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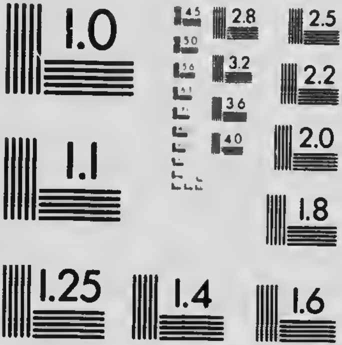

CANADA

DEPARTMENT OF MINES

GEOLOGICAL SURVEY BRANCH

Hon. W. Templeman, Minister; A. P. Low, Deputy Minister;
R. W. Brock, Director.

MEMOIR No. 13

SOUTHERN VANCOUVER ISLAND

BY

CHARLES H. CLAPP

OTTAWA
GOVERNMENT PRINTING BUREAU
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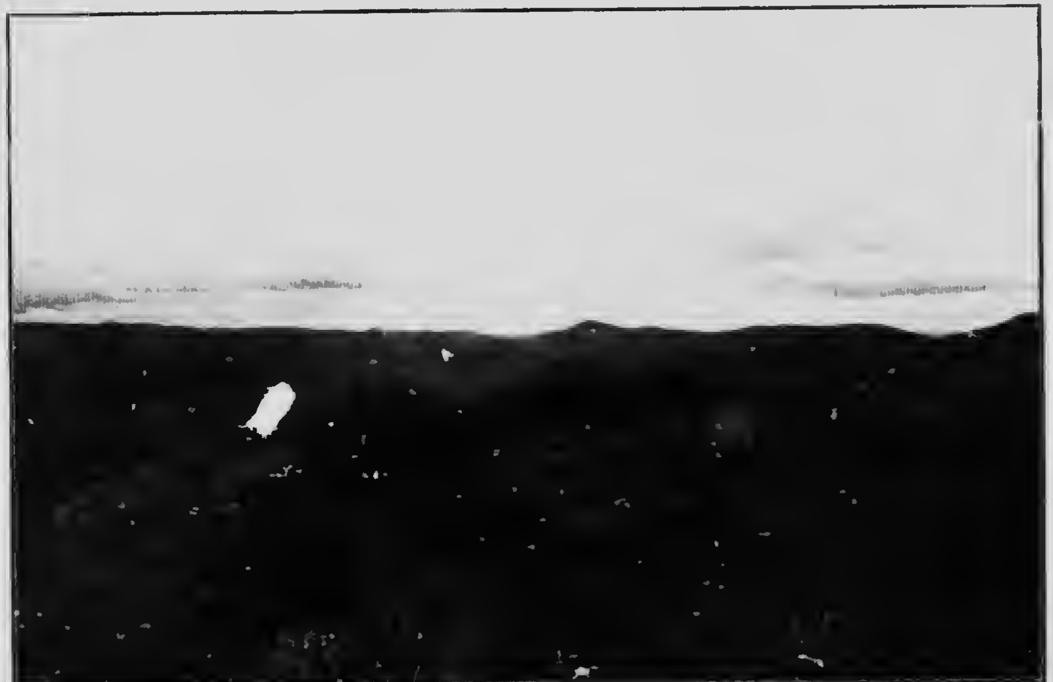
PLATE I.



Southern portion of the central belt of the upland of southern Vancouver island, showing Tertiary peneplain with few, and relatively low monadnocks. Southern part of Malahat district, looking northwest.

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No. 1121

LETTER OF TRANSMITTAL.

To R. W. Brock, Esq.,
Director Geological Survey,
Department of Mines, Ottawa.

Sir,—I beg to submit the following preliminary report on southern Vancouver island.

I have the honour to be, sir,
Your obedient servant.

(Signed) **Charles H. Clapp.**

April 14, 1911.

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PRELIMINARY REPORT

ON

SOUTHERN VANCOUVER ISLAND

BY

CHARLES H. CLAPP

INTRODUCTORY.

GENERAL STATEMENT AND ACKNOWLEDGMENTS.

The southern part of Vancouver island, which is described in this report is for the larger part mountainous and heavily wooded. In the extreme southeastern portion and along the east coast the general elevation is very much lower, and a large part of the timber has been cut and the cleared land cultivated. Outside of this portion, and beyond the general routes of travel, little indeed is known of the topography and mineral resources of this great island. Besides the coal deposits in the Cretaceous measures of the east coast, the mineral deposits occurring in the crystalline rocks are of considerable commercial interest. Although the nature and general extent of the coal measures have long been known, little is known, and less has been published concerning the older crystalline rocks.

A geological examination was begun by the writer in 1908, and was continued in 1909 and 1910. Reconnaissances have been made over the entire southern part of Vancouver island, and detailed work has been done in the southeastern portion. The object of this report, which is based chiefly on the reconnaissances of 1908 and 1909, is to make available the material already collected. The report is preliminary in nature.

The writer is indebted to many of the 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. Especial acknowledgment is due to Mr.

W. J. Sutton, for many years geologist for the Wellington Collieries Company and now with their successors the Canadian Collieries (Dunsmuir) Company, who has given the writer much information and assistance. Much help has been given by the members of the geological department of the Massachusetts Institute of Technology. Professor R. A. Daly has been very kind in discussing the general geology of the region, and its relation to the geology of western North America; and the fossils collected at Cowichan lake were determined under the direction and with the assistance of Professor H. W. Shimer. The account of the topography was written under the supervision of Professor W. M. Davis, of Harvard University.

The report is based on the reconnaissances made in 1908 and 1909, corrected by the detailed work and short reconnaissances of 1910. During this time the southern part of Vancouver island, with the exception of the east coast north of Ladysmith, was explored. All the roads and principal rivers, also timber cruiser's and prospector's trails, were traversed, and short trips of a day or two were made from the main traverses. The coast line, and the shores of the principal lakes, notably Sooke, Shawnigan, Cowichan, and Nitinat lakes, were also examined.

The time spent in the field in 1908, was from July 1 to September 15; and in 1909, from June 22 to September 17. In 1910 a detailed examination of the Victoria and Saanich map areas was carried on from June to September, while the rest of the summer was spent applying the results of the detailed work to the former reconnaissances.

In 1908 the writer was assisted by Mr. K. G. Chipman. In 1909 the writer was associated with Mr. J. A. Allan, who, assisted by Mr. F. J. Barlow, spent two months on Saltspring island and on the east coast of Vancouver island, doing more detailed work. During the last month Mr. Allan made a reconnaissance across the island from Mount Brenton to Alberni. A traverse was also made by him up Franklin river to the headwaters, across the divide, and down China creek to the Alberni road; while Mr. Barlow made a traverse along the eastern end of the Beaufort range from Great Central lake to Horne lake. During 1910 the writer was assisted in the detailed work by Messrs. J. D. MacKenzie and Alexander G. Haultain. Mr. MacKenzie also made a short reconnaissance in the Malahat district.

AREA AND MEANS OF ACCESS.

The area described in this report includes that part of Vancouver island which is south of the Alberni-Nanaimo road, and east of the Alberni canal and Barkley sound; and also includes Saltspring island, and several smaller islands off the east coast of Vancouver island, in Haro straits. This area is approximately 4,000 square miles.

Much of the southeastern and eastern part of the region is accessible by road. In the vicinity of Victoria, on the Saanich peninsula, and along the east coast north of Cowichan bay, the country is well settled, and there are many good roads. Main roads extend from Victoria west to East Sooke and Jordan river, and northwest by way of Sooke and Shawnigan lakes to Duncan. There is a stage road from Duncan to Cowichan lake, and another from Nanaimo to Alberni. There are two railroads in the area, the Victoria and Sydney, and the Esquimalt and Nanaimo. The former is located on the Saanich peninsula, while the latter follows the east coast as far north as Nanoose. At the present time an extension is being built across the island to Alberni. Other extensions and new railroads and tramways are projected, to open up the interior of the island.

At present the inlets and lakes, a few of the rivers, and the Cowichan lake and Alberni roads furnish ready access to the interior of the island, and no very long packing trips need be made. Such trips at the present time must be made without the aid of pack animals, as the trails are not numerous, and with two or three exceptions are suitable only for men. Even these trials, when well located and cleared of brush, are of the greatest assistance, for on them seven or eight miles may be readily travelled in a day by one carrying a heavy pack; while without a trail three miles is often the limit which it is possible to travel in a day, with the hardest sort of muscular work. The establishment of more trails is, therefore, of the greatest importance, and would fill a most urgent need.

A large part of the shore may be safely traversed in a small boat. Coasting steamers run between Victoria and ports on both the east and west coasts.

Previous work.—Little work of a general and correlative nature has been done in the southeastern part of Vancouver island. The first geological work of any great value was that of Dr. A. C. Selwyn and Mr. James Richardson, who explored the eastern coast of the island in 1871. The results of their work was published in the Report of Progress of the Geological Survey of Canada for 1871-72. They gave brief notes of value, but made no generalizations. Mr. Richardson continued work on the coal areas of the island for four years. A final summary of his work is given in the Report of Progress, 1876 77, pages 160-192, and is accompanied by a map.

In April, 1876, Dr. G. M. Dawson made a reconnaissance of Leech river and vicinity, paying especial attention to the origin and extent of the placer deposits. The result of his work in the southern part of the island is given in the Report of Progress, 1876-77, pages 95-102, and in several papers published on the physical, glacial and general geology of British Columbia.

In 1885, Dr. Dawson made an examination of the northern part of Vancouver island, and in the 1886 report of the Geological Survey, pages 1 B-107 B, made the most valuable of the published contributions to the geology of the island.

In the summer of 1902 Messrs. Webster and Haycock made a cursory examination of the west coast of the island. Their report is published in the Summary Report of the Geological Survey for 1902, pages 54-92.

In 1905, Dr. H. S. Poole visited Vancouver island to collect data on the coal deposits of the eastern coast. A summary of his work, chiefly of commercial interest, is given in the Summary Report of the Geological Survey for 1905, pages 55-59.

The palaeontology of the Cretaceous rocks has been very fully described by Dr. J. F. Whiteaves in volume I, Mesozoic Fossils, published by the Geological Survey, Part II in 1879, and Part V in 1903, and in other papers. Meek, White, and Woodward have also published papers concerning the palaeontology of the Cretaceous rocks. Professor J. C. Merriam has described fossils collected from the Tertiary formations of the west coast of Vancouver island, and has published his conclusions in the Bulletin of the University of California, Department of Geology, Vol. 2, 1896, pp. 101-108, and in two other papers.

Detailed notes of value on certain mineral claims, mining districts, and mineral industries have been made by the provincial mineralogist, Mr. W. F. Robertson, and by the provincial assayer.

Mr. Herbert Carmichael, in the reports of the Minister of Mines of British Columbia. Mr. E. Lindeman examined the iron deposits of Vancouver island for the Mines Branch of the Department of Mines, in 1907. His results are published in the Summary Report of the Mines Branch for 1907-8, pages 5 to 13, and in Publication No. 17 of the Mines Branch, 1910.

Several short magazine articles have been published on the mining districts and mineral industries of the island, the most valuable of which have been listed in the bibliography. More or less private and unpublished work has been done notably by Mr. W. J. Sutton.

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SUMMARY AND CONCLUSIONS.

GENERAL GEOLOGY.

The slaty and schistose rocks of the Leech River formation are apparently the oldest rocks of southern Vancouver island. They form a broad belt, with an average width of about five miles, which extends from near the east coast of the island to the west coast, in the vicinity of Port San Juan. They have been close folded, so that at present they have nearly parallel strikes, about N 85° W, and steep dips, chiefly to the north. They are presumably of marine origin, and are correlated with the group of slaty rocks, widely distributed in the Pacific Coast region, which are considered to be Carboniferous in age; forming in the interior of British Columbia the lower part of the Cache Creek group.

Apparently unconformable upon the Leech River formation, although separated from it largely by faults, are rocks of lower Mesozoic age, the Vancouver group. The Vancouver group has been subdivided into the Nitinat formation, the Vancouver volcanics, the Sutton formation, the Sicker series and the Metchosin volcanics. The Nitinat formation, which underlies a broad belt in the southwestern part of the island, consists of metamorphic calcareous rocks, chiefly marbles and amphibolites. They appear to be conformable with the other members of the Vancouver group, but are not definitely Mesozoic in age, and may be Palæozoic; if so, they are best correlated with the upper part of the Cache Creek group. The Vancouver volcanics, which compose the greater part of the Vancouver group, and which are the main rocks of Vancouver island, underlying a wide central axis, are chiefly metamorphic andesites, and include both flow and fragmental types. With them are associated dacite tuffs, and intrusive dykes and sills of andesite and basalt porphyrites. The Sutton formation consists of intercalations of crystalline limestones in the Vancouver volcanics. It is shown by its included fauna to be of marine origin, and in part definitely lowermost Jurassic in age; so that the Vancouver volcanics, presumably accumulated largely under submarine conditions, although some of the vents were probably above sea-level, are in part of lowermost Jurassic age also. It is probable, however, that the Vancouver volcanics include some Triassic members. The Sicker series consists of metamorphic, and chiefly schistose, sedimentary and volcanic rocks, with intrusive acid and basic porphyrites, the surface members of which are conformable with the Vancouver volcanics. They form a wide axis in the central part of the island, possibly extending from the east coast to near Alberni; although they have been mapped only for about one-half that distance. The Metchosin volcanics underlie a broad belt, 5 to 7 miles wide, along the southwestern coast of the island, separated from the rest of the members of the Vancouver group by the Leech River formation. They are composed of ophitic basalt flows, tuffs and agglomerates, with intrusive diabase dykes, and are less metamorphosed than the rest of the Vancouver group; and are, therefore, placed in a group with considerable uncertainty. Apparently they have been formed under conditions similar to those of the Vancouver volcanics.

