly 6 miles long and about a mile wide. One occurs along the northern axis and the remaining three along the southern axis; their locations are shown on the map. Although irregular in outline all of these larger stocks have a general northwest-southeast trend, corresponding to the strike of the intruded Metchosin volcanics and to the two principal axes along which the stocks are situated. Besides these larger stocks there are at least seven much smaller stocks less than a mile in diameter. Along the northern axis there are three south of Mt. McDonald, and two, composed entirely of the granitic facies, occur to the south of the Leech River fault. Along the southern axis there is only one small stock, to the east of Jordan river 5 miles from the coast. Another very small stock occurs to the south of Muir mountain, halfway between the two principal axes. There may be one or two other small stocks not discovered during the survey, but owing to the thoroughness with which the area was explored, they could not be more than a few hundred yards in diameter.

Owing to the excellent exposures in the eastern and northern portions of the Sooke map-area, the contacts of the stocks occurring there have been located for the greater part with considerable accuracy; the same may be said of the respective distribution of the granitic and gabbro facies of the intrusives. In the western portion of the map-area, however, the outcrops are small and separated by wide stretches of glacial drift; hence only the general outlines of the stocks of this portion could be determined, and even these may be shown on the map with a large error.

LITHOLOGICAL CHARACTERS.

Although the Sooke intrusives include a large number of rock types, in mapping on a scale of 1:125,000, they may be separated only into three types: the normal gabbro with its closely allied facies, an anorthosite, and a granite facies. Indeed, with the exception of the East Sooke and Rocky Point stocks, the stocks are almost entirely composed of the normal gabbro and the granite facies. The special types, olivine, hornblende, and feldspathic gabbros and anorthosites, are largely confined to the East Sooke and Rocky Point stocks which, curiously, contain but very little of the granite facies. Some hornblende and feldspathic gabbro and even some hornblendites are found, however, in small amounts in the other stocks.

Normal Gabbro.

The normal gabbro is a rather dark greenish mottled rock of medium to coarse grain, with an average specific gravity of 2·897. In a few places near the outer intrusive contacts the gabbro grows finer grained; and to the northwest of Ragged mountain where transitional into the granite facies it is fine-grained and porphyritic. The gabbro is composed largely of clear to greenish weathering plagioclase feldspar and dark green ferromagnesian minerals which are seen microscopically to be largely augite. The augite is, however, altering to hornblende, and the cleavage faces of the secondary but compact hornblende are so conspicuous microscopically that the impression is gained in the field that the gabbro is chiefly hornblendic[1]. This impression is further strengthened by the occurrence of coarse gabbro with large bladed hornblendes southeast of Empress mountain, and also in the Broome Hill stock. The Broome Hill stock is virtually the northwestward extension of the East Sooke stock and the lithology of the two stocks is similar: they are composed of hornblendites and other special types of gabbro. Feldspar and augite in the normal gabbro for the greater part occur in nearly equal amounts. The feldspar is ordinarily rectangular, but may form long lath-shaped crystals. Augite is interstitial to the feldspar in most rocks, but in a few rocks forms rather long prisms, which with the lath-shaped feldspars have a diverse to sub-parallel arrangement, thus giving the rock

[1] See Geol. Surv., Can., Sum. Rept., 1912, on the Sooke map-area, p. 49.

a peculiar and conspicuous columnar texture.[1] Accessory magnetite may be detected macroscopically in some varieties, and in one or two places, especially to the north of Ragged mountain, magnetite is present in sufficient quantity to affect the compass considerably. Besides altering to hornblendic gabbros, the normal gabbro is considerably sheared in places and may be slightly mineralized with pyrite.

Microscopically the normal gabbro is comp sed essentially of labradorite which varies from $Ab_{25}An_{75}$ to $Ab_{50}An_{50}$, and of augite. The more sodic feldspar is found chiefly in the gabbros of the northeastern part of the Sooke map-area, that are closely associated with the granite facies, but these same gabbros also contain the more calcic feldspar. Magnetite and apatite are virtually the only accessory minerals, magnetite forming in places fully 10 per cent of the rock.

As mentioned, in many and perhaps in most of the rocks there is a pale brownish green, weakly pleochroic hornblende that is in part secondary after augite, and to the writer it appears as if it were entirely secondary. It occurs surrounding and intergrown with the augite, forming a pattern not unlike a micrographic intergrowth of quartz and feldspar. In addition to this hornblende the following secondary minerals, uralite, chlorite, epidote, and calcite are present, although seldom in large amounts, the gabbros being only slightly to moderately altered. Epidote, calcite, and quartz also form veinlets, and as mentioned, pyrite has been introduced into some of the sheared gabbros. In nearly all the gabbros, as seen macroscopically, the feldspars are euhedral, forming rectangular to lath-shaped grains with a diverse arrangement. The augite also forms euhedral, rectangular grains, but it appears to have finished crystallization after the feldspar, since it fills the interstices of the feldspar grains and in some rocks is intersertal or partly ophitic, surrounding the ends of the feldspars or nearly enclosing them. In the sheared and more altered gabbros the texture has been destroyed to some extent, the feldspars having been distorted and broken and the augite broken and granulated.

---

[1] Cf. gabbro from Rocky point. Geol. Surv., Can., Mem. 13, 1912, p. 115.

Granite.

The granite facies of the Sooke intrusives is a light grey, brownish or reddish to white weathering, fine to medium-grained rock, with an average specific gravity of 2·688. The fine-grained variety is confined to the contact zone of the stocks and to the abrupt transitions into the normal gabbro. The granite is composed largely of feldspar, which may form rectangular grains, quartz, which is largely interstitial, and interstitial dark minerals. Portions of the rock are sheared and traversed by interstitial dark minerals.

Microscopically the essential minerals of the granite are quartz, orthoclase, albite-oligoclase about $Ab_{90}An_{10}$, a little oligoclase, and hornblende; and the accessory minerals are magnetite, ilmenite, titanite, and apatite. The principal minerals occur in about the following amounts:

Orthoclase	15 to 20 per cent.
Albite-oligoclase	30 „ 35 „
Oligoclase	8 „ 10 „
Quartz	25 „ 35 „
Hornblende	5 „ 10 „
Magnetite and ilmenite	1 „ 2 „

The oligoclase and part of the albite-oligoclase occur in rather long, rectangular grains and are surrounded by a wide zone of a rather coarse micrographic intergrowth of quartz and either orthoclase or albite-oligoclase. These minerals also form separate anhedral grains interstitial to the euhedral feldspars. In the fine-grained varieties the texture is anhedral to sub-porphyritic, and some of the quartz grains are embayed. The shape of the original hornblende grains cannot be determined since the hornblende has been almost completely altered. As a whole the rocks are slightly to moderately altered. The hornblendes are replaced by epidote, chlorite, and limonite; the feldspars are partly replaced by epidote and sericite, and the ilmenite has been altered to leucoxene. In the sheared rocks the primary minerals have been granulated, and with the exception of quartz have been largely replaced by epidote.

Apophysal Phases.

Apophysal dykes similar to those found in the East Sooke and Rocky Point stocks occur cutting the gabbro and intruded Metchosin volcanics, although they are not so numerous or so varied in character as those of the East Sooke and Rocky Point stocks. They are chiefly of similar mineral composition to the granite, although as a rule they are finer-grained and aplitic in character, and some of the aplites are fine-grained graphic granites. Coarser-grained pegmatitic apophyses are also found although they are not very common except in the Broome Hill stock. The pegmatitic apophyses are composed largely of feldspar and quartz, some having a medial portion of hornblende and others medial lenses of quartz.

Metamorphism.

With the exception of the gabbros of the East Sooke, Rocky Point, and Broome Hill stocks the Sooke intrusives are, as may be learned from the description given above, only slightly to moderately metamorphosed. The most characteristic changes are: the change of augite into hornblende, and the distinctly later alteration of both augite and hornblende, and to some extent of feldspar, into epidote with which is associated some uralite, chlorite, calcite, and rarely sericite, the latter being virtually confined to the granite facies. This latter change has apparently followed the shearing and other deformation the intrusives have suffered; it has doubtless taken place under moderate conditions of temperature and pressure, and has been accompanied by a mineralization of the sheared gabbro with pyrite and chalcopyrite. However, with the exceptions noted above, the shearing has not been at all extensive, and consequently the accompanying alteration and mineralization has been slight. The change from augite into the compact hornblende has apparently taken place soon after the crystallization of the augite, at high temperature and pressure, under deep-seated conditions, and possibly under magmatic conditions before the complete solidification of the intrusive masses.

STRUCTURAL RELATIONS.

INTERNAL.

As noted under metamorphism the Sooke intrusives have been deformed slightly, producing shear zones, which, with the exception of those traversing the East Sooke, Rocky Point, and Broome Hill stocks, are not extensive. The interest in the internal structure of the Sooke intrusives, therefore, centres in the relations of the various rock types to each other.

At several places, in fact along all of the exposed contacts between the two, the gabbro, which greatly predominates, and the granite may be seen to grade into one another within a distance of 1 to 3 feet. At most places the two rocks maintain their normal character to the narrow transitional zone, although usually the gabbro is more feldspathic near the transitional zone than is normal elsewhere. In a few places, as to the southeast of Empress mountain, the gabbro is fine-grained and porphyritic near the transition and even the granite is fine-grained. In the vicinity of Empress mountain the granite clearly overlies the gabbro, and grades abruptly downward into it. As may be seen on the accompanying geological map, the granite forms three or four small knolls about 100 feet high surmounting the gabbro ridge; and a mile to the southeast of the summit of Empress mountain, the granite occurs at the top of the intrusive stock, forming a zone or layer 100 feet or more in thickness capping the gabbro and immediately underlying the apparently flat roof of Metchosin volcanics. For the most part, however, the contacting facies of the stocks is gabbro, and at several places the granite forms irregular masses, many of them too small to map, partly or entirely surrounded by the gabbro, and in some places not situated in any definite position with respect to the gabbro. Most of the granite masses are, however, situated near the periphery of the gabbro stocks and the two small stocks occurring along the boundary between the Sooke and Duncan map-areas are composed entirely of granite. In addition it should be noted that the granite facies is largely confined to the smaller, less eroded stocks and is virtually absent in the larger and more eroded stocks like those of East Sooke and Rocky point. From the above description, it is quite clear that the granite is a differentiate from the gabbro magma, and that in places, as near Empress mountain, the differentiation has taken place under the control of gravity, so that the lighter rock, the granite, overlies the much heavier, gabbro.[1]

Both the gabbro and granite facies are cut by aplitic apophyses which are granitic in composition, and the gabbro is cut also by a few feldspathic pegmatitic apophyses. In addition the Broome Hill stock, like the East Sooke stock, is cut by dykes of gabbro porphyrite and of diabase.

EXTERNAL.

Relations to Older Formations. The Sooke intrusives are clearly intrusive into the Metchosin volcanics. At several places there is a narrow zone of shatter-breccia at the contact of the intrusive stocks with the Metchosin volcanics, apophyses of feldspathic gabbro and of granite penetrate the volcanics, and a few inclusions of volcanics are found in the gabbro. The gabbro is usually either unchanged or coarser-grained and more hornblendic near the contacts with the intruded volcanics, but in a few places is finer-grained. Little change occurs in the granite near the contacts although southeast of Empress mountain it grows finer-grained. The Metchosin volcanics, on the other hand, have been considerably metamorphosed to hornblendic meta-basalts and even to amphibolites. Near the intrusive contacts the volcanics are also greatly sheared and altered, and partly replaced by quartz and epidote which form veinlets traversing the sheared and altered volcanics. As noted, the masses, with the exception of the small stock south of Muir mountain, have been intruded along two principal axes. These may be axes of especial deformation in the Metchosin volcanics—a conclusion that, owing to the indefiniteness of the bedding of the volcanics, cannot be definitely supported.

Relations to Younger Formations. In the western part of the Sooke map-area the Sooke formation rests unconformably on top of the Sooke intrusives. Small patches of the Sooke

[1] The differentiation is discussed further under the mode of origin of the intrusives, p. 301.

formation are seen to lie in hollows in the Sooke intrusives, and the basal conglomerates of the Sooke formation contain boulders of the gabbro and granite. Hence it is clear that the Sooke formation was deposited after the cover of Metchosin basalts, possibly not very thick, was stripped away from part of the intrusive rocks.

MODE OF ORIGIN.

The Sooke intrusives, which have clearly been crystallized from a molten or magmatic state under deep-seated conditions, form small stocks intrusive into the Metchosin volcanics. They have been intruded chiefly along two principal axes which correspond with the general strike of the Metchosin volcanics and which may be axes of special deformation. The larger stocks are elongate in the same direction (north 70 degrees west) so that it is clear that the stocks were intruded during or following the deformation of the Metchosin volcanics, and that the loci of intrusion was partly controlled and determined either by the forces causing deformation or by the deformed rocks. Since the date of the irruption of the Sooke intrusives is that of the deformation of the upper Eocene Metchosin volcanics, that is lower Oligocene, it appears as if the same forces were responsible for both deformation and irruption.

Whether or not the exposed stocks and bosses are protuberances of the two larger bodies of gabbro that follow the principal axes is, of course, doubtful, but the writer is inclined to believe that they are. Along the southern axis, extending from Rocky point to the western edge of the map-area, a distance of 24 miles, the stocks are in no case more than 3 miles apart, and of the total length the intrusives directly underlie at least 17 miles, or over 70 per cent. In addition, the rocks separating the stocks are in some places the unconformably overlying Sooke sediments, which may rest in these places directly upon the intrusives. Along the northern axis, which extends from south of Mt. McDonald to the headwaters of Bear creek, a distance of 13 miles, the stocks, although separated in no case by more than 3 miles, are smaller and only underlie a little more than half the total length of the axis. But in these stocks the granite facies is best developed, and since it appears that the granite facies occurs near the top of the intrusive masses, it may well be, that the small stocks of the northern axis are "cupolas" overlying a much larger, but unexposed mass of gabbro.

Although unlike lithologically, the close structural relations and the gradation between the granite and gabbro facies of the Sooke intrusive indicate clearly that the two facies are differentiates of the same body of magma which, since the gabbro facies greatly predominates, must have been gabbroidal in composition. In the vicinity of Empress mountain the granite facies clearly overlies and is transitional downward into the gabbro. In other places, although the positional relations of the two rocks may not be definite, the granite usually occurs near the periphery of the gabbro masses and in the smaller, less eroded stocks, and hence in the upper portion or protuberances of the supposed larger stocks or batholiths. In the vicinity of Empress mountain it seems quite clear that the differentiation of the original gabbroidal magma took place under gravitative control, so that the facies are arranged according to their densities, the granite (average specific gravity 2·688) on top, and the gabbro (average specific gravity 2·897) below. Such an arrangement of rocks is common in injected bodies, laccoliths, and sills[1] but is not common in batholiths and stocks which in most cases have an outer peripheral shell of a more femic rock than that of the central and main portion of the batholith. However, a clearly defined example of a batholith with its rocks arranged according to their density has been previously described by the writer.[2]

Whether the actual differentiation of the original magma into the granite and gabbro facies took place through diffusion, fractional crystallization, or liquidation is much more uncertain. Owing to the homogeneity of the two facies and the abruptness of the transition, it is quite clear that differentiation occurred while at least some of the constituents were in a molten and

[1] See Daly, R. A., "Igneous rocks and their origin," McGraw-Hill, 1914, pp. 229-243.
[2] Clapp, C. H., "Igneous rocks of Essex county, Mass." Abstract of thesis, Mass. Inst. of Tech., 1910, pp. 5-8.

mobile condition, allowing the products of differentiation to separate from each other almost perfectly. If the separation occurred while both facies were in a molten condition, on account of their increasing immiscibility as the crystallizing temperature was approached, it is doubtful if the two facies would have separated so perfectly as they have[1]. Furthermore, Bowen[2] has almost proved that silicate magmas do not become immiscible in the liquid state, but that differentiation is caused largely by fractional crystallization followed by a separation of the crystallized and uncrystallized portions of a magma. It is quite certain that in the Empress Mountain stock the separation of the earlier crystallized, basic, or femic constituents of the Sooke magma was due to their sinking in the magma by reason of their greater density. In consequence of the crystallization and subsequent elimination of the mafic constituents the upper portions of the magma became acidic or felsic, and crystallized to form the granite. It is possible that where the granite does not appear to be on top of the gabbro its differentiation did not take place, because of the rapid, almost simultaneous crystallization of all the constituents of the original magma against the relatively cold, intruded Metchosin volcanics, until after an outer and heat preserving shell of gabbro had solidified as a result of the quick cooling.

The top layer of granite in the Empress Mountain stock is not much more than 100 feet in thickness, so that in this stock the amount of granite as compared to the amount of gabbro is insignificant. It is not likely, therefore, that the granite of the small granite stocks to the northwest of the Empress Mountain stock extends to any great depth. Either these small stocks are small intrusions which were drawn off from the upper part of lower and differentiated bodies, or else, as seems more probable, they are the upper portions of larger stocks, the unexposed bulk of which is gabbro.

---

[1] Such complete separation may not have occurred in the East Sooke stock; but Cooke prefers to explain the intimate mixture of rocks that are found there by the mixing of separated facies by dynamic movements before their complete solidification.

[2] Bowen, N. L., "The later stages of the evolution of igneous rocks," Jour. Geol., supplement vol. 23, 1915.

The thickness of the Metchosin volcanics which formed the original cover of the Sooke intrusives and which were removed by erosion, may not have been great; for the time required for the removal of the volcanics covered the comparatively brief interval between the irruption of the stocks and the deposition of the lower beds of the Sooke formation upon the Sooke intrusives. This period was not longer than from lower Oligocene to lower Miocene and possibly not longer than from lower Oligocene to middle Oligocene. It should be noted, however, that before the deposition of the Sooke formation the extensive fault scarp, which must have been developed along the profound Leech River fault, had been destroyed by erosion, since the Sooke formation was deposited upon the eroded and virtually planed-off fault.

The conformity of the effusive rocks of the Vancouver group and the batholithic and injected rocks of upper Jurassic age forming the general irruptive cycle of three phases of igneous activity in the following sequence, the volcanic, the batholithic, and the phase of minor intrusions,[1] has already been noted. The Metchosin volcanics, the Sooke intrusives, and the diabase and the gabbro porphyrite dykes cutting the Sooke intrusives, constitute a second irruptive cycle also conforming with the general cycle. In this cycle the close magmatic relation of all the rocks is very clear, since the lithological characters of the rocks are similar, the chief differences being those of texture, and since, judging from the mineral composition of the rocks, the bulk chemical composition of the three phases is nearly identical. It thus appears that the three phases were derived from the same source, and that the nature of the activity, as Harker has so admirably argued, was determined by the character of the dynamic forces forcing the molten magmas from a lower to a higher level within the crust, or through the crust to the surface.

AGE AND CORRELATION.

The age of the Sooke intrusives may be determined fairly definitely, since they are intrusive into, and hence older than,

[1] Harker, A., "The natural history of igneous rocks," Macmillan, 1909, p. 25.

the upper Eocene Metchosin volcanics; and they are unconformably overlain by, and hence younger than the Sooke formation which is of middle Oligocene to lower Miocene age.[1] The Sooke intrusives may, therefore, be quite certainly determined to be of lower Oligocene age, and were probably intruded during or immediately following the deformation of the Metchosin volcanics at the close of Eocene time. It has already been suggested[2] that two of the minor intrusives, the gabbro dykes and masses and the quartz diorite porphyrite dykes intrusive into the Leech River formation and Malahat volcanics, are possibly related to the gabbro and granite facies of the Sooke intrusives. However, owing to the lack of positive information, the two minor intrusives have been correlated tentatively with the upper Jurassic irruptives. No other irruptives are known to occur in the Coast region which appear to be definitely related to the Sooke intrusives; but dykes and sills of dacite and trachyte porphyrite occur near the east coast of Vancouver island[3] cutting the deformed Nanaimo series of Upper Cretaceous age, and they were apparently deformed at the same time as the Metchosin volcanics; it is, therefore, possible that these dykes and sills were injected at about the same time as the Sooke intrusives.

Gabbros of East Sooke and Rocky Point.

(*H. C. Cooke.*)

INTRODUCTION.

Of the small masses of Sooke gabbro and allied facies intrusive into the Metchosin volcanics, two have been made the subject of special study by the writer. The larger underlies the greater part of East Sooke peninsula and is elliptical in outline. Its major axis is about 5 miles in length and its minor axis about $2\frac{1}{2}$ miles. It is of economic interest as it forms the country rock of East Sooke copper deposits, and of scientific interest as it affords an excellent example of the course of differ-

[1] See page 335.
[2] See pages 214 and 216.
[3] Clapp, C. H., "Geology of the Nanaimo map-area," Geol. Surv., Can., Mem. 51, 1914, pp. 80-81.

entiation of a gabbro magma. The smaller, or Rocky Point mass, lies about 3 miles to the east; it contains no mineral deposits, and a much larger proportion of it is beneath the sea, but in the variety and character of its rocks it is identical with the East Sooke body.

SUMMARY.

The Sooke gabbro is an intrusive of probable lower Oligocene age. The body of the gabbro is very basic, composed of approximately equal parts of bytownite, Ab_{20} An_{80}, and diopsidic augite, with about 5 per cent of olivine and accessory ilmenite. It has undergone fairly complete differentiation, probably after its intrusion. Differentiation has produced rock types varying in composition from gabbros high in pyroxene and olivine, through olivine-less gabbros and anorthosites, to granites and aplites; while wide variations in texture are found even among rocks of approximately the same composition. During its final stages of consolidation, the intrusive emitted heated juvenile waters which deposited two series of igneous veins. The earlier of these were replacement veins formed by solutions which converted all the constituents of the gabbro into hornblende; therefore, they have been termed hornblendite veins. The later set consisted of both fissure fillings and replacement veins and were of aplitic composition. The solutions which carried and deposited the copper ores were of a still later age than those which formed the aplites, and in default of evidence of origin other than that afforded by the mineralogy of the copper deposits, they are considered juvenile, the last exhalations of the cooling magma.

The gabbro mass has been affected by regional movements at several periods during its history. Some of these took place before its complete solidification, with resultant stirring, mixing of rock types already differentiated, and production of gneissic structures and textures. Certain of the more liquid portions of the magma were at the same time forced into intrusive relations with more solid portions. After consolidation, the stresses which affected the mass were relieved by jointing and faulting. There were two periods of faulting which resulted in the formation of shear zones varying from a few feet in width up to 250 feet. There were several periods of jointing. Faults appear to have been confined to the East Sooke mass, as none were observed in the Rocky Point area. The joint and fault planes formed the channels along which escaped the juvenile solutions which hornblendized and aplitized the rocks. The fault fissures in particular have an economic significance, as through them alone passed the latest solutions which deposited the copper ores. Prospecting may, therefore, be confined to the East Sooke peninsula, and should be directed to the discovery and exploration of the shear zones.

GENERAL CHARACTER OF THE DISTRICT.

The surface of the Sooke peninsula, as the map shows, is rather rough, and for so small an area possesses considerable relief. On the west it rises rapidly to Mt. Maguire, a peak 860 feet in height and only 1 mile to 1½ miles from the coast. This peak overlooks the country to the southeast, which maintains a general level of 500 to 600 feet, although surmounted by Signal hill which attains an elevation of 760 feet, and by a few bare knobs. From Signal hill the country slopes rapidly to the sea on the south and east, and slopes more gradually on the northeast to the low valley which divides the peninsula from the mainland.

The district has been thoroughly glaciated, resulting in the almost complete removal of the soil. There remain only patches of stony drift on the uplands, while good alluvial soil is confined to a narrow strip along the northern and western coasts, and to a few low valleys in the interior. There are no permanent streams, and during the nearly rainless summer season it is difficult to get a continuous supply of water even from wells. Timber is not heavy, except where patches of fairly deep soil occur; the salal bush, however, grows luxuriantly everywhere to a height of 3 to 6 feet and forms a great impediment to travel.

The peninsula is easily accessible from Victoria either by launch or by road. The roads are unusually good, though hilly.

LITHOLOGICAL CHARACTERS AND MODE OF OCCURRENCE.

GENERAL DESCRIPTION.

Clapp[1] has described the principal rocks found in East Sooke and Rocky Point intrusions. He distinguished hornblende, augite, olivine, and feldspathic gabbros; anorthosite and olivine anorthosite; pegmatite, aplite, and hornblendite. In addition he described a granite facies which he found in other bodies in the Sooke map-area, although not in those under discussion. Closer examination has revealed the presence of a small amount of this granite facies on Possession point, in East Sooke peninsula, and as dykes in the Rocky Point stock. By the writer the rocks are grouped into four principal types: olivine gabbro, augite gabbro, anorthosite, and granite. The four principal types are, however, further differentiated into numerous sub-types or sub-varieties, characterized by differences in texture, grain, and composition. A detailed study has made it clear that the various types and sub-varieties grade into one another, in places gradually, and in other places abruptly. Olivine gabbro passes into augite gabbro by decrease of olivine; and either olivine or augite gabbro may pass into anorthosite by the decrease of both olivine and augite. Suites of specimens can be obtained to show all stages of these gradations, with the differences between the various members of the suite as minute as may be desired. The more acid types also form a series ranging from quartz diorites to very siliceous granites, and are intrusive into the gabbroid rocks. This relation, however, appears to be the result of movements that affected the masses prior to their complete solidification; since, as described by Clapp, some of the other bodies which have not suffered from movement contain similar acid types that grade downwards into the ordinary gabbro.

There is a general regularity in the arrangement of the four principal types. The olivine gabbro occupies the centre of the intrusive mass, the augite gabbro and anorthosite are peripheral

[1] Geol. Surv., Can., Mem. 13, pp. 113–119, 1912.

to it, while the single outcrop of granite is at the extreme periphery. The greatest irregularity is found in the arrangement and relations of the sub-varieties and is summarized as follows:

(1) Each sub-variety occurs in small, numerous, and irregular masses that appear to possess no definite position within the body as a whole, but may outcrop at almost any point and in contact with any other sub-variety of the same principal type or of a different, but adjoining type.

(2) At some points one sub-variety may grade quite gently into another, at others, very rapidly.

(3) Obscure and contradictory intrusive relations are frequently found between the various sub-varieties, and even between the principal types. At one place, for instance, a certain rock, characterized by a definite composition and texture, may be observed to have a faintly chilled edge at its contact with another rock, to send off intrusive stringers into it, and to include fragments of it; whereas at another place the contact relations between the two rocks are reversed.

(4) The different types and sub-varieties are often found associated in primary gneissic bands. Flow textures are also present in numerous places, particularly at the contacts between two varieties of rocks.

In consequence of these irregularities, the present surface of the gabbro mass is marked by widely varying textures and compositions, suddenly changing from one into another, and bewildering to the observer by reason of their number and the rapidity with which they succeed one another. Owing to this complexity, it is impossible to map the different types even on the accompanying large scale map. However, an attempt has been made to indicate the positions of a few of the larger masses, but the boundaries of these are only approximate.

The rock complex is cut by a great number of dykes and igneous veins which vary widely in composition. The earliest are of nearly the same composition as the normal gabbro, and are often porphyritic; a few of them contain olivine, but the majority do not. More acid types form a later generation, approximating the granite in composition, and are characterized by the presence of free quartz, sodic feldspars, hornblende, and titanite. These dykes, though often large, are never porphyritic. The dykes and older rocks are cut by great numbers of replacement veins of all sizes, from a fraction of an inch in width up to 2 feet. These veins are composed of long bladed hornblende crystals, without, as a rule, other constituents than magnetite. Frequently large zones of hornblendite, up to 250 feet in width, are found. These do not appear, however, to have been formed by the deposition of hornblendite in a single large fissure, but rather by the ascent of solutions through a multitude of closely spaced, slip planes of a large shear zone, with consequent thorough and rapid alteration of a large mass of country rock.

Still younger than these hornblendite veins, and cutting them, are large numbers of aplite veins. These are always of small size, rarely over an inch in width, and form both replacement veins and true fissure fillings. They are composed of quartz and albite or oligoclase albite, with very little ferromagnesian minerals.

DETAILED DESCRIPTION.

Normal Gabbro—Olivine Gabbro.

The normal, or olivine, gabbro constitutes approximately 85 to 90 per cent of the surface of the intrusive, and occupies its central portions. It is a rather dark grey, greenish, or black rock of medium to coarse grain, and is composed of white, greenish, or purplish to black plagioclase and dark green augite, with accessory olivine and ilmenite. When the feldspar is of a dark purplish, almost black tint, as frequently happens, it may easily be mistaken in the hand specimen, unless closely examined, for a ferromagnesian mineral, and the rock classified as a basic augitite or hornblendite. The augite is altering to hornblende, and the cleavage faces of the latter are often so conspicuous macroscopically that the impression is gained in the field that the gabbro is chiefly hornblendic. Microscopic examination, however, shows clearly that the hornblende never occurs as a primary mineral, except in the granitic rocks and hornblendite veins, but it is always secondary after augite. The proportion of the different constituents varies greatly from place to place, feldspar from 40 per cent to 90 per cent, olivine from zero to 25 per cent; but in the average rock the proportions (by volume) of augite and feldspar are about equal, with about 5 per cent of olivine and 1 per cent of magnetite.

The common type of gabbro is equigranular of rather fine grain, with crystals of an average diameter of 1 to 2 mm., and with the feldspar tending to form squarish or rectangular crystals whose length is rarely more than twice the breadth. The augite in these cases is interstitial to the feldspar, and of much the same general shape. Several variations from this normal equigranular texture are found frequently enough to be worthy of separate description.

Type A, which was termed pegmatite in the field on account of its coarse grain, possesses the same equigranular texture and mineral composition as the common olivine gabbro, but the component minerals attain a much larger size. An average crystal diameter of 4 to 5 mm. would perhaps characterize the majority of rocks of this type. In addition, the feldspars, as a rule, are zonally banded. Another, less common, and much more coarsely crystalline rock, which may be classed with these "pegmatites," was occasionally found in rounded masses 6 feet or more in diameter or included in the rock of ordinary grain, into which they graded rapidly. In these masses the average grain would approximate 15 to 25 mm.

Type B is a rock of the ordinary grain, but is characterized by rather long prisms of augite and long laths of feldspar. The feldspar is also usually very white and the augite more diopsidic in appearance than ordinarily. In some varieties there exists a subparallel arrangement between the feldspars and augites, which gives the rock a peculiar and conspicuous columnar texture; but in others this is absent and the two minerals form an interlacing network.

Type C is characterized by the occurrence of augite in large crystals and crystal aggregates which enclose the feldspars poicilitically. These clumps of ferromagnesian minerals are more resistant than the surrounding, more feldspathic portions, so that the weathered surface acquires an uncommon, embossed appearance. In one variety these clumps have an average diameter of 4 to 5 mm., in a second of from 2 to 3 cm.

Microscopically, the feldspar of the normal gabbro,[1] including the special varieties, was determined as bytownite, $Ab_{15}\ An_{85}$ to $Ab_{28}\ An_{72}$ in the great majority of cases, although variations are found from pure anorthite in one or two cases to $Ab_{40}\ An_{60}$. The composition of this feldspar does not seem in the least dependent on the proportion in which it is present, as that in the anorthosites is as calcic as that in the most femic gabbro. One example might be cited. On Bentinck island, south of Rocky point, were found four parallel gneissic bands, each 3 to 6 feet in thickness. The proportion of feldspar varied from about 50 per cent in the most femic to about 90 per cent in the most feldspathic, but its composition in all four bands was $Ab_{20}\ An_{80}$. The augite of the gabbro is invariably almost colourless and non-pleochroic; it is probably low in iron, and approaches diallage in composition. As a rule it is more or less altered to uralite. The olivine is also colourless, generally without much serpentinous alteration; its axial angle varies about 90 degrees, so that some crystals may be found that are optically positive, and others in the same slide that are optically negative, although most of the crystals are optically negative. Such a behaviour, according to Rosenbusch, indicates an FeO content of about 12 per cent.

Augite Gabbro

The augite gabbro contains no olivine but is otherwise identical, macroscopically and microscopically, with the normal olivine gabbro. The unusual columnar texture, type B, that distinguishes some of the varieties of olivine gabbro was not found in any of the augite gabbros; but otherwise most of the variations of grain and composition found in the one can be duplicated in the other. The composition of the constituent minerals is also much the same in both. Most of the feldspar is

[1] The composition of the feldspars in these rocks was very carefully determined from the magnitude of the extinction angles given by the albite twinning lamellæ on the (001) face. To obtain these values with certainty, 5 to 10 grammes of the rock specimen were crushed fine, sifted, washed, and examined for suitable cleavage flakes. All fragments were rejected in which the readings of the extinction angles of the one set did not correspond within 2 degrees with those of the complementary set.

bytownite, near Ab_{20} An_{80}, but while in the olivine gabbros the range of composition extends only to Ab_{40} An_{60} in the augite gabbros it attains Ab_{60} An_{40}. The augite, so far as could be determined by microscopic means, is the same in both rocks.

Gneissic Phases of the Gabbros.

Both the olivine and augite gabbros frequently assume gneissic structures and textures. These may be found over the whole surface of the intrusive, but are much more common near the periphery than toward the centre. Altogether, gneissic rocks may form 2 or 3 per cent of the whole surface. The most usual structure is primary gneissic banding in which gabbros of widely differing grain and composition are arranged in long parallel ribbons or bands. These bands vary from 1 to 6 feet in thickness; the contacts between them are always gradational, but the gradation zone is always very narrow, and rarely exceeds 1 or 2 inches in width. The gabbros composing these bands are fresh and unsheared. They occasionally are characterized by flow textures arranged parallel to the long axis of the band. The grain of the different bands may vary from an average of 1 mm. in one band to 4 or 5 mm. in an adjacent band. The composition may also vary from that of a rather basic olivine gabbro, containing perhaps 60 per cent of ferromagnesian mineral, in one band, to a highly feldspathic gabbro, almost an anorthosite, in the adjoining band. The composition of the feldspar, however, rarely varies from one band to another.

Flow textures are also common in these rocks. As described, they occur frequently in the bands of primary gneiss. They may be observed occasionally at the contacts of the principal types or the sub-varieties with one another. In some places near the periphery of the intrusives they may characterize the whole rock mass. Where flow textures occur, the pyroxenes of the rock always form long narrow laths or needles which are arranged with their long axes parallel; while at the same time a certain amount of parallelism of the feldspars has also been induced.

Anorthosites.