The rocks of the Vancouver group, with the possible exception of the Metchosin volcanics, were greatly deformed during the upper Jurassic period of folding and faulting, the axes of folding and faulting being in general parallel with the strike of the island, in the southern part about N 65° W. Following the deformation, and perhaps during it, they were invaded and partly replaced by batholithic and 'minor' intrusives, especially along two main axes, a southern and a northern, separated by a wide area in the central part of the island in which few granitic rocks are exposed. It is probable that all the intrusive rocks were erupted during one general period of intrusion, but in detail they may be subdivided into three main and two minor types, which were erupted in a definite sequence. The three main batholithic types are, in the probable order of their eruption, Wark diorite and quartz diorite gneisses, Beale diorite, and Saanich granodiorite and quartz diorite. The two minor types are, a phase of 'minor intrusions,' that is, dykes and small intrusive bodies of acid and basic porphyrites, and Sooke gabbro. The 'minor intrusions' are in part younger than the Saanich granodiorite; and it is probable that the porphyrites of the Sicker series, referred to above, are related to these 'minor intrusions.' The Sooke gabbro, which consists of gabbros and anorthosites, with gabbro porphyrite and diabase dykes, is intrusive into the Metchosin volcanics, forming a main stock on East Sooke peninsula, and three other smaller stocks. The Wark gneiss, which is the oldest batholithic type, was probably erupted during the deformation, since it is gneissic. It consists of two sub-types, diorite-gneiss, and later, intrusive quartz diorite gneiss; but the two sub-types form virtually a single batholith, in the southeastern part of the island. The gneisses have been contact metamorphosed, presumably by the younger Saanich granodiorite, and more or less recrystallized, developing in the quartz diorite gneiss, quartz-feldspar (salic) and complementary hornblendite (femic) facies, which occur interbanded. The Beale diorite is closely associated with the Saanich granodiorite batholiths intrusive into the Nitinat formation, and is restricted to the periphery of the granodiorite batholiths. It occurs, however, in large masses, and is brecciated by the granodiorite, and was, therefore, probably intruded separately. The Saanich granodiorite or quartz diorite is the principal batholithic rock, and is widely distributed along the two main axes in relatively small but numerous batholiths. The minor intrusions are more or less restricted to the contacts of the Saanich granodiorite and the rocks of the Vancouver group. It is suggested that the small but numerous exposed batholiths are protuberances or 'cupolas' of one or more much larger Coast-Range-like batholiths. The Sooke gabbro cannot be definitely correlated with the other intrusives, but was probably intruded soon after the deformation of the Metchosin volcanics, which, if the Metchosin volcanics are members of the Vancouver group, probably took place during the upper Jurassic period of folding and faulting.

Upon a subdued, but not smooth erosion surface, developed on the above mentioned rocks during a pre-upper Cretaceous erosion cycle, the upper formations of the Cowichan group, the Nanaimo and conformably overlying formations, were deposited in upper Cretaceous and possibly Eocene times. The lower portion of the Cowichan group contains a formation lithologically identical with the Nanaimo formation, but unconformably underlying it, and apparently conformable with and transitional into the sedimentary members of the Sicker series. Presumably, therefore, the lower portion of the Cowichan group is of Triassic or more probably Jurassic age. In mapping, the various formations of the Cowichan group, erected only for convenience in mapping and description, are not distinguished. The Cowichan group occurs in three principal basins in the northeastern part of southern Vancouver island—the Comox, Nanaimo, and Cowichan basins; and in three smaller basins—one at Alberni and the others in the upper parts, respectively, of Chemainus and Kokasilah valleys. The rocks of the Cowichan group are chiefly conglomerates, sandstones, and sandy shales, and near the base of the Nanaimo formation coal is found, and in the Nanaimo and Comox basins in commercial quantities. The rocks of the Nanaimo formation were deposited under marine conditions, in the down warped basin between Vancouver island and the mainland. The marine conditions alternated with those of brackish water, and were apparently replaced in time by terrestrial conditions, when the unfossiliferous overlying formations were deposited. The rocks of the Cowichan group were deformed, probably during the Laramide revolution, those of the Comox basin and northern part of the Nanaimo basin into open folds with minor faults, and those of the southern Nanaimo basin and Cowichan basin into closed folds, overturned to the southwest, and in the Cowichan basin with overthrust faults. The axes of the open folds correspond with that of the island, while those of the closed and overturned folds strike about N 70° W. Since the folds were overturned to the southwest, the forces producing the folding must have acted from the northeast, probably having their origin below the basin between Vancouver island and the mainland.

The erosion cycle initiated by the deformation of the Cowichan group greatly subdued all the deformed rocks, developing by late Tertiary time a peneplain in the central and southern part of southern Vancouver island, while the northern part retained considerable relief, with numerous and large monadnocks and divide residuals. During the erosion cycle, a coastal plain of coarse detritus—the present Carmanah and Sooke formations—was built up along the southwest coast, probably against a submerged mountainous slope, chiefly in Oligocene and Miocene times. The Carmanah and Sooke formations were uplifted, but not greatly folded, although they were broken by numerous, but small, normal faults, in late Teritiary and early Pleistocene time; at which time the subdued Tertiary erosion surface developed on the hard rocks was also uplifted. The uplifted surface was maturely dissected before the Glacial period, and the areas along the east and west coasts underlain by the relatively soft sedimentary rocks of the Cowichan group and of the Carmanah and Sooke formations, as well as the extreme southeastern portion of the island, were reduced to lowlands.

During the Glacial period Vancouver island was covered by an ice cap, and valley glaciers filled the larger valleys, scouring them out, and converting them into fiords and glacial troughs in which lakes have formed. The resulting glacial till now remains on the upland, somewhat modified by sliding on the steep slopes, but in the larger valleys and on the coast lowlands, stratified deposits consisting largely of glacial detritus occur, deposited 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 eroded and covered with later glacial till.

A recent uplift of some 250 feet has taken place, bringing the coastal lowlands with their covering of stratified deposits, largely of marine origin, 200 to 300 feet above the present sea-level. With the uplift the larger streams which had previously developed flood plains revived and the present marine cycle was initiated, during which the stratified deposits have been sub-maturely retrograded, while the portion of the coast composed of the hard, underlying rocks is in a very youthful stage.

ECONOMIC GEOLOGY.

The mineral resources of southern Vancouver island include deposits valuable, or possibly valuable, for gold, copper, iron, fuels, fluxes, lime and cement, pigment, clay, sand and gravel, and stone. Coal has been the chief source of mineral wealth, and copper and some gold have also been commercially produced. Lime, cement, clay, sand and gravel, and crushed stone, as well as coal are being produced at present.

Gold occurs in the gravels of a large number of the streams of southern Vancouver island, but with two or three exceptions, the principal deposits all occur in the streams which drain the area underlain by the Leech River slates, and have been derived from very low grade quartz veins in that formation. The gold-bearing gravels are usually of fair grade, but are not very abundant. A large accumulation of gravel at the old mouth of Lost river and near the mouth of the present Sombrio river, is being exploited at present. Mineralized shear zones occur throughout the rocks of the Vancouver group, and although they are usually more important as possible sources of copper, they also carry small amounts of gold.

The copper deposits of southern Vancouver island are all more or less closely connected with the igneous rocks erupted during the upper Jurassic period of batholithic and dyke intrusion. They may be subdivided into three main types,—contact deposits, impregnated and replaced shear zones with accompanying quartz veins, under which is the special Sooke type, occurring in the shear zones of the Sooke gabbro, and lastly the Tyee type, a large lens of ore which was formed in a syncline in the Sicker schists of Mount Sicker. The contact deposits, which are developed chiefly in metamorphic limestones near their contacts with intrusive igneous rocks, are the more numerous. They are, as a rule, small, irregular, and of low grade, but some of them are of considerable economic interest. The deposits occurring in shear zones are of little importance, with the exception of the special Sooke type, which is of great prospective interest. The Tyee deposit, now largely worked out, is the only deposit from which there has been a commercial production.

The iron ore deposits are of four types, contact deposits, impregnated schists, replacement or segregation deposits in the Sooke gabbro, and bog ore deposits. The contact deposits are by far the most important; and consist of bodies of magnetite, which have been formed in the metamorphosed Nitinat limestones, near the intrusive Beale diorite. The bodies are large, and low in phosphorus, but high in sulphur. The chief deposits occur in the valleys of Gordan river and its tributary, Bugaboo creek. The impregnated schists occur in the Sicker series. The mineral-bearing rocks are dark red, jaspery schists, with 10 to 15 per cent of magnetite. Since the magnetite can be easily concentrated they are of prospective importance. The other two types are apparently of no value.

Coal is the source of a very important industry on the east coast: the coal being obtained near the base of the Nanaimo formation in the Comox basin, and in the northern part of the Nanaimo basin, from 600 to 1,500 feet above the base. These coal deposits have not been examined during the present investigation. Coal of commercial value is apparently absent from the other basins of the Cowichan group, and is almost certainly absent from the Tertiary sediments of the west coast. These sediments have also been prospected for oil, but the conditions for the accumulation of oil do not seem to be favourable.

The crystalline limestones of the Nitinat and Sutton formations furnish excellent and ample material for flux, and for the manufacture of lime and cement. Cement is manufactured in the southeastern part of the island by the Vancouver Portland Cement Company, and lime is burned by several manufacturers also in the southeastern portion of the island.

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

There are two types of clay deposits in southern Vancouver island, the shales of the Nanaimo formation and the clays of the stratified superficial deposits. The greater part of the shales of the Nanaimo formation are sandy and impure, but associated with the coal in the Nanaimo and Comox basins are thin, lens-like beds of clay-shale. This shale is mined by the coal companies and used by the British Columbia Pottery Company at Victoria, where it is mixed with the clays of the superficial deposits, for the manufacture chiefly of sewer pipe. The clays of the stratified superficial deposits are used for the manufacture of common bricks and drain tiles, at Victoria, Sidney, Sidney island, and Somenos.

Sand and gravel also are obtained from the stratified, superficial deposits of southeastern Vancouver island.

The fractured and sheared character of the rocks renders most of them unfit for building stones. In rare instances the marbles may be of value, and some of the dark granites (granodiorites) exposed near Alberni canal would doubtless make good building stone. The sandstones of the Cowichan group, especially of the Nanaimo and Comox basins, offer excellent material for stone of that kind.

The traps, especially those of the Metchosin volcanics, offer abundant material for an excellent quality of crushed stone. The Metchosin volcanics are quarried at Albert head, in Esquimalt district, by the British Columbia Trap Rock Company.

GENERAL CHARACTER OF THE DISTRICT.

TOPOGRAPHY.

General Account.—Regional.—Vancouver island is a mountain range, characterized by both flat-topped and ridge-like summits, and is the result of the mature dissection of an uplifted, subdued surface formed during a Tertiary erosion cycle acting on a heterogeneous group of deformed rocks. It lies to the west of the great marginal depression of North America, known as the Pacific Coast downfold,[1] and is one of the border ranges which characterize the western shore of the American continents. The Pacific Coast downfold extends from the gulf of California to north of the Queen Charlotte islands. This downfold is in part above sea-level in California, Oregon, and Washington, but both the southern and northern ends are submerged. The submerged northern end forms the sound region separating Vancouver island and the Queen Charlotte islands from the mainland. The downfold is flanked on either side by great mountain ranges. Those on the east side are the Sierra Nevada of California, the Cascade range of Oregon and Washington, and the Coast range of British Columbia; those on the west are the Coast range of California, the Klamath mountains of Oregon, the Olympic mountains of Washington, the Vancouver range, and the low range of the Queen Charlotte islands. The last two ranges have been grouped by Dawson[2] and designated the Vancouver system.

The Vancouver range constitutes virtually the entire island, which is 290 miles long and 50 to 80 miles wide, the total area being about 20,000 square miles, or about the same as that of the province of Nova Scotia. The upwarped range and island trend N 55° W. This range is separated from the ranges of the mainland by Haro, Georgia, Johnstone, and Broughton straits, and Queen Charlotte sound; and from the Olympic mountains, which lie to the south, by the strait of Juan de Fuca.

The Tertiary erosion surface, the general outlines of which are now preserved on the upland of Vancouver island, had reached before uplift a stage varying from late maturity to old age. It was peneplained in the southern part where a few rounded, monadnock-like

[1] Bailey Willis, Tacoma Folio, No. 54, U.S. Geol. Survey, 1899.

[2] G. M. Dawson. Physiographical Geology of the Rocky Mountain Region in Canada. Proc. Can. Royal Soc. Vol. 8, Sec. 4, p. 4, 1890.

PLATE II.

Southern belt of the upland of southern Vancouver island, showing late mature dissection of the Tertiary peneplain, and a small glaciated north-south transverse valley. Lower Goldstream valley, looking south.

hills remained a few hundred feet above the general level. In the central region larger and higher monadnocks and small ranges of mountains—divide residuals—survived, which apparently had elevations of from 1,000 to 3,000 feet above the general Tertiary erosion level, and which are now from 5,000 to 7,000 feet above sea-level, a few peaks being even higher. The elevation of the Tertiary peneplain is at present less than 1,500 feet near the southern coast, but increases rapidly to 2,000 feet, and then increases more slowly until the peneplain merges into the more rolling and mountainous country which, as mentioned above, is characteristic of the central part of the island.

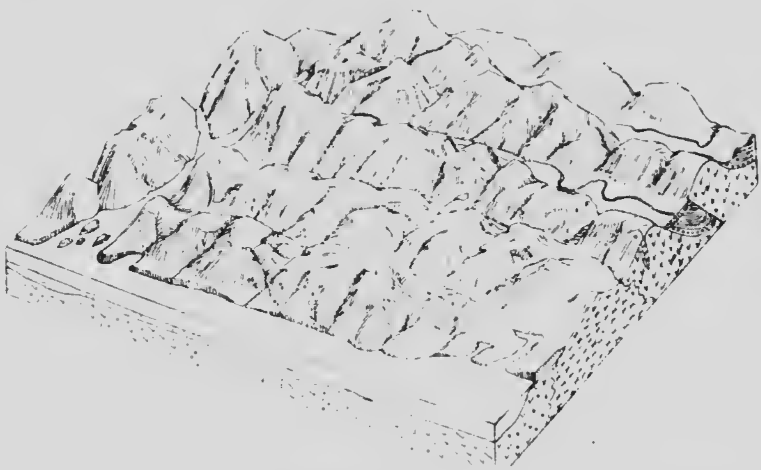


FIG. 1.—Block diagram, illustrating topography of southern Vancouver island.

The uplifted Tertiary erosion surface was maturely dissected during a pre-Glacial cycle by transverse rivers with large subsequent tributaries. Along the east coast are relatively narrow areas underlain by rocks softer than those forming the larger part of the island, which were, therefore, during the pre-Glacial cycle, reduced more nearly to base-level. Off the west coast in Tertiary time a coastal plain, which had been built up apparently against a submerged mountainous slope with bold promontories, and then uplifted with the rest of the island, was, after uplift, eroded nearly to base-level during the pre-Glacial cycle, thus exposing the mountainous slope against which the coastal plain sediments had been deposited.

It seems as if at some time following mature dissection of the uplifted peneplain, part of the region were depressed and formed the drowned coast of the southeastern portion of the island.

During the Glacial period the island was apparently smothered by a thick ice cap, and only mountains over 4,000 feet high escaped rounding, although in the southern part of the island, even those nearly 5,000 feet high were severely glaciated. Valley heads in the higher mountains were excavated by local glaciers, and the mountains now have characteristic serrated summits. Valley glaciers occupied and scoured out the larger valleys, converting many of the westward flowing valleys into fiords, and deepening many of the interior valleys into large lake basins.

It looks as if the relatively narrow strips of lowland, seldom more than one or two miles wide, occurring at intervals along the west coast, were in part uplifted marine platforms, since it is known that at a comparatively recent date an uplift of from 200 to 300 feet took place. Although along the southeastern coasts there are no conspicuous marine platforms, unconsolidated, stratified deposits in part of marine origin were uplifted, and have been sub-maturely retrograded during the present marine cycle, forming steep, wave-cut cliffs some 250 feet high.

Local.—In the southern part of Vancouver island the Tertiary cycle reached its most advanced development. In the south central portion of southern Vancouver island the peneplain must have been very smooth and the monadnocks few and comparatively low, because the present upland is occupied by marshes, swampy ponds and lakes. In the northern and western parts of the area occur the larger monadnocks, or residual mountains, and one of the irregular, small, residual ranges characteristic of the central part of the island. This range culminates at the west end in Mount Arrowsmith, a mountain with several rocky peaks, the highest of which is now nearly 6,000 feet above sea-level.

In the southern part of Vancouver island, except in the southeastern portion, the dissection of the Tertiary peneplain by the pre-Glacial cycle was similar to that characteristic of the rest of the island, that is mature. In the southeastern portion, although the region is largely underlain by crystalline rocks, the pre-Glacial cycle reached old age; so that a new surface of low relief was developed several hundred feet below the Tertiary peneplain, and is at present

PLATE III

Large glaciated monadnock of the northern half of the upland of southern Vancouver island. Mt. Grey, Barkley district, about 4,800 feet above sea level.

from 200 to 300 feet above sea-level. Surmounting this, from 100 to 800 feet, are relatively small, rounded monadnocks. It was upon this low-lying surface that the stratified drift was deposited, which has been rapidly retrograded by the present marine cycle, resulting in the steep cliffs, with their attendant sand spits, characteristic of much of the southeastern coast.

Detailed Account.—Upland.—The present upland of southern Vancouver island, which has been described as having been formed by the mature dissection of an uplifted, subdued, Tertiary erosion surface, may, for purposes of description, be divided into three belts, which have a general westerly, or somewhat north of westerly trend. Each belt has its more or less characteristic topographic features, which, however, merge into each other along the very indefinite boundaries of the three belts. The central belt, which is from 20 to 30 miles in width and virtually extends across the island, is characterized by a mature dissection of the Tertiary peneplain, which is well represented by interstream areas. The Tertiary peneplain was so well developed in the southern part of the belt, that the present upland, when viewed from one of the small, knob-like hills which surmount it, appears, except where interrupted by valleys smooth and gently rolling, with relatively few, isolated, rounded monadnocks, whose summits are only a few hundred feet above the general level, and many of which resemble low cones, with rounded apexes. In general the interstream areas are smooth and covered with drift which is partly glacial, but minor irregularities such as marshes and small lakes occur in drift-filled hollows between steep-sided rock ledges, 50 to 100 feet high. In the northwestern part of the central belt the Tertiary peneplain was not so well developed, so that the present upland has very much more relief, and the residual elevations are more numerous and larger, and may be as much as a thousand feet above the general level. The elevation of the Tertiary peneplain increases from 1,500 to 1,800 feet in the southern part of the belt to over 3,000 feet in the northern part.

The southernmost belt, which is from 5 to 10 miles in width, extends across the southeastern part of the island as far as the lowland in the extreme southeastern portion. It is characterized by a late-mature dissection of the Tertiary peneplain, so that now only flat-topped and ridge-like hills occur, with summits about a thousand feet above sea-level, and separated by numerous, rather irregularly patterned, deep valleys. In the northern belt, which in the western part is 20 to 25 miles wide, narrowing and pinching out to the east, a peneplain was not developed by the Tertiary cycle, for at the time of uplift there were, as already mentioned, numerous and large residuals, and residual divides; however, the two-cycle development of the present mountainous topography is occasionally shown. By two-cycle development it is meant that the present mountains owe their form to two erosion cycles, their summits being subdued as a result of the first cycle, while their sides are steep as a result of the less advanced second cycle. With the exception of a more or less continuous range which occurs along the northern side of the belt, the mountains are more or less isolated, being separated by wide, irregular valleys, which are at grade with the valleys of the central belt. The mountains are chiefly from 4,000 to 5,000 feet high. They are usually bold and rocky, often with steep slopes, but most of them are characterized by rounded rather than angular surfaces, having been glaciated by the ice cap which covered Vancouver island in the Glacial period. The highest mountains occur in the range above mentioned, a few of them having sharp and serrated summits and obscure cirques excavated by local mountain glaciers; of such a type is Mount Arrowsmith, which occurs at the west end of the range, and is the highest mountain in southern Vancouver island, towering for nearly 6,000 feet above the low valley at the head of Alberni canal.

Valleys.—Transverse.—The mature valleys which dissect the uplifted Tertiary erosion surface are of two principal systems: those which are transverse to the strike of the underlying rocks, their origin being unknown, and those which conform to the strike of the underlying rocks, having been developed by the more rapid erosion of the weaker formations; such valleys being known as subsequent valleys. The transverse valleys have in general a north-south to northeast-southwest trend, while the subsequent valleys, following the strike of the rocks, have a northwest-southeast trend in the southeastern part of the island, and an east-west trend in the western part. The larger valleys, and notably the transverse valleys, have the characteristics of mature glaciation, that is, steep sides and wide, rounded floors; although hanging valleys are inconspicuous. The valleys were greatly deepened by the glacial scour, and two of the transverse valleys were converted into fiords; one of these occurs in the southeastern part of the island, and is known as Saanich inlet, while the other forms the natural western boundary of southern Vancouver island, and is called Alberni canal and Barkley sound. Another transverse valley in the southwestern part of the island was eroded far below sea-level almost at its mouth. It is now occupied by a lake—Nitinat lake— whose surface is only a few feet above low tide, so that at high tide the salt water rushes into it through a narrow rock gate. Another transverse valley occurring in the eastern part of the island was glacially deepened in two portions, in which are situated lakes, the southern, Sooke lake, being 571 feet above sea-level, and the northern, Shawnigan lake, 380 feet above sea-level. Sooke lake is drained southward by Sooke river flowing in a sub-maturely glaciated valley. Shawnigan lake is drained northeastward by a small stream flowing in the wide lowland developed by the more mature erosion of the relatively soft sediments of the east coast. Several of the smaller transverse valleys are also maturely glaciated, especially in the eastern part of the island, but the larger number are relatively immaturely glaciated, and are, therefore, V-shaped, although where confluent with subsequent valleys they widen out for a short distance.

Subsequent.—The larger subsequent valleys, since they have been developed on wide belts of weak rocks, are as a rule wider and more extensive than the transverse valleys. Although they have been glaciated, the glaciation, with two or three exceptions, has not been so severe as that which has affected the larger transverse valleys, therefore, the subsequent valleys have gentler side slopes and narrower bottoms. The largest of the subsequent valleys drains southeastward, and nearly divides the southern part of Vancouver island into two halves. It is known as Cowichan valley, since it is occupied by Cowichan lake, river and bay. It is underlain by a closely folded syncline, slightly overturned to the southwest, of conglomerates, sandstones and shales of the Cowichan group, flanked on either side by resistant volcanic rocks. The less resistant sedimentary rocks were more easily eroded by the cycle following the uplift of the Tertiary peneplain, and a late mature valley was formed, which during the Glacial period was maturely glaciated, being deepened especially in the upper portion where Cowichan lake occurs. Cowichan lake is drained by the Cowichan river, which flows eastward to Cowichan bay, and for the greater part of its 20 mile course meanders in its flat, valley floor, some two or three miles wide, between cut banks of stratified drift 10 to 200 feet high. It seems, therefore, as if the river had been revived by the recent uplift which has affected Vancouver island, and had been entrenched in its own flood plain. In the middle part of its course, as might be expected in a recently revived stream, the river is confined between rock walls and has a steep grade with two or three small falls.

Five miles to the north occurs another, but smaller valley of the same type, now occupied by the upper part of Chemainus river. Other valleys, such as the Nanaimo, still farther to the north, and the upper part of the Kokasilah, to the south of Cowichan valley, appear to be of the same general type, though the Kokasilah valley is relatively small, and in the case of Nanaimo valley, except in the lower part, only traces of the underlying soft rocks are seen. A similar valley, developed on a large basin of sedimentary rocks, which have, however, a more southerly trend, occurs at the head of Alberni canal; and is drained southward into Alberni canal by Somass river and its tributaries.

In the southern part of the district also, are two similar, wide, subsequent valleys, not greatly glaciated, which have been developed in the nearly vertically dipping slates and schists of the Leech River formation, near the northern and southern contacts with more resistant volcanic rocks. The northern valley is drained westward by San Juan river and its eastward extension, Meadow creek. The southern valley is occupied by several paired streams, which drain southward by transverse streams that flow in deep but relatively narrow valleys, and empty into [illegible] strait. This paired arrangement of drainage develops on [illegible] structures of alternate hard and soft rocks by the rapid headward growth of the tributaries of the transverse streams along the belts of soft rocks. In the later stages of the cycle the divides in the subsequent valleys between the contiguous river systems are greatly reduced; and if the soft rock belts are wide, the subsequent tributary valleys become correspondingly so. This stage has been reached by the valley along the southern boundary of the Leech River formation, which will be referred to during this report as Leech River valley. The streams which occupy the valley are, from east to west, Wolf creek and Leech river drained south by Sooke river, Bear creek, the central part of Jordan river, and Y creek drained southward by Jordan river, and Lost river, which flowing westward occupies the western part of the valley. Lost river does not empty into Fuca strait at the mouth of the valley, but probably owing to the recent uplift of Vancouver island, was diverted by a large deposit of sand and gravel, which accumulated near the mouth of the valley, and now turns directly south, somewhat over a mile from the shore, where it has an elevation of about 320 feet, and tumbles through a narrow rock cañon to Fuca strait.

There are other large east-west valleys, such as that of Sarita lake and river, which flows westward into Barkley sound, that appear to have been developed along contacts of the underlying formations.

'*Meadows.*' In the central part of the island are large relatively flat basins at elevations near 1,500 feet above sea-level, and 1,000 to 1,500 feet below the Tertiary peneplain, whose origin is not always clear. They are usually drift-filled and marshy, and frequently contain lakes. The largest of the basins, or 'meadows' as they are locally called, occurs at the headwaters of Jordan river, and is known as Jordan meadows. It is about three miles long by a mile wide, and is underlain by the easily eroded Leech River slates. Some of the other 'meadows,' however, appear to be underlain by the more resistant crystalline rocks.

Coastal lowlands.—Along the east and west coasts are relatively narrow areas underlain by sedimentary rocks, indurated, but not metamorphosed to any great extent, which, partly on account of their low resistance to erosion, have been worn down to a lowland during the pre-Glacial cycle. The sediments along the east coast, the Cowichan group, have been folded into open and closed folds, and also faulted, so that strata of varying hardness have been exposed to erosion, which, although it has reduced the area underlain by the sediments to a lowland, has not progressed far enough to reduce the hard and soft strata to the same general level.