The anorthosites consist usually of bytownite, Ab_{20} An_{80}, with less than 5 per cent of ferromagnesian constituents. They are equiangular and medium to coarse-grained, with an average grain of 2 to 3 mm. They are remarkable chiefly on account of their manner of occurrence. While no large masses were noted on Rocky point, there are a few large masses in the East Sooke body; one several hundred feet long on the top of mount Maguire, a smaller one on the east shore of the peninsula near Beechy head, and a third on the west coast; however, such large masses are uncommon and are apt to contain in places considerable quantities of pyroxene and olivine. The remainder of the anorthosite is scattered throughout the gabbro in small rounded lumps 6 inches to 1 foot in diameter, which grade rapidly into the gabbro. The impression gained from field observation was that these feldspathic patches were apophysal in their nature and were produced by the action of aplitic solutions on the normal gabbro. However, under the microscope it is clearly seen that the feldspar is highly calcic, instead of sodic as might be expected under the latter hypothesis, and that the component minerals show no sign of being other than primary crystallizations; so the conclusion is inevitable that these bodies are really small segregations of anorthosite which were in process of separation from the molten magma when solidification took place.

Granite.

Granite is relatively very small in amount, and, as mentioned, is found only on Possession point at the southwest corner of the peninsula. The main mass lies almost horizontal, with a low dip to the north, and is some 30 feet in thickness. It is very clearly intrusive into the complex of gabbro and Metchosin basalt that occurs there. The complex is extensively brecciated and penetrated by long stringers of granite. The granite is light greenish white, weathering to a brownish white, in colour. Its grain averages less than 1 mm. It is composed approximately of quartz 20 per cent, oligoclase feldspar, Ab_{85} An_{15}, 70 per cent, hornblende about 6 per cent, and accessory magnetite and titanite. Many of the feldspars show zonal banding.

Dykes.

As already mentioned, the dykes are of two main types, gabbroid and granitic, although there are many sub-types, due to minor variations of composition and texture. The dykes usually have wide chilled edges, indicating that the gabbros into which they were intruded had become fairly cold.

The gabbroid dykes may be subdivided into the porphyritic and non-porphyritic types. The latter are of a basaltic composition, equigranular, and basaltic to granitic in texture according to size; they are almost identical in composition, so far as can be determined microscopically, with the gabbro which they cut. Bytownite forms 45 to 55 per cent of the dykes and varies in different specimens from $Ab_{15}An_{85}$ to $Ab_{40}An_{60}$, but averages about $Ab_{20}An_{80}$. The only other essential mineral is a colourless augite, though olivine is almost constantly accessory. The porphyritic dykes vary somewhat from the non-porphyritic both in composition and texture. They are distinguished by the presence of phenocrysts of feldspar which, in a dyke 6 feet or more in width, may attain a diameter of ½ to 1 inch. These phenocrysts were invariably developed in place, as they do not appear in the chilled edge of the dyke for a distance of 1 or 2 inches from the margin, and from this point inwards they become progressively larger until their full size is reached about 2 feet from the border. So far as could be determined, the composition of the phenocrysts was approximately that of the feldspar of the groundmass, although in some of the sections they were zoned, indicating that their separation caused a decrease in the lime-soda ratio in the magma.[1] The feldspar is uniformly a bytownite, about $Ab_{15}An_{85}$, as in the non-porphyritic dykes, and is present in approximately the same proportion, 45 to 55 per cent. The ferromagnesian mineral is the usual colourless augite in many cases altered to a greenish amphibole; but, unlike the non-porphyritic dykes, olivine was not identified.

The granitic dykes although few in number form a fairly complete series, always characterized by the presence of free quartz, in amounts varying from 2 to 3 per cent in the most basic

[1] One case was observed in which the outer zones of the feldspar phenocrysts were more calcic than the inner.

to 35 per cent in the most siliceous. The nature of the feldspar varies with the quartz content: in the dykes low in quartz the feldspar is andesine, $Ab_{60}An_{40}$, and, as the proportion of quartz increases, the feldspar becomes progressively more sodic until in the most acid it becomes $Ab_{90}An_{10}$. The ferromagnesian mineral undergoes a corresponding change. In the basic types a little pyroxene may be present, but hornblende predominates in all; a small amount of biotite, up to 4 or 5 per cent, is always present, indicating that water was being concentrated in these acid magmas, but not necessarily in large amount. The total ferromagnesian material may amount to 40 or 45 per cent in the more basic types, but rapidly decreases with increasing acidity, until in the very siliceous dykes there is less than 5 per cent. Titanium, which in the ordinary gabbros is always combined with iron as titaniferous magnetite, in the granitic dykes always takes the form of titanite.

Only five of the granitic dykes were found, confined to the Rocky Point mass. This fact, coupled with their petrographic resemblance to the granites of the East Sooke and other bodies, strongly suggests that the dykes are the granitic differentiate which in this mass has been forced into more definitely intrusive relations with the gabbro than in the other bodies.

The sequence of irruption of the dykes has not been determined satisfactorily owing to lack of sufficient data. The sole facts at hand are: (1) On Bentinck island a dyke of the granitic type was observed to cut one of the non-porphyritic type; (2) One dyke of the porphyritic types cuts the granitic differentiate on Possession point. If the granite dykes of the Rocky Point mass are assumed to be identical in age with the granite of the Sooke peninsula, the age sequence of the dykes and the rocks they intrude must be

Porphyritic dykes.
Granite and granitic dykes.
Non-porphyritic dykes.
Gabbros.

However, the data at hand is so insufficient as to render this determination far from certain.

Hornblendite Veins.

The hornblendite veins are replacement veins formed by the action of solutions rich in iron and magnesia on the gabbro as they rose through joint cracks and other fissures. The majority of the veins are only a few inches in width, but some are very large, 50 to 250 feet wide. Like most replacement veins, they are characterized by great variability in width along their strike, and have no clean and definite vein wall but grade into the unaltered wall rock. Under the microscope, the replacement of the various constituents of the wall rock by hornblende can be observed in all its stages. When it is complete, nothing but a felted mass of long bladed crystals of dark green, common hornblende, or pargasite, remains. A very small amount of feldspar in minute interstitial grains is usually present, but it is doubtful whether it has been deposited from the solutions or is simply residual. The middle of the small veinlets is usually occupied by a string of magnetite grains with some pyrrhotite, indicating that the solutions carried iron in excess of the amount necessary to hornblendize the rock.

The very large hornblendite zones are identical with the smaller in composition, but differ from them in two important respects: they have been faulted, and copper ores have been deposited within them. The faulting has granulated the large bladed hornblende crystals, so that much of the hornblende is now no more than cemented dust; it has also produced numerous slickensided cracks and fissures along which the hornblende has been frequently converted into chlorite. The solutions which carried the copper ores appear to have ascended through these fissures and deposited chalcopyrite with small amounts of calcite, quartz, pyrite, and zeolites.

The mode of formation of these wide hornblendite zones is a matter of some doubt. It seems impossible that alteration could have extended to such distances from the walls of a single narrow fissure, since in all unfaulted hornblendite veins such alteration may be observed to extend only a few inches from the central joint crack. There is no evidence to show that this hornblendite was ever deposited in open fissures, or produced in any way but by the interaction of the solutions with the wall rocks. The most probable hypothesis is, that these zones represent pre-existent sheeted fault zones which afforded the solutions a multitude of closely-spaced planes of slip through which to rise, and thus gave them power to alter broad ban[illegible]untry rock.

Aplite Veins.

The aplite veins generally fill well-defined fissures rarely more than a few inches in width and commonly only a fraction of an inch, with clean-cut walls very slightly altered by the aplitic solutions.

The aplites are equigranular rocks with an average grain of less than 1 mm. and they are nearly pure white in colour. They always carry free quartz, often in large amount; this constituent has been observed to form 60 per cent of the total mass of a vein, while proportions of 35 to 40 per cent are common. Very sodic feldspar near Ab_{85} An_{15}, often graphically intergrown with the quartz, is the other principal component, and the ferromagnesian elements are represented by a few shreds, rarely amounting to more than 2 or 3 per cent, of hornblende, chlorite, or mica. A little titanite is commonly present. The middle of a vein or of an apophysis is frequently composed largely or entirely of quartz.

The aplite-forming solutions did not, however, always rise through and deposit their load in well-defined fissures, but frequently forced their way through minute cracks and the interstitial spaces of the rock minerals. In such cases their metamorphic effect, though very local, was profound, and resulted in the conversion of the augite of the gabbro to hornblende and biotite, the calcic feldspar to more sodic feldspar, and the ilmenite to magnetite and titanite, with deposition of free quartz in interstitial spaces. The aplitizing solutions did not affect the gabbro as strongly or as readily as the hornblendizing solutions, but their tendency was to convert it into a mass of aplite.

ROCK ALTERATION.

The gabbros are on the whole only slightly altered. They have, however, been affected subsequent to consolidation, by shearing movements, juvenile solutions, and meteoric solutions. As regards the first, regional stresses have caused a certain amount of faulting throughout the mass, with production of wide shear zones. Undoubtedly, granulation of the gabbro and its partial conversion into schist took place along these zones at this time, but any secondary minerals so produced have since been completely removed by the later juvenile hornblendite-forming solutions which later passed through the shear zones. The later faulting has sheared the hornblendite and resulted in the formation of much chlorite. The second type of alterative agent, the juvenile solutions, tended to convert the rock with which they came in contact into aplite and hornblendite. The result was to produce swarms of veinlets of these two types throughout the whole mass of gabbro.

It is probable that weathering and subsequent erosion have removed at least 300 or 400 feet of rock from the top of the East Sooke intrusive. This is inferred from the facts that level differences of some 300 feet are found at present along the summit line of the mass, and that, with the exception of the Maguire anorthosite, none of the acid phases, several hundred feet thick, characteristically occurring about the periphery of the mass, are found in the interior of the peninsula. If this inference is correct, it is probable that a mantle of well weathered material probably cloaked the surface before glaciation took place; but glaciation has very thoroughly removed any such mantle and has left the rock surfaces clean and fresh. The only positive evidence that still exists to indicate the supposed previous condition, is the occasional occurrence along the shores of the Sooke basin, of vertical dyke-like bands of gabbro, averaging 5 to 10 feet in width, now completely altered to soft kaolinic material of the consistency of clay, but still preserving the original texture of the gabbro and containing unaltered nodules of it. These seem to have been caused by alteration by meteoric waters along joint cracks.

Weathering since glaciation extends only a fraction of an inch from the surface in massive material and a few inches where jointing has allowed the rain and air to penetrate more rapidly and easily. The feldspars have been partially kaolinized, the augite uralitized, the olivine converted to serpentine, and the ilmenite to leucoxene.

Epidotization has occurred in some of the aplite veins due probably to meteoric waters. Its localization in these veins is probably due to the good channels afforded the solutions, and perhaps also to the composition and fineness of grain of the veins. The feldspars have been converted in some cases completely to iron-poor varieties of epidote, zoisite, clinozoisite, and in places to an iron-poor pistacite. Kaolin has usually been formed at the same time, and probably also quartz, although any quartz thus formed cannot be identified on account of the presence of original quartz as well. Some aplite dykes were found consisting wholly of quartz, kaolin, and epidotes, while nearly all have undergone this change to a greater or less extent.

INTERNAL STRUCTURAL RELATIONS.

The relations between the different rocks of the mass are of two classes: general arrangement in space, and contact relations. Although both of these have been taken up to some extent in the petrographic descriptions, the statements made there are here recapitulated and somewhat enlarged.

In space, the olivine gabbro occupies the whole central portion of the mass. If its upper horizons were originally of other composition, all trace of this condition except the anorthosite remnant on the summit of Mt. Maguire, has been removed by erosion. Erosion has also eaten deeply into the edges of the mass locally, especially on the western and southeastern coasts and there the olivine gabbro outcrops directly on the seashore. The augite gabbro is found over the remainder of the coast-line, occupying a position peripheral to the olivine gabbro and forming a partially removed shell around it. It is found in a narrow strip around the southwestern end of the peninsula, and as a wider band along the north coast. Anorthosite does not occur in any continuous mass; small bodies of it are scattered throughout the strip of augite gabbro and larger bodies at or near the contact of the olivine and augite gabbros. Thus the largest mass on Mt. Maguire is directly underlain by olivine gabbro, and the moderately large masses on the western coast and near Beechy head lie fairly close to the contact of the olivine and augite gabbros. The only granite mass found on the Sooke peninsula occurs at the extreme southwestern tip on Possession point, intruding the augite gabbro there; this point is supposed to be very near the original periphery of the intrusive as the augite gabbro here forms an extensive contact breccia with the Metchosin basalt, and such bands of contact breccia are nowhere else found to be more than 200 or 300 feet in width.

Turning now to the relations between the different rock varieties as found at their contacts, it is necessary to consider those between the different varieties of each principal rock type and also those between the different types. The varieties of olivine gabbro described on page 310, are usually found to possess gradational relationships with one another so that although the zone in which gabbro of one texture passes into gabbro of another is usually only a few inches in width, sometimes as narrow as one inch, still there is no sharp line of demarcation between them. In several places, however, there are faintly intrusive relations found, and when these occur it is nearly always the common type of olivine gabbro which is intruded by the special-textured types. The relations which establish the fact of intrusion are: (1) in places long narrow stringers of the intrusive penetrate the intruded rock; (2) very slight decrease in the size of the grain of the component minerals of the intrusive occurs near some of the contacts; (3) flow textures in the intrusive rocks are developed along many of the contacts. It would seem evident, therefore, that during the cooling of the magma those portions which now form the special-textured types retained their liquidity somewhat longer than the ordinary olivine gabbro. Hence, when movement occurred, causing some fissuring of the more solid parts, the more liquid portions were forced into intrusive contact with considerably cooler solid parts.

The relations between the olivine and augite gabbros are of much the same character. At several points, as on Bentinck island and on the western end of the Sooke peninsula, the augite gabbro is clearly equivalent, or almost so, in age to the olivine gabbro, for it passes into the olivine gabbro by a gradual increase of olivine. Furthermore it is interbanded with the olivine gabbro to form a primary gneiss. At several other points, notably at the southwestern corner of the peninsula and on Race rocks, the augite gabbro was later than the olivine gabbro, since it has intruded it in the manner described in the last paragraph and also has broken off fragments which are now included in the augite gabbro. At two points, however, in the olivine gabbro areas to the east and to the west of Beechy head, these relations were exactly reversed, and similar phenomena showed the augite gabbro to be intruded by the olivine gabbro. It is evident, therefore, that the movement mentioned in the last paragraph was either greatly protracted or took place after the differentiation of the rock types but while they were still viscous or only partially solid. Liquid portions of both types were squeezed together into gneissic bands, while liquid portions of one were brought into intrusive relations with solid portions of itself or the other. The fact that so many more cases were observed in which the augite gabbro is in intrusive relations with the olivine gabbro than the reverse, probably indicates that at the time the movements took place the augite gabbro magma had crystallized to a less extent than the olivine gabbro magma.

The anorthosites possess similar relations to both olivine and augite gabbros. Their gradational relations can be best seen on Mt. Maguire where in the fairly pure anorthosite are large segregations, which contain relatively large amounts of augite and olivine, sufficient in places to convert the anorthosite into a true gabbro. The same condition obtains, although the gradations are sharper, in the large masses on the south and west coasts and in the small masses found throughout the augite gabbro. However, the liquidity of the anorthositic differentiate was evidently more pronounced when movement took place than that of either of the two gabbros, as in two cases, near Beechy head, well-defined dyke-like masses of the anorthosite were found cutting the olivine gabbro, and the intrusive nature was fairly well-defined in contrast to the vaguer intrusive relations found where one of the gabbros intrudes the other.

The granite on Possession point is distinctly intrusive into the augite gabbro, and forms an extensive contact breccia with it. However, it is assumed that the granite was once gradational with the older rocks of the stock, but that the gradational relations were obliterated by the movements which took place before consolidation, in the same way as the gradational relations of the two gabbros were partly obliterated. The more definite intrusive relations are supposed to be due to the greater liquidity of the granitic differentiate, and its consequent greater mobility when stirring took place. This assumption is not based on facts found in the masses under discussion, but on the conditions observed by Clapp in Empress mountain and in other masses where solidification took place without movement. As described (see pages 298) these bodies possess an upper granitic horizon, which grades downwards through a quartz diorite into gabbro of the ordinary type.

DIASTROPHISM, JOINTING, AND FAULTING.

The dynamic movements which have affected the rocks have been numerous but not large. At least seven periods of movement can be recognized. The first of these already described occurred after partial crystallization had taken place, and brought about the internal relations described in the previous section. The second and third preceded the intrusion of the basic and granitic dykes. They evidently resulted in the formation of the fissures into which the dykes were intruded; and these were of the nature of joint rather than fault fissures, as little or no movement along them was detected. The fourth movement appears to have resulted in the formation of large faults with wide shear zones and accompanying joints. Although wholly inferred, this movement is necessary to explain satisfactorily the formation of the wide hornblendite zones. Deposition from the hornblendizing solutions apparently sealed most of the joint and fault fissures resulting from this movement, so that it was not until the next, or fifth, period of movement which produced new joints and small fissures cutting the old, that the aplitizing solutions could escape. The sixth movement was again a fairly important one, and resulted in further faulting. No new faults were produced, but the stresses were relieved by slip along the fault zones of the fourth movement, with consequent brecciation of the hornblendite which filled the former fault zones. A seventh movement took place causing more jointing, and probably later movements also occurred, for two or three sets of joints may be observed cutting the aplite veins and each other; but as it is difficult to distinguish between the different sets the actual number of movements which produced them is unknown.

In spite of the large number of observations of the strike and dip of the various fault, joint, vei , and dyke systems no regularity among them could be determined, even among those systems which belonged rather definitely to a single set. It is possible that a regularity of arrangement would be elucidated by a more intensive study which might show that much of the jointing was due to compressional forces; on the other hand it is probable that many of them are tension joints, formed by the strains set up during the cooling of the mass, and hence without regularity of arrangement. That definite compressional movements occurred in at least two different periods is shown by horizontal faults. The strikes of these faults vary considerably but in general fall into two sets, one varying from north 10 degrees west to north 20 degrees east, the other from north 45 degrees east to north 65 degrees east. In most cases the fault planes have a steep or vertical dip. The amount of displacement is difficult to estimate, because of the lack of good horizon markers, but it is probably not much over a thousand feet even in the largest. The displacement of all the faults noted is nearly horizontal, for the dip of the striæ on slickensided surfaces was not observed to exceed 20 degrees; this dip is toward the southwest.

MINERAL DEPOSITS.

GENERAL DESCRIPTION.

The mineral deposits of East Sooke peninsula are of two types, copper and iron deposits. The former are of much the greater economic importance. They are found in the large hornblendite zones which have suffered from a second period of faulting with consequent trituration of the hornblende crystals. The universal association of the ores with the hornblendites is apt to lead to the conclusion that the same solutions which carried the ores also hornblendized the rock; but that the true sequence of formation was (1) hornblendite, (2) fault, (3) ore deposition, is shown clearly by the following facts:

(1) Fresh slickensided surfaces are common in the large hornblendite zones, while all other textures are destroyed; hence these surfaces were formed subsequent to hornblendization.

(2) Small unfaulted hornblendite zones are coarse and pegmatitic in texture, while the large ones are principally made up of fine-grained hornblende which under the microscope is seen to be brecciated material. Hence, again, faulting followed hornblendization.

(3) Aplitic stringers cut the small unfaulted hornblendite zones, but none cut the large ones. Presumably such stringers once existed, but have been destroyed by faulting.

(4) Non-faulted hornblendite zones carry no chalcopyrite, hence deposition of copper did not accompany hornblendization.

(5) The sulphides in the ores are universally found in distinct cracks in the hornblendite, not intergrown with the hornblende; hence deposition is subsequent to and not contemporaneous with hornblendization.

(6) The sulphides are sometimes found deposited in cracks, the walls of which are slickensided, and sometimes ore veinlets cut across slickensides; hence ore deposition was subsequent to faulting.

As mentioned, the ores consist largely of chalcopyrite disseminated more or less thickly in small cracks and veinlets throughout the hornblendite mass. The percentage of chalcopyrite present may vary all the way from zero up to 100 per cent; occasionally ore chutes occur consisting of dense massive chalcopyrite. The average good ore, however, runs about 5 or 6 per cent copper. Very few other minerals of any kind are found accompanying the chalcopyrite. A little quartz, feldspar, calcite, magnetite, pyrite, molybdenite, and zeolites have been observed, but the amount of these is so small as to be negligible; and restricted to the surface is a little native copper, oxidized copper minerals, and limonite. For practical purposes it may be said that the only gangue present is the hornblendite itself.

As the large shear zones in which the ores are found yield more readily to erosional influences than the hard unaltered gabbros, they are topographically expressed by the presence of small valleys on land, and on the sea coast, where wave action is strong, as on the southwest coast, by narrow wave-eroded chasms. These chasms sometimes run in for 100 feet or more and thus form an infallible indicator of the presence of these zones. The valleys on land, however, have been filled in with soil, so that they are now only shallow depressions, difficult or impossible to trace in the present uncleared condition of the country.

The shear zones in which the ores are found are strong and persistent, and can usually be followed for several hundred feet. The largest, that exposed on the Margaret, Copper King, and Eureka claims, is traceable for at least 4,500 feet. The strike as described under "Faulting," page 323, varies greatly between the different zones; but there are two principal sets of shear zones one having strikes between north 10 degrees west and north 20 degrees east, the other between north 45 degrees east and north 65 degrees east. They vary in width from a few feet to one which is at least 250 feet wide. Their size and persistence render these deposits of considerable prospective value, and render it likely that they will continue to carry good values to considerable depths. There is, however, no reason to believe that they will increase in value with depth. They will more probably decrease gradually in value, probably with gradual increase of the proportion of pyrite. Native copper, which is found in small amounts at the surface, is due to surface alteration only, and cannot be expected beyond depths of a few feet.

A second typ[illegible]ral deposit, very subordinate both as regards qu[illegible]alue, is the magnetite-pyrrhotite deposits. Under [illegible] of differentiation as previously outlined, such d[illegible]ht be formed at two periods in the history of t[illegible]lation of the stock. They might have resulted fr[illegible]rly separation and aggregation of iron minerals [illegible] gabbro magma, as at Sudbury, and th[illegible] consolidation of nearly all its other pha[illegible]have been formed in the last stages of differenti[illegible]ime of the formation of the hornblendite veins, and the [illegible]hat formed these been laden with excess of iron. That these [illegible]ters did carry iron in excess of that required for the conversion of the rock into hornblendite is shown by the almost universal presence, in the middle of the small hornblendite veinlets, of strings of magnetite and pyrrhotite grains.

One of the two deposits observed on the peninsula belongs without doubt to the second type, as it is found in a large shear zone, in the form of lenses greatly cracked and cut by the later depositions of chalcopyrite. This is the deposit at Iron mountain, section 79. Here the only gangue mineral is hornblende in bladed forms and granulated, while the metallic minerals are magnetite and pyrrhotite. The pyrrhotite is found in fairly large, comparatively pure masses. The other body is found on section 83; it was not examined by the writer.

These massive deposits are too low grade in copper to be even of prospective value. They are rich in the valueless metallic minerals, and it would be difficult and expensive to separate the chalcopyrite from them. The deposits have been exploited for iron as well as copper, but the sulphur is too high for the deposit to be a possible source of iron, with the present conditions existing in the iron industry of this continent. It is possible that at some future time they may have some value as a source of sulphur for the manufacture of sulphuric acid. Their chief value has been as an iron flux in copper smelting.

GENERAL STATUS.

All the ore-bodies found have been confined to the East Sooke mass; the Rocky Point mass has not been faulted, so far as observed, and hence mineral deposits are lacking in it. Several claims have been taken up on the Sooke deposits and numerous prospect pits made, but only a small amount of mining has been carried on. One thousand tons of picked ore from the Willow Grouse and Blue Bird claims was shipped to Tacoma in the autumn of 1916, and brought returns averaging about 5 per cent copper. A few tons of ore was also shipped from the adjoining King George claim. A few attempts to mine the Iron Mountain deposit have been made, and some of the ore has been shipped. A road was built to a deposit on the southern coast several years ago, and presumably some ore was obtained, but the project has long since been abandoned.

DESCRIPTION OF PROSPECTS.

The prospect on the Willow Grouse and Blue Bird claims is one of the three more important ones. It is situated on the northwest slope of Mt. Maguire, on section 111. The ore is developed in a shear zone 50 to 100 feet wide, having a strike of north 40 degrees east. The entire shear zone is not, however, hornblendized or mineralized, but is subdivided into subsidiary shear zones, of which only those close to the northwest wall are well exposed. These are 6 feet, 15 feet, and 20 feet wide. They are nearly parallel to the main shear zone but vary somewhat in strike, and dip steeply to the northwest at an angle of about 70 degrees.

The ore mineral is chalcopyrite, and occurs disseminated through all the subsidiary shear zones although best developed in those along the northwest wall. The principal deposit is exposed for a distance of about 150 feet in a caved stope and in an open-cut adjoining the stope. Five hundred feet to the southwest mineralized rock is exposed in a shallow prospect pit, and it is probable that the zone between the two exposures is mineralized. Three hundred feet to the northeast in the bed of a creek which drains the shear zone a prospect adit is driven in the sheared gabbro, which is there rather feldspathic, and has not been hornblendized or mineralized. Samples from the deposit range from 1 to a maximum of 18 per cent of copper with hardly more than traces of gold and silver.

The deposit has been developed chiefly by a small shaft about 50 feet deep, and by a stope which was brought to the surface to the northwest of the shaft. From this stope about 3,000 tons of rock was removed during the autumn of 1916. Of this amount about 1,000 tons were shipped to Tacoma.

On the southern slope of Mt. Maguire are three claims: the Margaret, Copper King, and Eureka, located on a shear zone some 200 feet in width and having a strike of north 43 degrees east; the zone is traceable for the whole length of the three claims. This zone is intersected near the southwestern boundary of the Copper King claim by a smaller shear zone about 100 feet wide, striking north 10 degrees east. As a rule, the metallic minerals, chiefly chalcopyrite, are disseminated throughout the shear zones. Occasionally the chalcopyrite occurs in small lenses and veins and quartz stringers are very abundant. Extensive mineralization is exposed only near the intersection of the two shear zones, and the north 10 degrees east zone is mineralized for about 1,000 feet north of the intersection, although the outcrops are not continuous. Samples from the shear zones range from 1 to 6 per cent of copper, with traces of gold and silver. The deposit has been opened only by four or five small pits and short open-cuts. Considerable work had been done on the Copper King property a short time before the writer's visit, in stripping and clearing the claims for development.

Another prospect on the King George claim half a mile northwest of the Willow Grouse claim, is on a poorly defined shear zone about 100 feet wide striking nearly east and west. Only sections of the shear zone are hornblendized and mineralized, the best defined section occurring along the southern wall for a width of about 30 feet. The deposit has been developed by two fairly large open-cuts and numerous shallow prospect pits. Fourteen tons of picked ore was shipped in the autumn of 1916, and the smelter returns showed an average copper content of 13·1 per cent.

Several other prospects have been started in the shear zone deposits. One, the so-called "old copper mine" is located on the southern coast, a mile east of O'Brien point, and is in a shear zone 50 feet wide, striking north 15 degrees east.

At the head of Becher bay a shaft said to be 90 feet deep, from which ore is said to have been shipped, is located on a shear zone in the Metchosin basalts. The ore consists of disseminated patches and veinlets of chalcopyrite associated with vein-like masses of epidote and with quartz veinlets. Another prospect was started on a deposit in the sheared basalt to the southeast of Sooke harbour.

The magnetite-pyrrhotite type of deposit has been developed at Iron Mountain, and on section 83. The Iron Mountain deposit is fairly well exposed in several pits and in a drift 50 to 60 feet long. Some of the ore has been shipped.

Sooke Formation.

Fringing the west coast of Vancouver island is a group of marine sediments of Tertiary age. The group includes at least two formations, but only one of these, named by Merriam[1] the Sooke formation, occurs within the Sooke map-area. Although the term Sooke had been previously used by Dawson[2] to designate the Eocene volcanics, which are called by the writer the Metchosin volcanics, Merriam's use of the term has been retained by the writer[3] and by other geologists who have worked in the district recently.

DISTRIBUTION.

The Sooke formation occurs in general in several small, isolated basins along the southwest coast of Vancouver island from Becher bay west to Sombrio river, 15 miles west of the Sooke map-area. There are two relatively large basins within

[1] Merriam, J. C., Bull. Univ. of Cal., Geol. Dept., vol. 2, No. 3, pp. 101-108, 1896.
[2] Dawson, G. M., Geol. Surv., Can., Rept. of Prog., 1876-77, p. 95.
[3] See Geol. Surv., Can., Mem. 13, 1912, p. 86.

the map-area, one to the south of Sooke harbour, extending for 5 miles along the coast and inland for a little more than a mile, and the larger basin, 5 miles farther west, which extends for 3½ miles along the coast but reaches inland for over 4 miles. This basin is drained by Tugwell, Muir, and Kirby creeks and will be called the Muir Creek basin. The easternmost exposure of the Sooke formation consists of a very small patch of conglomerate and sandstone occurring on the west shore of Becher bay, about three-fourths of a mile northeast of Beechy head. Other small basins occur along the coast to the west of the Muir Creek basin between Sheringham point and Glacier point, and to the west of Glacier point. Besides these there are several small outliers of the Muir Creek basin, from a few yards to half a mile in greatest diameter, situated from a few hundred feet to over a mile from the periphery of the main basin. These outliers rest in hollows in the underlying crystalline rocks and are exposed chiefly in creek beds. Knobs of the crystalline rocks also protrude through the sediments of the Muir Creek basin.

The relatively unresistant sediments have been eroded to form comparatively low flat areas, 100 to 300 feet above sea-level, between ridges of the much more resistant, crystalline rocks. On the flanks of the ridges, however, the sediments occur up to 1,000 feet above sea-level. The sediments are fairly well exposed along the shore where they form in places, notably between Muir and Kirby creeks, a notched sea cliff, 100 to 150 feet high. Inland, the sediments are largely covered with stratified drift, exposed at the shore in steep, wave-cut cliffs, so that almost all the inland exposures are found in the beds of the larger streams, Sooke and Demaniel creeks, and Tugwell, Muir, and Kirby creeks, and a few of their largest tributaries. Hence the inland boundaries of the basins are located in most places with a large possible error. However, the probable error is not large, since in most places the crystalline rock ridges steeply surmount the low areas underlain by the sedimentary rocks. As noted, the outliers have been found along stream beds but doubtless many others occur, covered by the stratified drift.

LITHOLOGICAL CHARACTERS.

The Sooke formation consists chiefly of sandstones and conglomerates, with thin beds of sandy shale and marl. The sandstones are yellow to grey, and less commonly dark from carbonaceous matter. They vary from fine to very coarse-grained and pebbly sandstones, the yellowish coarse-grained varieties predominating. The sand is angular to sub-rounded and is composed largely of quartz, plagioclase feldspar, and magnetite grains and small rock fragments, almost entirely fragments of the Metchosin meta-basalts. In the sandstones exposed along the shore of Sooke bay, one-half mile west of Muir creek, are small, flat, angular fragments of a dark brown basaltic obsidian or tachylyte, cut by veinlets of pyrite and calcite. Accessory minerals, chiefly biotite, muscovite, hornblende, epidote, chlorite, serpentine, and limonite, are numerous and occur in relatively large amounts. The sandstones are rather firmly cemented chiefly by abundant calcite, but in places by limonite, and although soft when fresh, harden with seasoning. Many of the sandstones are concretionary and some are cross-bedded (Plate IX). Although fairly uniform, the sandstones may be either thick or thin-bedded, and certain, usually thin-bedded and even shaly layers may be more highly ferruginous or carbonaceous. A spring flowing from a sandstone exposed in the west bank of Muir creek, almost 3 miles from the shore, has a very strong iron taste. Calcareous fossils, chiefly molluscs, composed largely of their original material, are common in the sandstones and some layers are crowded with them.

The conglomerates vary from pebbly sandstones to coarse conglomerates in which the pebbles predominate over the sandy matrix. The basal conglomerates are in many places exceptionally coarse, containing fragments up to 30 feet in diameter (Plate IX). The fragments are subangular to rounded, and consist almost entirely of the immediately underlying crystalline rocks, the Metchosin meta-basalts and Sooke gabbro. The matrix is similar to the sandstones and has also a calcareous cement. The conglomerates are also fossiliferous, rather more so than the sandstones, although most of the fossils are broken.

The shales are all carbonaceous and sandy and form hardly more than thin layers or lenses in the sandstones. The shaly beds are usually highly fossiliferous and certain beds contain such a large percentage of shells that they are shaly marls. Thin, sandy, and shaly lignitic layers, seldom more than 1 to 2 inches thick, are also rather numerous, but in places as near the bridge over Kirby creek, are nearly a foot in thickness. Thin, cigar-shaped lenses of lignite are also found, especially in the small basin between Sheringham and Glacier points.

The sandstones and conglomerates usually alternate rather rapidly both vertically and laterally. A conception of the character of the sedimentation may be gained from the following section, the best exposed one, measured along Kirby creek, and extended to include the beds exposed along the shore to the east of Kirby creek.

	Thickness in feet.
Unconsolidated, stratified sand and gravel (Pleistocene)	20
Sandstone; soft, ferruginous, banded yellow and red, and concretionary	10
Conglomerate, fossiliferous	5
Sandstone; coarse to medium-grained, buff coloured, cross-bedded and concretionary	65
Sandstone; grey, argillaceous, and fossiliferous	4
Alternating soft sandstone and marl	10
Unexposed (mouth of Kirby creek to road crossing)	173 ?
Sandstone	20
Lignite, sandy and impure ... 8 inches	
Unexposed	42
Conglomerate	10
Sandstone	5
Shale; sandy and micaceous	7
Conglomerate, fine-grained	2
Unexposed	17
Sandstone; with two highly carbonaceous layers	5
Conglomerate, fine-grained	32
Sandstone	18
(Protuberating knob of metal-basalt).	
Conglomerate; with thin layers of sandstone	36
Sandstone	4
Fine conglomerate	2
Unexposed	?
Basal conglomerate	10 to 30
	497 to 517 +

More complete sections, but of the same character, are afforded by the bore-holes which have been put down in the hope of finding coal or oil, but only one, located near Whiffen spit at the entrance to Sooke harbour, is available for publication, and it has already been published.[1]

STRUCTURAL RELATIONS.

INTERNAL.

In general the rocks of the Sooke formation strike parallel to the shore and dip at very low angles off-shore, that is, to the southwest. The general off-shore dip is at no place more than 5 degrees, and averages less than that. In detail, each of the larger individual basins is synclinal, the average dip towards the centre being from 2 to 3 degrees. In places at the edges of the basins, near the ridges of crystalline rocks that steeply surmount them, the dip of the basal sediments, which appears to be largely initial and which is always away from the crystalline rock ridges, is in many places as large as 10 degrees, and at one place on the west shore of Sooke bay to the northeast of Sheringham point, it is as large as 30 degrees. There are also one or two broad low anticlines in the Muir Creek basin, best exposed along the shore between Muir and Kirby creeks, that plunge to the southwest in conformity to the general dip.