The sediments of the west coast of Vancouver island were deposited in small embayments off a mountainous coast with bold promontories, during the Tertiary period,[1] and were afterwards uplifted with very little folding, hence presenting to erosion, strata of nearly uniform resistance. They were, therefore, worn down during the pre-Glacial cycle to relatively flat areas, exposing the steep slope

[1] See page 140.

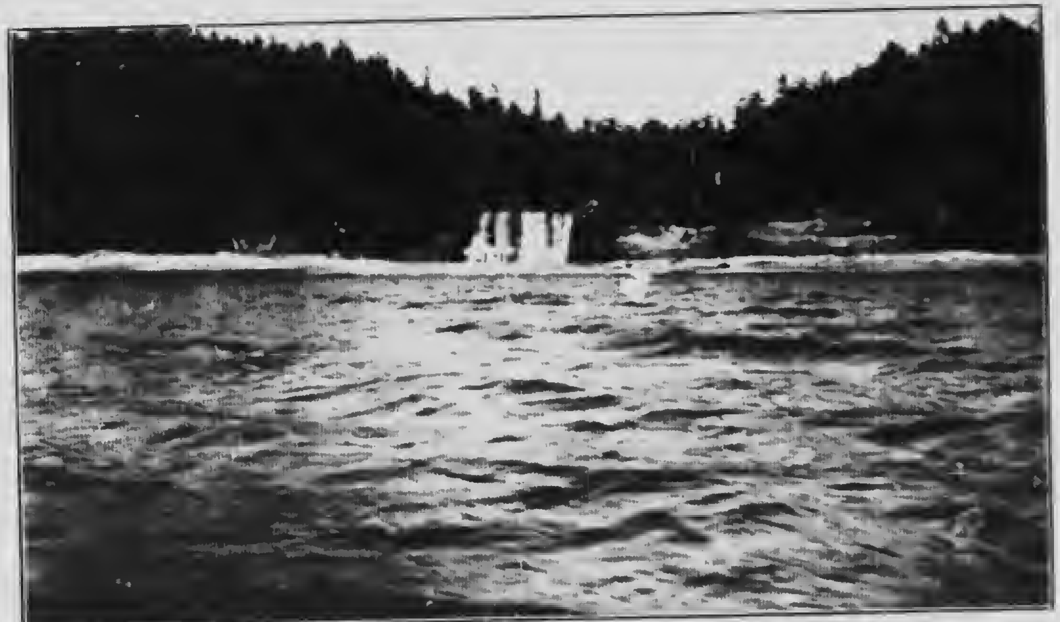
against which they were deposited. The flat areas were uplifted during the recent uplift, and are now 150 to 250 feet above sea-level. The larger streams, such as Jordan and Sooke rivers, which cross the sedimentary basins, have eroded the sedimentary rocks along their course nearly to sea-level, and have also widened their valleys; but the numerous smaller streams cross the basins in narrow gorges, and in one instance, four miles west of the entrance to Nitinat lake, a stream, the Tsusiat river, falls about 80 feet over a sandstone cliff into the ocean.

In the vicinity of Cape Beale, at the entrance of Barkley sound, the granitic rocks, which underlie this district, have been worn down to a narrow lowland, similar to that underlain by the Tertiary sediments to the southeast. This lowland is comparatively level, one to two miles wide, and now about 125 feet above the sea. It is terminated inland by a steep slope to the upland. The lowland looks as if it were formed by wave cutting, and since it is known that there has been a comparatively recent uplift of about 200 feet, it seems most probable that it is an uplifted marine platform.

In the extreme southeastern portion of the island, in the neighbourhood of Victoria and the Saanich peninsula, although the region is largely underlain by crystalline rocks, the pre-Glacial cycle apparently reached old age, developing a lowland with rounded monadnocks, similar in appearance to the Tertiary peneplain already described. Its average elevation is now about 200 feet. The monadnocks surmount the lowland by a few hundred feet, the largest, Mount Newton, in the Saanich district, being 1,000 feet above sea-level. In the western portion this lowland grades fairly abruptly into the southern belt of the upland of southern Vancouver island, already described as characterized by a late-mature dissection of the Tertiary peneplain. Since a large part of the lowland is covered by marine deposits, it may have been in part developed by marine planation, although no evidences of such planation have been noted, and the region is protected by its inland position from powerful wave action. It seems most probable, therefore, as its appearance suggests, that it has been formed by sub-aërial erosion.

The lowland areas of the coast regions are covered, as already mentioned, by unconsolidated, usually stratified deposits, in part of marine origin. The drift deposits present more or less relief, which appears to be due to erosive rather than to constructive agencies, the

Plate IV.



Young sea-cliff of Tertiary sandstones formed by recent uplift at [illegible] falls 80 feet into the ocean. Tsusiat falls, Barkley District.

Lowland developed by pre-glacial cycle in southeastern Vancouver island, in the vicinity of Victoria: looking west to the upland, the maturely dissected Tertiary peneplain.

drift having been overridden by glaciers during a second period of glaciation. In some of the hollows in the drift, lakes up to two miles in length occur. One of these lakes, seven miles north of Victoria—Elk lake—furnishes the present water supply of the city.

Shore-lines.—The present shore-line of southern Vancouver island is in a sub-mature stage where developed on the stratified drift deposit of the southeastern portion, and also along the west coast, formed largely of the Tertiary sediments, where wave erosion is very powerful; but it is in a youthful stage where developed on the crystalline rocks. T esent marine cycle was initiated by the uplift which affected Vancouver island recently, and which, in the southeastern part of the island, was a partial recovery from an earlier, probable depression.

Along the northern part of the east coast of southern Vancouver island the glaciated old age surface, developed during the pre-Glacial cycle, on the deformed sediments of the Cowichan group, was apparently depressed; and the valleys were drowned and the ridges of hard rock became islands, reefs, and long promontories, elongate in the direction of the strike, that is, in general, N 50° W to N 80° W. The partial recovery was not sufficient to materially change the character of this shore-line. Wave erosion in the present marine cycle is not very great along the east coast since it is protected by its inland position. Hence the beaches are narrow and non-continuous, and are confined for the greater part to the vicinity of drift-filled valleys between hard rock ridges. The front or obsequent slopes of the islands, usually the southwestern since the prevailing dip is to the northeast, are steep, while the back or dip slopes, where the dip is low, are gentle, so that the water is shallow and the shore is marked by many reefs.

Along the southern part of the east coast the sub-maturely glaciated and drift-covered old age surface developed during the pre-Glacial cycle on the crystalline rocks, was first depressed into what was probably a simple shore-line with smooth flowing outlines where the crystalline rocks were drift-covered. However, it is probable that some of the crystalline rocks were not drift-covered, and that in such instances the initial shore-line must have been characterized by many irregularities such as bays, promontories, and small islands. But since the old age surface had been glaciated the shore-line was probably free from minor irregularities, that is, the rocks had been smoothed to a rounded and knobby outline, the minor features of relief developed by normal erosion having been destroyed. The partial recovery of about 250 feet from the initial depression was not sufficient to revive the larger drowned valleys, but uplifted the stratified drift deposits which have been sub-maturely retrograded during the present marine cycle, developing steep cliffs up to 250 feet high, with coarse boulder beaches and attendant sand-spits. Some of the bays formed in the depressions of the drift deposits have been nearly closed by bay bars or wall beaches, behind which lagoons occur.

Since the drowned irregular valleys of the east coast of southern Vancouver island were maturely to sub-maturely glaciated, the present inlets and passes between the islands are fiord-like in character. A typical fiord is the maturely glaciated, drowned, transverse valley, now occupied by Saanich inlet, which extends southward into the late-maturely dissected portion of the upland.

In spite of the fact that the inlets are fiord-like in character, the glaciation does not seem to have been sufficient to have developed the present shore-line. Some of the inlets and passes are intricate and very large, the region in general is of low relief, the character of the topography appears to be the result of normal erosion and merely sub-mature glaciation, and the glaciation was accomplished chiefly by a large piedmont glacier which occupied Georgia and Haro straits and flowed southward at a wide angle to many of the inlets and channels. However, the glacier conformed to a rather striking degree to the irregularities of the surface over which it flowed. It seems best to conclude, therefore, that the present irregular shore-line is due to depression rather than to glaciation.

Along the west coast of southern Vancouver island the Tertiary sediments, which as described, had been worn down to a smooth lowland during the pre-Glacial cycle, and the flat, described above, which was developed near Cape Beale on the granitic rocks, possibly a marine platform, were uplifted and the rocks are being retrograded in the present marine cycle. The wave action is very powerful and has formed a cliff about 100 feet high, with many dangerous reefs off shore. Since the uplifted lowlands were probably without much relief the initial shore-line may have been fairly straight and regular, and may have been further straightened by the retrogression during the present cycle. It is now, therefore, nearly straight, and is in great contrast to the irregular fiord coast of the more northerly portion of the west coast of Vancouver island. At the base of the rock cliffs, near large deposits of stratified drift which were formed in the pre-Glacial valleys before uplift, are coarse boulder and shingle beaches; while at the base of the cliffs of stratified drift are finer grained beaches of limited extent. The shore-line is broken by only two broad open bays, both of which are apparently glacially deepened valleys. One is in the middle portion of the shore-line at the mouth of the subsequent San Juan valley and is known as Port San Juan; while the other is four miles east of Cape Beale, at the mouth of a transverse valley, and is called Pachena bay. The west coast of southern Vancouver island is terminated at Cape Beale by the Barkley sound-Alberni canal fiord, which, as described, is the natural western boundary of southern Vancouver island.

CLIMATE AND VEGETATION.

The climate of southern Vancouver island varies widely in different parts of the island. Along the west coast it is exceptionally wet with about 120 inches of rainfall a year, while on the east coast of the island, in the lea of the main range, it is comparatively dry, with only from 30 to 60 inches of rain a year. The greater part of the rain falls in the winter months, while the summer is dry. The temperature along both coasts is remarkably uniform and temperate, due in large part to the influence of the Japan current. The average temperature is 40° F. in winter and 55° F. in summer.[1] In the interior of the island, on the upland and mountains, the differences in temperature are, of course, much greater.

The following tables, giving statistics of rainfall and temperature, have been compiled from data furnished by the Meteorological Service of Canada, and the United States Weather Bureau:—

[1] The climate of Victoria, which is representative of the southeastern part of the island, has been treated very adequately and interestingly by Arthur W. McCurdy of Victoria in a short article in the National Geographic Magazine, Vol. XVIII, pp. 345-348, with two sketch maps, May, 1907.

TABLE No. 1.

VICTORIA, B.C.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature— Mean of 26 years ending 1906............	38.4	39.1	43.2	47.5	52.6	56.2	59.3	59.1	54.8	49.5	44.0	41.3	48 75
Precipitation— Mean of 18 years ending 1908..........	4.54	3.57	2.71	1.80	1.35	0.96	0.35	0.59	2.10	2.26	6.07	6 27	32.57

QUATSINO, WEST COAST, V.I., B.C.

Mean of 11 to 14 years ending 1909.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature.......	36.4	38.3	39.4	43.9	47.6	53.4	57.5	57.8	53.5	48.7	42.2	40.1	46.6
Rainfall.............	12.23	13.29	9.43	8.18	7.69	4.98	3 02	4.53	7.56	13.56	17.15	18 16	119.78
Snowfall...........	7.4	3.7	3.6	1.1	.....	.....	.....	.....	.....	..	1 2	1.1	18.1

VANCOUVER, B.C.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature— Mean of 5 years ending 1906	37.5	38 6	42.7	47 2	53 6	58 2	62.7	62.0	55.8	50.6	41.4	39.6	49 09
Precipitation— Mean of 7 years ending 1908	8.39	6.55	5 49	3.49	3 70	3.19	1.30	1 35	4.40	5.85	11.37	6.47	61.55

SEATTLE, WASHINGTON.

Mean of 18 years ending 1908.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature	40.8	47.9	44.9	50 0	55.0	59.7	64.5	64 0	58 6	52.3	46.1	42.6	52.20
Precipitation	4.42	3.98	3.19	2 66	2.22	1 56	0 68	0.49	1.91	2.73	5.94	5.88	35 66

Only the drift-covered, coast lowlands of the eastern and south-eastern parts of the island, and a few of the larger subsequent valleys, such as Cowichan and Alberni valleys, are cultivated to any great extent. Garden vegetables, fruit chiefly berries and grain are the principal products.

In the interior and along the west coast there is little agriculture, and not more than 10 per cent of the whole land is suitable for farming purposes. This portion occurs chiefly as narrow strips bordering the rivers and lakes in the broad, glaciated valleys, and must for the greater part be cleared of heavy, thick timber. Occasional open meadow lands occur, such as Jordan meadows.

With the exception of the cleared land, virtually the entire southern part of Vancouver island is heavily forested. The principal forest trees are Douglas fir, cedar, hemlock, and spruce, with balsam and pine. 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 Vancouver island, and should, therefore, be conserved properly.

Where the forest is thick on the higher land the underbrush is not very abundant. In the more open and damper areas, however, the underbrush is extremely thick, and is a great impediment to travel. It consists of dense shrubs, such as salal, salmon, and huckelberry, and varieties of maple and alder. In the poorly drained, glaciated valleys, high, broad-leafed ferns, and devil's club abound.

GENERAL GEOLOGY.

GENERAL STATEMENT.