The rocks are broken by rather numerous small faults. These are all, so far as known, normal faults which strike nearly at right angles to the shore, that is parallel to the general dip, and which dip both to the east and west at rather low angles for normal faults, from 45 to 60 degrees. The displacement or slip is small, usually from 5 to 15 feet. Along the western boundary of the Muir Creek basin, to the northeast of Sheringham point, there are faults of larger, but not of significant slip.

The thickest exposed sections are those along Muir and Kirby creeks and in the shore cliffs between the creeks. The entire Kirby Creek section, given above, is only about 500 feet thick; and the sections exposed along the shore, from the basal conglomerates on either side to the highest beds in the middle of the basins, are even thinner, the shore section of the Muir Creek basin being about 400 feet thick. Yet near the mouth

[1] Richardson, James, Geol. Surv., Can., Rept. of Progress, 1876–77, pp. 190–191.

of Muir creek a bore has been put down in the search for oil, to a depth of at least 1,560 feet, without passing through the formation. This shows that the sediments were deposited in deep embayments in the crystalline rocks and that the upper sediments of the formation, the only ones exposed, overlap the crystalline rocks.

EXTERNAL.

Relations to Older Formations. The Sooke formation clearly rests unconformably upon the Metchosin volcanics and the Sooke gabbro. The unconformity is especially well exposed along the shore. The basal conglomerate of the Sooke formation not only contains boulders of the underlying rocks, but rests on rounded, wave-polished ledges of the crystalline rocks. What were seemingly small coves and bays in the Sooke coast (Tertiary) are filled with coarse conglomerate and sandstone which have also filled wave-cut, dyke, and shear zone chasms in the crystalline rocks (Plate X). The crystalline rock ridges between the sedimentary rock basins are not upfolds, but bold promontories which projected into the Sooke (Tertiary) ocean. Near these promontories the sediments are composed of large angular boulders with a sandy matrix, and have, as already stated, a steep, initial dip away from the promontories, so that they resemble modified talus deposits.

Relations to Younger Formations. The Sooke formation is overlain by stratified, unconsolidated, or only partially consolidated, gravels, sands, and clays of Pleistocene age, formed during both the interglacial Puyallup period and the post-Glacial Colwood period. The overlying sediments appear in places to be conformable with the Sooke formation, but their difference in age is shown by their relative degrees of consolidation, by the lithological character of the overlying sediments which have been largely derived from glacial detritus, and by the difference in the fossils contained in the two formations.

MODE OF ORIGIN.

The Sooke formation, as is shown by its lithological character, structural relations, and enclosed fauna, was deposited in the ocean, chiefly near a steep mountainous shore composed of resistant crystalline rocks, of the debris from which the Sooke sediments are largely composed. The thin layers of lignite have been formed by the accumulation of carbonaceous matter along the coast, and the thin cigar-shaped lenses and flattened cylindrical deposits of lignite appear to have been drift logs that were buried by the Sooke sands, and converted more or less completely into lignite. The steep, mountainous coast of to-day with its bold promontories, coarse boulder beaches, accumulations of drift wood, and wave-eroded shore-line, is strikingly similar to the coast recorded by the unconformity of the Sooke formation with the underlying crystalline rocks and by the coarse basal conglomerates. As sedimentation proceeded, the upper beds of the Sooke formation were deposited against the submerged mountainous shore, building up a coastal plain of which the present sedimentary rock basins are only remnants. However, since at present time the underlying crystalline rocks steeply surmount the relatively soft, sedimentary rock basins, and since no outliers of the Sooke formation occur on the crystalline rock upland, it is probable that the Sooke formation never extended inland over the present upland surface.

AGE AND CORRELATION.

The Sooke formation is of middle Tertiary age, but apparently no more precise determination that is not disputable can be made. Merriam[1], who first studied in detail the fossils from the Sooke formation, arrived at the conclusion that the Sooke formation was of middle Neocene age, that is upper Miocene or lower Pliocene, and was considerably younger than the Tertiary sediments of the Carmanah basin occurring several miles to the northwest of the Sooke map-area. Later, Arnold[2], without, however, doing any field work on the Vancouver Island side of Juan de Fuca strait, placed the Sooke formation in the upper Miocene which he separated from the lower Miocene

[1] Merriam, J. C., Bull. Univ. of Cal., vol. 2, 1896, pp. 101-108.
[2] Arnold, Ralph, "Geological reconnaissance of the Olympic peninsula, Washington," Bull. Geol. Soc. Am., vol. 17, 1906, pp. 461-465; and "Tertiary fauna of the Pacific coast," Jour. Geol., vol. 17, 1909, pp. 509-533.

by an unconformity. In the lower Miocene and Oligocene Arnold placed most of the Tertiary sediments of the Washington shore of the strait, grouping them together as the Clallam formation. Still later Weaver[1] mapped all the Tertiary sediments of the Washington shore of Juan de Fuca straits as lower Miocene although noting the possible occurrence of unfossiliferous Oligocene (Lincoln formation) near Cape Flattery. With the lower Miocene sediments Weaver correlated the Tertiary sediments of Vancouver island. Most recently, Arnold and Hannibal[2] —the latter having done all the later field work and having determined most of the more recently collected fossils—have concluded that the Sooke formation is of middle Oligocene age and older than the sediments at Carmanah point, which, with some of the sediments on the Washington shore, are considered to be a portion of the San Lorenzo formation, one of the members of the Astoria series, and middle Oligocene in age. There is seen, therefore, to be a considerable difference in opinion with regard to the precise dating of the Tertiary sediments of Vancouver island, and also as to the relative ages of the Sooke formation and the sediments at Carmanah point. As previously pointed out by the writer[3], there is no apparent structural unconformity between the two formations, although the Carmanah beds are more indurated and resistant, and their separation must depend solely on their included fauna.

The writer has collected fossils at several localities, from the Tertiary sediments of the southwest coast of Vancouver island, both from the Sooke formation and from the so-called Carmanah formation, and these fossils have been determined and reported upon by Weaver as follows:

List of fossils from Locality No. 314. (Shore of Sooke bay, east of Kirby creek, Sooke formation.)

Mytillus ficus? Dall, specific determination uncertain.
Ostraea sp. probably new.
Solen conradi Dall
Dentallium conradi Dall
Numerous broken fragments of molluscs.

---

[1] Weaver, Charles E., "Preliminary report on the Tertiary palæontology of western Washington," Bull. No. 15, Wash. Geol. Surv., 1912.

[2] Arnold, Ralph and Hannibal, Harold, "The marine Tertiary stratigraphy of the north Pacific coast of America," Proc. Am. Phil. Soc., vol. 52, 1913, pp. 559-605.

[3] Geol. Surv., Can. Mem. 13, 1912, pp. 139-141.

List of fossils from Locality No. 317. (Shore of Sooke bay, east of Kirby creek, Sooke formation.)

Anomia sp. near *macrochisma* Desh
Macrocallista newcombei Merriam
Mytillus near *ficus* Dall
Ostraea sp. probably new
Bullia buccinoides Merriam
Crepidula praeupta Conrad
Fusinus n. sp.
Patella geometrica Merriam
Polineces galianoi Dall
Trochita inornata Gabb
Trochita filosa Gabb

List of fossils from Locality No. 315. (Shore, 1½ miles east of Glacier point, Sooke formation.)

Cryptomya? ovalis? Conrad
Mytillus near *ficus* Dall
Pecten sp.
Trochita inornata Gabb

List of fossils from Locality No. 600. (Shore, Glacier point, Sooke formation.)

Ostraea sp
Aturia angustata Conrad

List of fossils from Locality No. 601. (Shore, 1½ miles northwest of Glacier point, Sooke formation.)

Macoma astori
Pelecypod indet.
Fusinus n. sp.
Polineces galianoi Dall
Echinoid n. sp. near genus *Astradapsis*.

List of fossils from Locality No. 602. (Shore, 1½ miles northwest of Glacier point, Sooke formation.)

Spisula albaria
Pecten sp.
Polineces galianoi Dall
Bullia buccinoides Merriam
Fusinus sp. new
Nassa newcombei Merriam
Gasteropod indet.

List of fossils from Locality No. 603. (Shore, 1½ miles east of Jordan river, Sooke formation.)

Mytillus sammamishensis Weaver
Pecten sp.
Spisula albaria
Brachysphingus washingtonianus Weaver
Trochita inornata Gabb
Trochita filosa Gabb

List of fossils from Locality No. 607. (Shore, 1½ miles west of Boulder point, Sooke formation.)

Ostraea sp.

List of fossils from Locality No. 608. (Shore, 1½ miles west of Boulder point, Sooke formation.)

Macrocallista newcombei Merriam
Ostraea n. sp.
Pecten propatulus Conrad
Pecten n. sp. near *branneri*.

List of fossils from Locality No. 612. (Shore, Carmanah point, Carmanah formation.)

Mytillus near *ficus* Dall
Pelecypod indet
Dentallium conradi Dall

List of fossils from Locality No. 631. (Shore, Carmanah point, Carmanah formation.)

Teredo sp.

List of fossils from Locality No. 756. (Shore, west of Clo-oose, Carmanah formation.)

Marcia oregonensis Conrad
Placunomia sp. near *macroschisma* Desh
Thracia trapezoidea Conrad
Natica oregonensis Conrad
Polineces galianoi Dall
Dentallium conradi Dall
Teredo sp.
Crab remains

List of fossils from Locality No. 1144. (Shore of Sooke bay, east of Kirby creek, Sooke formation.)

Pectunculus patulus Conrad
Macrocallista newcombei Merriam
Macrocallista vancouverensis Merriam
Mytillus near *ficus* Dall
Spisula albaria
Schizodesma? abscissa? Gabb
Tellina sp.
Bullia buccinoides Merriam
Brachysphingus washingtonianus Weaver
Crepidula praeupta
Fusinus sp. new
Ficus clallamensis Weaver
Liomesus? sulculatus Dall
Nassa newcombei Merriam
Polineces galianoi Dall
Polineces callosa Gabb

"The above list of fossil maraine faunas are of Miocene age. In Washington the Miocene consists of two divisions: the Lower or Clallam Series, and the Upper or Montesano Series. The latter rests unconformably upon the older. The Clallam Series is well represented along the south shore of the Strait of Juan de Fuca in Clallam county, Washington. Altogether, approximately twenty thousand feet of strata are represented. Within this series there are several faunal zones.

Lower Miocene.	Pysht Zone[1]
	Twin River Zone
	Porter Zone

"The beds outcropping between Jordan river and Sooke harbour contain a fauna most similar to that occurring east of Clallam bay in Clallam county, Washington. A number of species occur in the Sooke formation which are not present in the Washington Miocene. The presence of *Aturia angustata* certainly indicates that the Sooke is older than upper Miocene.

"The faunas occurring in the vicinity of Carmanah point do not appear to differ greatly from those at Sooke bay. It is possible that they may be slightly older.

"The Sooke formation from such evidence as is available is probably the equivalent of the upper portion of the lower Miocene of Washington. The Carmanah beds may be in part contemporaneous and in part middle lower Miocene."

The writer is greatly indebted to Dr. Weaver for his careful determinations, and although because of his lack of special knowledge he cannot himself judge of the relative merits of Weaver's and Hannibal's determinations, he feels that from the standpoint of the field geologist Weaver's conclusions are the better, and he has the most complete confidence in them.

Superficial Deposits.

Most of the Sooke and Duncan map-areas is covered with drift of several kinds, which, although deposited by various agencies, is, for the larger part, primarily of glacial origin. The drift with other features, such as glacial grooving and erosion, records two epochs of glacial occupation and two corresponding epochs of glacial retreat. These two epochs of glaciation have

[1] Correlated by Weaver in a recent publication, "Post-Eocene Formations of Western Washington." Proc. Cal. Acad. Sc., vol. 6, 1916, pp. 19-40, with Wahkiakum horizon—*Arca montereyana* zone of lower Miocene age, with the fauna of which, the Sooke fauna most closely corresponds.

been previously noted[1] and have been called by Willis from his studies in the Puget Sound region, the Admiralty and Vashon epochs, the interglacial epoch being called the Puyallup. The glacial and interglacial epochs recorded in the superficial deposits of Vancouver island have been correlated with those of the Puget Sound region; and the distinctive geographic names proposed by Willis have been used in the writer's later and more detailed reports on Vancouver island. The same superficial formations are found in the Sooke and Duncan map-areas as are found in the adjacent Victoria and Saanich map-areas and consequently the same formation names are used in this report as were used in the report on the Victoria and Saanich map-areas. Distinguishing the various post-Glacial as well as Glacial deposits we may subdivide the superficial deposits as follows:

- Post-Glacial epoch.
  - Rock debris.
  - Alluvium.

- Vashon Glacial epoch.
  - Stage of glacial retreat.
    - Colwood sands and gravels.
  - Stage of glacial occupation.
    - Vashon drift.
- Puyallup interglacial epoch.
  - Puyallup clays, sands, and gravels. (Subdivided in the Victoria and Saanich map-areas into the Cordova sands and gravels and Maywood clays.)

- Admiralty Glacial epoch.
  - Admiralty till.

No map of the superficial deposits accompanies this report, partly on account of the predominance of the Vashon glacial drift, but largely because of the lack of sufficient information to distinguish between the various stratified deposits. The general occurrence of each of the different deposits is, however, described in some detail.

---

[1] Dawson, G. M., Trans. Royal Soc. Can., vol. VIII, 1890, sec. 4, pp. 43–44.
Willis, Bailey, "Drift phenomena in Puget sound," Bull. Geol. Soc. Am., vol. IX, 1898, pp. 112–162.
Willis, Bailey, and Smith, G. O., Tacoma folio No. 54, U.S. Geol. Surv., 1899.
LeRoy, O., Geol. Surv., Can., Pub. 996, 1908, p. 27.
Clapp, C. H., Geol. Surv., Can., Mem. 36, 1913, pp. 107–121.

DISTRIBUTION AND CHARACTER OF DEPOSITS.

ADMIRALTY TILL.

The Admiralty till which is the oldest of the superficial deposits of the region, cannot be clearly distinguished in the Sooke and Duncan map-areas. In a few places, however, the stratified deposits overlie an older till, 3 to 10 feet thick, which may be the Admiralty till. It occurs chiefly in the bottom of the narrower and deeper valleys, such as the valley of Leech river. The overlying stratified deposits appear to be largely of post-Glacial age, so that the till deposits may be of Vashon as well as of Admiralty age. On the other hand it is probable that some of the glacial drift on the upland, considered as Vashon drift, is referable to the Admiralty epoch, but certainly at present, the Admiralty till cannot be distinguished from the more abundant Vashon drift. What is supposed to be Admiralty till is a yellowish grey, fine sandy, and in places rudely stratified till, with numerous and irregularly distributed rounded pebbles or boulders up to 6 inches in diameter.

PUYALLUP CLAYS, SANDS, AND GRAVELS.

The Puyallup interglacial deposits consist of well stratified clays, sands, and gravels. In general the clays occur near the base of the deposits and the sands and gravels near the top. In the Victoria and Saanich map-areas[1] it was possible to separate the Puyallup deposits into two members: the lower Maywood clays and the upper Cordova sands and gravels; but within the Sooke and Duncan map-areas these two members may be distinguished only in the southeastern portion, adjoining the Victoria map-area. The Puyallup deposits are found only on the coastal lowlands and largely in the eastern part of the Sooke map-area to the northwest of Parry bay and to the north of Sooke harbour; and in the east central part of the Duncan map-area, to the south of Cowichan bay and along the west shore of Saanich inlet, largely north of Mill bay. The deposits are almost everywhere found below elevations of 300 to 350

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 107–121.

feet, and largely below 250 feet, although on the south side of Mt. Metchosin, to the northwest of Parry bay, sands and gravels similar to the Cordova sands and gravels of the Victoria map-area occur at nearly 500 feet above sea-level where they appear to have been protected from glacial erosion during the Vashon epoch by Mt. Metchosin. The Puyallup deposits doubtless occur elsewhere on the lowlands, but are not readily distinguished in places from the Colwood sands and gravels, and over a large portion of the lowlands have either been eroded during the Vashon glacial epoch or are hidden by a cover of Vashon drift. Even in those places where the deposits are best developed they are usually covered by a thin but fairly persistent mantle of Vashon drift. The country underlain by the deposits is usually gently rolling or smooth although somewhat diversified by the valleys of small intermittent streams, and in most places has been cleared and cultivated. Here and there the deposits slope gently to the shore, but in most places they terminate in steep, wave-cut cliffs, 30 to 150 feet high.

The clays are yellowish grey to bluish grey, and sandy, and most of them are of poor plasticity, although plastic clays are found in many places. They are interbedded with clayey sands and even with coarse sands and gravels which predominate in the upper part of the Puyallup deposits. The sands and gravels are well stratified and occur in flat lying beds up to several feet in thickness, although the individual beds are more or less lens-shaped and overlap and replace one another. Many of the beds of sand are also cross stratified. Irregularly distributed throughout the deposits, but more conspicuous and apparently more numerous in the sandy clays and in the lower portion, are subangular to rounded, glacially scratched and polished pebbles and boulders, up to 2 feet in diameter, of the crystalline rocks of the region. Some of the clays and clayey sands are carbonaceous and contain plant remains and impressions. They doubtless contain marine organisms also, as do the Puyallup deposits of the Victoria and Saanich map-areas; but the organisms are not numerous and none were found during the present investigation.

A typical section of the Puyallup deposits is exposed in the sea-cliffs to the west of the entrance to Sooke harbour.

	Thickness in feet.
Ferruginous, grey to reddish, sand and gravel with a little clay	30
Sandy clay, with carbonaceous patches and bits of broken and compressed leaves, stems, bark, and so forth	30
Clayey sand	20
Yellow ferraginous sand	10
Gravel	10

The Puyallup deposits rest directly, in most places, upon the glaciated surfaces of the underlying hard rocks; and although in a few places they may rest upon the Admiralty till, in the exposures where such seems to be the case, within the Sooke and Duncan map-areas, the Admiralty till cannot be positively distinguished from the Vashon drift nor can the Puyallup deposits be surely distinguished from the Colwood. The Puyallup deposits vary greatly in thickness, owing largely to irregularites in the underlying hard rock surface. Sections from 40 to 80 feet are numerous and those of 100 feet or more, like that given above, are exposed at several places along the shore. It is fairly certain, therefore, that the deposits average at least 100 feet thick ; and since they commonly occur up to elevations of 250 feet, with in places, no rock exposures along the neighbouring shore, they doubtless have a maximum thickness of 250 feet or possibly more. As already stated the deposits are unconformably overlain by the Vashon drift and are commonly strewn with large glacial, erratic boulders.

VASHON DRIFT.

The Vashon drift covers the greater part of the Sooke and Duncan map-areas, mantling the interglacial deposits of the lowland and covering a large portion of the upland. On the lowland, except in places on the points and islands of the north-eastern part of the Duncan map-area, the mantle of drift is thin, from 3 or 4 to 20 feet thick, and frequently thins out completely, so that over large areas it is absent or is represented only by the erratic, glacial boulders which occur strewn over the surface of the interglacial deposits. On the upland the larger part of the drift is of Vashon age, but it is probable that the Vashon drift is mixed with more or less of the Admiralty till, from which it is indistinguishable. The Vashon drift seldom forms distinct and characteristic topographic features, such as moraines, kames, and eskers, but merely forms a mantle covering either the hard rocks or the interglacial deposits. However, the form of the drift deposits is usually obscured by the heavy growth of timber and thick underbrush and in places, where the timber has been burned or cleared off, for example to the east of the north end of Shawnigan lake, and in places on the upland, there are low hummocky moraines that are apparently terminal moraines. Furthermore, near the heads of the larger valleys are ground moraines, in places, as to the south of Mt. Todd, esker-like in form, and along the sides of the valleys, well shown along the north side of Cowichan valley, there are apparently lateral moraines. The drift has, of course, filled up many of the smaller hollows and valleys in the surface upon which it rests, and its own surface is marked by small irregularities, such as low rounded hills and undrained shallow basins, many of which hold small lakes or have been filled with alluvium. The maximum exposed thickness of the drift is from 30 to 50 feet, but it doubtless attains a much greater thickness in places. It is reported that in building the upper dam in Bear creek, piles were driven 125 feet into the drift before striking bedrock. The drift may even exceed 125 feet in places, but its average thickness is probably not much more than 20 to 40 feet.

The Vashon drift is largely an unsorted mixture of coarse to fine, yellow sand, gravel, and bluish grey, boulder clay, with numerous subangular to rounded glaciated cobbles and boulders, chiefly of the granitic rocks, scattered irregularly through it (Plate XI). In places, striated boulders are found, but they are not abundant. The boulders are mostly from 1 to 4 feet in diameter, but those 10 feet in diameter are not uncommon and in places on the upland, where the drift as a rule is coarser, the boulders may be 20 feet or more in diameter. The boulders have usually been derived from the immediately underlying hard rocks, and have apparently not been carried far; and since the drift mantle is thin and fails to cover small rounded outcrops, these cannot always be distinguished from large boulders. Near Malahat station, however, in a very coarse boulder deposit, there are large angular boulders of Nanaimo conglomerate, up to 20 feet in diameter, which must have been carried for at least 9 or 10 miles. In several places on the lowland and in a few places on the upland, the drift, where composed largely of fine sand, is rudely stratified. This is an especially characteristic feature of the drift on the islands of the northeastern part of the Duncan map-area, and it appears as if the drift were composed largely of the disintegrated Nanaimo sandstones and sandy shales. Near the surface the drift is usually oxidized to dark brown and passes into a dark, sandy and gravelly loam that usually covers it.

The Vashon drift over the greater part of the map-areas rests directly upon the glaciated hard rocks, but on the lowlands it commonly overlies the Puyallup deposits. In several places on the lowland it is in turn overlain by the Colwood sands and gravels (Plate XI).

COLWOOD SANDS AND GRAVELS

A large part of the lowlands of Vancouver island, not including the islands of the northeastern portion of the Duncan map-area, is covered with the Colwood sands and gravels. This is especially true of those portions near the terminals of the larger valleys, the valleys of the Chemainus, Cowichan, Goldstream, and Sooke rivers, and of Muir and Kirby creeks. The sands and gravels extend up all the larger valleys for a short distance, but completely cover the floor of the Cowichan valley. Small and isolated deposits of the Colwood sands and gravels are found also in the Leech and Koksilah River valleys. The upper limit of the deposits is rather strictly defined, and, except in the western part of the Cowichan valley and in the Leech and Koksilah River valleys, where the Colwood sands and gravels attain elevations of over 500 feet, the deposits are found below elevations of 400 feet above sea-level. They form rather smooth, but terraced plains, and the boundary of the deposits with the Vashon drift covering the valley sides follows closely, in places, the 400-foot contour. The terraces are 10 to 30 feet high, and are usually parallel to the larger streams crossing the deposits; although the deposits in the eastern end of Leech River valley are terraced parallel to the axis of the valley, that is northwest-southeast, whereas the valley is drained by the lower, northward flowing portion of Goldstream creek. In places, best developed in the deposit, called the Colwood delta,[1] which fills the eastern end of Leech River valley, and occurring one-fourth to one-half mile east of the Sooke map-area, are large kettle or ice-block holes, 100 to 800 feet across and 10 to 80 feet deep. Similar but smaller kettle-holes and kames as well, occur in the same deposit within the Sooke map-area to the north of Goldstream post-office. Kames and kettle-holes occur also in the Colwood deposits of the Nanaimo map-area,[2] and near the western inner border of the southern extension of these deposits into the Duncan map-area where they cover the rather extensive lowland between Ladysmith and Crofton. Kames and kettle-holes may occur in the deposits of the Cowichan valley but no good examples have been seen. Shallow hollows in the deposits are, however, rather numerous and contain lakes, such as Askew and Fuller lakes near Chemainus, Somenos and Quamichan lakes in the Cowichan valley, and Glen, Florence, and Langford lakes in the upper portion of the Colwood delta. On the Colwood sands and gravels, halfway between Muir and Kirby creeks, and about a mile from the shore, is an esker-like deposit, about 40 feet high, consisting of three radial ridges, each about 200 yards in length.

The Colwood deposits consist largely of yellow, coarse sands and fairly well rounded fine to coarse gravels, composed largely of pebbles of the undecomposed granitic rocks and of the Metchosin volcanics. In places the sands are highly ferruginous and partly cemented with limonite. Interstratified with the sands and gravels are a few beds of yellow to bluish grey, sandy clay which is rarely smooth or plastic. In a few places the clays are brown with carbonaceous matter. The upper or surface layer of the deposit is usually composed of horizontally stratified coarse gravels and is even strewn with a

[1] Geol. Surv., Can., See Mem. 36, 1913, pp. 112-113.
[2] Geol. Surv., Can., See Mem. 51, 1914.

few boulders 2 to 3 feet in diameter. The upper layer of horizontally bedded coarse gravels is from 5 to 25 feet thick and overlies finer-grained and thinner beds of coarse sand and fine gravel, which are usually steeply cross-bedded, with dips of 15 to 30 degrees to the eastward, and frequently display contemporaneous erosion and deposition. Thus almost any section of the deposit, that is of any terrace, reveals what is apparently a typical delta structure, with coarse horizontally bedded top-set beds overlying finer, steeply bedded fore-set beds. Whereas in places, as in the Colwood delta,[1] the apparent delta structure is real, in most places, as has already been pointed out[2], it is a pseudo-delta structure formed by the truncation of the steeply bedded sands and gravels which compose the larger part of the deposits, by the rivers that terraced the deposits, and the deposition by the rivers, of their own load on top of truncated beds, as horizontally bedded coarse gravels.

The Colwood sands and gravels are seen in several places (Plate XI) to overlie the Vashon drift and in places probably directly overlie the Puyallup deposits as they do elsewhere on Vancouver island. Except in the kettle-holes and the shallow basins of the deposits and in the river valleys cutting through them, the Colwood sands and gravels are not covered by any younger deposit, and even the soil covering is thin. However, at places in the valley of Leech river the deposits are apparently covered with glacial drift, but it seems quite obvious that the drift has been washed or has slid from the upper steep valley slopes onto the Colwood sands and gravels in the bottom of the valley.

ALLUVIUM.

In the shallow, undrained hollows of the drift mantle, and along sluggishly drained valleys in the drift mantle, or in the deeper valleys in the upland, which have been widened and deepened by glacial scour and partially filled and dammed by drift deposits, are thin deposits of black carbonaceous mud or muck, more rarely peat, and of fine-grained siliceous clays and silts. In addition, in the valley of Demaniel creek, in Sooke and Otter

[1] Geol. Surv., Can., Mem. 36, 1913, pp. 112–113, and pp. 119–120.
[2] Geol. Surv., Can., Mem. 51, 1914, p. 86.

district, is a deposit of an ochreous clay derived largely from the products of the chemical decay of the Metchosin basalts, decomposed pebbles and boulders of which are found embedded in it. All of these deposits were doubtless formed during post-Glacial or recent times in sluggish streams or in the standing water of small lakes or ponds, some of which are only partially filled and are now swamps, while others have been completely filled or have been drained artificially.

These deposits, as noted by several observers, recently by Hannibal[1] and Newcombe[2], contain, in the vicinity of Victoria, as elsewhere on Vancouver island, numerous freshwater shells, the species being identical with those found in the existing remnant lakes. In places on the lowland, these recent lake deposits overlie somewhat similar deposits which contain, as noted by Hannibal[3] and Newcombe[4], marine shells. These deposits are thin, seldom more than 3 or 4 feet thick, and in places, especially near the present shores, consist of a shell marl mixed with a brownish clayey sand, and are not readily distinguished from shell heaps made and uplifted for at least 30 feet above sea-level since the inhabitation of the region by man. The shell heaps and possibly the "raised beach" deposits are abundant along the north shore of Sooke harbour, in the lower portion of Cowichan valley, and on many of the islands of the northeastern part of the Duncan map-area. They are found on the lowland, largely below elevations of less than 50 feet above sea-level, although in the vicinity of Victoria Dr. Newcombe has discovered them at elevations of 110 feet above sea-level.[5] Within the Duncan map-area they were found, in 1909, by Mr. J. A. Allan who at that time was associated with the writer, above the west shore of Sansum narrows, 2 miles north of the southern end, at 180 feet above sea-level. On Texada island, only 30 miles northwest of the Duncan map-area,

[1] Arnold, R., and Hannibal, H., "The marine Tertiary stratigraphy of the north Pacific coast of America." Proc. Am. Phil. Soc., vol. 52, 1913, pp. 597–598.

[2] Newcombe, C. F., "Pleistocene raised beaches at Victoria, B.C." Ottawa Naturalist, vol. 28, 1914, pp. 107–110.

[3] Loc. cit.

[4] Loc. cit.

[5] Op. cit. p. 108

they have been found by Mr. R. G. McConnell[1] at elevations of 424 feet above sea-level. These deposits, as mentioned, are thin and should not be confused with the Puyallup interglacial deposits which contain a similar but not identical marine fauna. They form merely thin layers of small extent, resting upon the older deposits, the Vashon drift, the Puyallup deposits, and probably the Colwood sands and gravels. Furthermore, the underlying deposits were not submerged long enough at any one level to have been wave-cut into shore cliffs, or other characteristic beach forms.

Along the lower portion of the larger streams that, since the recent uplift, have been able to cut to grade, are flood-plains which with one exception are narrow. The flood-plain of the lower portion of the Cowichan river, however, spreads out into a broad flat, averaging 2 miles in width, which toward the east merges into the present delta which is rapidly filling Cowichan bay. Other much smaller deltas are being built by the other large streams such as the Chemainus, Goldstream, and Sooke.

Along the shores, as already described, part of the sand and gravel of the drift deposits, that have been retrograded during the present marine cycle, forms narrow beaches between rocky headlands; and in a few places, as at the entrance to Sooke harbour, the sand and gravel have been built by shore currents and waves into spits and bay bars.

ROCK DEBRIS.

Covering portions of the sandstone-conglomerate islands of the northeastern portion of the Duncan map-area is a thin mantle consisting largely of small to large angular fragments of the sandstones and conglomerates, mixed with more or less glacial till, and, in some places, even with the interglacial deposits. This mantle of rock debris appears to be the result of the breaking down by mechanical agencies, in post-Glacial times, of the underlying sandstones. Similar debris has been found at the base of some of the sandstone and conglomerate cliffs of Vancouver

[1] McConnell, R. G., Geol. Surv., Can., Mem. 58, 1914, p. 40.

island, such as Mt. Prevost in Somenos district; and in a few places, chiefly within the northern upland, a coarse talus of the crystalline rocks has been found at the base of steep rock slopes.

GLACIATION AND MODE OF ORIGIN OF SUPERFICIAL DEPOSITS.

From the character of the superficial deposits it is seen that they are composed largely of glacial detritus, so that a discussion of their origin is so closely linked with a discussion of the glaciation of the map-areas that the two topics are treated together. From the widespread distribution of glacial till on the upland of Vancouver island and from the severe glaciation of the upland, mountains nearly 5,000 feet high having been rounded, it is seen that Vancouver island was at some time during the Glacial period nearly hidden by a thick ice-cap. The ice-cap completely covered the upland of the Sooke and Duncan map-areas, removed virtually all of the surface soil, and smoothed off and rounded the angularities of the pre-Glacial rock surface. Striations, glacial grooves, and polished, "boat-bottomed" shaped ledges or roche moutonnées, not well preserved on the upland, indicate that the ice-cap had a general southward movement. However, as is clearly shown by polished roche moutonnées, and deep, sometimes undercut, grooves parallel to the trend of the valleys, at least the lower part of the ice-cap was deflected locally and followed the valleys, especially the north-south valleys, deepening them considerably and widening them somewhat, to form in places, as has already been described, lake basins, and even fiords.

A large glacier flowed eastward through Cowichan valley and with the other large glaciers flowing eastward from the east slope of the Vancouver range, joined with the larger and more numerous glaciers flowing westward from the ranges of the mainland and formed an extensive piedmont glacier which occupied the great valley between the Vancouver range and the ranges of the mainland. The southward or southeastward flowing portion of this piedmont glacier, known as the Strait of

Georgia glacier,[1] overrode the lowland of the northeastern part of the Duncan map-area, and rounded the sandstone and conglomerate ridges and locally overdeepened the soft sedimentary rock valleys and smoothed their slopes, completely abrading the minor irregularities produced by normal erosion.

A portion of the Strait of Georgia glacier turned at the southeastern end of Vancouver island, and flowed somewhat north of west through the strait of Juan de Fuca to the Pacific ocean. The Juan de Fuca glacier was doubtless swelled by the addition of ice from the southward flowing valley glaciers of Vancouver island and from the northward flowing glaciers from the Olympic mountains. It overrode in places the narrow "west coast" lowland and polished and grooved the hard rock headlands.

The only deposit that was clearly formed during this period of glaciation was the Admiralty till. It was doubtless more extensive than appears at present, and probably furnished much of the material of the Puyallup interglacial deposits, and, as mentioned, doubtless occurs on the upland mingled with the Vashon drift. It was deposited directly by ice, but part of it was apparently deposited in water, probably below sea-level, since it is partly stratified and directly overlain by the marine interglacial deposits.

On the retreat of the glaciers of the Admiralty epoch, the land apparently stood about 350 feet lower than it is at present as is shown by the occurrence of interglacial deposits up to an elevation of 350 feet, which are similar to those containing marine fossils in the adjoining Victoria, Saanich, and Nanaimo map-areas. Fossils doubtless occur in the deposits of the Sooke and Duncan map-areas but have not been discovered since they have not been carefully sought for. Hence the pre-Glacial lowland must have been submerged below sea-level, forming estuaries. In these estuaries under conditions of comparative quiet and of moderate temperature, shown by the remains of vegetable and animal life, the lower portion of the Puyallup deposits was deposited. The glaciers had not, however, completely disappeared from the region as the irregularly

[1] Dawson, G. M., "On the later physiographical geology in the Rocky Mountain region in Canada," Trans. Roy. Soc., Can., vol. 8, 1890, sec. 4, p. 29

distributed pebbles and large erratic boulders found in the Puyallup deposit were doubtless dropped from floating ice. During the later stages of the interglacial epoch, when the upper sands and gravels were deposited, either shallower water prevailed or else the rivers and streams issuing from the glacial front, perhaps advancing at this time, were more heavily loaded with coarser detritus.

The interglacial epoch was brought to a close by the second glacial advance, the Vashon glacial epoch. At this time the Vashon drift was deposited, largely by ice alone, but since some of it is rudely stratified it was doubtless in part deposited by water, either by streams flowing beneath the glaciers or issuing at their fronts. The Vashon glaciation was less intense than the Admiralty glaciation; for, although the Vashon drift rests directly upon the glaciated hard rocks of the upland, on the lowlands, the Vashon glaciers merely eroded portions of the older unconsolidated glacial and interglacial deposits.

To judge from the absence of conspicuous moraines composed of the Vashon drift, the retreat of the Vashon glaciers must have been fairly rapid.[1] Nevertheless the Colwood sands and gravels were deposited apparently by heavily loaded streams issuing from the larger valley glaciers. The Colwood sands and gravels, as is shown by their position at the mouths of the larger valleys, their flaring outlines, their steep stratification, and in places, well developed top-set beds, are quite clearly delta deposits. That they were deposited near the front of the ice during glacial recession is further substantiated by the presence of kettle-holes and kames near their inner border and by the coarse, ice-borne boulders with which the deposits are strewn. It is possible that some of the deltas were deposited in ice dammed lakes; but since it is positively known by the presence of marine shells in the recent alluvium, that an uplift of 400 feet has occurred recently and since that elevation is the upper limit of most of the delta deposits, it is more probable that the deltas were formed in salt water. Since the uplift, the delta deposits have been terraced by the revived streams crossing them.

[1] Cf. Dawson, G. M., Royal Soc. Can., vol. VIII, 1890, sec. 4, p. 45.

The uplift must have been comparatively rapid, for the beach deposits formed during it are thin and of small extent, and no well developed terraces, cliffs, or other characteristic shore features were cut even in the drift deposits. The Cowichan River delta, still in active formation, was, however, rapidly deposited and portions of it are now nearly 50 feet above sea-level.

The origin of the other post-Glacial deposits has been already sufficiently well indicated.

AGE AND CORRELATION.

There is, of course, little question as to the general age of the superficial deposits. The Admiralty till and Vashon drift were clearly deposited during two epochs of glaciation separated by the Puyallup interglacial epoch, during which the Puyallup clays, sands, and gravels, in part of marine origin, were deposited. The Colwood sands and gravels were clearly deposited during the recession of the Vashon glaciers, presumably during the transition between Pleistocene and Recent times. In Recent time, the Glacial deposits have been uplifted and the swamp, valley, and delta and beach alluvium has been deposited, and the bared glaciated rocks have been disintegrated into rock debris.

As has already been stated, the two glacial epochs of the Sooke and Duncan map-areas are correlated with the two glacial epochs which have been recognized in other parts of the north Pacific coast and called the Admiralty and Vashon epochs. The features of the superficial deposits of the Sooke and Duncan map-areas agree very closely with those of the adjoining Victoria and Saanich map-areas,[1] which are correlated with much certainty with those of the Tacoma quadrangle (map-area) and of the Puget Sound region[2]. The Vashon epoch[3] has been correlated with the last epoch of glaciation of the central and

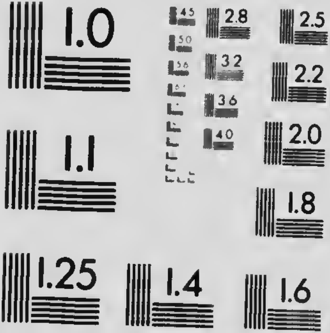
[1] See Geol. Surv., Can., 1913, Mem. 36, pp. 107-120.

[2] Willis, B., and Smith, G. O., Tacoma folio, No. 54, U.S. Geol. Surv., 1899.
Bretz, J. Harlen, "Glaciation of the Puget Sound region," Bull. No. 8, Washington Geol. Surv., 1913.

[3] Dawson, G. M., Roy. Soc. Can., vol. VIII, 1890, sec. 14, p. 54.
Bretz, J. Harlen, "Terminal moraine of the Puget Sound glacier," Jour. Geol., vol. 19, 1911, p. 174

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



eastern parts of North America, the Wisconsin. In the Puget Sound region the Admiralty till and Puyallup interglacial deposits are frequently weathered,[1] suggesting that they were long exposed before the Vashon glaciation. But on Vancouver island the till and interglacial deposits are unweathered. However, there must have been a long interval between the Admiralty and Vashon epochs; but the Admiralty epoch cannot be correlated with any certainty with one of the pre-Wisconsin glacial epochs of central and eastern North America. Willis and Smith do not indicate that any of the Puyallup deposits of the Tacoma quadrangle were deposited under marine conditions as were at least the lower (Maywood) clays of the Puyallup deposits of Vancouver island; but Bretz[2] states that a few clay beds at the base of the Puyallup deposits of the Puget Sound region do contain marine fossils, and these clays are doubtless to be correlated with the Maywood clays of Vancouver island. In fact, some of the fauna, *Cardium islandicum* Fabr., *Mya truncata* Lin., and *Leda fossa* Baird, are identical. It should be noted that Bretz places all of the pre-Vashon sediments in the Admiralty epoch and considers the Puyallup interglacial epoch to have been one merely of weathering and erosion.

The marine shell-bearing alluvium, that rests upon the Vashon and Puyallup and presumably the Colwood deposits, has been designated by Hannibal as the Saanich formation.[3] The use of the term Saanich is unfortunate since the term has been used since 1908 to distinguish certain of the upper Jurassic granodiorites.[4] Furthermore it is quite clear that the fauna listed from the so-called Saanich formation has been collected in part from the recent beach deposits and in part from the Puyallup interglacial deposits. This has been shown by correspondence with Mr. Hannibal and by the statement that the "formation carries numerous mollusca, usually species now living in adjacent waters, but others extinct or . . . now native

[1] Bretz, J. Harlen, Bull. No. 8, Wash. Geol. Surv., 1913, p. 14, states in contradiction to Willis and Smith, that "the Admiralty till is nowhere deeply weathered though in some places stained by percolating water."

[2] Bull. No. 8, Wash. Geol. Surv., 1913, p. 15 and pp. 180–182.

[3] Arnold, R., and Hannibal, H., Proc. Am. Phil. Soc. vol. 52, 1913, pp. 597–598.

[4] Geol. Surv., Can., Sum. Rept., 1908, pp. 55–56.

only off the Alaska coast or other Arctic points." The Saanich formation, therefore, as originally described, is not a single unit, and for the recent shell deposits, if a formation name is necessary, another name than Saanich should be adopted.

STRUCTURAL GEOLOGY.

The most striking feature of the geological structure of the Sooke and Duncan map-areas is the arrangement of the stratified or surface formed rocks in parallel belts. The belts strike about north 65 degrees west corresponding to the main axis of Vancouver island. The belts are separated from each other by profound faults, or intrusive batholiths, or mantles of younger rocks. They are the result of the two periods of profound deformation, the upper Jurassic and the lower Oligocene (post-Eocene), aided by erosion following deformation or following large uplifts without much folding.

There are six main belts, which are from north to south: (1) the Nanaimo basin of the Nanaimo series, (2) the Sicker series, (3) the Cowichan basin of the Nanaimo series, (4) the Vancouver volcanics and intercalated Sutton limestones, (5) the Malahat volcanics and Leech River formation, and (6) the Metchosin volcanics. Although flexed into large major folds as well as into many small or secondary longitudinal folds, the belts are further involved in great earth or "geo" folds. Belt (1) has a general dip to the northeast, although flexed into two large anticlines and two corresponding synclines, as well as into many smaller folds. Belt (2) is in general synclinal, inasmuch as the uppermost beds are exposed in the central part of the belt whereas the lowermost beds outcrop near the edges. Furthermore, a short distance to the north, within the Nanaimo map-area, the supposedly underlying, Vancouver volcanics again outcrop. With respect to the contiguous belts (1) and (3) of younger and unconformably overlying rocks, belt (2) is, however, distinctly anticlinal. Furthermore, Cooke has shown that the belt probably forms the north limb of a normal anticlinorium since the axial planes of the three major synclines into which the belt is folded dip to the south at angles varying from 45 degrees in the northern syncline to 75 degrees in the southern. Belt (3) is distinctly synclinal although actually deformed into two major faulted synclines. The general structure of belt (4) is obscure. Its rocks have a slightly predominating dip towards the southwest, and judging from the general structure of the neighbouring belts (2) and (5) it appears as if the general structure were synclinal, the axis of the syncline occurring not far from the southern edge of the belt. Belt (5) is homoclinal[1], that is the rocks of the belt all dip in the same direction, to the north. From the dip of the axial planes of the appressed folds, and from the relative movement of the limbs of the folds, as well as from the relative movements of the walls of strike faults, it seems fairly certain that the belt forms the southern limb of a large synclinorium. The northern part of belt (6) is also homoclinal. Its rocks all dip to the north at rather low angles of from 15 to 30 degrees. The dip of the rocks of the southern part of the belt is variable, so that it is possible that as a whole the belt is anticlinal, the axis of the anticline being situated not far from the southern edge of the belt.

Of the great earth folds recorded by the attitudes of the six belts, those comprised by belts (2), (4), and (5) are largely the result of the upper Jurassic deformation; and those comprised by belts (1), (3), and (6) are almost entirely the result of the lower Oligocene deformation. During the upper Jurassic deformation the rocks of belts (2), (4), and (5) were warped into two large synclinoria, the southern involving the rocks of belts (4) and (5) and the northern involving the rocks of belt (2) and the Vancouver volcanics as well lying farther north in the Nanaimo map-area. As Cooke has stated, the crest of the anticlinorium, the north limb of which is composed of the rocks of belt (2), coincides with the present Cowichan valley. The crest of the anticlinorium, which is situated, of course, between the two synclinoria, has been greatly denuded and is now covered by the rocks of belt (3). It appears further as if the anticlinoria adjoining the two synclinoria to the north and to the south were also greatly eroded and covered by the younger rocks of belts (1) and (6).

[1] Daly, R. A., Geol. Surv., Can., Mem. 68, 1915, p. 53.

Little can be definitely determined as to the character of the synclinoria. They were unquestionably open and relatively shallow, with limbs dipping at angles of not much more than 10 to 15 degrees; and hence they involved only a relatively thin shell of the earth's crust.[1]

It is probable that the two strike faults—one separating the western portions of belts (4) and (5) and the other beneath the covering of Nanaimo sediments apparently separating the rocks of belts (4) and (2)—the southern wall of each fault being the upthrown, were first developed during the upper Jurassic deformation. However, either faulting was renewed along the latter fault during the lower Oligocene deformation, or else all of the great longitudinal and parallel faults of the map-areas, the two referred to, and the Leech River fault between belts (5) and (6), and the northern boundary fault between belts (3) and (2) may have been produced entirely during the lower Oligocene deformation.

It is quite certain, however, that during and following the upper Jurassic deformation a large part of the deeper portions of the folded rocks was replaced by the batholithic rocks, a fact which has greatly obscured the relations of the stratified rocks. Along the contact between belts (4) and (5) the batholith of Wark and Colquitz gneiss was intruded; and along the contact between belts (2) and (4) as well as into the rocks of belt (2), chiefly along the northern boundary of the belt, the batholiths and stocks of Saanich granodiorite were intruded.

As mentioned, the rocks of belts (1), (3), and (6) were apparently deposited on the eroded anticlinoria of the upper Jurassic deformation, and were themselves folded during the lower Oligocene deformation. It appears from the attitude of the rocks of the three belts as if they were folded into three great synclinoria: one with its axis to the northeast of Galiano island, the rocks of belt (1) forming the southwestern limb; a second with its axis coincident with belt (3) and the Cowichan valley; and a third with its axis to the north of the northern boundary of belt (6), the rocks of the northern portion of belt (6) forming

[1]Cf. Leith, C. K., "Structural geology," 1913, pp. 124-127.

the southwestern limb. Whether or not all three of the synclinoria, immediately after folding, were joined by corresponding anticlines is uncertain, although it appears as if the two northern synclinoria were so joined. However, the corresponding anticlines have now been destroyed completely so that between the synclinal belts of post-upper Jurassic rocks are anticlinal areas of pre-upper Jurassic rocks which are with respect to themselves synclinal.

The central of the three Oligocene synclinoria, belt (3), consists, as already described, of two major synclines. The northern limb of each of these synclines has been broken by a strike fault. Of the two faults, the northern wall of which has in both faults been the uplifted, the northern separates belts (3) and (2) and the southern apparently coincides with the supposed upper Jurassic fault which appears to separate the rocks of belts (2) and (4). The northern limb of the southern of the three synclinoria has also been faulted by the great Leech River fault and completely eroded, so that now the oldest of the pre-upper Jurassic rocks, the Leech River formation, rests against the youngest of the pre-lower Oligocene rocks, the Metchosin volcanics. It is thus seen that during the lower Oligocene faulting the northern wall of each fault has been the upthrown, while during the supposed upper Jurassic faulting the upthrown wall of the faults has been the southern.

The rocks of the three lower Oligocene synclinoria have a prevailing dip to the northeast, so that it appears as if the southwestern, northeasterly dipping limbs were wider and had a gentler dip than the narrower and more steeply dipping northeastern limbs. However, as shown by the preceding paragraph, the structure is partly the result of faulting and erosion. Nevertheless, it is probable that the Oligocene synclinoria were somewhat inclined so that their axial planes dipped to the north. It appears from this fact as well as from the character of the lower Oligocene faulting as if the forces causing deformation acted from the northeast towards the southwest, perhaps having had their origin beneath the strait of Georgia.

After erosion the deformed rocks and the younger, upper Oligocene coastal plain sediments, the Sooke formation, were uplifted with very little folding but with rather extensive minor and usually normal faulting. The recent uplift of 250 to 400 feet appears to have been nearly uniform, although there may have been a slight tilting to the southwest, since the uplift of the northeast coast of Vancouver island appears to have been somewhat greater than the uplift of the southwest coast.

HISTORICAL GEOLOGY.

Presumably towards the close of the Palæozoic era, during the Carboniferous period, the oldest rocks of the region, those of the Leech River and Malahat formations, were deposited. The Leech River schists are apparently metamorphosed shales and shaly sandstones, and appear to have been deposited under uniform conditions which prevailed for a long time and which were, therefore, probably marine. They were doubtless deposited in shallow waters and were derived either from a low neighbouring land mass or, as is more likely, from a higher but more distant land which was probably situated far to the east. Towards the close of the deposition of the Leech River sediments vulcanism was initiated, and some of the volcanic ejecta, irrupted from explosive volcanoes apparently situated several miles from the region of southern Vancouver island, were deposited with the sedimentary material. With approaching and increasing vulcanism, largely of an explosive nature, the volcanic matter accumulated, largely under water, faster than the sedimentary, resulting in the Malahat volcanics. However, at no time during the accretion of the Malahat volcanics, does sedimentation appear to have ceased.

It is probable that at the close of the Palæozoic era a pronounced change of conditions took place; for fine-grained sediments like those of the Leech River and Malahat formations were no longer deposited in shallow seas. Instead, during the greater part of lower Mesozoic times extensive vulcanism took place, presumably under submarine and deep water conditions. In addition, a time interval is recorded by the almost certain angular unconformity between the Mesozoic volcanics and the Malahat volcanics; and further, rocks representative of the lowest

Mesozoic, early and perhaps middle Triassic, appear to be absent from the region. Little is known of the nature of the change that occurred near the close of the Palæozoic, since the structures produced at this time have been obscured by the intense deformation and intrusion that took place near the close of the Jurassic.

During lower Mesozoic times, from late middle Triassic to at least middle Jurassic, thick flows of moderately basic lavas, the Vancouver volcanics, were poured out upon the sea-floor from numerous fissures and in places eruptions of a more explosive nature occurred. Doubtless near eruption centres the accumulating volcanics were built above sea-level to form islands. On these islands marine organisms lived and built extensive shell and coral deposits which have since been metamorphosed into the crystalline limestones of the Sutton formation. At some time during the accretion of the volcanic rocks a change of conditions brought about the deposition of fine-grained sediments with and on top of the volcanics, thus forming the rocks of the Sicker series. This change seems to have taken place at the close of the period of vulcanism, and closely following it the rocks that had accumulated during the volcanic period, that is the rocks of the Vancouver group, were deformed.

At the time of deformation the thickness of all of the rocks of the Vancouver group must have been nearly 25,000 feet.[1] Possibly due to this heavy, extra load upon the earth's crust in this region, strong crustal movements were started. The movements initiated a long period of deformation which affected the entire Pacific Coast region of North America during upper Jurassic and Lower Cretaceous times. During this period the rocks of the Vancouver group, and the Leech River and Malahat rocks as well, were greatly deformed, the main axis of deformation corresponding with the trend of the island. Perhaps preceding, but chiefly during and closely following the deformation, batholiths and stocks of granitic rocks, and sills, dykes, and irregular masses of porphyrites were intruded into older surface formed volcanic and sedimentary rocks of the Vancouver group

[1] Taking into account the Nitinat limestones to the west of the map-area.

and of the Leech River and Malahat formations, metamorphosing them, and apparently replacing large volumes of them. 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 dykes, and their injection apparently closed the irruptive cycle, begun long before by the eruption of the volcanic rocks.

The irruptive rocks were subsequently exposed by erosion during the cycle initiated by the deformation, and upon an erosion surface of moderate relief composed of the irruptive rocks and of the rocks of the Vancouver group, a series of fragmental sediments, the Nanaimo series, were deposited in Upper Cretaceous times. The sediments were derived chiefly from the underlying irruptive and metamorphic rocks and were first deposited in a marine basin between Vancouver island and the mainland, which basin was probably one of deformation depressed during the upper Jurassic folding. The deposition took place under varying [illegible] since the different beds vary rapidly in both vertic[illegible]ral directions, and it is probable that marine (estuarin[illegible]s alternated with those of fresh and brackish water. [illegible] close of their deposition the sediments in the vicinity of the Duncan map-area averaged about 10,000 feet in thickness, but in places may have been 1,000 or 2,000 feet thicker. At that time they covered all of the present lowland areas of the Duncan map-area and extended far inland over the crystalline rocks of Vancouver island. They doubtless covered many of the higher hills of the surface upon which they were deposited, and though they appear to have been restricted chiefly to large depressions or basins, they may have formed a thin mantle over a part of the present upland of Vancouver island.

During the deposition of the Nanaimo series local movements occurred and at the close of sedimentation near the beginning of Eocene time the series was presumably uplifted without much folding. Later, during upper Eocene time, vulcanism occurred in the southern part of the map-areas, and extensive basalt flows were poured out on the sea-floor from numerous fissures, and in places eruptions of a more explosive nature occurred. As during the Mesozoic vulcanism, the accumulating volcanics, the Metchosin, attained a thickness sufficient to reach above sea-level and formed islands. On the shores of the islands lived the upper Eocene gastropods found in the basaltic sandstone beds, and there also the basaltic detritus was subject to wave action. At the close of the period of vulcanism probably in early Oligocene time the Metchosin volcanics and the Nanaimo series were both extensively folded and faulted. It is probable that the forces causing the deformation acted from the northeast, perhaps having their origin below the basin of deformation between Vancouver island and the mainland, that was partially filled by the Upper Cretaceous sedimentation and by Eocene sedimentation from the mainland. During or immediately following the deformation, the Metchosin volcanics were intruded by stocks of gabbro, the Sooke gabbro, which underwent differentiation largely in place resulting in granites and anorthosites.

During the cycle initiated by the early Oligocene deformation the Metchosin volcanics were greatly eroded, sufficiently to expose the gabbro stocks intrusive into them and to obliterate all fault scarps formed during the deformation, before the deposition of the Sooke and Carmanah formations in lower Miocene or possibly Oligocene time. The Sooke and Carmanah formations were first deposited off a mountainous shore, so that the region was not at first reduced to a peneplain. As erosion and deposition continued, it appears as if the region as a whole was depressed, until at the end of the cycle, in middle Miocene time, a coastal plain had been built up against a submerged mountainous slope. It is probable that this coastal plain, formed, with the old age erosion surface cut in the deformed rocks during the deposition of the coastal plain, virtually a continuous plain. In its southern part the erosion surface was a peneplain with a few monadnocks remaining a few hundred feet above the general level, but in its central part, the surface was one of considerable relief, with larger and higher monadnocks and small ranges of mountains.

The subdued and peneplained Tertiary erosion surface and the coastal plain deposits were subsequently uplifted, without much folding or tilting. Since sedimentation ceased near the close of the Miocene in this general region,[1] it appears as if the uplift took place in early Pliocene times.[2] The uplift initiated a new erosion cycle, which is called the pre-Glacial cycle, and during the cycle the uplifted Tertiary peneplain was maturely dissected largely by revived transverse streams with subsequent tributaries; and the less resistant sedimentary rocks along both coasts were reduced to lowlands, exposing the mountainous slope against which the Sooke and Carmanah formations were deposited.

The pre-Glacial cycle was brought to a close by the advent of the Glacial period during which the upland of the Sooke and Duncan map-areas was covered by a thick ice-cap. Twice during the Glacial period, valley glaciers descended from the ice-cap, scoured out some of the larger valleys, deepening some of them into large lake basins and converting others into fiords, and mingling with glaciers from the Coast Range and Olympic mountains, formed large piedmont glaciers which overrode the lowlands. Either before the advance or directly following the [illegible]eat of the earlier and larger glaciers, of the Admiralty epoch, the region was depressed, part of it below sea-level, apparently the eastern portion being depressed m[illegible] Hence, during the Puyallup interglacial epoch the pre-G[illegible] lowlands were covered by marine and delta deposits composed largely of glacial detritus. During the later and less intense epoch of glaciation, the Vashon, the interglacial deposits were partially eroded by the smaller glaciers, which upon their apparently rapid retreat left the deposits partly covered by a younger drift, and by large delta deposits, the Colwood sands and gravels, that were deposited at the front of retreating valley glaciers.

[1] See Weaver, C. E., Bull. 15, Wash. Geol. Surv., 1912, and
Arnold, Ralph, and Hannibal, Harold, Proc. Am. Phil. Soc., vol. 52, 19[illegible], pp. 559–605.

[2] Geologists working in the interior of British Columbia and of Washington place the uplift in late Pliocene or early Pleistocene times.

Doubtless soon after the retreat of the later glaciers the present cycle was initiated by an uplift of some 250 to 400 feet. The uplift revived the larger streams crossing the lowlands, and they have terraced the Glacial deposits and have cut narrow gorges in the underlying rocks. The uplift was not sufficient to offset the earlier depression, so that the valleys of the submaturely glaciated lowlands are still below sea-level, as are the maturely glaciated, larger, north-south valleys of the upland, the fiords. During the present marine cycle, the uplifted Glacial deposits and the Tertiary sediments of the southwestern coast as well have been retrograded to form steep cliffs, but in most places the shore-lines in the hard rocks present the initial irregularites of the drowned surface.

CORRELATION.

The correlation of each of the formations of the Sooke and Duncan map-areas has already been discussed under their respective sections, hence it is necessary to add only a few words regarding the correlation of the region as a whole with other geological provinces. As previously noted the formations of the Sooke and Duncan map-areas represent, with one principal exception, the Nitinat formation, virtually all of the formations of Vancouver island, and hence the geology of the map-areas is representative of the geology of the island as a whole. In general, the greatly deformed and schistose Leech River sediments and Malahat volcanics of late Palæozoic age, and the less metamorphosed but still greatly deformed Vancouver and Sicker volcanics and associated Sutton limestones and argillites of lower Mesozoic age, all of which are intruded and replaced by batholiths of diorite, quartz diorite, and granodiorite of upper Jurassic or Lower Cretaceous age are representative not only of the Vancouver system, consisting of Vancouver and Queen Charlotte islands, but of the Coast range of British Columbia and the western portion of the Interior plateaus as well. These two regions or systems compose the western geo[illegible]linal of the Canadian portion of the North American cordillera,[1] and since

[1] Dawson, G. M., Bull. Geol. Soc. Am., vol. 12, 1901, pp. 57–92.
Daly, R. A., Geol. Surv., Can., Mem. 38, 1912.

their early histories are virtually identical it is probable that throughout the Palæozoic and lower Mesozoic they constituted a single geological province or unit.[1]

Since the upper Jurassic or early Cretaceous folding, the Coast range and the western portion of the Interior plateaus and the Vancouver system have been separated by the northern portion of the Pacific Coast downfold, which appears to have been first depressed during the folding; and have acted more or less independently or reciprocally. The late Jurassic and Lower Cretaceous vulcanism and heavy sedimentation of the eastern system, represented by the Pasayten series,[2] and the Spence Bridge volcanics and Jackass Mountain sediments,[3] have no equivalents in the Vancouver system; and the Upper Cretaceous (Nanaimo) sedimentation of the Vancouver system is represented only locally in the eastern system. During the Eocene, local terrestrial and marine sedimentation in the eastern system built the Puget group of the coast region and the Coldwater group of the interior,[4] while in the western system in the southern part of Vancouver island at least, local vulcanism built the thick Metchosin volcanics; and it is probable that Eocene vulcanism took place in the Queen Charlotte islands as well,[5] to form a portion of the Etheline volcanics. During either the Oligocene or Miocene and perhaps during both periods, the conditions were in general reversed, for while marine sedimentation took place in the Vancouver system extensive vulcanism occurred in the interior, accompanied by only local sedimentation. However, it appears as if local vulcanism occurred in the Vancouver system, for middle Tertiary volcanics are found in the northern part of the Queen Charlotte islands.

Both regions were glaciated during the Pleistocene period, and two periods of maximum glaciation are apparently recorded in the interior[6] as well as in the coast region.

---

[1] Daly, R. A., Geol. Surv., Can., Mem. 68, 1915, pp. 131–132.
[2] Daly, R. A., Geol. Surv., Can., Mem. 38, 1912, pp. 479–490.
[3] Drysdale, C. W., Geol. Surv., Can., Sum. Rept., 1912, pp. 115–150.
[4] Drysdale, C. W., Geol. Surv., Can., Sum. Rept., 1912, pp. 140–141.
[5] MacKenzie, J. D., Geol. Surv., Can., Sum. Rept., 1913, pp. 47.
Clapp, C. H., Geol. Surv., Can., Sum. Rept., 1912, pp. 25–27.
[6] Drysdale, C. W., Geol. Surv., Can., Sum. Rept., 1912, p. 149.

CHAPTER V.

ECONOMIC GEOLOGY.

The mineral resources of the Sooke and Duncan map-areas have not been greatly developed, and only a few of the non-metallic resources are being exploited at present. The most valuable production is of portland cement manufactured from the Sutton limestones and Malahat tuffaceous argillites. The superficial clays are being utilized to a slight extent in the manufacture of common brick and a little sand and gravel is derived from the superficial deposits. In the past there has been a moderate production of copper and also of gold. The limestones have been used for the manufacture of lime as well as of cement, and building stone has been quarried from the Nanaimo sandstones. Other resources which have been or are of prospective value are silver, zinc, iron and sulphur, fuels, fluxes, pigments, clay shales, and crushed stone.

In the following description the deposits are classified according to the products for which they are valuable. This classification groups together fairly well, deposits of like origin; although in some instances deposits of like origin are valuable for different metals. Thus under copper are described certain deposits containing besides copper subordinate amounts of silver bearing galena and sphalerite. The deposits valuable chiefly for metals are described first and in the following order: gold, copper, and iron and sulphur; and under each division the deposits are further classified according to their manner of occurrence. The non-metallic resources are then described in the following order: fuels including coal and oil, lime, cement and fluxes, pigments, clays and clay shales, sand and gravel, and stone. The soils and water resources are also briefly described.

GOLD.

PLACER DEPOSITS.

Placer deposits have been the only source of gold in the Sooke and Duncan map-areas. Placer gold occurs almost exclusively in the gravels of the streams that drain the area underlain by the Leech River slaty schists; and in the gravels of virtually all of these streams fairly coarse gold may be obtained. With the gold are concentrated in places, more or less magnetite and garnet. Although the gold-bearing, recent, stream gravels are usually of fair grâde, except in the two large valleys along the northern and southern boundaries of the Leech River formation, they occur in very small amounts, since the gradients of the streams are steep. Even in the two large, boundary valleys—on the north the San Juan valley drained largely within the Duncan map-area by Meadow and Floodwood creeks, and on the south the Leech River valley drained within the map-areas by Goldstream creek, Wolf creek, and Leech river, and Bear creek and Jordan river—the amount of recent gold-bearing gravel is small. The greater portion of the valleys is filled with glacial drift and in places in the valleys there are rather relatively large deposits of the Colwood sands and gravels which were apparently formed during the recession of the glaciers which filled the valleys in Glacial time. It is possible that the glacial drift carries very small amounts of gold; but even the Colwood sands and gravels, while carrying some gold, are of very low grade. Since the recent uplift of Vancouver island, the streams mentioned, with the notable exception of the greater portion of Bear creek, have cut steep narrow gorges 50 to 400 feet deep in the bottom of the main valleys which have relatively, broadly flaring sides. In these gorges the higher grade gravels occur. They are, however, as would be expected, small in amount, and very coarse and bouldery.

The gold in the recent gravel deposits has doubtless been derived from the quartz veins in the Leech River slaty schists and has presumably been directly derived in places from the glacial drift and Colwood deposits. The quartz veins are seldom more than small stringers and lenses a few inches wide and a few feet long, but are very numerous. With the quartz of the vein is a little albite which in the sheared veins has altered to sericite. The only metallic minerals are a little pyrite or chalcopyrite and free gold. The veins are all, so far as known, very low grade and are too small and too barren to be profitably mined; all attempts to work them have been unsuccessful.

In the "sixties," the deposits in Leech and Jordan rivers were discovered and rather extensively worked, and the ruins of some of the old dams, ditches, and flumes may still be seen. The yield at that time is estimated at from $100,000 to $200,000. A few years later the gravels of Floodwood and Meadow creeks were worked. For a number of years previous to 1908 Chinamen worked on Leech river and Wolf creek, and one or two more extensive but unsuccessful attempts were made to obtain gold from the gravel of Leech river and its North fork.

The writer concluded from his reconnaissance of 1908 and 1909[1] that it was possible that relatively large amounts of gold-bearing gravel might be found on the wide, comparatively smooth interstream areas. However, no evidence of extensive gravel deposits, either post-Glacial or pre-Glacial, were discovered during the more detailed examination. Not only does the heavily timbered, glacial drift interfere with prospecting, but apparently the drift and recent valley and swamp alluvium constitute the only extensive surface deposits on the upland. Although the Colwood sands and gravels are in places in the large valleys fairly extensive they are low grade, probably nowhere more than a few cents per cubic yard, and are not extensive enough to warrant the establishment of a plant sufficiently large to work them cheaply. The recent gravels do not occur in sufficient amounts to warrant more than the simplest and cheapest development, but it is possible, and even probable that the individual miner can work some of them with a fair profit.

VEIN AND SHEAR-ZONE DEPOSITS.

Besides the quartz veins in the Leech River schists which, as noted, are too low grade to be profitably mined, there are large and well-defined quartz veins in some of the other formations, notably in the Malahat, Sicker, and Metchosin volcanics. Although some of these veins contain small amounts of pyrite and in places even chalcopyrite, none carrying significant

[1] Geol. Surv., Can., Mem. 13, 1912, p. 154.

amounts of gold have been discovered. They are high temperature veins, and contain significant amounts of feldspar and in places even muscovite and biotite mica.

Furthermore, some of the quartz-feldspar veins that were formed during the intrusion of the granitic rocks have been prospected for gold, entirely without success. Apparently the true nature of these veins, which are apophyses of the granitic rocks, has not been recognized. They have the appearance of ordinary quartz veins, since the altered, sericitized feldspar resembles, on the weathered surface, white milky quartz. In addition the veins contain pyrite which, altering to limonite, has stained the weathered outcrops, still further hiding the true character of the veins. Such veins as these are not known to be gold-bearing, and it is not likely that those of the Sooke and Duncan map-areas contain gold in commercial quantities.

Mineralized shear zones occur throughout the metamorphosed volcanics and associated limestones, but are best developed near the intrusive granitic rocks; and similar mineralized shear zones occur in the granitic rocks themselves. Deposits of this character are usually more important as possible sources of copper, but they also carry low values in gold. Some of the contact deposits carry small amounts of gold and certain of the deposits, with relatively large amounts of sphalerite and galena, carry silver. The contact deposits like the shear zone deposits are, however, more likely to be sources of copper and hence are described with the other copper deposits.

COPPER.

GENERAL FEATURES.

The copper deposits of the Sooke and Duncan map-areas are, with the exception of the deposits in the Sooke gabbro and the Metchosin volcanics, closely associated with the igneous rocks irrupted during the upper Jurassic period of batholithic and dyke intrusion; and hence, although found in various rocks with different structures, they have many common features. The same metallic minerals—pyrrhotite, magnetite, pyrite, and chalcopyrite—are found in virtually all the deposits, and although their relative quantities vary somewhat in different deposits, they are about as named. Sphalerite and galena are found in many deposits, but in only a few deposits in relatively large amounts. The gangue minerals are chiefly quartz, and less abundantly calcite and dolomite, with minerals such as feldspar, diopside, garnet, and epidote, that have resulted from the replacement of the country rocks. The deposits are found chiefly in the metamorphosed volcanic and sedimentary rocks at the contacts with or in the vicinity of the intrusive igneous rocks. Quartz veins carrying sulphides are, however, found in the intrusive rocks; and the Tyee porphyrite and to a less degree the Sicker porphyrite, which have been foliated and intruded by younger porphyrites and granitic rocks, are extensively mineralized. The deposits are as a rule irregular, and they occur chiefly in shear zones or in contact-metamorphosed Sutton limestones or Vancouver volcanics; but, as mentioned, in places there are metal-bearing veins, and in the Sicker series there is a large and rather regular lens of fairly massive ore. The deposits may, therefore, be classified into four types: (1) contact deposits, (2) impregnated and replaced shear zones with accompanying quartz veins, (3) quartz veins, and (4) the large lens of ore called from its only known occurrence, the Tyee type. The various types are not sharply separated from one another and many of the deposits are transitional in character, and most of them occur in shear zones rather than in clear-cut, well-defined fractures or in easily replaceable beds.

The deposits in the Sooke gabbro and Metchosin volcanics also occur in shear zones, chiefly in the Sooke gabbro. Furthermore, the deposits are largely confined to the East Sooke peninsula, and have been made the object of special study by Cooke and are described separately by him.

The deposits have already been rather fully described by the writer in his preliminary report on Southern Vancouver island[1]; and inasmuch as virtually no development has been done on the deposits since the writer's previous examination, with the exception of the work done during 1913 on the King Solomon

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 158–187.

group southwest of Cowichan, little new information on the deposits is available. Hence the following description of the deposits is little changed from the description already published.

CONTACT DEPOSITS.