Regional. Vancouver island and the neighbouring region form the western part of the western geosyncline of the Canadian portion of the North American cordillera as defined by Dawson.[1] The strata comprising this geosyncline consist of a series of sediments and vol-

[1] G. M. Dawson. Geographical Record of the Rocky Mountain Region in Canada. Bull. Geol. Soc. Am., Vol. 12, 1901, pp. 57-92. The following description is taken largely from this paper and particular reference is not given.

canic rocks, with a thickness, conservatively estimated, of 89,600 feet. The pre-Cretaceous rocks are for the greater part heavily mountain-built, and invaded by eruptive rocks; and in places rocks as late as Miocene have been tightly folded and metamorphosed.[1] The axes of folding correspond in general with the axes of the present mountain ranges, which throughout this region are nearly parallel, the strike being northwest-southeast.

At the base of the folded geosyncline, exposed only in the central or eastern part of British Columbia, is a complex of gneisses, mica schists, marbles, and quartzites, with igneous intrusives, the Shuswap series, unconformably overlain by the Nisconlith and Adams Lake series, which consist of metamorphic sedimentary and volcanic rocks, argillites and mica schists, and chloritic and feldspathic schists. These rocks are largely of pre-Cambrian, Cambrian, and Ordovician ages, but probably contain infolded younger rocks. The above formations are overlain by the Cache Creek group, referable for the greater part to the Carboniferous. The lower subdivision of the Cache Creek group consists of argillites, cherty quartzites, and volcanic rocks, with serpentine and interstratified limestones. The upper division consists almost entirely of massive limestones, with occasional intercalations of rocks similar to those of the lower part. Similar rocks occur in the Coast region and on Vancouver island, where they are the oldest exposed rocks, and probably in large part are of Carboniferous age.

Unconformable upon the above formations are a great group of basic volcanic rocks, largely submarine flows, with relatively thin, intercalated limestones and argillites. In the central plateau region the group is known as the Nicola group, but in the Coast region and on Vancouver and Queen Charlotte islands it has been called by Dawson, the Vancouver group. The Vancouver group is very thick and widespread, and is apparently the predominating surface formation of the Coast region, and forms the greater part of Vancouver island. It appears on Vancouver island to be largely Triassic and Jurassic in age.

The Vancouver group, and the older rocks as well, were greatly folded and faulted, probably in upper Jurassic time, and invaded by granitic rocks. In the Coast range the granitic rocks, largely grano-

[1] G. O. Smith and F. C. Calkins, Snoqualmie Folio No. 139, U.S Geol. Survey, 1906.

diorites, form virtually a single continuous batholith about 1,000 miles in length, but on Vancouver island the granitic rocks are exposed in relatively small, irregular batholiths.

Unconformably upon an eroded surface of the granitic and older rocks occur upper Mesozoic and Eocene sediments. The sediments consist largely of conglomerates, sandstones and shales, with coal at certain horizons. The oldest sediments occur on Queen Charlotte islands, and are lower Cretaceous or Comanche in age, and are equivalent to the Shasta of California. To the south the basal sediments are progressively younger, upper Cretaceous on Vancouver island, and Eocene in southern British Columbia and Washington. The three successive formations or series have been named, the Queen Charlotte islands, the Nanaimo, and the Puget formations, the Nanaimo being equivalent to the Chico of California. These rocks have all been folded, but whether during the same or different periods of folding is not clear.

Unconformable upon the Cretaceous, and possibly the Eocene sediments as well, are sediments and volcanics of younger Tertiary, chiefly Oligocene-Miocene age. In the coast region they are best developed in western Washington, but they also occur in small basins fringing the southwest coast of Vancouver island.

The Tertiary strata of the Coast region have been uplifted, gently folded, but rather extensively faulted. In the interior, Miocene strata have been close folded and invaded by granitic rocks. Extensive vulcanism occurred in the Coast region in middle Miocene time and continued into the Pleistocene. Farther south in California, and farther north in Canada and Alaska, volcanic activity lasted to very recent times, and in Alaska and the Aleutian islands volcanoes are still active.

Deposits of Pleistocene age are very extensive. They consist of glacial till, and of stratified deposits in part of marine origin but consisting largely of glacial detritus. The Pleistocene deposits have recently been uplifted; the amount of uplift in the vicinity of Vancouver island and neighbouring coast region being from 200 to [illegible] feet.

Local.—Apparently the oldest rocks in southern Vancouver island are a series of what were originally shales and shaly sandstones, composed chiefly of quartz, which have been metamorphosed into slates and quartz schists. They have been closely folded and faulted, and are now nearly isoclinal, with steep dips chiefly to the north. They underlie a broad belt, having an east-west strike, which nearly crosses the island. The series has been called, from its occurrence on Leech river, the Leech River formation. The Leech River formation is correlated with the lower part of the Cache Creek group, and is considered, therefore, to be Carboniferous in age.

The larger part of the crystalline rocks of southern Vancouver island belong to the Vancouver group, which embraces rocks of Triassic and Jurassic ages. They consist chiefly of metamorphosed basic volcanic rocks principally meta-andesites, with both flow and fragmental types, the flow types predominating. There is also a series of basaltic flows, with intrusive diabases, underlying the southernmost part of Vancouver island, which have been called the Metchosin volcanics. Since the Metchosin volcanics differ lithologically from the typical volcanic rocks of the Vancouver group, and are less metamorphosed, they cannot be definitely correlated with the Vancouver group. With the exception of a rather limited series of rocks, partly of sedimentary origin, the Vancouver volcanics are exceptionally free from sedimentary rocks other than limestone. The limestone usually occurs in relatively small intercalated lenses, which have been called the Sutton formation. In the southwestern part of the island limestones apparently form a thick horizon, without any volcanic members, and have been called the Nitinat formation. The limestones have been converted into marbles, and in many instances, especially in the Nitinat formation, have been metamorphosed by intrusive granitic rocks into rocks consisting chiefly of garnet and diopside, locally called 'garnetite,' or into rocks consisting of hornblende and feldspar, known as amphibolite. The other sedimentary rocks, spoken of as exceptional in the Vancouver group of southern Vancouver island, consist of stratified slaty and cherty rocks, composed partly of volcanic material and interstratified with volcanic flows, chiefly andesites. These rocks have been greatly metamorphosed and converted into schists by intrusive acid, quartz-feldspar porphyrite, and basic, gabbro-diorite porphyrite, and both the greatly metamorphosed rocks and intrusive porphyrites have been grouped and mapped together, and called the Sicker series.

The entire Vancouver group has been greatly deformed, the axes of deformation corresponding roughly with the trend of the present island, that is in the southern part, about N 65° W. Granitic rocks were intruded during or after deformation, penetrating far into the overlying rocks along two main axes, a southern and a northern, separated by a wide area in the central part of the island in which few granitic rocks occur. The granitic rocks are chiefly a basic granite or granodiorite with marginal faces of diorite, and in the southwestern and southeastern parts of the island large bodies of diorite and diorite gneiss occur. All of the granitic rocks seem to have been erupted during the same general period of intrusion, but the three main types were erupted in a definite sequence, apparently as follows: Wark diorite and quartz diorite gneiss, Beale diorite, and Saanich granodiorite and quartz diorite. Erosion has exposed the granitic rocks, and to-day they occur in relatively small masses or batholiths, generally with an irregular and elongate outline corresponding in trend with the axes of folding, which are very numerous, especially along the two axes mentioned previously. Associated with the granitic rocks, especially near their contacts, are irregular and dyke-like masses, sometimes intrusive into the granodiorite, of an acid, quartz-feldspar, or granodiorite porphyrite; and dykes of a more basic, andesite porphyrite. The granodiorite porphyrites appear to be related to the quartz-feldspar porphyrites of the Sicker series, and it is probable that the gabbro-diorite porphyrites of the Sicker series were erupted during this same general period of intrusion. Along the southern coast, intrusive into the Metchosin volcanics, are small bodies or stocks of gabbro, which has been called the Sooke gabbro, which may have been erupted during the general period of granitic intrusion. The gabbro stocks range from a very basic gabbro to an alkaline gabbro, and even to a true anorthosite, composed almost entirely of a basic feldspar. The alkaline types are confined to very small masses and veins, intrusive into the normal gabbro.

Unconformable upon an erosion surface of all the above mentioned rocks, with the possible exception of the Metchosin volcanics and Sooke gabbro, is a great series of sediments, chiefly conglomerates, sandstones, and shales, with some coal near the base, which are largely of upper Cretaceous age, but may be in part lowermost Tertiary (Eocene) age. The upper Cretaceous portion has been called the Nanaimo formation. The Nanaimo formation has not been distinguished in mapping from the conformably overlying, possibly Eocene sediments, and also from a lithologically similar formation that unconformably underlies it. All the above sediments have been grouped together and mapped as the Cowichan group, but the group is chiefly composed of the Nanaimo formation.

At some time following the close of the Cretaceous the Cowichan group was deformed, in general into broad open folds of large extent, but in places close folded, overturned to the southwest, and broken by overthrust faults. The period of deformation initiated a long period or cycle of erosion in Tertiary time, which wore down all the older rocks to a greatly subdued surface, and during the same general period, sediments were deposited under marine conditions along the southwest coast, building up a coastal plain. The coastal plain deposits, chiefly conglomerates and sandstones, were uplifted with very little folding, although with rather extensive minor faulting, and have been very greatly eroded, and now form low, narrow basins fringing the southwest coast, the Sooke and Carmanah formations. The greatly subdued erosion surface was also uplifted and subsequently greatly or maturely dissected, and now forms the plateau like country, characteristic of the larger part of southern Vancouver island.

In Pleistocene times Vancouver island was covered by a thick ice cap, and large glaciers, fed by valley glaciers from the ice caps of Vancouver island and the mainland, filled the straits of Georgia and Juan de Fuca. On the retreat of the glaciers the morainal deposits were greatly 'modified,' and even transported considerable distances and redeposited in part by marine agencies, for at that time the land stood some 250 feet lower with respect to the ocean than it does at present; and the uplift which brought the marine Pleistocene deposits, and the region in general, to the present position, was of comparatively recent date.

DESCRIPTION OF FORMATIONS.

LEECH RIVER FORMATION.

A belt of slaty and schistose rocks, probably the oldest in southern Vancouver island, extends from Goldstream river to the west coast, and has been called the Leech River formation. As this formation contains the quartz veins from which the placer gold of the Leech river was derived, it has been known for a long time. The

TABLE OF FORMATIONS.

Superficial deposits	Pleistocene and Recent	Gla. ' till and unconsolidated gravels, sands and ays, mostly stratified.
Sooke and Carmanah formations	Oligocene—Miocene	Conglomerates and sandstones.
Cowichan group. Nanaimo formation in part.	Upper Cretaceous (Nanaimo), and may include Triassic or Jurassic, lower Cretaceous, and Eocene.	Unmetamorphosed conglomerates, sandstones, and shales, with some coal.
Batholithic and dyke intrusives	Upper Jurassic and possibly lower Cretaceous. Correlated with Coast Range batholith.	
Sooke gabbro		Gabbros, amphibole gabbros, anorthosites and olivine anorthosites, (allivalite), cut by gabbro porphyrite and diabase dykes.
Dykes and minor intrusions (Injected types.)		Andesite and granodiorite porphyrites; and may include quartz-feldspar and gabbro-diorite porphyrites of Sicker series, and gabbros of Wark diorite gneiss.
Saanich granodiorite and quartz diorite.		Granodiorite and quartz diorite with granites, and basic and hybrid contact facies.
Beale diorite		Quartz bearing diorite and diorite, peripheral facies of Saanich batholiths (?).
Wark diorite and quartz diorite gneisses		Diorite gneiss and intrusive quartz diorite gneiss; with metamorphic quartz-feldspar (salic) and hornblendite (femic) facies, and minor intrusions of gabbro.
Vancouver group	Triassic and Jurassic.	
Metchosin volcanics	Jurassic?	Ophitic basalt flows, tuffs, and agglomerates with intrusive diabase dykes. Less metamorphosed than rest of Vancouver group.

than rest of Vancouver group.

Sicker series...	Jurassic or Triassic, gabbro-diorite porphyrites, may be lower Cretaceous.	Andesitic volcanic flows and tuffs, with interbedded tuffaceous, slaty and quartzose sedimentary rocks, more or less metamorphosed into schists, with intrusive quartz-feldspar and gabbro-diorite porphyrites.
Sutton formation....	Lower Jurassic....	Intercalations of crystalline limestones in Vancouver volcanics.
Vancouver volcanics.	Largely lower Jurassic, but probably includes Triassic and middle Jurassic, and possibly Palaeozoic members.	Metamorphic andesites and augite andesites, amygdaloids, porphyries, tuffs and breccias; with dacite tuffs, and intrusive dykes and sills of andesite and basalt porphyrites.
Nitinat formation.	Jurassic or Triassic?.....	Marbles and metamorphic varieties, garnet-diopside rocks and amphibolites.
Leech River formation.	Carboniferous?	Slates, slaty schists, greywackes and quartz and quartz-feldspar schists.

rocks were called the Leech River slates by the miners in the late sixties, and were described by Dawson[1] in 1876, who refers to them as a distinct formation or series. The western part of the formation has been called the Port Renfrew shales in a somewhat popular article by Hall.[2] As the rocks form a continuous belt, and are clearly of one formation, or at least of one series, which cannot at present be subdivided, the older name has been retained.