General Features and Distribution.

The contact deposits are developed in contact-metamorphosed Sutton limestones and Vancouver volcanics near intrusive granitic rocks, the Saanich granodiorite, Wark gabbro-diorite gneiss, and Colquitz quartz-diorite gneiss. The deposits may be further divided into two sub-types, which, however, merge into each other—(1) those which occur at the main or molar contacts of the bodies of granitic rocks, and (2) those which occur in the zone of contact metamorphism at a distance of at least several hundred feet from the main contacts. The former are characterized by a higher percentage of magnetite and pyrrhotite, and the latter by a higher percentage of pyrite and chalcopyrite. The former are more closely associated with limestones which have been converted into garnet-diopside-epidote rocks and occur in irregular masses composed largely of metallic minerals; whereas the latter occur more commonly in shear zones in silicified volcanics as well as limestones, with the metallic minerals disseminated through the shear zones in grains and small replacement lenses.

The contact deposits, although perhaps the most abundant type in Vancouver island as a whole, are not common in the Sooke and Duncan map-areas. Those of the first type are found only on Malahat ridge east of Shawnigan lake, although some mineralization has taken place in the lens of limestone enclosed in the Wark and Colquitz gneisses southwest of the upper Goldstream reservoir; and those of the second type are found in Sterling and Glen Apa claims on the upper Koksilah river in southern Helmcken district, and in the King Solomon and adjoining claims, about 3½ miles southwest of Cowichan. There has been no commercial production from any of the deposits, and the deposit in the King Solomon and adjoining Koksilah claims is the only one which has been developed during recent years.

Contact Metamorphism.

The character of the contact metamorphosed rocks ha already been described in considerable detail.[1] The limestone have as a rule been converted into rather fine-grained massiv rocks, composed chiefly of garnet, diopside, and epidote, cut b veinlets of quartz and calcite, and impregnated and replace by the metallic sulphides. Identical rocks have resulted from th metamorphism of what appear to have been porphyritic vo canics; but more commonly the Vancouver volcanics have bee altered into massive, dense, silicified, and sericitized rock which contain large amounts of diopside and epidote and, lik the metamorphic limestones, have been impregnated and re placed by the metallic minerals. However, the limestones als have been converted into dense, light greenish rocks consistin largely of diopside, quartz, and sericitized feldspar; hence i many places the nature of the original rock cannot be determine unless the field relations are clear or the metamorphosed rock re tains some characteristic texture of the original volcanic rock Rarely the limestone has merely been recrystallized and onl partly replaced by irregular streaks of the metamorphic mineral The intrusive rocks are seldom more altered near the contac deposits than they are elsewhere, although as described, certai hybrid types may be developed near the contacts with th Sutton limestones.

Mineralogy.

The metallic minerals found in the contact deposits, i about the order of their relative abundance, are pyrrhotite magnetite, pyrite, and chalcopyrite, far less abundantly sphal erite and galena, and in the King Solomon deposit tetrahedrite In one of the small deposits, presumably not of the contac type, about a mile to the south of King Solomon claim, arsenc pyrite and native arsenic are reported to occur. Oxidize minerals are not abundant, although limonite is generall present, and the exposed surfaces of the deposits are staine with malachite, and in places with the black, earthy, coppe oxide, melaconite. The non-metallic gangue minerals are largel

[1] See pages 101-104 and pages 109-111.

those derived by the contact metamorphism of the limestones and volcanics, chiefly garnet, diopside, and epidote, with some actinolite, sericite, and quartz, and secondary serpentine and kaolin. Quartz, epidote, calcite, and in the deposit on the Sterling and Glen Apa claims dolomite, occur in veins and replacements more closely associated with the metallic minerals, and cutting the earlier formed gangue minerals, and in some deposits the earlier formed metallic minerals as well. The dolomite of the Sterling and Glen Apa deposits occurs in light brown flat rhombohedrons, and is irregularly interbanded with the metallic minerals, galena, chalcopyrite, and a little sphalerite.

Chalcopyrite is virtually the only copper-bearing mineral. It is massive and occurs chiefly in disseminated grains or small lenses and veinlets in the other metallic minerals and in the contact metamorphosed rocks. In some deposits it is irregularly intergrown with pyrrhotite and less commonly with pyrite. Chalcopyrite is usually the last of the metallic minerals to have finished crystallization, and where massive pyrrhotite and chalcopyrite have replaced the older silicate minerals of the contact metamorphosed rocks (see Plate XII B) it is usually closely associated with the inclusions of the silicate minerals, penetrating them in small veinlets. The chalcopyrite has weathered slightly to limonite, and less abundantly to malachite and melaconite, which form merely surface stains.

Pyrrhotite is usually the most abundant of the metallic minerals, especially in the deposits close to the main contacts. It occurs in finely granular, relatively large masses, replacing the dark silicate minerals resulting from the contact metamorphism, and, as mentioned, is intergrown in places with chalcopyrite and also with pyrite.

Magnetite is usually present and is one of the most abundant minerals. It is more or less complementary to pyrrhotite, for when either one is the chief mineral the other occurs in rather small quantities. It is finely granular to massive, usually occurring in the deposits developed near the main contacts, in fairly large, irregular masses, which may contain only a small amount of the sulphide minerals, usually pyrite.

Pyrite occurs in small amounts, either intergrown and associated with pyrrhotite and chalcopyrite, or in veinlets cutting the magnetite and pyrrhotite. It also forms a few small but well shaped cubical crystals.

Sphalerite and galena are virtually restricted to the deposits at some distance from the main contacts. They are intimately associated and occur either as finely disseminated grains or in irregular veinlets, and, as mentioned, occur in the Sterling and Glen Apa deposits with chalcopyrite irregularly interbanded with dolomite. In the deposits in the vicinity of the King Solomon they are closely associated with both pyrite and chalcopyrite.

Tetrahedrite, as mentioned, is restricted to the King Solomon deposit and occurs there with pyrite and chalcopyrite in small granular masses and grains disseminated through the sheared and altered volcanics.

Texture and Paragenesis.

The masses of metallic minerals commonly include fragments of dark greenish silicate minerals resulting from the contact metamorphism of the limestone and volcanics. On polished surfaces the metallic minerals appear to be replacing the rounded and irregular inclusions of silicate minerals, by impregnating them along contacts and by penetrating them in tiny apophyses and veinlets (see Plate XII B). As mentioned, veinlets of chalcopyrite, and to a less extent of pyrite, in pyrrhotite are more abundant near the inclusions, which the chalcopyrite penetrates and impregnates more freely than does the pyrrhotite or pyrite. It thus appears as if the contact silicate minerals were crystallized earlier than the metallic minerals. To the west of the map-area, however, it has been found[1] that garnet occurs in well shaped crystals, that appear to be of later generation than the massive garnet and other contact silicates, and to have crystallized after or with magnetite. As mentioned, both the contact metamorphic silicates and metallic minerals as well, are cut by veinlets of quartz, epidote, and calcite, possibly of several generations.

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 161-162.

The intimate association of the metallic minerals indicates that in general they are virtually contemporaneous, and indeed in many instances there is little question that they are actually so. However, in many deposits irregular veinlets of both chalcopyrite and pyrite cut magnetite and pyrrhotite (Plate XII A) and hence it appears as if chalcopyrite and pyrite at least finished crystallization somewhat later than the pyrrhotite and magnetite. The relations between magnetite and pyrrhotite are not clear. As mentioned, they are somewhat mutually exclusive. In the magnetite portion of the deposits, pyrrhotite may form short irregular veinlets, but in places along the contact between the pyrrhotite and magnetite areas, pyrrhotite is cut and apparently brecciated by the magnetite, although in other places along the contact the two minerals are so intimately intergrown that it is not possible to determine which is the younger. In some deposits pyrite, intergrown with pyrrhotite, is clearly cut by chalcopyrite, and as a rule chalcopyrite seems to have finished crystallization somewhat after pyrite; but rarely pyrite occurs also in later veinlets cutting the other metallic minerals. As mentioned, the relations of sphalerite and galena to the other sulphides are not definite. They are most closely associated with chalcopyrite and appear to be virtually contemporaneous with it, although in some mineral specimens galena surrounds and fingers into sphalerite and chalcopyrite. So far as can be determined, therefore, the paragenesis appears to be pyrrhotite, magnetite, pyrite, chalcopyrite, sphalerite, and galena; but the texture of the minerals impresses one chiefly with the contemporaneity of the minerals and their apparent rapid crystallization, presumably from highly concentrated solutions.

Mode of Occurrence and Development of the Deposits.

The deposits near the main contacts, those on Malahat ridge, are irregular bodies composed largely of metallic minerals. They are usually more or less elongate and rudely lenticular and one deposit to the northwest of Mt. Wood, is apparently tabular, following a bed in the altered limestone for a short distance. The largest deposits are only 8 to 10 feet wide, and apparently 30 or 40 feet long; and most of the deposits are much smaller.

The deposits occur chiefly to the northwest of Mt. Wood, in the outer, metamorphosed portion of a lens of crystalline limestone, about 2,000 feet long and 200 feet wide, enclosed in a complex of Wark and Colquitz gneisses. Where not contact metamorphosed, the limestone in common with the other Sutton limestone is pure, consisting almost entirely of finely to coarsely crystalline calcite. Slightly over a mile to the northeast of Mt. Wood are other deposits which have been developed in a greatly sheared and altered roof pendant or inclusion of Vancouver meta-andesites. In the two places both the intrusive and the intruded rocks are greatly sheared and to some extent the mineralization is restricted to sheared zones in the contact-metamorphosed rocks. The deposits have been developed by prospect pits and open-cuts, shallow shafts, and prospect adits, but there has been no commercial production.

The deposits at a greater distance from the main contacts occur more commonly as impregnating grains and small replacement lenses in the sheared, contact-metamorphosed rocks, and less commonly as relatively large bodies composed of metallic minerals mainly. They follow, therefore, more or less well-defined shear zones from 4 or 5 feet to 30 feet wide and 100 to 1,000 feet long. At both places where the deposits of this type are known—in the Sterling and Glen Apa claims and in the vicinity of the King Solomon claim—the country rock is chiefly a dense greenish rock which seems to be the result of the silicification of the sheared Vancouver volcanics. At both places, however, small lentils of Sutton limestones occur in the volcanics in the immediate vicinity, and calcite and dolomite are prominent gangue minerals; and to the east of the King Solomon claim the metallic minerals occur disseminated through a garnet-diopside-quartz-calcite rock, which looks as if it were the result of the contact metamorphism of limestone. No granitic rocks outcrop within half a mile of the deposit in the Sterling and Glen Apa claims, but several bosses of Wark gabbro-diorite occur within a mile, and the large batholith of Wark gabbro-diorite occurs a mile to the southeast. Although not in contact with the mineral deposit there are several small stocks of Saanich granodiorite in the vicinity of the King Solomon claims, and in contact with the ore-body is a dyke-like mass of quartz-bearing feldspathic gabbro, which is apparently closely related to the Saanich granodiorite. It looks, therefore, as if in both places, the granitic rocks underlay the deposits at no great depth.

In the King Solomon claim the ore minerals form at least one fairly distinct lens in a shear zone striking about north 40 degrees east and dipping about 45 degrees to the southeast. The richer portion of the lens in contact with the quartz-bearing, feldspathic gabbro, which forms the hanging-wall, is said to contain from 4 to 5 per cent of copper; and 303 tons of picked ore from the outcrop, shipped in the autumn of 1912, contained an average of over 5 per cent copper. The richer portion of the lens is about 20 to 30 feet wide with an outer and lower grade zone, averaging about 2 per cent copper, 15 to 20 feet wide, the foot-wall of the deposit being rather indefinite. The exposed length of the lens is about 200 feet, but its true length may be greater. The King Solomon deposit was actively developed, largely by means of an adit, during 1913, but little or no work was done in 1914, and the results of the development are not known. The neighbouring Blue Bell claims were extensively developed several years ago by the Tyee Copper Company, by means of a shaft and drifts, and other claims in the vicinity have been prospected. No work has been done on the Sterling and Glen Apa claims for many years.

Genesis of the Contact Deposits.

Deposits similar to those described above have been recognized in many parts of the world, and are classified as contact deposits, the invariable feature being the development of metallic minerals in contact-metamorphosed rocks near intrusive igneous rocks, which are usually granitic. The contact-metamorphosed rocks are chiefly altered limestones, and are characterized by such minerals as garnet and diopside. The principal metallic minerals also are those found in the deposits just described, magnetite, pyrrhotite, pyrite, and chalcopyrite. There are two general hypotheses regarding the origin of contact deposits:

the first is that the garnet, diopside, and other non-metallic minerals, and in part perhaps the metallic minerals, were derived from the crystallization of an impure limestone, which contained before metamorphism enough of the ingredients of the deposits to form by rearrangement and recrystallization, through the heat and mineralizers escaping from the intrusive magma, the minerals of the present deposits; the second hypothesis is that the limestones were relatively pure, and that additions of silica, iron, copper, and sulphur were received from the intruding magma, by means of thermal solutions, well above the critical temperature of pure water, which entered the limestones and metasomatically replaced them.

It has been shown[1] that the contact-metamorphosed rocks of the Sooke and Duncan map-areas were formed both from pure limestones and associated volcanics by the addition of silica, iron, and alumina, through the agency of thermal solutions escaping from the crystallizing intrusives, the formation of garnet in the metamorphosed volcanics necessitating the addition of lime as well as of silica and iron.[2] Although in some places on Vancouver island garnet crystallized during or after the formation of some of the metallic minerals, in many places in common with the other metamorphic silicates, it clearly preceded the deposition of the metallic minerals. It cannot be deduced, however, that the formation of the metamorphic silicates and of the metallic minerals represents two separate, independent stages of silicate formation and of metallization. Instead it appears as described under the mode of origin of the contact-metamorphic rocks[3] as if the two were formed by one continuous process, but one which, owing to changes in temperature and pressure and probably to changes in the escaping solutions as well, was subdivided into various overlapping and dependent stages, each characterized by certain typical reactions resulting in characteristic minerals.

While it seems, as Lindgren[4] has stated, that the development of contact metamorphic rocks and of their associated metal-

[1] See mode of origin of the Vancouver volcanics and Sutton limestones, pp. 119-122.

[2] Geol. Surv., Can., Mem. 36, 1913, pp. 46-50.

[3] See page 121

[4] Lindgren, W., "The origin of 'garret zones' and associated ore deposits," Bull. Am. Inst. Min. Eng., June, 1914, pp. 949-956.

lic minerals is a rather continuous process, beginning at the moment of irruption yet, as Harker[1] has pointed out, leakage does not go on with equal freedom at all stages, although it is likely that a large part of the volatile constituents of the magma is retained down to a late stage. The earlier emanations were perhaps above their critical temperature and, therefore, gaseous, owing to the high temperatures prevailing at the time of the escape; consequently they would carry only a small load of non-volatile matter[2], chiefly such substances as would be present in the magma in large amounts and would be readily soluble, such as silica, alumina, and alkalis, chiefly soda.[3] The high pressures existing during the early stage of crystallization, consequent upon the recent intrusion and expanded nature of the heated country rocks, would also prevent the wholesale escape of the volatile constituents of the magma. Hence the proportion of the volatile constituents in the magma would increase as crystallization progressed, and the relative amounts of the predominating constituents of the earlier emanations, silica, alumina, and soda would decrease since these substances would have entered largely into the solid minerals.[4] Thus during the later stages of crystallization, when cooling and fracturing of the intruded rocks and of the outer shell of the intrusive body had begun, emanations would escape more freely and would carry a greater percentage of metals. Owing to the prevailing lower temperatures, the emanations, although still above the

---

[1] Harker, A., "Natural history of igneous rocks," 1909, p. 303.

[2] Johnston and Niggli, Jour. Geol., vol. 21, 1913, state that in general there is a very marked falling off in solubility just below the critical point; although they state further that this fact in itself is no reason why at still higher temperatures and pressures the dissolving power of gases should not again increase.

[3] This conclusion is supported by field evidence not only from Vancouver island, but also from other parts of the world, showing the increase in soda in rocks near irruptive contacts, especially in slates converted into adinole.

Harker, A., "Natural history of igneous rocks," 1909, pp. 304-305.

Lindgren, W., "Mineral deposits," 1913 p. 667.

Goldschmidt. Die Kontakt metamorphose im Kristianiagebit, Christiania, 1911, see especially pp. 33-38, 119, and 180-186.

Collins, W. H., "Gowganda mining division," Mem. 33, Geol. Surv., Can., 1913, pp. 77-83.

It is also a direct theoretical conclusion from what is known of the fractional crystallization of magmas with consequent differentiation.

Bowen, N. L., Jour. Geol., supplement to vol 23, 1915, see p. 49.

[4] Johnston, J. and Niggli, Paul, "Principles underlying metamorphic processes," Jour. Geol., vol. 21, 1913, p. 618.

critical temperature of pure water, would probably be liquid and hence would be capable of carrying a larger load of non-volatile constituents. However, as Johnston and Niggli have pointed out[1] when the volatile components can escape slowly and continuously they will obviously not be under very high pressure, and the amount of material carried by them will be small. Consequently the stage of effective metallization is short-lived, a feature which has been impressed upon many mining geologists.[2] During the last stages of metamorphism, therefore, little appears to have taken place but the formation of the veinlets of quartz, epidote, and calcite.

It is clear that magnetite and pyrrhotite finished crystallization before pyrite and chalcopyrite; hence it is to be expected that those deposits formed nearer the source of the metal-bearing emanations or close to the main contacts, would be richer in magnetite and pyrrhotite than those deposits formed at some distance from the main contacts, which, as would be expected, are found to be relatively rich in pyrite and chalcopyrite.

General Status and Future Possibilities.

There has been no commercial production from the contact deposits. They are very similar, as has been indicated, to a well recognized type which includes notable producers of copper ore. The productive deposits are, as a rule, much larger than the known deposits of the Sooke and Duncan map-areas, and in many cases they have been enriched by secondary processes forming high grade copper minerals, chiefly chalcocite. The known deposits in the contact-metamorphic rocks adjoining the main contacts are too small and irregular and too high in magnetite and pyrrhotite, which cannot be cheaply separated from the chalcopyrite, to be probable sources of copper ore. The deposits which have been developed some distance from the main contacts, owing to their freedom from pyrrhotite and magnetite, and to the readiness with which the pyrite and chalcopyrite could be concentrated by milling or flotation, are, however, of prospective importance.

---

[1] Johnston, J., and Niggli, P., op. cit. p. 619.
[2] Lindgren, W., "Mineral deposits," 1913, p. 61?

IMPREGNATED AND REPLACED SHEAR ZONES, WITH ACCOMPANYING QUARTZ VEINS.

General Features.

Throughout the metamorphic and intrusive granitic rocks of the map-areas, chiefly in the metamorphic volcanic rocks, are sheared zones, mineralized to a greater or less extent, chiefly with pyrite, chalcopyrite, pyrrhotite, and less commonly magnetite, and in a few places—largely confined to deposits occurring in the Sicker series and associated, schistose, Tyee, quartz-feldspar porphyrites—bornite and chalcocite. Associated with the mineralized shear zones are small veins and lenses of quartz which frequently contain chalcopyrite and other metallic minerals. Many claims have been taken up on these mineralized shear zones, and some of them appear to be promising prospects; but there has been no commercial production from them, and in no place has any large body of ore been proved.

Description of Deposits.

As stated, mineralized shear zones are found in all of the crystalline rocks of the map-areas, but they are, of course, more plentiful in certain formations, such as the Malahat volcanics and the Sicker series and associated porphyrites, than they are in others. The deposits are, therefore, for the purpose of description, grouped according to the formations in which they occur.

Leech River Formation and Malahat Volcanics. Although cut by numerous gold-bearing quartz veins the Leech River schists are not otherwise mineralized to any great extent; the Malahat volcanics on the other hand, especially the sheared meta-andesites and tuff-breccias, are mineralized almost throughout their entire extent, in places rather extensively. The only significant mineralization in the Leech River schists occurs in highly sheared quartz-sericite schists near the Leech River fault, where the shear zones are cut and replaced by small irregular quartz veins carrying pyrrhotite, chalcopyrite, and a little pyrite. The deposits differ from most of the deposits of the shear zone type in their large amount of quartz. A few prospects have been opened in the deposits in the vicinity of Leech river.

The deposits in the Malahat volcanics consist chiefly of pyrrhotite and chalcopyrite with less pyrite, in a gangue of quartz and in places calcite. The minerals occur disseminated or in small veins or stringers through shear zones which are usually parallel to the foliation of the rocks and which may be limited by fairly massive, impervious walls. Rarely, as in the southwest slope of Mt. Skirt, half a mile northeast of Goldstream post-office, there has been considerable replacement of the sheared rock. In this deposit there is also a little chalcocite in very small grains associated with chalcopyrite in veinlets of chalcedonic quartz. The metallic minerals have been weathered to limonite and the shear zones are usually heavily stained throughout their entire width to a rusty brown, so that the outcrops are fairly conspicuous. The deposits have been developed at several places: in the Highland district east of Sooke lake, and near Survey mountain, but most extensively in the Fair group of claims, located on the deposit in the southwest slope of Mt. Skirt. The deposit or deposits there are situated in five shear zones in silicified dacite tuffs and interbedded cherts. The shear zones strike about north 50 degrees west, parallel to the foliation of the country rocks. A large amount of replacement has taken place and the shear zones are traversed by numerous but irregular quartz and calcite veins. The deposits have been developed by a prospect adit, a shaft, and several pits.

Vancouver Volcanics. Many of the deposits in the Vancouver volcanics and all of those in the associated Sutton limestones, although they may occur in shear zones, are of the contact-metamorphic type and have already been described. There are, however, many mineralized shear zones throughout the Vancouver volcanics where the rocks have not been typically contact-metamorphosed. Instead they have been converted into sheared greenstones, consisting largely of residual, sericitized feldspar, uralite, actinolite, and chlorite. They are cut by numerous stringers of quartz, quartz and epidote, and, near intrusive rocks, of quartz and feldspar, and are impregnated with metallic sulphides, chiefly pyrite, and some pyrrhotite and chalcopyrite. The outcrop of the mineralized shear zones is usually greatly stained with limonite, so that they are fairly attractive prospects; but most of them are clearly too small and too low grade to be of commercial value. They have, therefore, been opened only by shallow prospect pits. One deposit on one of the upper forks of the Koksilah, nearly 4 miles southeast of Mt. Waterloo, showed relatively large amounts of chalcopyrite; and arsenopyrite and native arsenic are reported to occur in one of the small, presumably shear zone deposits, in the vicinity of the King Solomon contact deposits.

Sicker Series and Associated Porphyrites. Mineralized, sheared or schistose zones occur at many places in the schistose rocks of the Sicker series and of associated Tyee quartz-feldspar porphyrite, largely confined, as Cooke has stated,[1] to a greatly deformed belt in the southern limb of the northernmost of the three major synclines into which the Sicker series is deformed. The deformed and mineralized belt extends from Maple mountain through Mts. Richards, Sicker, and Brenton, to beyond Coronation mountain. The principal deposits occur in the central part of the belt, in Mt. Sicker, and also in Mt. Richards and in the southeastern slope of Mt. Brenton. The metallic minerals are chiefly chalcopyrite, pyrite, pyrrhotite, and in places magnetite, and sparingly bornite, chalcocite, and sphalerite. The gangue minerals are chiefly quartz, but barite also occurs, showing the relation of the shear-zone deposits to the Tyee deposit. The metallic minerals occur disseminated through the shear zones, in places in small, irregular replacements, and in quartz veins cutting the shear zones. As is true in the other shear zone deposits, the metallic minerals have weathered slightly to limonite, which, however, colours the entire mineralized zone reddish brown. More commonly than in the other shear zone deposits, perhaps owing to the higher percentage of copper in the zones in the Sicker series, the outcrops are also stained with malachite and chrysocolla. The intrusive Sicker gabbro-diorite porhyrite along the mineralized belt is also traversed by numerous mineralized shear-zones, and in places, notably in Mt. Richards, to the north of the old Lenora railway, contains

[1] See page 148.

throughout the entire mass, finely disseminated grains of chalcopyrite and possibly some chalcocite; and on Mt. Richards the mineralized porphyrite is reported to contain about one per cent of copper. The Sicker porphyrite is also cut by quartz veins, up to 2 feet wide, which are, however, virtually barren.

The mineralized shear zones have been developed by a great many prospect drifts and pits, and by not a few adits and shafts, especially in Mts. Sicker, Richards, and Brenton. Except from the Tyee deposit, however, there has not been any commercial production of either copper or gold ore.

Batholithic Rocks. The batholithic rocks, especially the Wark and Colquitz gneisses, are traversed by numerous but not extensive shear zones, which from an economic standpoint are sparingly mineralized, chiefly with pyrite. The mineralized shear zones have been prospected slightly, chiefly in the Highland district, near the Goldstream lakes, south of Shawnigan lake, on Malahat ridge, and in the lower part of Koksilah valley.

Metchosin Volcanics. Mineralized shear zones occur also in the Metchosin volcanics, but are not numerous except near the intrusive stocks of Sooke gabbro, although they are found near the Leech River fault. As in the other shear zones the metallic minerals are pyrite, chalcopyrite, and less abundantly pyrrhotite and magnetite. The shear zones are cut by irregular veins of quartz and epidote, some of which carry small amounts of pyrite and chalcopyrite. Many of the more promising deposits occur in shear zones parallel to the general strike of the volcanics, that is about north 65 degrees west in the vicinity of the East Sooke stock, and have been prospected slightly on the shores of Becher bay, and in the east shore of Otter point. The mineralized shear zones near the Leech River fault have been prospected a mile to the west of Sooke river and three-quarters of a mile to the east of the river. Mineralized shear zones in the Metchosin volcanics were also noted in 1909[1] about a mile west of the Sooke map-area, in the east side of Jordan River valley nearly 3 miles from the mouth. It was thought that these deposits were not associated with the Sooke gabbro, but granite float was noted

[1] Geol. Surv., Can., Mem. 13, 1912, p. 172.

in the vicinity of the deposits, and doubtless a small stock of the Sooke intrusives like that 2 miles to the northeast occurs in close association with the deposits.

Sooke Intrusives. On the East Sooke peninsula the Sooke gabbro is traversed by wide shear zones, which have been impregnated and partly replaced by chalcopyrite and by pyrite, pyrrhotite, and magnetite. This type has many characteristic features and has been designated the Sooke type.[1] The deposits are more valuable than any of the other shear-zone deposits. They are, however, so far as known, confined to the East Sooke peninsula, although some mineralization has occurred elsewhere. The East Sooke deposits are separately described by H. C. Cooke in the chapter on the gabbros of East Sooke and Rocky Point.

Genesis of the Shear-Zone Deposits.

The association of metallic minerals and the character of the alteration of the sheared rocks indicate that the mineralization took place under conditions of high to moderate temperatures and pressures. That the mineralization in the Malahat and Vancouver volcanics, Sicker series and associated porphyrites, and batholithic rocks occurred soon after the period of batholithic and dyke intrusion in upper Jurassic and possibly Lower Cretaceous times is proved by the occurrence of fragments of mineralized rocks in the basal conglomerates of the Nanaimo series of Upper Cretaceous age. It is, therefore, virtually certain that the mineralization is genetically connected with the batholiths and dykes. The mineralization of the sheared rocks occurs throughout a thicker and wider zone than that characteristic of the contact deposits, and has been accomplished at somewhat lower temperatures, as is shown by the absence of such minerals as garnet and diopside, and by the smaller relative amounts of pyrrhotite and magnetite. They appear, however, to have been formed by similar, ascending thermal solutions, somewhat cooled by their longer journey from the intrusives, and presumably by mingling with deep meteoric waters. The mineralization appears to have been less rapid than the mineralization

[1] Geol. Surv., Can., Mem. 13, 1912, pp. 174–180.

of the contact deposits and hence was probably effected by somewhat less concentrated solutions and during a longer period of time.

The mineralization in the Metchosin volcanics and Sooke intrusives was clearly deposited under similar conditions, following the irruption of the Sooke intrusives in lower Oligocene time. The relative rapidity of the mineralization is shown by the occurrence of fragments of the mineralized rocks in the conglomerates of the Sooke formation of Oligocene or lower Miocene age.

General Status and Future Possibilities.

Although a large number of claims have been located on the shear-zone deposits and some of them developed slightly, there has been, as mentioned, no commercial production. Owing to their low grade character, pyrite usually predominating over the copper-bearing minerals, and to the irregular distribution of the metallic minerals, most of the deposits, especially in the Leech River schists and in the batholithic rocks, are improbable sources of copper ore. The more abundant mineralization and the presence of bornite and chalcocite in the shear zones of the Sicker series and associated porphyrites, and in the Malahat volcanics render these two formations more favourable to prospecting. This is especially true of the Sicker series, where further prospecting may lead to the discovery of another lens of ore of the Tyee type. The shear-zone deposits in the Sooke gabbro (the Sooke type) are of considerable prospective importance, and recent development in 1916, of the shear zone deposits in the Metchosin volcanics in the Jordan River valley, has given encouraging results. In the Metchosin volcanics prospecting may be limited to the vicinity of stocks of Sooke intrusives. Although the discovery of any large well-defined body of metallic minerals in any of the shear zones is doubtful, yet owing to the amenability of the deposits to cheap concentration, such as flotation, some of them may be found to be of commercial value. To be of value, however, such deposits must be large, and prospecting should be limited to wide persistent shear zones.

QUARTZ VEINS.

Traversing the Sicker gabbro-diorite porphyrite and the Saanich granodiorite are, in places, quartz veins from a few inches to 2 or 3 feet in width and from a few feet to 100 or 200 feet in length. Those associated with the gabbro-diorite porphyrite are also found cutting the Sicker series in the vicinity of the intrusive masses of porphyrite. One, on the west shore of Sansum narrows, a mile north of Separation point, is a saddle vein, about a foot thick, filling an opening formed at the crest of an anticline, during the folding of the Sicker porphyrite. Some of the quartz veins contain chalcopyrite, pyrite, and pyrrhotite, and in places, a little bornite. A few prospects have been located on these veins, especially in the vicinity of Mt. Brenton and Coronation mountain.

Near the western boundary of the Ladysmith batholith of Saanich granodiorite, about 1½ miles west of Coronation lake, the granodiorite is cut by a large quartz vein, striking nearly east and west, in places 60 feet wide. The vein consists of coarse-grained quartz with pyrite, chalcopyrite, and a little pyrrhotite, but is not of sufficient value to be ore. It has been developed by a 300-foot adit and is crosscut at the end of the adit by a 30-foot crosscut. Other much smaller veins occur in the Ladysmith batholith, but within the Duncan map-area none of the others has been prospected.

There can be little question but that the quartz veins are closely associated with the intrusions of the Sicker porphyrite and Saanich granodiorite, and have been formed at fairly high temperatures and pressures. Indeed it appears that the veins in the Ladysmith batholith, like the Thistle vein a few miles to the north[1], are aplitic in character.

TYEE TYPE.

General Character and Distribution. The only known deposit of the Tyee type occurs at Mt. Sicker and consists of a single lens of ore extending through three claims, from east to west, the Richard III, Tyee, and Lenora. The lens occurs in a

[1] Geol. Surv., Can., Mem. 51, 1914, pp. 124–126.

synclinal trough of the quartz-sericite, and graphitic schists resulting from the metamorphism of the Sicker sediments and Tyee quartz-feldspar porphyrite which in the vicinity of the lens are cut by large dykes of Sicker gabbro-diorite porphyrite. The ore is chalcopyrite, associated with pyrite, sphalerite, and some galena, in a gangue consisting chiefly of barite with some quartz and calcite. The production from the deposit has been large, and during its activity from 1903 to 1907 the Tyee mine was the most important copper producer of the coast region of British Columbia. At present most of the ore has been worked out and the mines are shut down.

The deposit has been described in considerable detail by Musgrave[1], Weed[2], and the writer,[3] and as no new information is available the following summary is given of the description published in Memoir 13.

Mineralogy. The number of minerals found in the ore is comparatively small. The metallic minerals are, in the order of their abundance: pyrite, chalcopyrite, sphalerite, pyrrhotite, and very small amounts of galena. The non-metallic minerals are chiefly barite, which forms about 37·5 per cent of the ore deposit, quartz, feldspar and sericite, calcite, and a little dolomite. Feldspar and sericite are in part residual from the unreplaced country rocks.

The ores of the deposit may be classified as banded and massive. The banded ore consists of albite, pyrite, barite, chalcopyrite and galena, sphalerite, quartz, and calcite, apparently deposited in about the order named, but in general deposited contemporaneously during a short rapid period of mineralization. It is not crustified but the banding appears to be due in part to a slight crushing and movement after the minerals had been crystallized, and in part perhaps to the replacement of an originally banded rock. The massive ore consists of chalcopyrite and a little intimately and irregularly intergrown pyrrhotite, including small well crystallized grains of pyrite. The minerals

---

[1] Musgrave, Robt., Eng and Min. Jour., vol. 78, 1904, pp. 673–674.
[2] Weed, W. H., Eng. and Min. Jour., vol. 85, 1908, pp. 199–201.
[3] Clapp, C. H., Geol. Surv., Can., Mem. 13, 1912, pp. 180–187.

are virtually contemporaneous, although pyrite appears to have first crystallized.

Mode of Occurrence. The ore-body is an irregular lens, with a proved length of 2,800 feet, a mean width of 20 feet, and a depth of 150 feet[1]. It occurs in the southern limb of a closed syncline, striking about north 75 degrees west and pitching at a low angle towards the west. The country rock is graphitic, quartz-sericite, and quartzose schists, derived by the metamorphism of the Sicker sediments and Tyee quartz-feldspar porphyrite.[2] The trough of schists, which in the vicinity of the ore-body is almost 300 feet wide, is limited on both sides by dykes of Sicker gabbro-diorite porphyrite, which has been converted along its contacts into chloritic schists, by shearing. The shearing and faulting along the contact with the southern dyke is partly post-mineral, since there the ore-body is broken and slightly displaced. Another smaller body of "low and irregular grade" occurs in the northern limb of the syncline, and about 100 feet north of the main deposit is a vein of quartz and dolomite carrying chalcopyrite. The entire zone or syncline of schist is impregnated with chalcopyrite and other sulphides, and by bornite as well, but no other distinct lenses of ore minerals have been discovered in spite of extensive and thorough prospecting.

Genesis. From the following facts it is concluded that the ore deposit has been formed by ascending thermal solutions: the occurrence of barite in the ore deposit and in depth in the schistose zone, the character of the metamorphism of the enclosing rocks, the massive character of the ore, and the presence of such minerals as albite and pyrrhotite. The solutions appear to be genetically connected with the intrusion of the neighbouring igneous rocks, most probably with the intrusion of the Sicker gabbro-diorite porphyrite but possibly with the intrusion of the younger Saanich granodiorite as well, although no stocks of Saanich granodiorite are exposed at the surface much nearer than 4 miles. The minerals have been deposited under at least moderate temperatures and pressures, and there seems

[1] Weed, W. H., Eng. and Min. Jour., vol. 85, 1908, p. 200.
[2] See pages 142 and 169.

to be little evidence that they have been deposited in a pre-existing cavity, as has been suggested.[1] The circulation of the solutions was doubtless controlled largely by the schistose zone and confining walls of Sicker porphyrite and partly by the pitching synclinal troughs, in one of which the ore-body was formed, largely by replacement.

General Status and Future Possibilities. As stated, the ore-body is apparently worked out, and there has been no production since 1907. Up to that time the Richard III had produced about 4,000 tons, the Tyee 166,000 tons, and the Lenora about 80,000 tons.[2] From the 166,000 tons produced by the Tyee mine there was obtained 14,715,336 pounds of copper, 415,446 ounces of silver, and about 26,000 ounces of gold. The thorough prospecting carried out by the Tyee company virtually precludes the finding of another lens of ore in the Tyee syncline. Similar synclines of mineralized, schistose rocks occur elsewhere in the Sicker series and in its associated porphyrites, and it is possible that there are similar ore-bodies as well. The location of the bodies from surface exposures is almost impossible. If it had not been for a happy accident, the uprooting of a tree which covered the only outcrop of the Tyee lens, the Tyee ore-body, which only near its one outcrop has a distinct covering of gossan, might have remained undiscovered for a long time. Not only are outcrops wanting or inconspicuous, but prospecting is greatly hampered by the thick layer of drift and by the heavy forest. The prospector should, however, pay particular attention to the closed synclines of mineralized schists.

IRON AND SULPHUR.

Iron ore has been sought in four types of deposits in southern Vancouver island: in contact deposits, impregnated schists, replacement deposits in the Sooke gabbro, and in bog ore deposits. Certain of the contact deposits of southern Vancouver island are fairly large and consist chiefly of magnetite. These contain large reserves of iron ore, but all of the known deposits of this

[1] Musgrave, R., Eng. and Min. Jour., vol. 78, 1904, p. 674.

[2] "Rept. on mining and metallurgical industries of Canada," Dept. of Mines, Mines Branch, 1907-8, pp. 171-173.

type in southern Vancouver island[1] occur in the metamorphosed Nitinat limestones to the west of the Sooke and Duncan map-areas. All of the magnetite type of contact deposits in the Sooke and Duncan map-areas, such as some of those of Mt. Malahat, which occur in the metamorphosed Sutton limestones and associated Vancouver volcanics—already described under copper deposits—contain large percentages of pyrrhotite, and are irregular in shape and of relatively slight extent. They are not, therefore, probable sources of iron ore.

Iron claims have been taken up on certain magnetite-bearing, jaspery schists of the Sicker sediments, near contacts with the intrusive Sicker gabbro-diorite porphyrite on the west slope of Mt. Bruce, Saltspring island, at an elevation of 825 feet above sea-level, and one-half mile from the east shore of Sansum narrows; claims have also been taken up on similar deposits on the northeast slope of Mt. Brenton. The deposit on Saltspring island consists of a schistose zone, about 100 feet wide, that in places is composed of the dark red, jaspery schists, consisting of very fine, irregularly intergrown grains of quartz with 10 to 15 per cent of magnetite. The magnetite, which occurs in small grains averaging about 0·02 millimetre in diameter, is arranged in rudely parallel streaks and lenses, with a few larger grains with crystal outlines, 0·1 millimetre in diameter. It is partly altered to hematite, which gives the rock its red colour. Toward the centre of the zone in particular, veinlets of magnetite occur, up to 3 inches wide, parallel to the schistosity, but with tiny offshoots extending across the foliation. Quartz veinlets also occur and appear to be of later development than the magnetite. Metallic sulphides are virtually absent. The deposit has apparently been formed by thermal solutions of quartz and magnetite, derived from the neighbouring intrusive gabbro-diorite porphyrite, that impregnated the sedimentary schists and to some extent replaced them. The deposit is exposed by an open-cut 75 feet long. The deposit is of fair grade in places and much of it could be readily concentrated to a high grade product; however, the deposit is hardly large enough to

[1] Geol. Surv., Can., Mem. 13, 1913, pp. 187–193.

warrant an attempt at mining. The deposit on the northeast slope of Mt. Brenton has not been examined, little or no development work having been done on it, but it is probably not large. If fairly large deposits of this type are discovered, they will be of great prospective value.

All of the replacement deposits in the Sooke gabbro occur in the East Sooke peninsula and have been described by Cooke. Briefly, they consist of massive pyrrhotite, magnetite, pyrite, and chalcopyrite, with very little gangue. Since the chief mineral is pyrrhotite, although magnetite is present in considerable quantity, the deposits are unlikely sources of iron ore.

In the Sooke district, in the vicinity of Demaniel creek, is a bog or lake deposit of yellow ochreous clay, which has been mentioned as a source of iron ore. Since the material contains only 15·5 per cent of iron, it is of too low grade for an iron ore. It is, however, suitable for cheap paint and the deposit is described more fully under pigments.

The massive sulphide deposits in the Sooke gabbro and the contact deposits that are rich in sulphide minerals, like those of Mt. Malahat, already described under copper deposits, are possible but not probable sources of sulphur. The deposits consist of irregular masses of pyrrhotite, pyrite, and magnetite, with small amounts of chalcopyrite. A little vein quartz and primary silicates, which the sulphides have more or less completely replaced, are the only gangue minerals. Owing to the large percentages of pyrrhotite and magnetite, the sulphur content is not high and, furthermore, the deposits are irregular and relatively small. They would be useful only in the manufacture of sulphuric acid; and if sulphuric acid were manufactured locally on a large scale, it is doubtful whether these deposits could compete with other deposits that are richer in copper or the precious metals.

FUELS: COAL AND OIL.

The Nanaimo series of the map-area has been considered as a possible source of coal, on account of the so-called "coal markings" (impressions of leaves and bark of coal-forming plants) which have been found in it, and because the Nanaimo series in the vicinity of Nanaimo and Comox contains commercial coal seams. The rocks of the Nanaimo series within the map-area are fairly well exposed; but no thick nor extensive coal seams are known, although small, lens-like seams are exposed in the northeastern part of the Cowichan basin, especially in the Haslam formation. These lenses, however, are rarely more than a few inches thick, but beds of impure sandy and shaly coal, from 3 to 6 feet thick, occur near the southern part of Maple bay, and along the shore of Saanich inlet, south of Cowichan bay. Although the Extension, Ganges, and Duncan formations of the Nanaimo series in the map-area are doubtless to be correlated with coal-bearing formations of the Nanaimo coal field, the Extension and Newcastle, the lithological character of the formations is notably different, and no indications of persistent coal seams occur at those horizons at which coal occurs in the Nanaimo district. In the Nanaimo district the coal seams occur fairly near the base of the Nanaimo series (within 2,000 feet) and on account of the folding which has occurred within the Duncan map-area, these horizons, except near their outcrops, occur only at great depths. The folding and faulting of the district also increase the difficulty of prospecting; and in the Cowichan basin and in much of the Nanaimo basin, it is so great as almost to preclude mining, unless especially thick and pure coal seams are found. Thus the geological conditions for the occurrence of commercial coal within the Duncan map-area are not favourable.

The Nanaimo series has been considered as a source of oil also. The structural conditions in the northeastern part of the map-area, where the series has been folded into rather broad, open folds of considerable length and breadth, are perhaps favourable to the accumulation of oil. However, there are no known bituminous beds in the Nanaimo series from which oil may have been derived in large quantities. In addition, no significant seepages of oil have ever been discovered in the Nanaimo series and no flow of oil has ever been obtained during the extensive boring carried on while prospecting for coal.

It does not seem probable, therefore, that oil will be found in great quantities in the Nanaimo series.

The Sooke formation along the southwest coast has been considered as a possible source of coal and oil, and has been prospected at Sooke, Muir creek, and Kirby creek. Near the mouth of Muir creek the Western Canadian Oil Prospecting Company drilled a well, from August, 1910, to August, 1913, for over 1,560 feet deep. The only indications of coal are thin seams of lignite and lignitic sandstones, with occasional cigar-shaped lenses and cylindrical masses of lignite. The Sooke formation consists largely of coarse detritus, which was deposited rapidly off a rather mountainous coast under marine conditions. These conditions were very unfavourable for the formation of coal. It seems as if the carbonaceous matter present was largely of drift origin, that is, composed of logs and other vegetable waste which accumulated along the shores of the Tertiary ocean during the deposition of the Sooke formation. The small seams of lignite that occur are very impure, the following being an analysis of the thickest seam known, 8 inches thick, exposed on Kirby creek, near the Jordan River road bridge. The sample was collected by W. L. Uglow and was analysed in the laboratory of the Mines Branch, Dept. of Mines.

Water	7·70
Vol. combustible	29·37
Fixed carbon	23·11
Ash	39·82
	100·00

In the Sooke formation there is no thick shale horizon rich in organic matter from which oil might have been derived, although some of the sandstones contain large numbers of marine organisms, from which the small amount of oil forming insignificant seepages has probably been derived. Since the rocks are coarse-grained and porous, without impervious layers, and not folded, but broken by very small faults, the structural conditions are unfavourable for the accumulation of oil. In addition the individual basins of the Sooke formation are small, and the thickness of the rocks, except locally, is probably less than 500 or 600 feet. It is, therefore, with a great deal of assurance that any extensive attempt at prospecting for coal and oil in the Sooke formation is discouraged. Furthermore, as has been shown by the Muir Creek well, the sandstones are flooded with water, which would be a very serious if not fatal menace to the commercial production of oil.

LIME, CEMENT, AND FLUXES.

The Sutton limestones furnish excellent material for the manufacture of lime and portland cement, and for fluxing, and are at present the most valuable of the mineral resources of the Sooke and Duncan map-areas. The Sutton limestones occur as relatively small lentils in the Vancouver volcanics, and also in the intrusive granitic rocks. Most of the lentils are of little value, because of their small size, metamorphic character, and because they are cut by numerous dykes and apophyses; but the largest and purest lentils found furnish abundant material. The limestones have been quarried for the manufacture of lime from three of the lentils located 2½ miles northeast of Goldstream in Highland district, west of Raymond crossing in Shawnigan district, and on the west shore of Saanich inlet, 5 miles south of Mill bay, at Bamberton. At present the limestones are quarried only at the last locality, where they are used in the manufacture of portland cement.

The purer limestones are grey to greyish blue, and even white, compact to medium-grained marbles, frequently brecciated but firmly recemented by calcite veinlets. They are, as a rule, pure, low in magnesia and insoluble material, and virtually free from phosphorus. Sulphur in the form of pyrite is in variable amount, but in the less altered varieties is usually low. Hence the limestones are suitable, as may be seen from the following analyses, not only for the manufacture of lime and cement but for flux in lead and iron smelting, even when it is proposed to utilize the slag for the manufacture of slag cement.

Analysis of Sutton Limestones from the Sooke and Duncan Map-areas.

		I	II	III	IV
Calcium carbonate	$CaCO_3$	93·12	99·5	91·5	97·24
Magnesium carbonate	$MgCO_3$	0·96	none	none	trace
Ferric oxide and Alumina	(Fe_2O_3) (and) (Al_2O_3)	2·00	trace	trace	1·60
Insoluble, chiefly silica	SiO_2	1·80	0·4	8·0	0·80
		97·88	99·9	99·5	99·64

I. Quarry 1 mile west of Raymond crossing, H. A. Leverin, Mines Branch, Dept. Mines, analyst.
II. Wriglesmith property, west of 17-mile-post, Saanich inlet, H. Carmichael, analyst, Rept. Min. of Mines, B.C., 1911, p. K209.
III. Elford quarry (now Associated Cement Co.) Saanich inlet, H. Carmichael, analyst, Rept. Min. of Mines, B.C., 1911, p. K209.
IV. Associated Cement Company's quarry, Bamberton, Saanich inlet—furnished by the company.

The only limestones that are being utilized at present are those quarried at Bamberton for the manufacture of portland cement. The lens in the Highland district was opened up in several quarries and the limestone was burnt in updraft, wood-fire kilns at two places. The limestone is somewhat metamorphosed and contains metamorphic silicates, and is also cut by numerous dykes. The failure to establish a profitable industry is, perhaps, partly due to these causes but more largely to the fact that the cost of transportation to the railway or to salt water was too great for the plants to compete successfully with those more favourably located. The same cause seems to have been responsible for the failure of the kiln west of Raymond crossing. The limestone at Bamberton, which was formerly used for the manufacture of lime, was taken over in 1911 by the Associated Cement Company (Canada) Limited, a subsidiary company of the Associated Portland Cement Company of England. A plant of 2,500 barrels capacity for the manufacture of portland cement by the wet process, with oil-burning, rotary kilns was constructed and was in operation in 1913; during that year 135,000 barrels of portland cement, valued approximately at $250,000, were produced[1]. The "shale" which is mixed with

[1] Rept. Min. of Mines, B.C., 1913, p. K292.

the limestone is quarried on the west shore of Finlayson arm, and is obtained from one of the tuffaceous argillites of the Malahat volcanics. A description of the argillite, accompanied by a partial chemical analysis kindly furnished by the company, has already been given[1]. During 1914, when the market for cement was somewhat limited, the output of the plant was valued at about $300,000[2].

PIGMENTS.

In the Sooke district, exposed in the bed of Demaniel creek, half a mile south of Young lake, is a deposit of yellow, ochreous clay, or impure bog-iron ore. It is traceable for 200 yards along the creek, and has an exposed thickness of 4 feet. Mr. Dan Campbell, who held a claim on the deposit, states that it extends as far north as Young lake, and that he has bored into the deposit for a depth of 12 feet. The deposit consists of a very fine-grained clay, with which is mixed fairly uniformly, bog-iron ore or limonite. Limonite occurs also in small concretions. An analysis of a sample from the deposit showed the iron content to be 15·5 per cent. Near the surface the deposit contains angular fragments of the Metchosin volcanics, but these have doubtless been washed in by Demaniel creek during times of high water, and they are not found much more than a foot below the surface. Farther down the stream t[illegible] firmly cements the underlying sands and gravels. The [illegible] has doubtless been deposited during late Pleistocene or rec[illegible] times in a bog, which probably represented the end stage in the filling up of one of the transient lakes which collected in the hollows of the drift mantle at the close of the period of glacial occupation. The material could readily be washed and purified, and the product, although valueless as an iron ore on account of its low iron content, would make a good base for coloured paints.

CLAYS.

Clay deposits are found, in the Sooke and Duncan map-areas, only in the Nanaimo series and superficial deposits. The clays of

[1] See page 75.
[2] Rept. Min. of Mines, 1914, p. K387.

the superficial deposits occur chiefly in the Puyallup interglacial deposits and to a less extent with the Colwood sands and gravels, and in the recent alluvium of the eastern part of the Cowichan valley. They are found in beds up to 10 or 20 feet thick, and have a wide distribution throughout the map-areas. They are chiefly yellowish grey, sandy, although fairly plastic clays, with a moderate air-shrinkage. Associated with the sandy clays in places, are very smooth, plastic clays, with little or no grit; but most of these crack greatly upon drying. Most of the interglacial clays contain numerous glacial pebbles and even small boulders of the crystalline rocks; although in places, as in the pits southeast of Ladysmith near Boulder point, the clays are virtually free from pebbles and boulders. When the pebbles are present the clays should be screened before using, if the best product is to be obtained. The clays contain more or less vegetable lignitic matter, usually plant remains. They are all of low fusibility and burn hard and red at a low temperature. The following is an analysis of a superficial clay, from near Duncan, that is typical of the superficial clays, which are all much alike.

Analysis of Superficial Clay from near Duncan.[1]

Silica, SiO_2	67·6
Alumina, Al_2O_3	13·6
Iron oxide, Fe_2O_3	8·8
Lime, CaO	3·6
Magnesia, MgO	0·2
Water and loss upon ignition	5·6

The clays of the superficial deposits are suitable for the manufacture of common brick and drain-tile, and for the manufacture of portland cement, and are similar to the clays in the vicinity of Victoria, which are used extensively for those purposes. Within the Sooke and Duncan map-areas they are at present used for the manufacture of common brick only at Somenos; but recently a small number of brick were burnt from the clays near Boulder point, southeast of Ladysmith.

Some of the shales of the Nanaimo series, notably those of the Haslam, Ganges, Cedar District, Duncan, and North-

[1] Herbert Carmichael, analyst. Rept. Min. of Mines, B.C., 1908, p. 188.

umberland formations are sources of shale-clay, which may be used for brick and various kinds of semi-porous ware and stoneware, either by the dry-press or stiff-mud process; but most of the Nanaimo shales are too sandy, of too low plasticity, and too expensive to work to be of value. Even the best of the shale clays[1] are of low plasticity, burn to a red or brown colour, are of low fusibility, and are interbedded with numerous thin layers of sandstone. Therefore, they hardly warrant development at the present time, especially because of their expensive handling due to their great hardness and density. Within the map-areas the shale-clays of the Nanaimo series are not at present utilized, although similar shale-clays are quarried, largely for the manufacture of brick, to the north of the map-area on Gabriola island and at East Wellington, and to the southeast of the map-area on Pender island.

SAND AND GRAVEL.

The superficial deposits, especially the Colwood sands and gravels and upper portion of the Puyallup interglacial deposits, occurring chiefly on the lowlands of the region, afford an abundant supply of sand and gravel of good quality for concrete, ordinary filling, road material, and for other similar purposes. The Colwood and Puyallup deposits, and to some extent the rudely stratified portions of the Vashon drift have been quarried to a limited extent at numerous places throughout the more settled portions of the map-areas for road material and railway ballast. By far the greater part of the material for these purposes has been obtained from the coarse gravel, top-set beds of the Colwood delta, chiefly from a large pit north of the Esquimalt and Nanaimo railway, east of Langford lake. Sand and gravel have been quarried for structural and building purposes from the upper portion of the Puyallup deposits on the east shore of Saanich inlet, south of Maple bay, and on the shore of Parry bay, between Albert head and William head; but the quarry in the former deposit was not in operation during 1913.

[1] See descriptions and results of tests. Ries, H., and Keele, J., Geol. Surv., Can., Mem. 47, pp. 56–61, and Mem. 66, pp. 17–21.

STONE.

The fractured and sheared character of the crystalline, metamorphic, and granitic rocks of the map-areas renders most of them unfit for building purposes other than foundation and other rough structural work. In places in the large mass of basic granite or granodiorite west of Ladysmith, the granite is fairly regularly jointed and comparatively free from small fractures, and moderately large, sound blocks could probably be obtained. The sandstones of the Sooke formation are too coarsely and irregularly grained, too soft, yet too greatly fractured, and too thin-bedded to be of much value, and even most of the rocks of the Nanaimo series are too greatly disturbed and fractured to yield stone of good quality. However, some of the less folded and fractured of the Nanaimo sandstones furnish building stone of fair quality. Only two of the sandstones have been at all extensively quarried, the Protection (Duncan) and the DeCourcy. There is, however, an old quarry on the east shore of the southern arm of Maple bay, in the lower sandstones of the Haslam formation. The Protection sandstone has been quarried on Saltspring island on the north shore of Booth bay, and to the east of the Esquimalt and Nanaimo railway, nearly a mile northwest of Cowichan station. At the last locality, which is the only place in the Cowichan basin where the Protection sandstone can be distinguished, the sandstone is mapped with the Duncan formation. The quarry at Booth bay is in an 80-foot bed of a uniform and rather fine-grained sandstone, striking north 65 degrees west and dipping 75 degrees northeast. The sandstone is light greenish grey on fresh fracture, but weathers quickly to a dirty or brownish grey. It is composed of angular grains of quartz and clear or white weathered feldspar, shreds of biotite and some of muscovite and a few greenish and reddish grains, seen microscopically to be epidote, zircon, titanite, and jaspery and meta-volcanic rocks. The sandstone is chiefly cemented by secondary silica, and is rather friable. Like most of the Nanaimo sandstones it is rather soft directly after quarrying but hardens with seasoning. The thick, steeply dipping bed is broken into large lenses up to 3 feet thick, by rather numerous, nearly horizontal but somewhat irregular joints. Stone for the construction of the government dry dock at Esquimalt was obtained from this quarry. The quarry has not been in operation for several years. North of Cowichan station a very similar thick-bedded, greyish white sandstone, with small interbedded lenses of coaly shale and conglomerate, is quarried. The sandstone strikes about north 75 degrees west and dips about 30 degrees northeast. The quarry has not been in operation for several years.

The DeCourcy sandstone has been quarried on Saltspring island on the north shore of Vesuvius bay. It is obtained from a 20-foot bed limited by beds of shaly sandstone and sandy shale. The sandstone is medium to coarse-grained, light greenish grey on fresh fracture, but weathers to buff. It is composed of angular grains of quartz, feldspar, and flakes of biotite and muscovite and accessory zircon and titanite in a greenish matrix consisting largely of epidote and chlorite. The cement is siliceous and ferruginous. The fresh rock is strong although rather soft, but hardens with seasoning. The bedding is steep, 67 degrees northeast, the strike being north 60 degrees west. Except in the thick bed the sandstone is rather greatly fractured, but from the thick bed, blocks as large as 6 feet square and 4 feet thick have been obtained. The quarry is small and has not been in operation for several years.

Up to the present time there has been no commercial production of crushed stone from the Sooke and Duncan map-areas, although some, obtained largely by the cutting of highways, railways, and ditches through rock outcrops, has been used for ballast, road material, and concrete construction. However, the less altered basic volcanic rocks of the map-areas, especially the Metchosin basalts, quarried to the east of the map-area on Albert head, offer an unlimited supply of the best quality of trap rock for use in the crushed state.

SOILS.

The soils of the Nanaimo map-area are virtually all transported or drift soils, and a mixture of the superficial deposits with decayed vegetable and animal matter, called humus. Consequently their character at any locality is directly dependent upon the immediately underlying superficial deposits, being sandy or pebbly where underlain by sands or gravels and clayey where underlain by clays.

The soils formed from the Puyallup interglacial deposits range from fertile, fine, sandy loams to dry, coarse, sandy loams; the latter cannot hold much water and are subject to great changes of temperature and consequently are of poor fertility. The former soils occur where the subsoil is sandy or fine clayey sand. They are most common below elevations of 250 to 300 feet, and are found especially on the eastern lowlands of the Sooke map-area, to the northwest of Parry bay and to the north of Sooke harbour, and in the southeastern part of the Cowichan valley. The latter soils are found where the subsoil is coarse sand or gravel.

The Vashon drift forms chiefly a rather coarse, sandy loam, with a considerable proportion of clay and also numerous pebbles and boulders. The soil is fertile and supports a thick forest growth and heavy underbrush. The forest has not yet been cleared to any great extent nor has much land been prepared for cultivation on account of the numerous pebbles and boulders and because the country underlain by the Vashon drift is hilly.

The Colwood sands and gravels of the lowlands usually have a surface covering of coarse gravel; consequently their soil covering is thin and consists of a gravelly, porous loam that is comparatively sterile. Although the soil supports a fairly heavy forest growth, it does not support very much underbrush. The country underlain by the Colwood deposits is, therefore, more open than most of the lowland of Vancouver island. Much of the forest has been cut for timber, but little of the land is under cultivation. In a few places, however, where the subsoil is one of the sandy clays of the Colwood deposits or where they are covered by fine silt, the soil is of much greater fertility; but it is apt to be dry, since the subsoil is underlain by sands and gravels.

The swamp alluvium in its natural condition supports a heavy growth of swamp vegetation and coarse grass, and where cleared and drained is productive; but it is apt to become dry and light during the summer months. The soils formed from the flood-plain and delta deposits such as those in the Cowichan valley, are, however, more sandy, and are fertile, fine sandy loams.

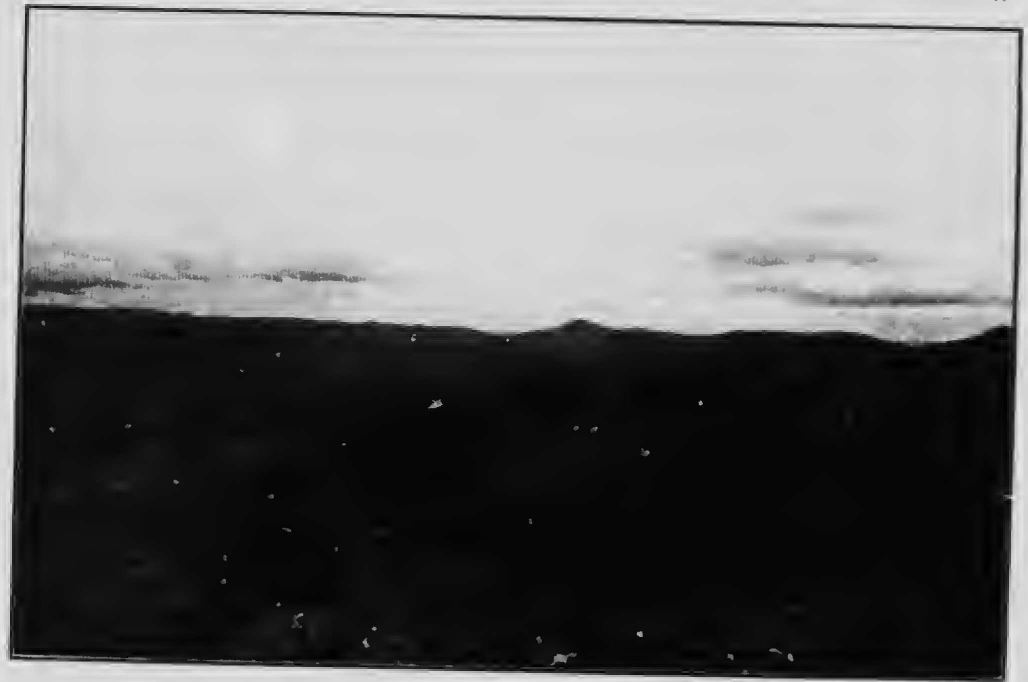
Over a very large part of the map-area, especially on the upland, the soil covering is thin and rock outcrops are large and numerous. Nevertheless such areas are covered by a heavy forest growth. They are, of course, unsuited for agriculture of any kind and should be reserved fo the gr wth of forest trees.

WATER.

Owing to the rather heavy rainfall, and luxuriant vegetation, surface water is abundant in most parts of the map-areas, and is of excellent quality. Along the eastern coast of Vancouver island, however, most of the streams become dry or intermittent in the summer; but by recourse to storage reservoirs the settlements are or may be readily supplied with sufficient water. Thus the city of Ladysmith has an abundant supply of excellent water, obtained from Stocking lake which is dammed at its outlet. To the southeast of the map-area the city of Victoria has had for several years an inadequate supply of water. In 1911 a project to obtain water from Sooke lake was started. This has been completed, and now water is brought from the lake, a distance of 27 miles, by a pipe line to the Humpback reservoir located south of Goldstream station, from whence it is taken to the city. Water is also obtained from the Goldstream lakes and is used by the city of Esquimalt and for hydraulic power.

Where wells are required ample wat of good quality may usually be obtained from shallow wells in the superficial deposits, especially in the Puyallup interglacial deposits consisting of alternating porous and impervious beds. In the Colwood sands and gravels the water table is low and it may be necessary to sink wells to a depth of a hundred feet or more. Occasionally in the search for water, wells have been driven into the hard rocks. With the exception of the sandstones of the Nanaimo series and of the Sooke formation, however, the hard rocks of the region are very dense and impervious, and water circulates through them only along occasional joints and sheared zones. The sandstones, as has been shown by the various wells which have been driven in them in the search for coal and oil, yield abundant water and some of the wells are artesian, that is they tap supplies of water that are under sufficient pressure to force the water to the surface. Much of the water obtained from the sandstones is palatable, but some of it, also to be found in springs in the sandstones, is rather saline, and in places it is ferruginous.

PLATE II.



Southern upland of the Sooke and Duncan map-areas, showing maturely dissected peneplain surmounted by a few relatively low monadnocks. Looking northwest from Mt. Shepherd. Largest monadnock in central part of background is Survey mountain (Page 28).

A. Reef of concretionary, honeycomb weathering DeCourcy sandstone, which dips steeply to the northeast. Southwest of Wallace island, Houston passage. Page 234

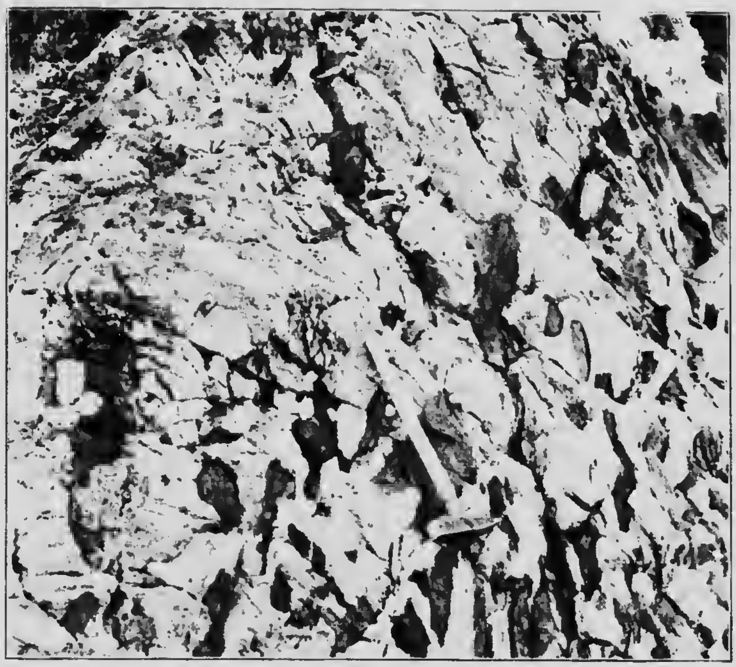
B. Telegraph harbour between Thetis and Kuper islands eroded in the lower shales of the Northumberland formation. In the background Thetis island and cuesta (Birchall hill) of Northumberland sandstone. Page 41

PLATE IV.

A. Epidote nodules in the Sicker volcanics, Maple mountain. (Page 130.)

B. Cherty tuffs and black slates of the Sicker sediments; southwest shore of Saltspring island. Rocks dip gently to the north. (Page 158.)

PLATE V.



Inclusions of the normal Tyee quartz-feldspar porphyrite in the granitic phase of the Tyee porphyrite; west shore of Saltspring island, due west of Mt. Belcher. (Page 169.)

PLATE VI.

Pillow basalts in the Metchosin volcanics; islets off the south shore of Albert head. (Page 260.)

PLATE VII.

Overturned and broken syncline in the cherty tuffs of the Metchosin volcanics, interbedded with massive flows. Axial plane of the syncline dips to the north. Cut along the Canadian Northern railway, east of Sooke river, 3 miles from the mouth. (Page 266.)

PLATE VIII

Sheared zone along the Leech River fault, separating the Leech River schists and the Metchosin volcanics; cut along the Esquimalt and Nanaimo railway, three-fourths mile west of Goldstream station. (Page 277.)

PLATE IX

Conglomerate and sandstone of the Sooke formation; shore near Kirby creek. Page 331.

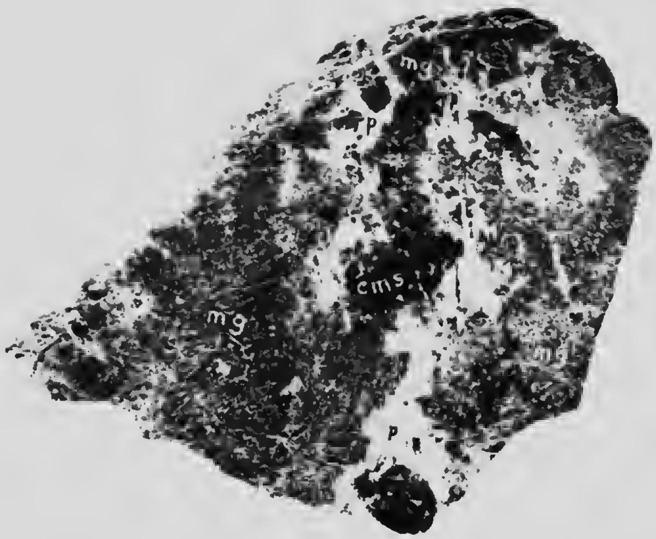
PLATE X.

Old dyke chasm of the Tertiary coast filled with the basal conglomerate of the Sooke formation. Sheringham point. (Page 334.)

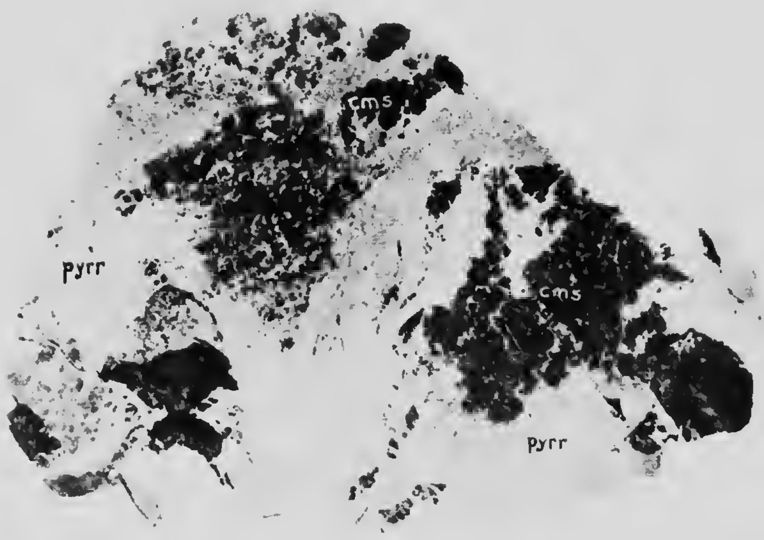
PLATE XI.

Colwood sands and gravels, 12 feet thick, overlying Vashon drift. Contact marked by line of bushes. Cut along the Esquimalt and Nanaimo railway, northwest of Goldstream. (Page 345.)

PLATE XII.



A. Fine granular magnetite replacing contact metamorphic silicates and cut by irregular veinlets of pyrite. Spec. 377, Malahat ridge. (Page 375.)



B. Massive pyrrhotite replacing dark contact metamorphic silicates, with irregular grains of pyrite and veinlets of chalcopyrite. Spec. 384, Malahat ridge. (Page 374.)

INDEX.

F.

G.

M.

Q.

R.

S.