Distribution.—The Leech River formation forms a broad belt of rocks which extends from Langford lake in the Goldstream district to the west coast in the vicinity of Port San Juan. The easternmost exposures are seen in the valley and bed of Goldstream river, near the sharp bend, a mile and a half from its mouth. Although the rocks may continue farther east and there underlie a part of the Colwood plain, where the surface is drift covered, there are no outcrops. The formation extends west in a widening zone, so that at the North fork of Leech river it is about three miles wide. The maximum width, about eight miles, is attained in the vicinity of Jordan river. The easternmost outcrops on the west coast occur near the mouth of Sombrio river. The zone is here about five miles wide, since it reaches north to San Juan river. The westernmost exposures on the coast occur a mile and a half west of Port San Juan. The formation probably extends farther west, but is not again exposed along the shore, being covered by the sandstones and conglomerates of the Carmanah formation.

The formation is well exposed along the deep cañons cut into the slaty and schistose rocks by the rivers and creeks that traverse the belt. It is also exceptionally well exposed on the shores of Port San Juan, and along the west coast. The inter-stream areas, although high, are relatively flat, drift covered, and often marshy, with wide stretches of meadow land, and therefore there are comparatively few outcrops.

The southern boundary has been fairly well determined, since it follows the large subsequent valley, called Leech River valley, formed near the fault contact separating the Metchosin volcanics and the Leech River formation. In the eastern part, the northern boundary has been rather indefinitely located, but west of Jordan

[1] G. M. Dawson. Geol. Survey of Canada. Report of Progress, 1876-77. pp. 95-102.

[2] C. W. Hall. Some geological features of the Minnesota Seaside Station. Postelsia. Year Book of the Minnesota Seaside Station, 1906, pp. 305-347

meadows it is marked by the valley of San Juan river and its eastward extension, Meadow creek.

Lithological Characters.—The formation consists of argillaceous and arenaceous sedimentary rocks dynamo-metamorphosed into slates and quartz schists. Although as a whole the formation possesses a uniform lithological character, yet, in detail, the individual beds differ considerably, especially as regards texture and their powers of resistance to corrasion. This difference is well shown along the creeks which cut across the strike of the formation, the hard quartzose beds often forming vertical walls over which the water spills into deep pools, worn out of the weaker slates and schists. A well known fall of this character, called Devil's Grip, occurs on the North fork of Leech river. The arrangement of the strata in alternating hard and soft beds is also well shown along the shores of Port San Juan, the less resistant beds having been worn out by the waves into little coves and chasms. As a rule the alternation of beds of varying characters is rapid.

The most common rock type is a black, schistose slate. The slates owe their dark colour to the presence of magnetite and graphite. Some of the slates are so carbonaceous, black, and lustrous, as to resemble a graphitic coal. The slates are as a rule quartzose and pass into greywackes and quartz schists. The greywackes are grey, compact to fine grained, quartzose rocks, passing into schistose varieties. The schistose varieties are usually light coloured, greenish or grey, fine grained rocks, frequently weathering brown on exposed surfaces. Certain types, such as occur on Mount Valentine south of Jordan meadows are black and coarser grained, and contain biotite and magnetite.

Microscopic.—The essential constituents of the greywackes and quartz schists are seen microscopically to be quartz and a light-brown variety of biotite. The quartz occurs in fine to coarse grains, irregular in shape, and with interlocking boundaries, and is fractured and distorted. The accessory minerals which have been noted are muscovite, cyanite, albite, calcite, and magnetite. Muscovite or sericite in many cases is an essential constituent, the rock passing into a quartz-sericite schist. In the dark coloured, coarser grained schists, such as occur on Mount Valentine, biotite and magnetite form a large percentage of the rock.

More rarely, types such as quartz-feldspar, or feldspar-chlorite schists occur, whose sedimentary origin is not always certain. Schists of these types are usually green in colour, but are otherwise similar in appearance to the more common types. On microscopic examination they are seen to contain a large percentage of plagioclase, probably albite-oligoclase, and quartz. Secondary minerals such as sericite, chlorite, epidote, and actinolite are usually abundant. The accessories are chiefly biotite and magnetite. The large percentage of feldspar suggests that some of the schists may be of volcanic origin, presumably tufaceous, or they may have been sedimentary feldspathic rocks.

Metamorphism.—The dynamo-metamorphism of the formation has been intense, the schistose texture of the rocks being very pronounced, and the weaker rocks are in some instances minutely contorted. Veins and lenses of quartz are exceedingly numerous, and are usually more or less parallel to the planes of schistosity or cleavage. These quartz veins are gold-bearing, although very low grade, and the gold found in the gravels of the rivers and creeks occurring in the slate belt has doubtless been derived from them.

Structural Relations.—Internal.—The rocks of the Leech River formation have been closely folded, so that the strikes are nearly parallel, and the dips chiefly to the north, the angles of dip being high. On account of the close folding and the general similarity of the formation throughout its entire thickness, the exact determination of the structure is practically impossible. There can be hardly any doubt, however, that the whole formation has been folded so that the strata are repeated across the belt at right angles to the strike. Evidence of one such fold is to be found on the divides between Jordan river and San Juan and Kokasilah rivers, where there is an infold of meta-volcanic rocks, with slates and schists on both sides.

The general strike of the formation follows the direction of the southern contact very closely. In the eastern part of the belt, in the vicinity of Goldstream and Leech rivers, the general strike is about N 65° W, the angle of dip averaging about 80° N. In the vicinity of Jordan meadows the strike is about N 75° W, and the dips are steep to the north, the average being about 75°. In the western part of the belt, in the Renfrew district, the general strike is about

S 80° W, and the dip chiefly to the north, but the angle of dip is less steep, averaging about 50°.

In detail the strikes and dips vary considerably. In the neighbourhood of the Leech river the strikes range from N 30° W to N 80° W, while in the Renfrew district they range from N 80° W to S 40° W. The dips have similar variation, which is sometimes greater on account of local crumpling. The true dip of the formation is often obscured by the creep of the slates, which is very great, and in some cases gives a false dip in a reversed direction to the true dip.

Sheared and slickensided rocks are very common, and many small faults occur. Larger faults are probably also present, although with the exception of the boundary faults, none have been located. They would not be readily recognized, however, if present, nor could their displacement be determined, on account of the uniform lithological character of the strata and the absence of horizon markers.

On account of the complexity of the structure, which has not been worked out, any estimate made at present of the thickness of the formation must be very unreliable. The formation has a maximum exposed width of about 35,000 feet; a thickness of 5,000 feet is, therefore, probably an under estimate.

External.—Relation to Younger Formations.—The Leech River formation is probably the oldest formation of southern Vancouver island. With the exception of the fragmental volcanic rocks, which occur to the north of the Leech River formation in the eastern part of the area, and the Nitinat limestones, the contiguous formations are clearly younger. In the cases of both of the exceptions it also seems best to consider them as belonging to younger groups, but their relations with the Leech River formation are not clear.

To the east of Jordan meadows the northern boundary of the Leech River formation is a rather indefinite contact with schistose and fragmental meta-volcanic rocks of the Vancouver volcanics. The nature of the contact is not known, but in the Goldstream valley, where both the slates and fragmental volcanics are well exposed, no large fault or unconformity was observed. Farther west the meta-volcanic rocks form a relatively narrow belt separating the slates and schists from foliated plutonic rocks which are intrusive into the meta-volcanics, but which do not, in this locality, cut typical Leech River rocks.

In the vicinity of Jordan meadows the slates are, as mentioned, apparently interfolded with green, schistose, meta-volcanics, similar to those which occur to the east. The green volcanic schists occur on the divides which separate the headwaters of the Jordan and Leech rivers from those of the San Juan and Kokasilah rivers. Typical Leech River slates occur in the creeks to the north and south of the divides. The nature of the contact, which is not exposed, is uncertain, but there is no apparent fault or unconformity.

Farther to the west, near Tod's crevice, bold ledges of volcanic rocks, belonging to the Vancouver group, rise abruptly on the north side of the wide east-west valley of the San Juan river and Meadow creek. In the valley occur the Leech River slates. The contact with the Vancouver volcanics, which is not exposed, occurs on the north slope, from 500 to 1,000 feet above the stream beds. The contact is straight, with a trend of S 85° W, and follows the San Juan valley westward to Port San Juan. In the vicinity of Port San Juan the rocks occurring to the north are the Nitinat limestones and plutonic rocks; the Leech River formation, therefore, with its east-west strike, bevels across the Vancouver volcanics and the apparently conformable Nitinat formation, which have a general strike of N 65° W. The straightness of the contact, the great dissimilarity of the formations on either side of the contact, and their non-conformity of strike, indicate, since there is no direct evidence of unconformity, that the contact is a fault. The Vancouver volcanics are much less affected by regional metamorphism than the Leech River slates with which they are in contact, and are, therefore, considered to be younger. Since the Vancouver volcanics are effusive, they presumably overlie the Leech River formation, and the downthrow side of the fault is therefore to the north.

The southern contact which is with the Metchosin volcanics, is also a profound fault.[1] The downthrow side of the fault, since the Metchosin volcanics are considered to be younger, is to the south.

Intrusive igneous rocks are not common in the Leech River formation. Intrusive plutonic rocks are reported, however, and doubtless occur, although they have not been seen by the writer. Mr. K. G. Chipman, of the Topographic Branch of the Survey, states that he found granitic rocks north of Jordan river and its tributary, Y creek, near the western boundary of the Esquimalt and

[1] See Structural relations of Metchosin volcanics, p. 92.

Nanaimo Railway lands; and Mr. T. M. Baird, of Renfrew, reports that they also occur farther west, on the high ridges between the San Juan and Sombrio rivers. Aplitic veins, which were probably injected during the general period of batholithic intrusion, occur throughout the formation. It is also probable that the very numerous quartz veins occurring in the formation were formed during this time.

Mode of origin.—The rocks of the Leech River formation were formed by normal sedimentary processes. The original rocks were shales and shaly sandstones, and were composed chiefly of quartz. The great thickness of the formation, the lithological similarity of the rocks throughout the entire thickness, and the absence of conglomerates, indicate that the rocks were deposited under very uniform conditions. Fossils and minor original structures, such as ripple marks and mud cracks, if ever present, have been destroyed by the intense metamorphism that has affected the formation. It is impossible to state definitely, therefore, whether the rocks are of marine or terrestrial origin. Their great uniformity and prevailing quartzose composition suggests that they are of marine origin.

The presence of feldspathic members, and the indefinite contacts, possibly conformable, with the fragmental volcanic rocks, suggest that a pronounced change of conditions occurred either at the beginning or the close of the deposition of the Leech River formation.

Age and Correlation.—The Leech River rocks very closely resemble, both lithologically and structurally, the slates which occur in the Pacific Coast region from California to the Yukon district, and which are referred to the Carboniferous. On the mainland east of the Coast range in British Columbia, these rocks form the lower portion of the Cache Creek group,[1] and are interbedded with rocks containing known Carboniferous fossils. The chief difference to be noted between the lower member of the Cache Creek group and the Leech River formation is the absence of calcareous and volcanic members in the latter. It is possible, however, that some of th schistose volcanics to the north of the Leech River formation between Goldstream river and Jordan meadows, and the Nitinat

[1] G. M. Dawson. Report on the area of the Kamloops Map Sheet, British Columbia. Geol. Survey of Canada. Ann. Report, Vol. VII, 1896, pp. 373-493.

limestones correspond with the upper series of the Cache Creek group. From the information available, the volcanics and limestones are best considered as Mesozoic. Since no such thickness of slaty rocks as occur in the Leech River formation is known in the Mesozoic of the Coast region, the Leech River formation is correlated with the lower part of the Cache Creek group, and with the Peshastin formation of Washington,[1] and is presumably of Carboniferous age.

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[2] the Vancouver group. The Vancouver group is subdivided 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. Of these, the first and the last are with some doubts included in the Vancouver group, since the first, the Nitinat formation, is possibly of Palaeozoic age, while the last, the Metchosin volcanics, appears younger than Jurassic, does not conform structurally with the rest of the Vancouver group, and is not intruded by any of the main batholithic types.

NITINAT FORMATION.

Distribution.—The name Nitinat formation is applied to masses of marble, and more highly altered calcareous rocks, separated by wide areas of intrusive granitic rocks, that underlie a broad belt, 10 to 12 miles wide, lying to the north of the Leech River slates and extending westward from the mouth of Gordan river to Barkley sound, a distance of over 30 miles. The rocks of the formation are best exposed along the shores of Nitinat lake.

Lithological Characters.—The rocks of the Nitinat formation are calcareous or have been derived from calcareous rocks. There are many areas of white, usually coarsely crystalline limestone or marble, but the larger portion of the original limestones appears to have been pro[illegible]lly altered by invading magmas. The purer.

[1] G. O. Smith. Mt. Stuart Folio, No. 106. U.S. Geol. Survey, 1904.
[2] G. M. Dawson. Ann. Report, 1886, Geol. Survey of Canada, p. 10B.

white marbles, are seen on microscopic examination to consist essentially of calcite, in irregular grains, firmly cemented by the same material. The accessory constituents are small in amount, and include quartz, which occurs in very small grains, sericite, and epidote. Pyrite is usually present in small disseminated grains, which weathering to limonite, slightly stain the exposed surfaces.

The chemical composition of one of the purer marbles of the Nitinat formation is as follows:—

Calcium carbonate, $CaCO_3$	96·89
Magnesium carbonate, $MgCO_3$	0·42
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3 .	0·40
Insoluble mineral matter	2·64
Sulphur, S	0·01
Phosphorus, P	trace
	100·36

West shore, southern end of Nitinat lake, northeast of Indian reservation. F. G. Wait, Analyst, Chemist Mines Branch, Dept. of Mines.