V.

W.

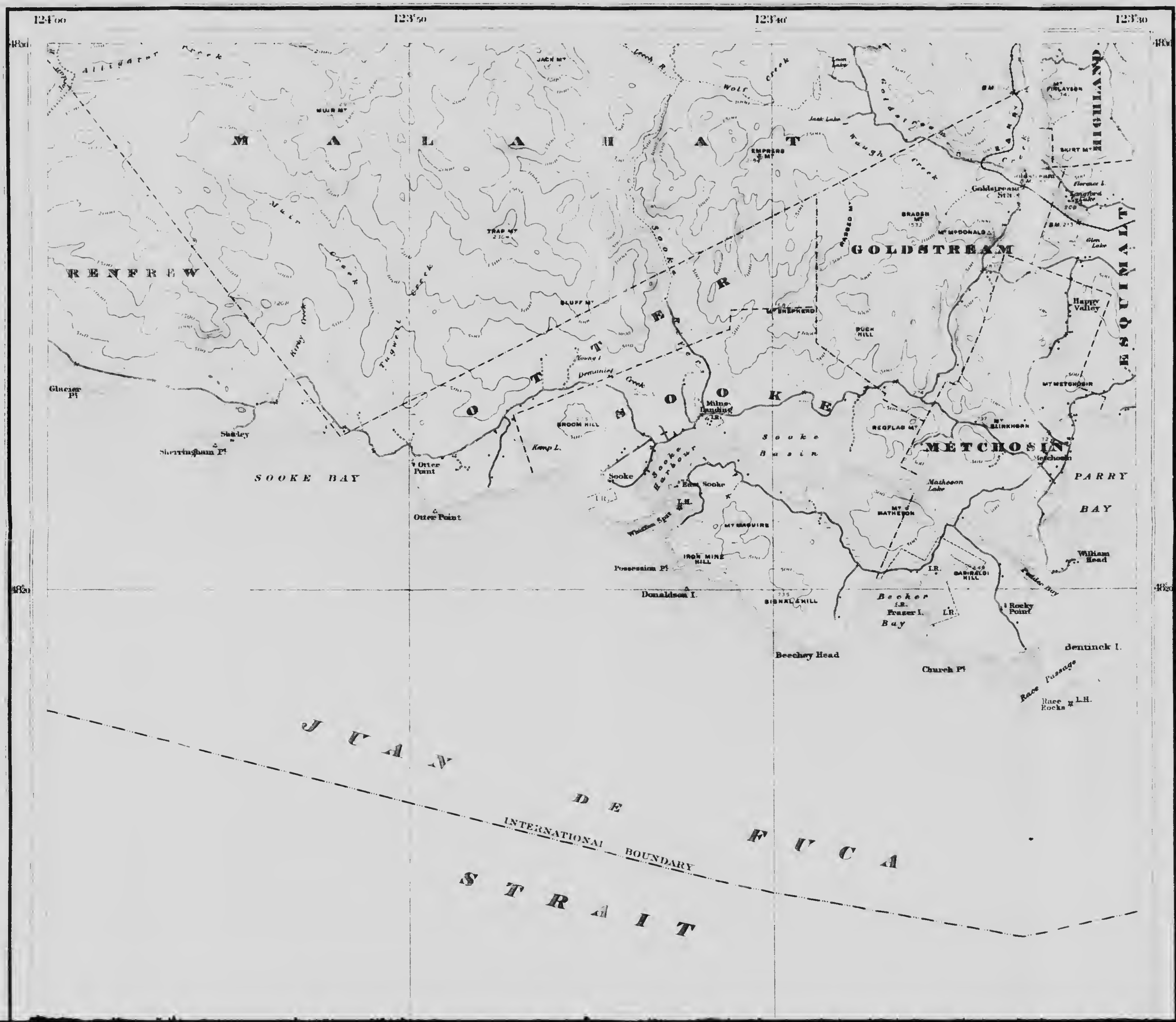
Canada

Department of Mines

HON L. CODERRE, MINISTER; R.W. BROCK, DEPUTY MINISTER.

GEOLOGICAL SURVEY

TOPOGRAPHY



LEGEND

Culture

Roads and buildings

Private roads, or roads not well defined

Trails

Railways

Tramways

Bridges

Churches

Schools

Post offices

Prospects

Wharves

Lighthouses

International boundary

District boundaries (lines shown approximately)

Triangulation stations

C O Senécal *Geographer and Chief Draughtsman*
G.G Aitken, *Draughtsman*

MAP 43A
(Issued 1914)

SOOKE S

VANCOUVER IS

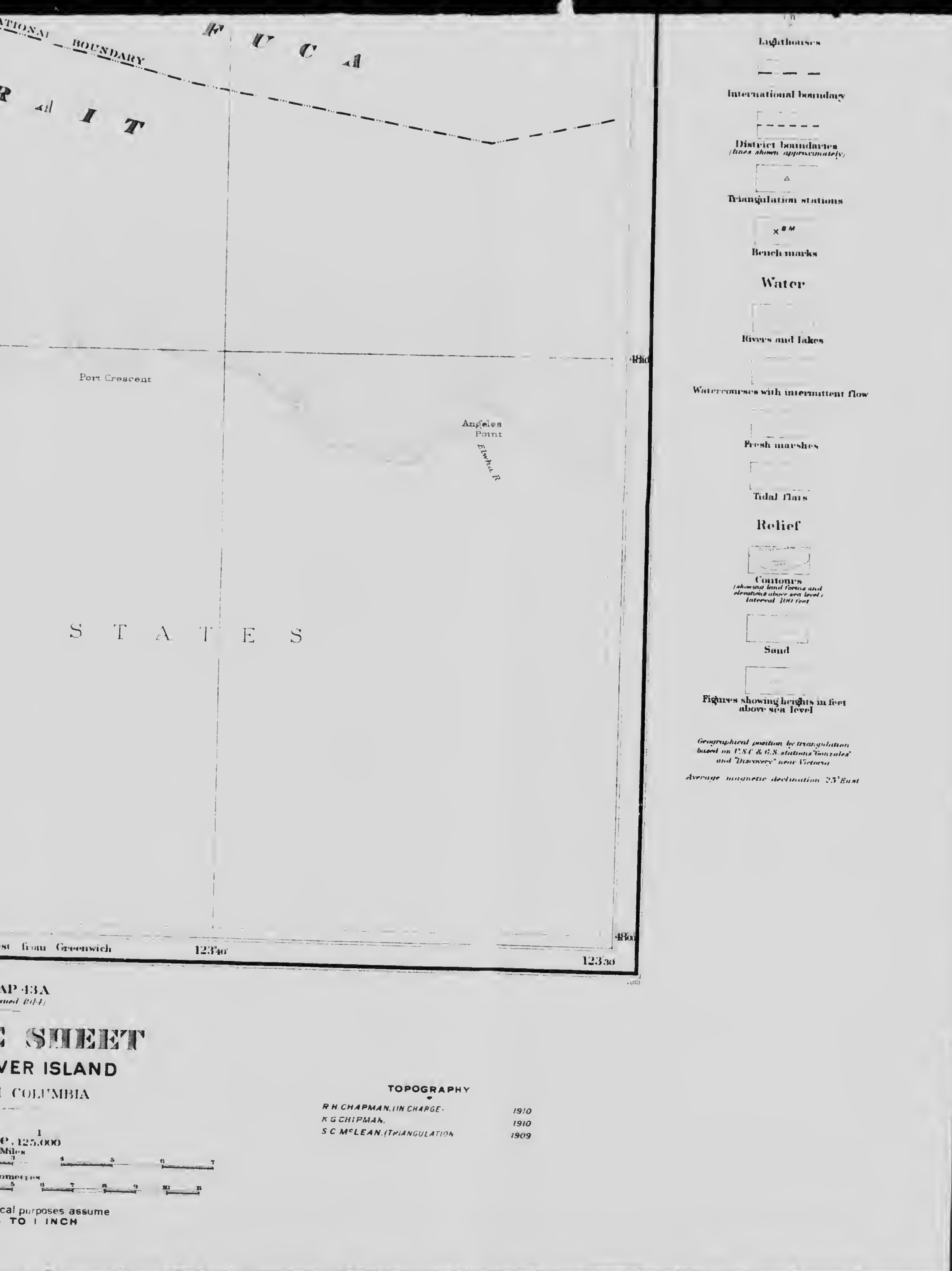
BRITISH COLU

Scale, 1/125,00

Miles

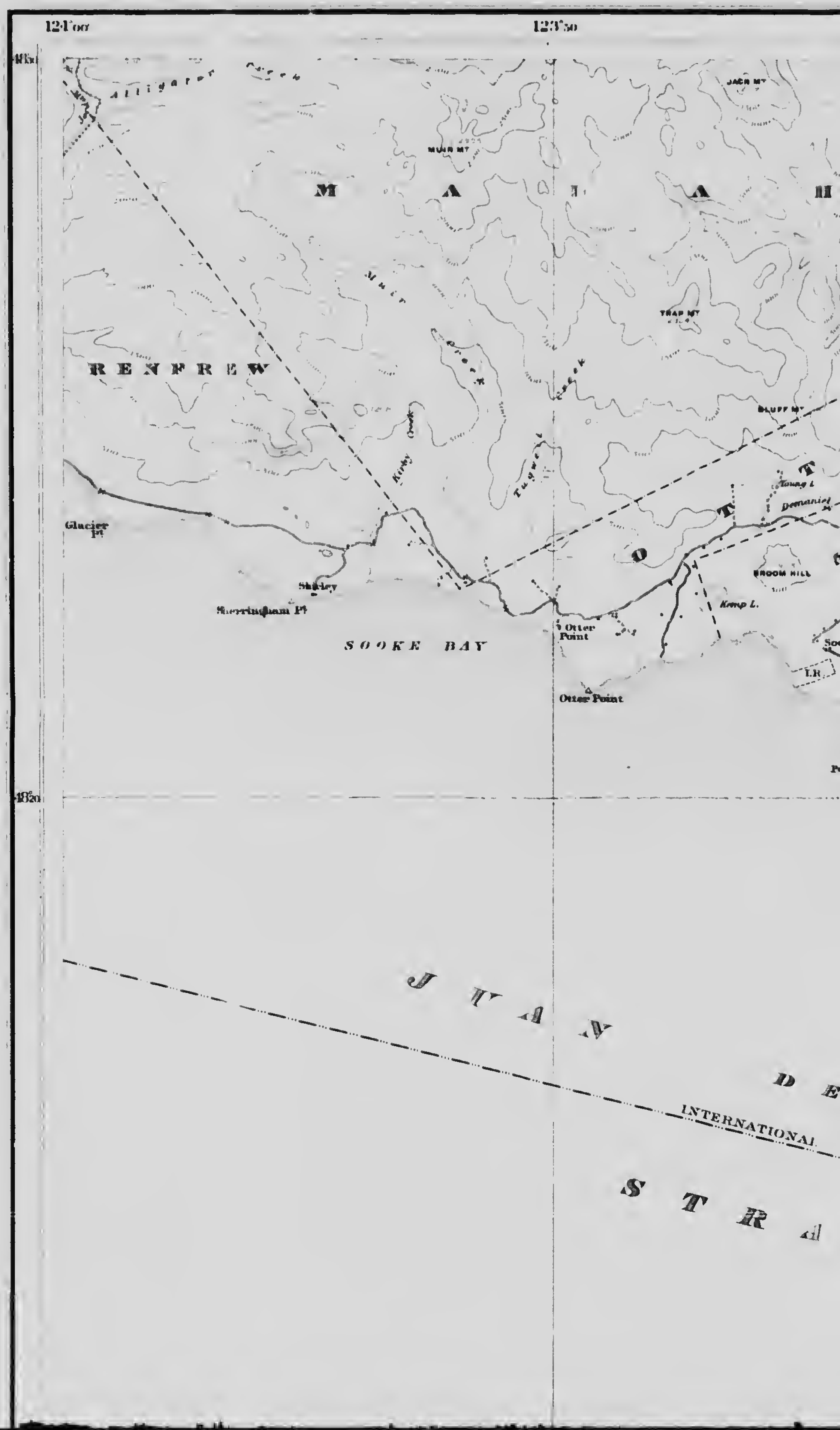
Kilometres

Note For practical purpose
2 MILES TO 1 IN



BOUNDARY
F U C A
R I T
Port Crescent
Angeles Point
Elwha R
S T A T E S
from Greenwich
123°40'
123°30'
Lighthouses
International boundary
District boundaries
(lines shown approximately)
Triangulation stations
B M
Bench marks
Water
Rivers and lakes
Watercourses with intermittent flow
Fresh marshes
Tidal flats
Relief
Contours
(showing land forms and elevations above sea level)
Interval 100 feet
Sand
Figures showing heights in feet above sea level
Geographical position by triangulation based on U.S.C & G.S. stations "Gonzales" and "Discovery" near Victoria
Average magnetic declination 25° East
AP 43A
SHEET
VER ISLAND
COLUMBIA
125,000
Miles
cal purposes assume
TO 1 INCH
TOPOGRAPHY
R H. CHAPMAN, (IN CHARGE) 1910
K G CHIPMAN. 1910
S C McLEAN, (TRIANGULATION 1909

Canad
Department of
HON L. CODERRE, MINISTER; R.W.B
GEOLOGICAL SU



...anada
...ent of Mines

...ER, R.W. BROCK, DEPUTY MINISTER

...SICAL SURVEY

TOPOGRAPHY

LEGEND

Culture

Roads and buildings

Private roads, or roads not well defined

Trails

Railways

Tramways

Bridges

Churches

Schools

Post offices

Prospects

Wharves

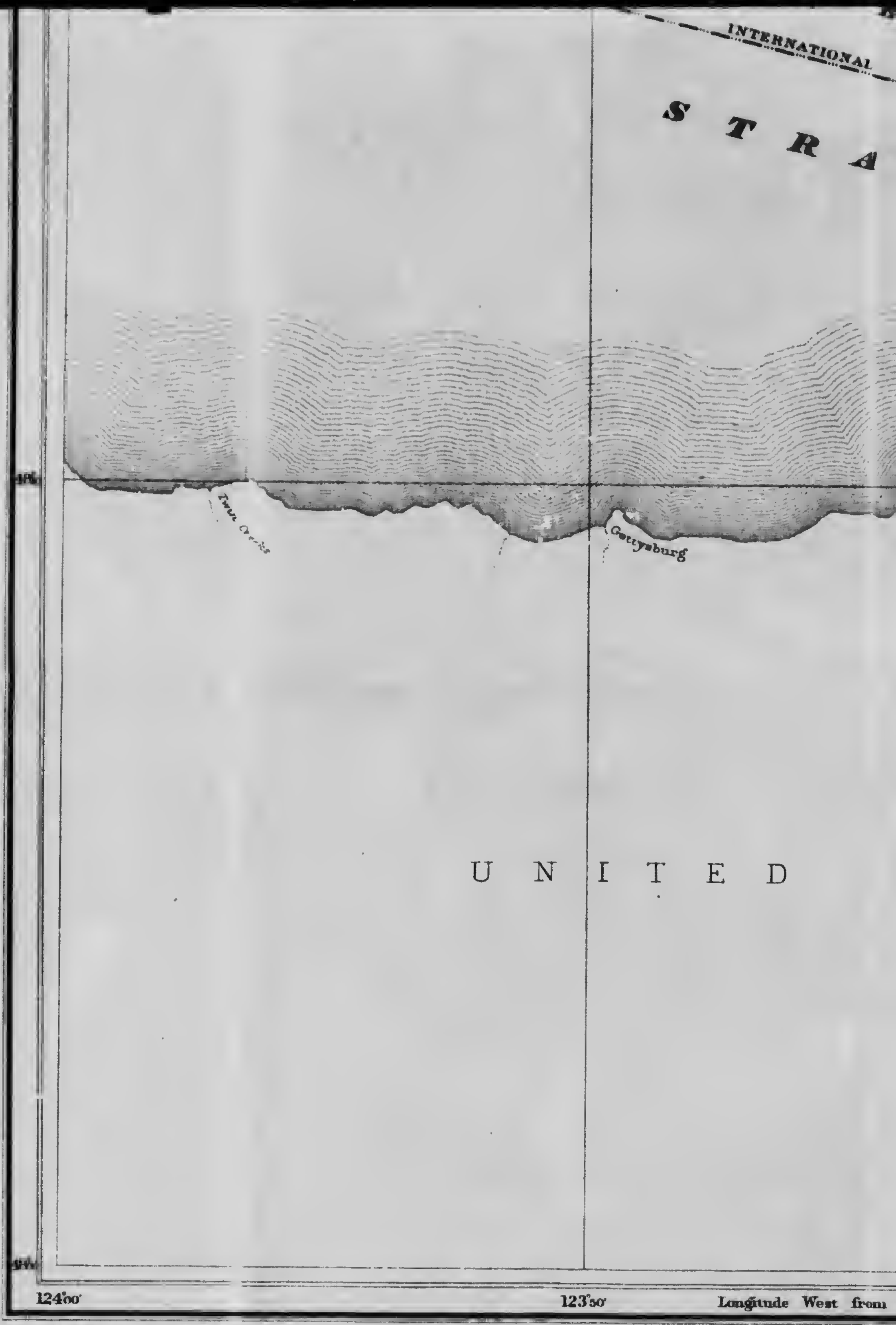
Lighthouses

International boundary

District boundaries *(lines shown approximately)*

Triangulation stations

Bench marks



C.O.Senécal, *Geographer and Chief Draughtsman.*
G.G.Aitken, *Draughtsman.*

MAP 43A
(issued 1914)

SOOKE SH

VANCOUVER IS

BRITISH COLU

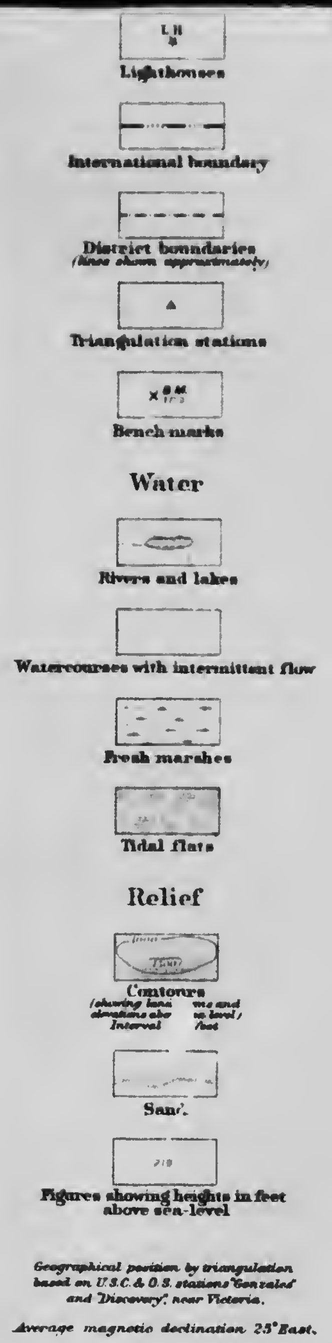
Scale, 100 Miles to 1 Inch

Scale. $\frac{1}{125,00}$

Miles

Kilometres

Note. For practical purpo
2 MILES TO 1 I



AP 43A

(…sued 1914)

E SHEET

VER ISLAND

H COLUMBIA

le, $\frac{1}{125,000}$

Miles

ilometres

tical purposes assume

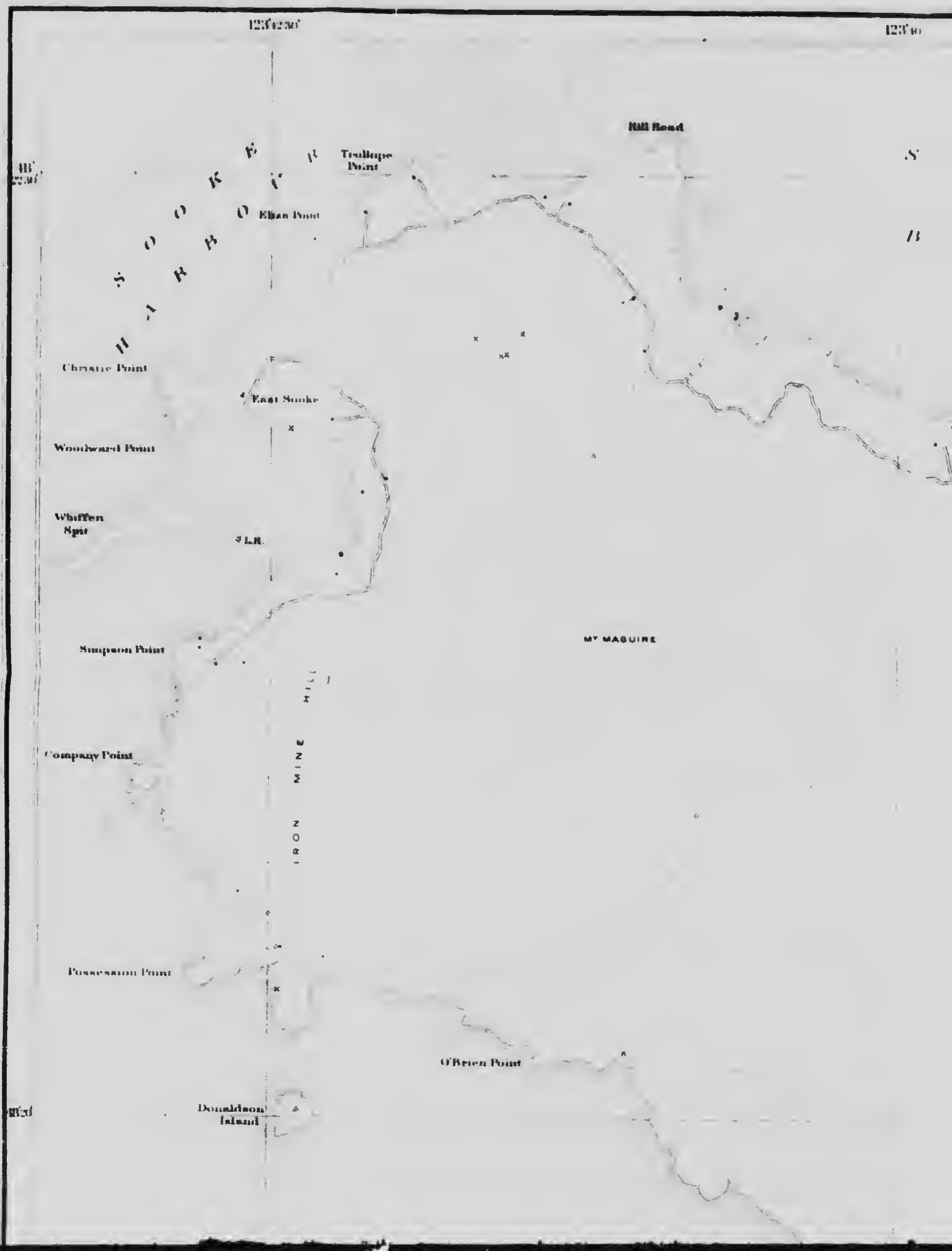
S TO 1 INCH

TOPOGRAPHY

R.H. CHAPMAN, (IN CHARGE)	1910.
K.G. CHIPMAN,	1910.
S.C. McLEAN, (TRIANGULATION)	1909.

Canada
Department of Mine

GEOLOGICAL SURVEY



f Mines

URVEY

LEGEND

Culture

Roads and buildings

Roads *not well defined*

Trails

Schools

Post Offices

Shafts

Prospects

Wharves

Lighthouses

Triangulation stations

Water

Streams

Watercourses *with intermittent flow*

Fresh marshes

Tidal flats

C. O. Senecal, *Geographer and Chief Draughtsman*
S. G. Alexander, *Draughtsman*

MAP 157A
Issued 1917

EAST SOOK

VANCOUVER ISLAN

BRITISH COLUMBIA

Scale, $\frac{1}{24,000}$

Feet

Meters

2000 FEET TO 1 INCH

Triangulation stations

Water

Streams

Watercourses
with intermittent flow

Fresh marshes

Tidal flats

Shore line
position approximate

Relief

Contours
showing land forms and elevations above sea level
Interval 20 feet

Sand beaches

Geographical position based on the latitude and longitude of U.S.C. and G.S. stations "Beechy Head" and "Island"

Approximate magnetic declination 23° East

A

OOKE

SLAND

UMBIA

TOPOGRAPHY

F. S. FALCONER, 191

INCH

Figures showing heights in feet above sea level

488

123

Publication No 1193

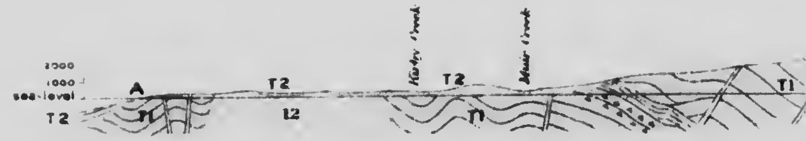
1912 1913

OGRAPHY

1910

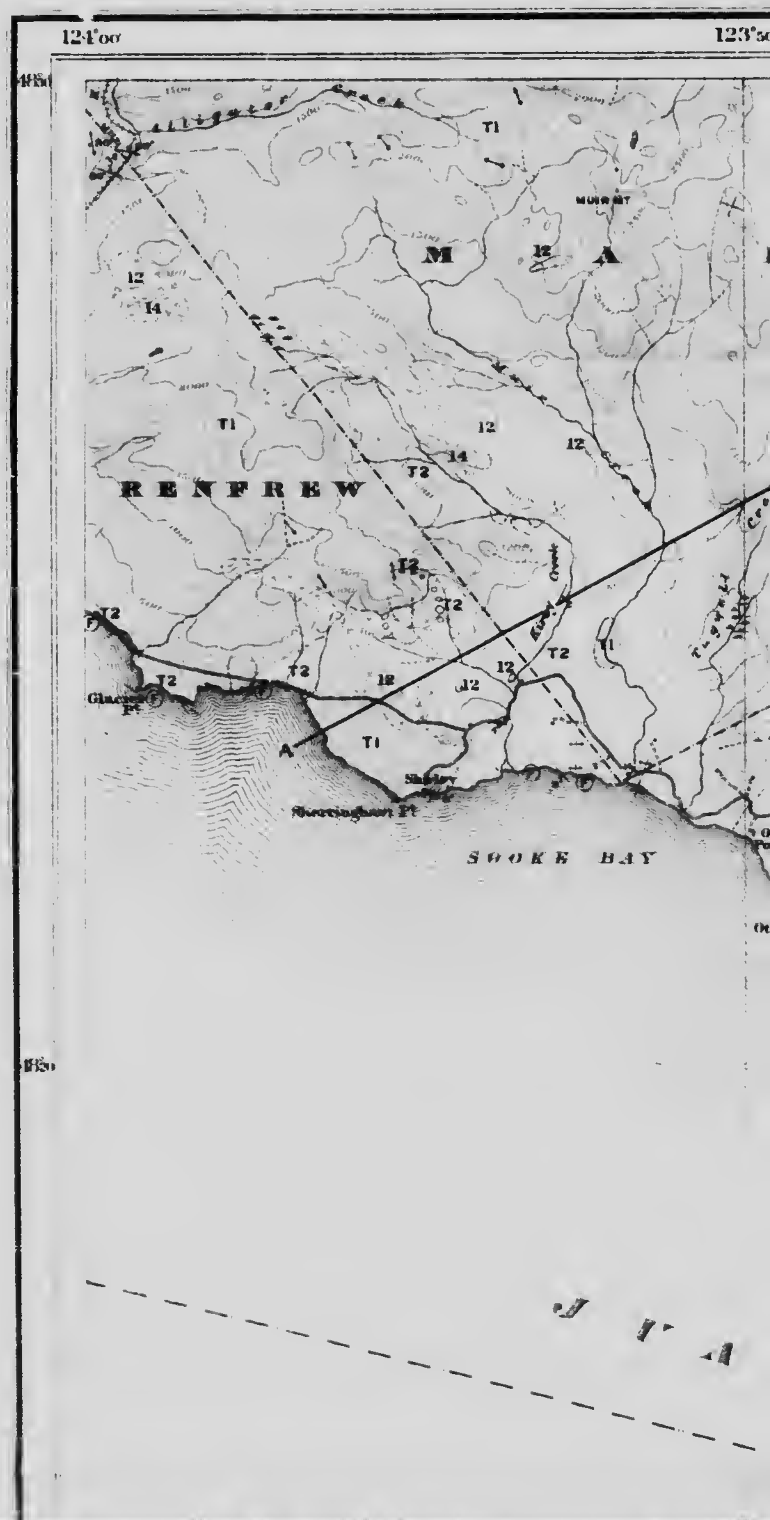
1910

1909



Structural section along line A.B.

Scale, horizontal and vertical, 1/126,000



LEGEND

QUATERNARY

Q

Superficial deposits
(completely masking bed rock)

TERTIARY

LOWER MIOCENE?

T2

Sooke formation
(sandstone and conglomerate)

LOWER OLIGOCENE

SOOKE INTRUSIVES

14

Granite

13

Anorthosite

12

Olivine and Augite Gabbro

UPPER EOCENE

T1

Metchosin Volcanics
basalt, diabase tuff and chert

T1

Metchosin Volcanics
...

UPPER JURASSIC / LOWER CRETACEOUS

10

Quartz Diorite Porphyrite
dykes

9

Gabbro
dykes

Symbols

Geological boundary
(position determined)

Geological boundary
(probable error of location less than 250 feet)

Geological boundary
(probable error of location less than 1500 feet)

Geological boundary
(position assumed)

Fault
(probable error of location less than 250 feet)

Fault
(probable error of location less than 1500 feet)

Probable fault
(position assumed)

Dip ... 18

Canada
Department of Mines

HON. ... BURRELL, MINISTER; R. G. McCONNELL, DEPUTY MINISTER

GEOLOGICAL SURVEY

WILLIAM McINNES, DIRECTING GEOLOGIST

Structural section along line C.D.

Scale, horizontal and vertical

LEGEND

Culture

Roads and buildings

Private roads, or roads not well defined

Trails

Railways

Tramways

Bridges

Churches

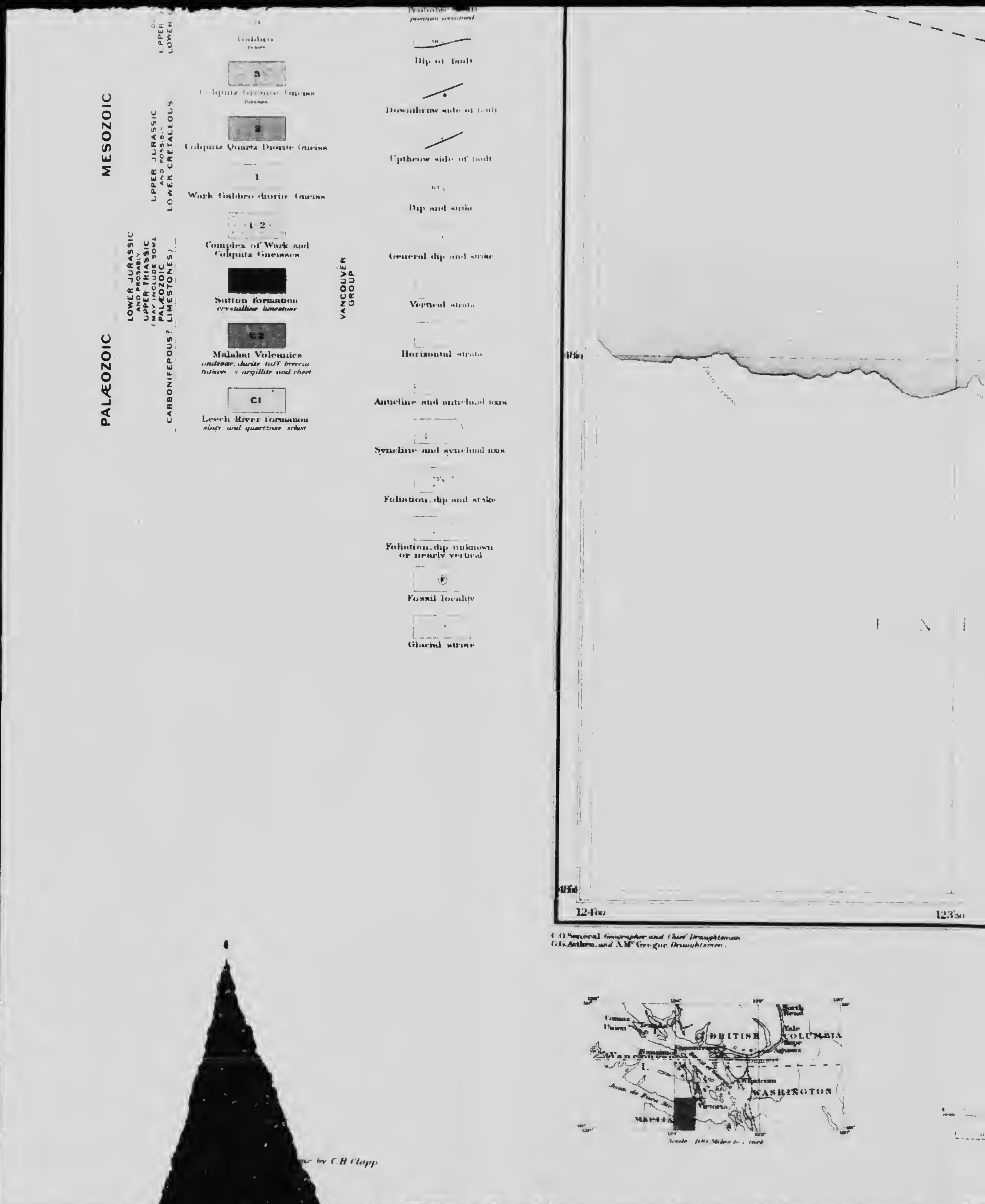
Schools

Post offices

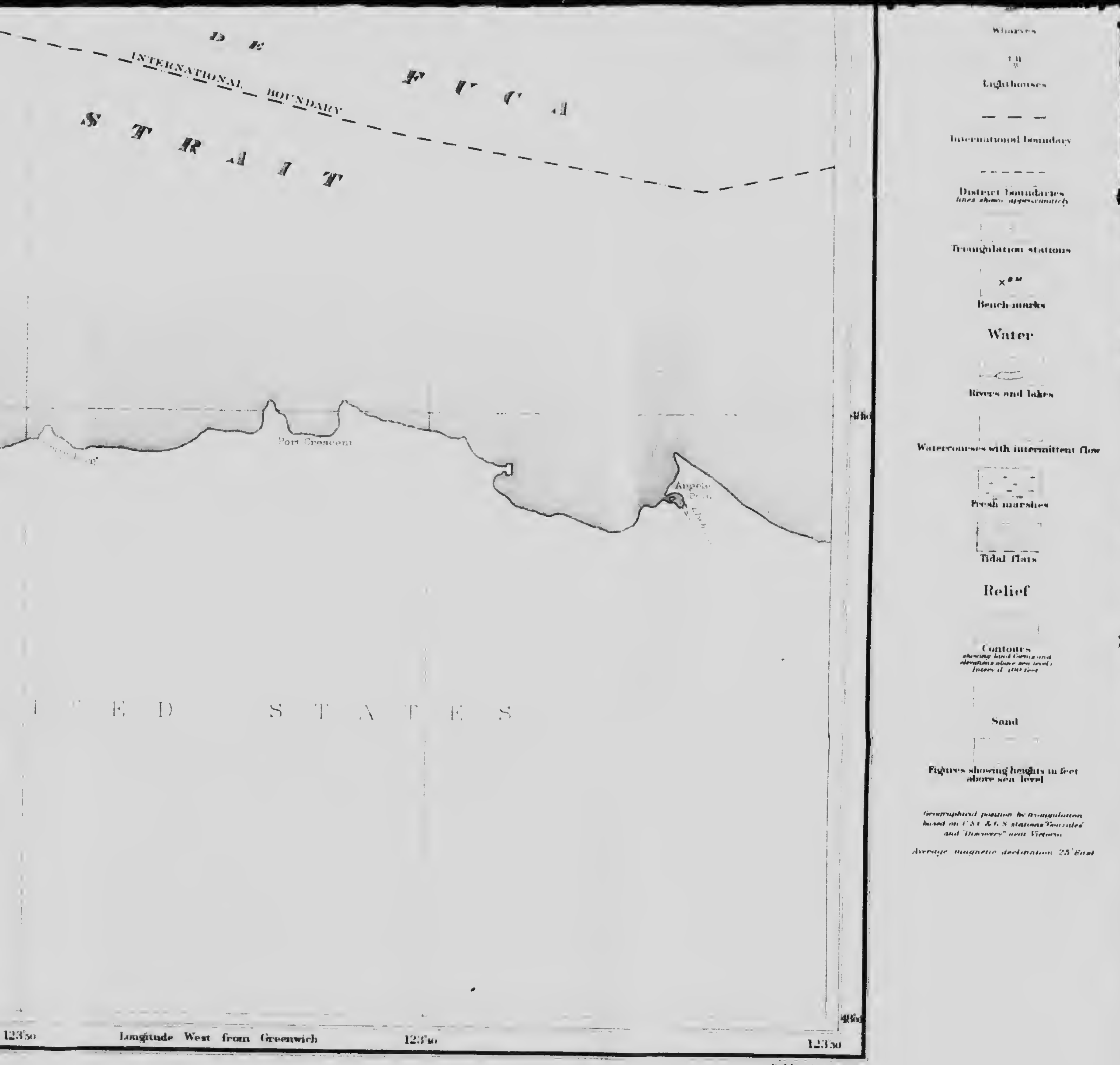
Prospects

Wharves

Lighthouses



C.O. Senécal, Geographer and Chief Draughtsman
G.G. Aitken and A.M'Gregor, Draughtsmen.