Metamorphism.—The pure marbles have been altered near intrusive granitic rocks, and along shear zones, passing in such places into dark, almost black weathering varieties, in which quartz and sericite are in much larger amount, and in which diopside and sometimes feldspar, probably an acid plagioclase, occur. At times, especially where associated with masses of almost pure magnetite, which occur along the contacts with intrusive granitic rocks, the limestones have been metamorphosed into typical garnet-diopside rocks, which have been recognized as characteristic of similar limestone contacts in many parts of the world. The garnet is a brown massive variety of andradite, and the diopside occurs in green, finely granular masses. The garnet and diopside are associated with quartz, epidote, and calcite, which occur as interstitial grains, or more commonly as veinlets.

No example has been observed where the pure marble of the Nitinat formation is in actual contact with a large body of the intrusive granitic rock. The contact zone of the marble is occasionally relatively narrow, and composed of the garnet-diopside, 'contact rock,' described in the previous paragraph. More commonly the contact zone is very wide, even wider than the masses of pure marble, and is composed chiefly of amphibolite; and the numerous inclusions or xenoliths in the granitic rocks are also amphibolites, although the granitic rocks, clearly in many cases, invaded a relatively pure limestone.

The amphibolites are dark green, very fine grained rocks, consisting of amphibole and feldspar, and they have been fractured, and recemented by sericite and epidote veinlets.

Microscopic. On microscopic examination the essential constituents are seen to be a pale green, or greenish brown hornblende, and clouded feldspar, and, rarely, small grains of pyroxene. The accessory constituents are titanite and magnetite, and the secondary minerals are sericite and limonite. Quartz is sometimes present in small amounts. The rock has usually a somewhat foliated appearance due to a subparallel arrangement of the hornblende, and occasionally types occur in which the feldspar forms large, euhedral grains, giving the rock a porphyritic appearance. These amphibolites resemble those associated with the Laurentian marbles of Ontario, described by Adams,[1] especially the type described as the final product of alteration.

Structural Relations. Internal. The strike of the Nitinat formation varies, but is in general about N 65° W. On account of the recrystallization of the limestones and their replacement over wide areas by granitic rocks, the bedding and structure is often obscured, but they have probably been closely folded, since the recorded dips are all high, in a large number of cases, approximately vertical. Rarely, contortion is to be observed.

The marbles are sometimes thick-bedded and not greatly jointed, such as those exposed at the southern end of Nitinat lake to the northeast of the Indian reservation; more commonly, however, the marbles are thin-bedded, and greatly jointed and fractured. Shear zones are frequent, along which alteration of the marble has taken place, producing the dark weathering, silicified varieties described above.

[1] F. D. Adams. On the Origin of the Amphibolites of the Laurentian Area of Canada. Journ. of Geol., Vol. XVII, 1909, pp. 1-18.

External.—Relation to older formations.—The Leech River formation, which lies to the south of the eastern end of the belt underlain by the Nitinat formation, is considered to be older, but there is no definite structural or paleontological evidence. The contact of the two formations was not seen, although near the mouth of Gordon river it was located within a distance of one or two hundred feet. The contact appears to be straight, and is considered to be a fault with the downthrow side to the north. On account of the great lithological dissimilarity of the two formations, as well as the intense contact metamorphism of the Nitinat formation by intrusive granitic rocks, the respective amount of metamorphism of the two formations cannot be used to determine their relative ages. The only reason, therefore, for considering the one formation to be older or younger than the other, is their respective correlations, the Leech River formation being at present best correlated with the Carboniferous slates of the Pacific coast, while the Nitinat formation, as afterward pointed out, is best correlated with the Vancouver group, and is, therefore, considered as Triassic or Jurassic.

Relations to younger formations.—The Vancouver volcanics occur to the north of the Nitinat formation but over considerable distances the two formations are separated by bodies of igneous rocks intrusive into both groups. At one known locality only, near the northern end of Nitinat lake, are the two formations believed to be in contact with one another, and there the actual contact was not seen, and possibly, since the contact is marked by a valley and appears to be fairly regular and straight, is represented by a fault. Therefore, since the nature of the contact between the two formations is unknown, no definite information has been obtained concerning the relations of the Nitinat and Vancouver volcanics. But the strike of the Nitinat formation and its general structure is conformable with the strike and structure of the Vancouver group, and therefore, for this and other reasons discussed under correlation, the Nitinat formation is best considered as a part of the Vancouver group, and is, therefore, supposedly conformable with the Vancouver volcanics, probably underlying them.

The Nitinat formation is older than the Beale diorite and Saanich granodiorite which are clearly intrusive into it. As already described, the diorite and granodiorite are never in direct contact with the pure marbles of the Nitinat formation, although on Point Mark, south of Numukamis bay, on the east shore of Barkley sound, the marble is cut by dykes of the quartz-feldspar or granodiorite porphyrite, which is closely related to the plutonic rocks. Near the contacts the limestones are altered in virtually every case to the characteristic garnet diopside 'contact rocks,' or to amphibolites. The contact metamorphosed varieties are cut by numerous apophyses of the granitic rock, and form contact breccias with the Beale diorite. No large granodiorite masses, although granodiorite is the chief rock type of the invading batholiths, occur in contact with the metamorphic varieties of the limestones, but diorite is the contact phase. In some instances, especially near the areas of pure marble, the diorite grades into a rather fine grained basic variety, so that it appears, since this is a feature only of the limestone contacts, as if the limestone had had an influence on the composition of the plutonic rocks near the contacts.

Mode of Origin.—Little or no evidence has been found which indicates the origin of the original limestones of the Nitinat formation. The other limestones of the Vancouver group, the Sutton formation, are of organic accumulation, and if the Nitinat formation is correctly correlated with the Vancouver group, it may be presumed that it, too, has been formed by the accumulation of calcareous organisms under marine conditions.

That the garnet-diopside rocks are the product of contact metamorphism of the limestones can hardly be doubted, especially in view of the large number of cases described from many parts of the world of the development of similar rocks along limestone contacts. A debatable question is whether the limestones so altered were originally impure, containing the necessary ingredients to form garnet and diopside when they were recrystallized by the heat of the invading magma, and by mineralizers escaping from it; or were relatively pure, the silica and iron being introduced from the invading magma. Very little evidence of a definite nature can be given from the occurrence of the garnet-diopside rocks of the Nitinat formation. These rocks are, as far as examined, always in close association with the relatively large areas of pure marble. It is shown elsewhere[1] that the iron of the large magnetite bodies associated with the garnet diopside rocks has apparently been introduced in concentrated solu

[1] Under Iron Deposits, see pages 192-193.

tions, and since the original limestones, judging from the character of the portions preserved as marbles were seemingly pure carbonates, it is to be presumed that the silica and iron necessary to form the andradite garnet and diopside were also introduced.

The origin of the amphibolites is not so apparent. From the close association and structural relation of the amphibolites and marbles it appears as if the amphibolites were formed by the contact metamorphism of the marbles, but no transitional types such as Adams[1] describes, were seen. In other parts of the island similar amphibolites occur developed along contacts of the Vancouver volcanics and intrusive batholiths, and in the Nitinat formation even [illegible] have been converted into amphibolites. There are not, however, any large bodies of clearly recognizable volcanic rocks associated with the Nitinat formation, and since Adams has shown by his very extensive and careful work that amphibolites may be formed from limestones, the best working hypothesis is to consider the amphibolites of the Nitinat formation as metamorphosed limestones.

[illegible] *Correlation.* No definite evidence of the age of the [illegible] is at hand, other than that it is pre-batholithic, that is, pre-upper Jurassic. If the formation ever contained fossils, they have been destroyed by the recrystallization and intense contact metamorphism of the original limestone.

Limestones of both upper Palaeozoic and [illegible] Mesozoic horizons are known to occur in the [illegible] of British Columbia, in the upper part of the [illegible], and in the Vancouver and related groups. [illegible] of the Cache Creek group occurs a very thick [illegible] the Marble Cañon limestones.[2] No such thick [illegible] is known in the Pacific Coast region of British [illegible] Washington that is assuredly lower Mesozoic. The [illegible] formation appears as if it were originally composed almost entirely of limestone, and to judge from the width of the belt that it underlies, was probably of considerable thickness. From purely lithological evidence we might, therefore, correlate the Nitinat formation with the Marble Cañon formation of the Cache Creek group. However, the Nitinat

[1] F. D. Adams. Journ. of Geol., Vol. XVII, 1909, pp. 1-18.
[2] G. M. Dawson. Report on the area of the Kamloops Map-Sheet. Ann. Report, Geological Survey of Canada, Vol. VII, 1895, p. 46B.

formation does not appear to be conformable with the Leech River formation, which has been correlated with the lower part of the Cache Creek group; although this appearance is not at all conclusive, since the two formations are separated by a probable fault. On the other hand, the Nitinat formation appears to be conformable in structure with the Vancouver volcanics, and all of the other limestones of southern Vancouver island are apparently lower Mesozoic in age, belonging to the Vancouver group. The evidence appears to be slightly in favour of correlating the Nitinat formation provisionally with the Vancouver group.

Dykes of altered andesite or basalt porphyrite cut the Nitinat limestones, and appear to be pre-batholithic, since they have been converted to amphibolites. They may be related to the volcanic members of the Vancouver group. The absence of interbedded volcanic rocks, and the presence of the dykes, suggests that the Nitinat formation may be the lowest member of the Vancouver group, having been deposited before volcanic activity began.

VANCOUVER VOLCANICS.

Under the name of Vancouver volcanics are grouped and mapped those volcanic rocks of the Vancouver group which are not included in the Metchosin volcanics and Sicker series. The Vancouver volcanics comprise the great bulk of the rocks of the Vancouver group. The Sicker series as mapped includes some typical Vancouver volcanics which could not be separated on small scale, reconnaissance mapping; while some schists and fragmental volcanics of the Sicker series are doubtless included in and mapped with the Vancouver volcanics.

Distribution.—The Vancouver volcanics underlie the greater part of a central belt in southern Vancouver island, which has a trend roughly parallel with that of the whole island, which is, in the southern part of the island, about N 60° W. The belt is 35 to 40 miles wide in the western and central portions, and narrows to the east to about 20 miles, where the volcanics are largely replaced by intrusive granitic rocks or partly covered by younger sedimentary rocks of the Nanaimo formation. The southern boundary is the contact with the Nitinat and Leech River formations; and the northern boundary is the unconformable contact with overlying sedimentary rocks of the Nanaimo formation. These boundaries are very definite and have been located fairly accurately. The Vancouver volcanics are more or less interrupted by areas underlain by the Sicker series, the Cowichan group, and intrusive granitic rocks. Since the rocks of the belt are fairly well exposed, except on the smooth upland and in the larger valleys, the contacts of the various formations are, where crossed by traverses, well located, but are otherwise, as indicated on the map, only approximately located.

Lithological Characters.—The Vancouver volcanics are basic, chiefly andesites, and augite andesites, with some dacite-tuffs. Both flow and fragmental types are present, and include amygdaloids, porphyries, tuffs, and breccias. Intrusive dykes and sills of andesite and basalt porphyrites also occur. All of the rocks have been metamorphosed, and in part recrystallized. They are seamed with quartz and epidote, and at one locality veins of common opal occur.

Normal Meta-andesite. The principal rock type is a meta-andesite, often with essential augite. Megascopically the andesites are aphanitic, and sometimes porphyritic, with small but numerous phenocrysts of feldspar and altered hornblende. They are usually dark green in colour, but the finer grained, sometimes silicified varieties, are light green. They have been sheared and altered, and the green colour is largely due to secondary chlorite. They are also cut by veinlets of quartz, epidote, and calcite, and are commonly impregnated with pyrite.

Microscopic.—Microscopically the groundmass is seen to consist essentially of small, lath-shaped crystals or microlites of andesine feldspar, and originally hornblende and augite, now largely altered to and replaced by chlorite and calcite. The only important accessory mineral is magnetite, which occurs in fine grains in relatively small amount. The phenocrysts, when present, are of andesine, and altered hornblende and augite. They are usually of medium size, and numerous, although the groundmass is virtually always dominant. The degree of alteration is large, and besides the secondary minerals chlorite and calcite, mentioned above, epidote, sericite, and pyrite and limonite are very common. More rarely the femic minerals have altered to uralite or biotite. In silicified varieties, quartz is, of course, an important secondary constituent.

Certain textural varieties of the normal andesite occur, chiefly amygdaloids. The amygdules are seldom large, although often numerous, and consist chiefly of chlorite, calcite, and more rarely quartz. Taxitic or eutaxitic varieties occur, which, although flow rocks, contain fragments of similar composition but different texture.

Porphyritic Augite Andesite.—A type, characterized by large hornblende phenocrysts, which are pseudomorphs after augite, occurs in close association with the Sicker series, and, where they could not be separated in the small scale mapping, are mapped with the Sicker series. Large areas composed chiefly of this type of augite andesite occur, however, south of the Sicker series, immediately to the north of Cowichan lake; and again to the north of the Sicker series, south of Ladysmith.

Megascopically they are dark green porphyritic rocks, with an aphanitic groundmass, and numerous, relatively large (up to 2 cm. in diameter), stout, prismatic phenocrysts of dark green hornblende, which have, very commonly, a nucleus of light green augite. Where exposed to unusual rapid weathering by solution, as along the shores of lakes and inlets, the phenocrysts have been left in relief, often preserving their crystalline form, which is that of a pyroxene.