Publication Nº 1194

MAP 44A
(Issued 1918)

SOOKE SHEET

VANCOUVER ISLAND

BRITISH COLUMBIA

Scale, $\frac{1}{125,000}$

Miles

Kilometres

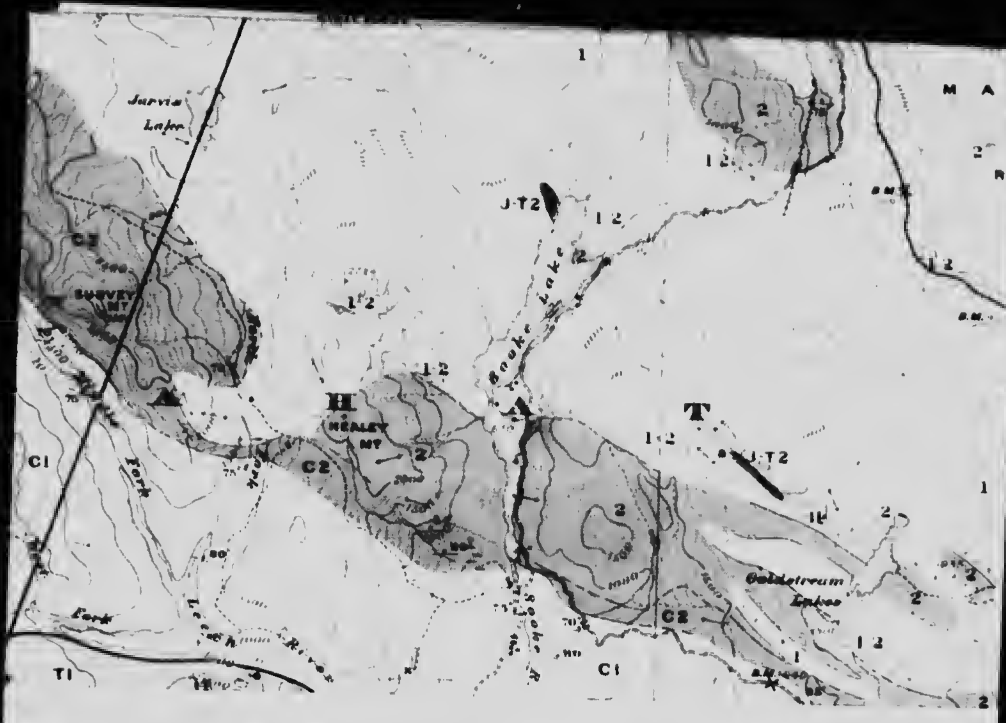
Note For practical purposes assume
2 MILES TO 1 INCH

GEOLOGY

C.H CLAPP	1912 1913

TOPOGRAPHY

R H CHAPMAN (IN CHARGE	1910
K G CHIPMAN.	1910
S C McLEAN, (TRIANGULATION	1909



Longitude West from Greenwich 123°10'

MAP 42 A
(Issued 1918)

DUNCAN SHEET

VANCOUVER ISLAND

BRITISH COLUMBIA

G

C H CLAPP
W L UGLOW
H C COOKE

TO

R H CHAPMAN,(I
K G CHIPMAN,
S C McLEAN,(TR

Scale $\frac{1}{125,000}$

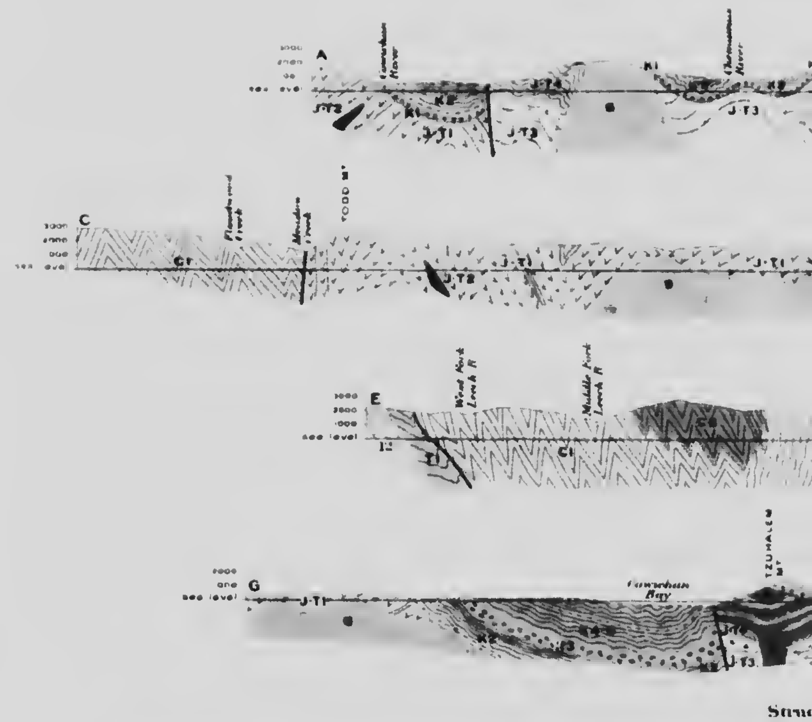
Miles

0 1 2 3 4 5 6 7

Kilometres

0 1 2 3 4 5 6 7 8 9 10 11

Note. For practical purposes assume
2 MILES TO 1 INCH



LEGEND

TERTIARY

UPPER EOCENE

LOWER OLIGOCENE

SOOKE INTRUSIVES

T4 Granite *stocks*

T1 Metchosin Volcanics *basalt and diabase*

UPPER CRETACEOUS

NANAIMO SERIES

K9 Gabriola formation *chiefly sandstone*

Northumberland formation *conglomerate sandstone and shale*

K7 De Courcy formation *chiefly sandstone*

K6 Cedar District formation *chiefly shale*

K4-6 Duncan formation

K5 Protection formation

Ganges formation

K3 Extension formation

K2 Haslam formation

K1

Symbols

Geological boundary *position determined*

Geological boundary *probable error of location less than 250 feet*

Geological boundary *probable error of location less than 1500 feet*

Geological boundary *position assumed*

Fault *probable error of location less than 250 feet*

Fault

Probable fault

Dip of fault

Downthrow side of fault

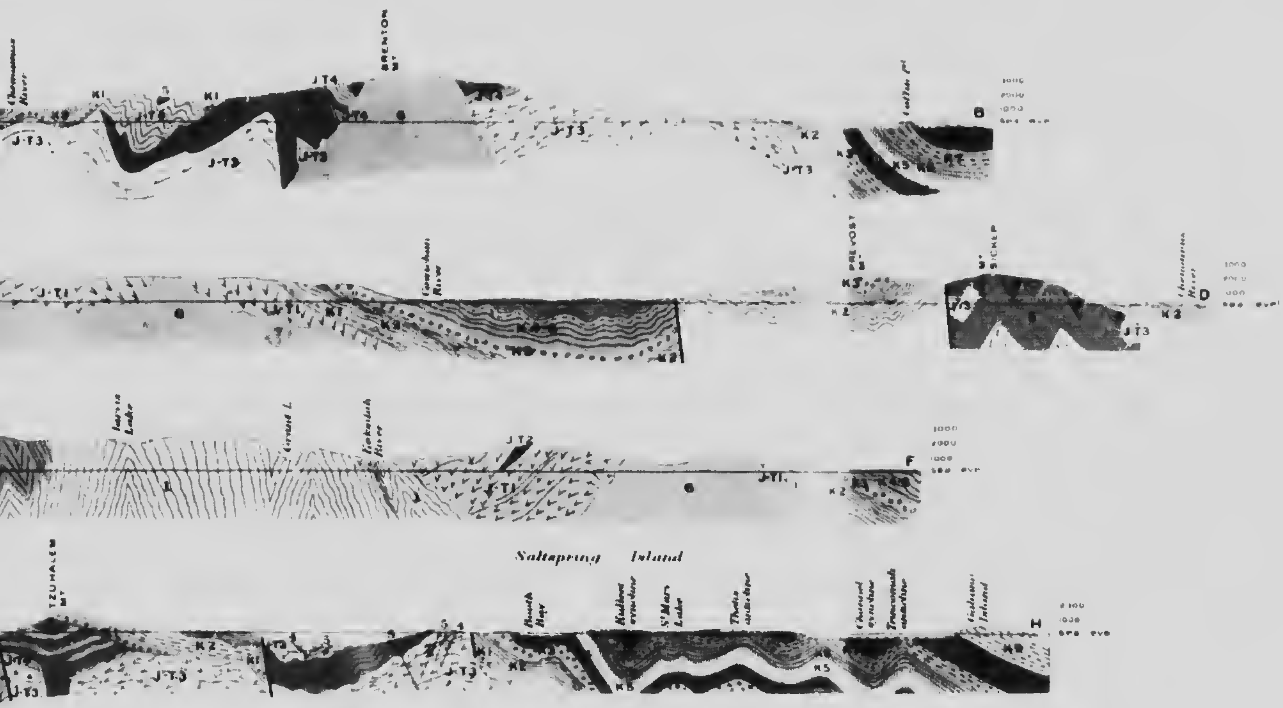
Upthrow side of fault

Canada
Department of Mines

Hon. Martin Burrell, Minister; R. G. McConnell, Deputy Minister

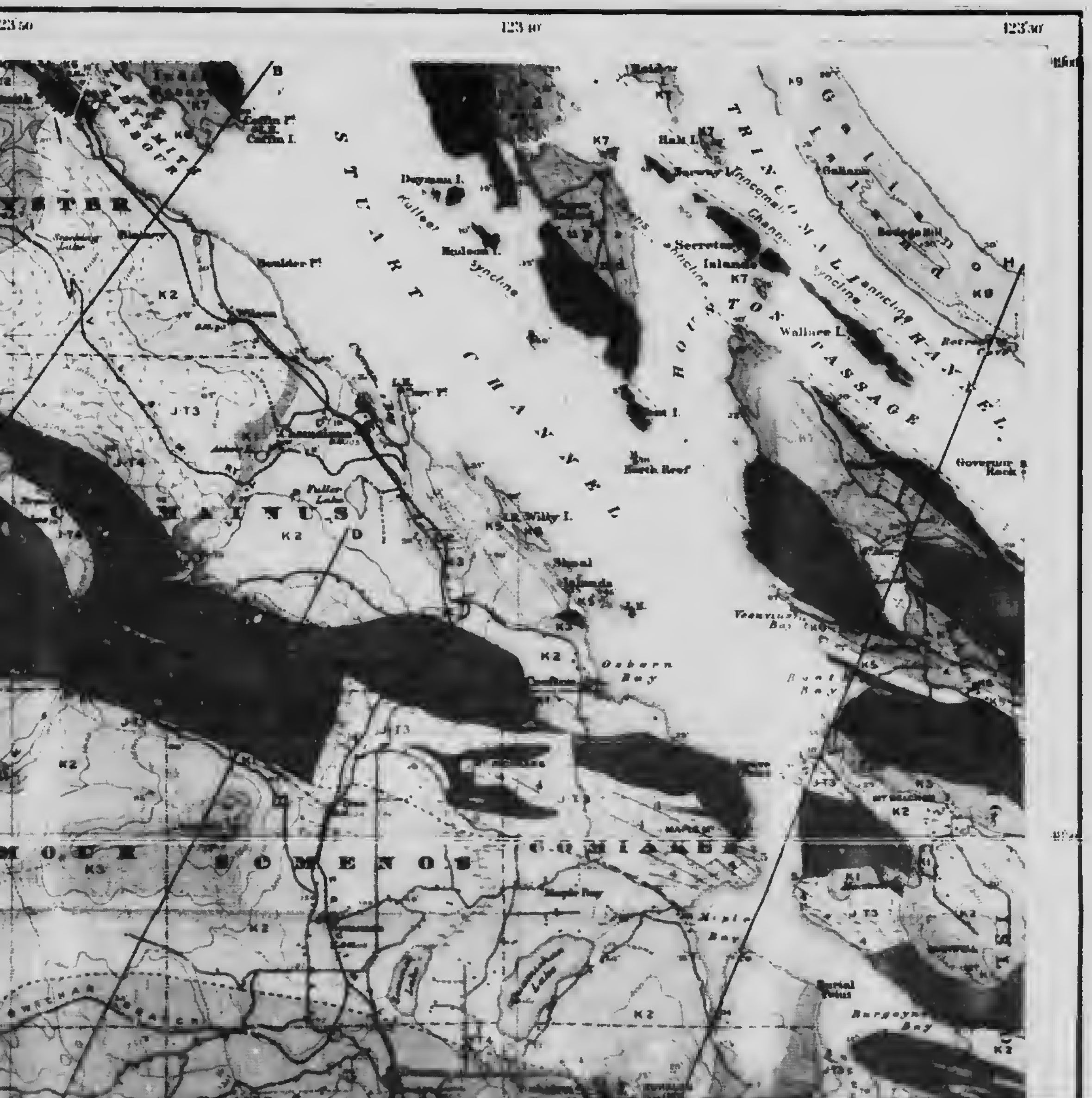
GEOLOGICAL SURVEY

William McInnes, Directing Geologist



Structural sections along lines A-B, C-D, E-F, G-H.

Scale: horizontal and vertical, 1/48,000



LEGEND

Culture

Streets, roads and buildings

Private roads, or roads not well defined

Trails

Railways

Tramways

Aerial tramways

Bridges

Churches

Schools

Offices

Mines

Prospects

Dams

MESOZOIC

DOUBTFULLY UPPER JURASSIC OR LOWER CRETACEOUS

UPPER JURASSIC AND POSSIBLY LOWER CRETACEOUS

LOWER AND MIDDLE JURASSIC

LOWER JURASSIC AND PROBABLY UPPER TRIASSIC (MAY INCLUDE SOME PALÆOZOIC LIMESTONES)

PALÆOZOIC

CARBONIFEROUS

SICKER SERIES

VANCOUVER GROUP

K8 — Nanaimo formation (shale and sandstone)

Benson formation (basal conglomerate and arkose)

11 — Hornblende-augite Andesite Porphyrite (dykes)

10 — Gabbro (dykes)

7 — Granodiorite Porphyrite (dykes)

Saanich Granodiorite

Sicker Gabbro-diorite Porphyrite (masses, sills and dykes)

Tyee Quartz-feldspar Porphyrite (masses, sills and dykes)

Colquitz Granite Gneiss (stocks)

Colquitz Quartz Diorite Gneiss (batholiths, stocks, apophyses and dykes)

Wark Gabbro-diorite Gneiss

Complex of Wark and Colquitz Gneisses

J-T4 — Sicker Sediments (tuff, cherty tuff and slate)

J-T3 — Sicker Volcanics (hornblende-augite andesite)

Sutton formation (crystalline limestone)

Vancouver Volcanics (andesite and basalt flows and pyroclastic rocks, tuff breccia and cherty tuff)

Malahat Volcanics (andesite dacite tuff breccia, tufaceous argillite and chert)

C1 — Leech River formation (slate and quartzose schist)

Dip and strike

General dip and strike

Vertical strata

Horizontal strata

Anticline and anticlinal axis

Syncline and synclinal axis

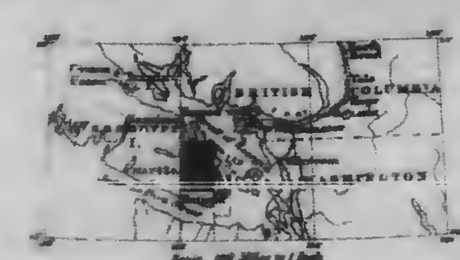
Foliation, dip and strike

Foliation, dip unknown or nearly vertical

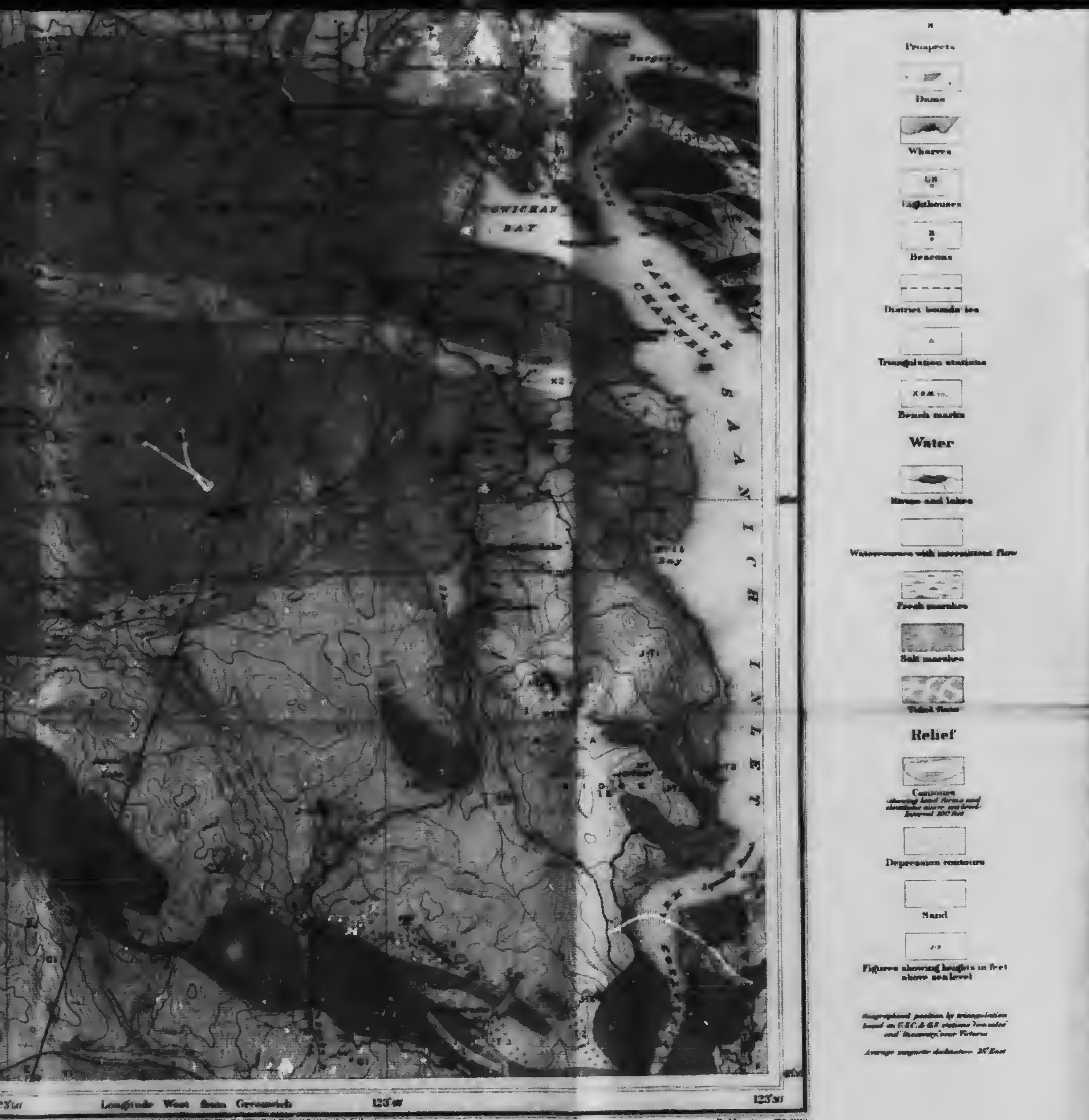
Fossil locality

Glacial striae

C.O. Senécal, Geographer and Chief Draughtsman.
G.G. Aitken, and A. McGregor, Draughtsmen.



To accompany Memoir by C.H. Clapp



MAP 42 A

DUNCAN SHEET

VANCOUVER ISLAND

BRITISH COLUMBIA

Scale, 1/125000

Miles

Kilometres

Note. For practical purposes assume
2 MILES TO 1 INCH

GEOLOGY

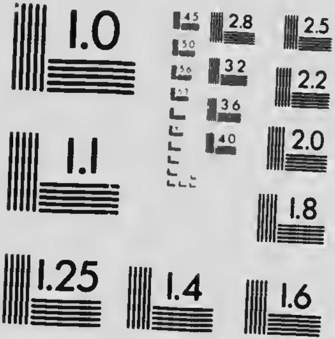
C. H. CLAPP.	1912 1913
W. L. UGLOW.	1912
H. C. COOKE.	1913

TOPOGRAPHY

R. H. CHAPMAN (IN CHARGE)	1910
K. G. CHIPMAN.	1910.
S. C. McLEAN (TRIANGULATION)	1909

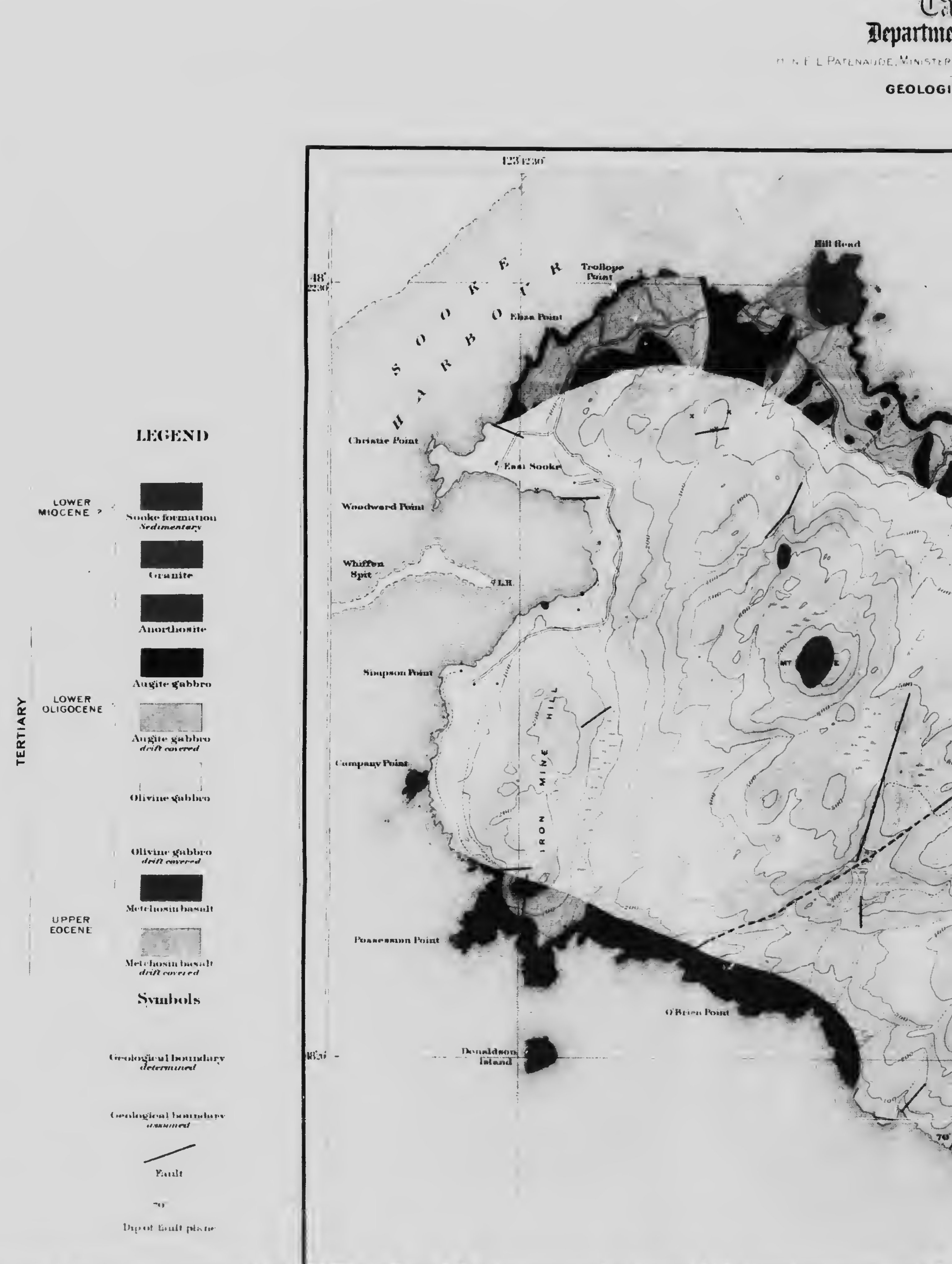
MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc

1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

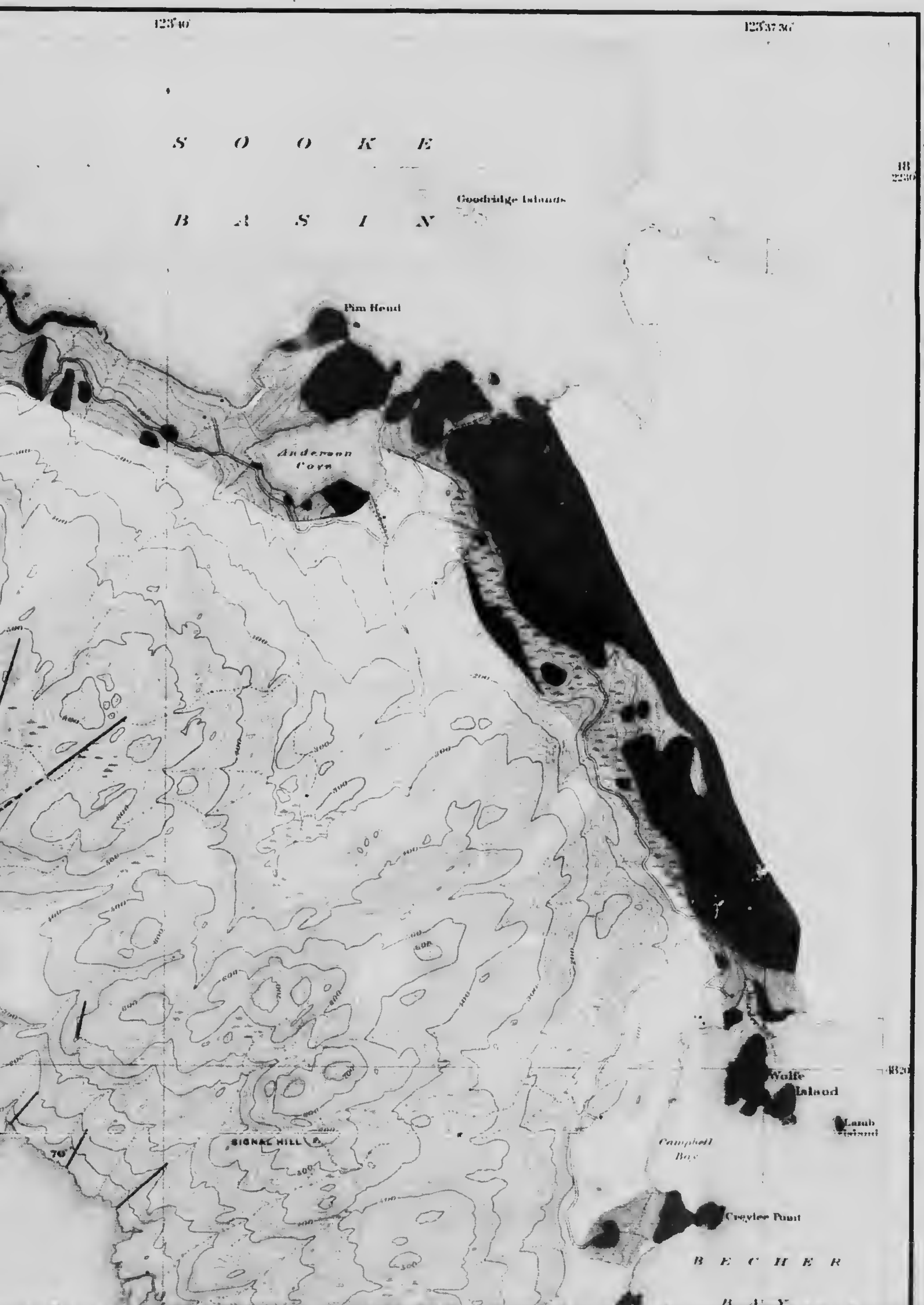


LEGEND
LOWER MIOCENE ?
Sooke formation
Sedimentary
Granite
Anorthosite
Augite gabbro
Augite gabbro
drift covered
Olivine gabbro
Olivine gabbro
drift covered
Metchosin basalt
Metchosin basalt
drift covered
TERTIARY
LOWER OLIGOCENE
UPPER EOCENE
Symbols
Geological boundary
determined
Geological boundary
assumed
Fault
70°
Dip of fault plane
SOOKE HARBOR
Trollope Point
Hill Head
Ella Point
Christie Point
East Sooke
Woodward Point
Whiffen Spit
L.H.
Simpson Point
Company Point
IRON MINE HILL
Possession Point
O'Brien Point
Donaldson Island

Canada
partment of Mines

Minister, R.G.M ... Deputy Minister

SEOLOGICAL SURVEY



LEGEND

Culture

Roads and buildings

Roads
not well defined

Trails

Schools

Post Offices

Shafts

Prospects

Wharves

Lighthouses

Triangulation stations

Water

Streams

Watercourses
with intermittent flow

Fresh marshes

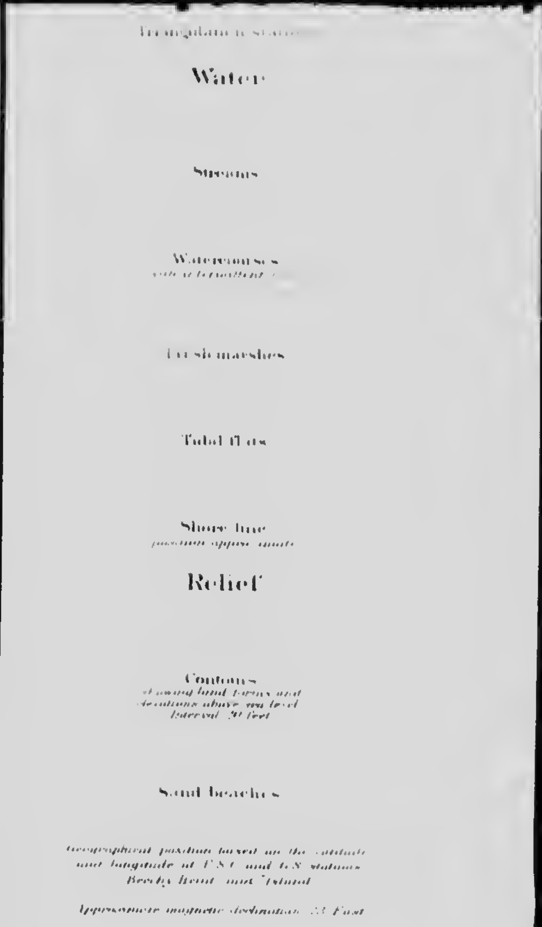
Tidal flats

Shore line
position approximate

Relief

Contours

Metchosin basalt
UPPER EOCENE
Metchosin basalt drift covered
Symbols
Geological boundary determined
Geological boundary assumed
Fault
70
Dip of fault plane
Possession Point
O'Brien Point
Donaldson Island
J U A N DE F
Longitude West from Greenwich
C.O. Senecal Geographer and Chief Draughtsman
S.G. Alexander and A.S. Jost, Draughtsmen
BRITISH COLUMBIA
Victoria
Scale: 100 Miles to 1 Inch
EAST
VANCOUV
BRITISH
Scal
2000 FE
To accompany Memoir by C.H. Clapp



MAP 167A
Issued 1917

AST SOOKE
NCOUVER ISLAND
BRITISH COLUMBIA

Scale $\frac{1}{24,000}$

2000 FEET TO 1 INCH

GEOLOGY
H C COOKE 1913

TOPOGRAPHY
F S FALCONER 1913