Microscopic.—Microscopically the groundmass is seen to consist of a fine mat of amphibole (probably uralite) needles and andesine feldspar, with accessory magnetite. The phenocrysts are, with the exception of a few small phenocrysts of altered andesine, of pale green, weakly to moderately pleochroic hornblende, and, as seen megascopically, often with a nucleus of augite. The hornblende not only surrounds the augite, but fingers into it, along irregular cracks. The hornblende is unquestionably secondary after augite, but since it is a compact variety such as would only form under conditions of high temperature and pressure, it is probable that it crystallized under magmatic conditions. The augite andesites have also been altered in a manner similar to that of the normal andesites, the chief secondary minerals being uralite, chlorite, epidote, and calcite.

Amygdaloidal and taxitic varieties, similar to those of the normal andesite, also occur, which are, however, always porphyritic.

Fragmental varieties.—There are associated with the flow rocks numerous fragmental varieties. They vary from fine grained tuffs

Andesite breccia of the Vancouver volcanics, east shore of Saanich inlet, Highland district

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to breccias with angular fragments of volcanic rocks up to several inches in diameter (see Plate VI). They are commonly red or purplish weathering, while the more dense included fragments are green. Some of the amygdaloids and more altered phases of the normal andesites are also red weathering, but as a general rule the red weathering fragmental varieties are in striking contrast with the green weathering flow-types. The fragmental varieties of the typical Vancouver volcanics are rarely stratified.

Microscopic.—The fragments are seen on microscopic examination to include mineral as well as rock fragments. The tuffs and breccias are similar mineralogically to the flow rocks, but are invariably more feldspathic. They are more altered, and the secondary minerals include besides chlorite, epidote, calcite, and sericite, which are also characteristic secondary minerals of the flow-types, kaolin and hematite. In certain cases, near the intercalated limestones of the Sutton formation, as on the south shore of Cowichan lake, between Croft creek and the type locality of the Sutton formation, the tuffs contain large fragments of limestone, and secondary calcite has almost completely replaced the original minerals of the tuff, but without entirely destroying the original texture.

Dacite Tuffs.—There are exposed in the vicinity of Finlayson arm of Saanich inlet in the Highland and Malahat districts, a series of fragmental rocks, which are stratified, but apparently of volcanic origin, and which contain essential quartz, and are, therefore, classed as dacites. They resemble certain types of the Sicker series, but cannot at present be correlated with them. They are seen megascopically to be dark to light grey in colour, fine to medium grained, the more metamorphosed being slaty in appearance, clearly stratified, and composed of angular fragments of quartz, feldspar, and a dark cherty rock. They are usually cut by quartz and quartz-feldspar veinlets, and are impregnated with pyrite.

Microscopic.—On microscopic examination they are seen to consist essentially of quartz, plagioclase and orthoclase feldspar, brown biotite, kaolin, and fragments of a silicious, microcrypto-crystalline volcanic rock. The accessory constituents are magnetite, zircon, epidote, chlorite, and carbonaceous matter. These are not readily distinguishable from the numerous secondary minerals which are present—chlorite, sericite, pyrite, limonite, quartz, and calcite. As stated above, the fragments are angular. The tuffs have been dynamo-metamorphosed and are now somewhat schistose.

A peculiar variety of these tuffs, not seen elsewhere, is exposed in a cut on the Esquimalt and Nanaimo railway, one-half a mile north of the 14 mile post in Malahat district. It is coarse grained, with fragments up to 2 or 3 cm. in diameter. The fragments consist of a white weathering, cryptocrystalline feldspathic rock, and occur in a black, fine grained groundmass. The contrast of the white fragments and black groundmass is very striking, and is accentuated by the fracturing and shearing the rock has undergone.

Microscopic.—Both the fragments and groundmass are seen on microscopic examination to consist essentially of feldspar (probably plagioclase), and quartz, the groundmass being coloured with carbonaceous matter. The feldspar and quartz of the fragments occur in clear, colourless grains of microscopic size, which are irregularly intergrown. Quartz also forms irregular veinlike replacements in the fragments. Sericite is the only important secondary mineral. The rock has been dynamo-metamorphosed and somewhat silicified. Although of rather doubtful origin, the rock is probably a dacite tuff-breccia.

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

Microscopic.—The mineral composition is seen on microscopic analysis to be similar to that of the normal andesites. The essential constituents are andesine and originally hornblende, now largely altered to uralite and chlorite. Magnetite and apatite are both accessory. The alteration is also similar to that of the normal andesites, and the same secondary minerals occur. The texture is, however, distinctive. The andesine occurs in wide, lath-shaped crystals, diversely arranged, sometimes with prismatic hornblendes. The original femic minerals were, however, largely interstitial to the andesine.

Basalt porphyrites.—Especially well exposed along the east shore of Barkley sound and Alberni canal, although they occur in other parts of the island, are injected rocks in which the feldspar is labradorite, seldom very basic, about Ab40, An60, and are, therefore, basalt rather than andesite porphyrites. They are similar in megascopic appearance to the andesite porphyrites, but the phenocrysts are larger and more numerous, and the lath-shaped character of the feldspars of the groundmass more pronounced.

Microscopic.—On microscopic examination the phenocrysts are seen to be not only of labradorite, but also of augite and a light green, weakly pleochroic hornblende, which occur in rather small subhedral grains. The essentials of the groundmass are labradorite and the light green hornblende, and commonly augite. The accessories are numerous and in large amount, and include ilmenite and magnetite, titanite, apatite and apparently quartz. The labradorite of the groundmass occurs in lath-shaped crystals, with interstitial, and rarely poikilitic, hornblende and augite. They have been less altered than the flow rocks, but secondary minerals, uralite, biotite, chlorite, epidote, sericite, calcite, and leucoxene are fairly abundant.

Basalt flow-breccia.—A peculiar type, apparently related to the basalt porphyrite, is exposed on the east shore of Alberni canal, a mile and a half north of Coleman creek. It is an agglomerate with angular to rounded fragments of volcanic rocks ranging from aphanitic types to relatively coarse grained basalt porphyrites; and may represent an old volcanic neck. The matrix is dark green, aphanitic, seen on microscopic examination to have been originally glassy, with a taxitic texture which resembles the texture of the welded pumice of Yellowstone park.[1]

Metamorphism.—As already mentioned and as may be seen from the petrographic descriptions, the Vancouver volcanics are all greatly metamorphosed. The metamorphism, resulting in the alteration

[1] J. P. Iddings. Monograph 32. U.S. Geol. Survey, 1899, p. 404.

described above, the secondary minerals being chiefly uralite, chlorite, epidote, calcite, and sericite, is characteristic of that which takes place under conditions of moderate to shallow depths, and moderate temperature. It has probably taken place in large part during the folding and shearing that the volcanic rocks have undergone during periods of mountain building movements. Extreme cases of this type of metamorphism occur, the typical meta-volcanics passing into sheared and schistose varieties.

A horizon of schistose meta-volcanics occurs to the north of the Leech River formation, from Langford lake, in Esquimalt district, to Jordan meadows. They are greenish-grey schistose rocks, varying in composition from rocks similar to the normal meta-andesites and andesite tuffs to rocks consisting of fine aggregates of actinolite and uralite, with epidote and secondary quartz and albite. These rocks are also very commonly mineralized in a varying degree, with pyrite, pyrrhotite, and chalcopyrite, which occur in disseminated grains and irregular veinlets. These rocks pass into varieties which are more quartzose, and in the dacite tuffs, which occur to the north, dense cherty rocks composed almost entirely of feldspar and quartz occur. It is probable that this type of metamorphism was not due solely to dynamic movement, but since the rocks occur near the intrusive Wark diorite and quartz diorite gneiss, may be due in part to contact metamorphism.

Similar types to those described above occur associated with contact metamorphosed limestones, near intrusive granitic rocks, and contact deposits of magnetite and iron and copper sulphides. They are green, fine grained, sheared rocks, mineralized and cut by quartz and calcite veinlets. They consist almost entirely of secondary minerals, actinolite, epidote, chlorite, serpentine, and sericite, more or less replaced by later quartz and calcite. Similar altered and mineralized rocks also occur along shear zones in the volcanics. These mineralized types weather rapidly, forming a thick coating of limonite, which attracts the prospectors, but they are too low grade to be of value.

At times the contact metamorphism of the volcanics resembles that produced in the intercalated limestones, so that it is impossible to tell in some cases what the original rock was. Amphibolites, formed by the metamorphism of the volcanic rocks are quite common. They resemble those formed from the limestones, especially those of the Nitinat formation, but are rather more feldspathic, and occasionally show traces of what is apparently an original porphyritic or amygdaloidal texture.

The volcanic rocks in the vicinity of Victoria and Esquimalt are much more generally metamorphosed than the rest of the Vancouver volcanics. They resemble, however, the contact metamorphosed types described above, and as they are intruded by numerous masses of granitic rocks, it is probable that they are not an older series of volcanic rocks, but are contact metamorphosed phases of the Vancouver volcanics.

Structural relations.—Internal. The various effusive varieties of the Vancouver volcanics are apparently conformable, since flow and fragmental varieties occur interbedded with each other. Nevertheless, as noted above, the fragmental varieties of the normal andesites are seldom stratified. The relations of the dacite tuffs with the normal andesites is not clear, but they are probably conformable. The relation of the schistose varieties which occur to the north of the Leech River formation, from Langford lake to Jordan meadows, is not definite, and they may represent an older series of volcanics. As already mentioned, the volcanic rocks in the vicinity of Victoria and Esquimalt are considered to be contact metamorphosed phases of the Vancouver volcanics, and this conclusion is supported by their occurrence in the strike of the Vancouver volcanics, their lithological and structural similarity to them, and by the presence in both, of beds of similar crystalline limestone.

Although the fragmental varieties indicate explosive eruptions, no occurrence resembling an ancient and denuded volcanic neck was observed, other than the basalt flow-breccia described as occurring on the east shore of Alberni canal. There the relations were not clearly observed, but the basalt flow-breccia apparently forms an injected mass in the porphyritic meta-andesites. Old lava channels are probably represented by the dykes of andesite and basalt porphyrite, which clearly cut the effusive varieties. As observed, the dykes do not appear to be very numerous, but they are easily overlooked.

On account of the massive and metamorphic character of the Vancouver volcanics, their attitude is rarely determined by direct observation. They have a general strike parallel to that of the belt which they underlie, that is about N 60° W. The dips are appar ently large, approximately vertical in most of the few cases where the dip could be determined. The recorded strikes, obtained chiefly from the folded fragmental types, are usually in the northwest-southeast quadrants, but to the south of the central part of Cowichan lake the tuffs, flows, and intercalated limestones of the Sutton formation strike north-south to northeast-southwest. Small folds, and more rarely contortions, are to be seen in places. From the above evidence it is probable that the Vancouver volcanics are closely folded into large rather than small folds, whose axes have a general strike parallel to that of the southern part of the island.

The volcanics are jointed, greatly faulted, and sheared, largely owing to dynamic movement. Very rarely, as on Mount Todd, in the western Malahat district, the regularity which is observed in the jointing suggests that it was formed during the cooling of an old lava. The observed faults were both normal and reversed, and of small throw, except in the case of boundary faults; but doubtless larger faults occur, not readily recognized on account of the lithological similarity of the volcanics. The sheared volcanics are commonly silicified and mineralized as described above, and are cut by veins of quartz, quartz and epidote, and calcite. At one locality, in the bed of Gordon river near its source, about three miles south of Cowichan lake, the sheared volcanics are cut by irregular veins, a foot or slightly more in width, of an opaque, cream-coloured opal. The opal is seen on microscopic examination to occur in irregular grains, sometimes with a fibrous structure and anomalous birefringence. Sericite, which has largely altered to kaolin, and calcite are also present.

EXTERNAL RELATIONS TO OTHER MEMBERS OF THE VANCOUVER GROUP.

The Sutton formation, which consists of the intercalated limestones in the Vancouver volcanics, is clearly conformable in a general way with the volcanics. As described under the Sutton formation, the contacts are, however, usually intrusive.

The Nitinat formation occurs to the south of the western part of the belt of the Vancouver volcanics. As already described, the contact, although located fairly accurately, was not actually observed. In the western portion the contact is marked by a valley, and may, as suggested, be a fault. In the eastern portion, on Gordan river, the southern contact of the volcanics is with the

Saanich granodiorite, which is intrusive into both the Nitinat formation and the Vancouver volcanics. The Nitinat formation appears to be conformable in structure with the Vancouver volcanics, and for this and other theoretical reasons[1] the Nitinat formation is considered provisionally to be a part of the Vancouver group, and, therefore, conformable with the Vancouver volcanics. It is suggested that it underlies the volcanics, and that the andesite porphyrite dykes which cut it are to be correlated with those of the volcanics.

The Sicker series forms a tongue-shaped mass in the central part of the belt of Vancouver volcanics, extending west from Saltspring island to north of Cowichan lake. It contains flow rocks, the porphyritic augite andesites, typical of the Vancouver volcanics, which are conformable with rocks of the Sicker series. As already mentioned, these porphyritic augite andesites are so intimately interbedded with the Sicker series that in some cases they could not be mapped separately. Since the Sicker series apparently grades upward into relatively unmetamorphosed sediments, it is to be presumed that it overlies the Vancouver volcanics; but there are certain objections to this idea (see page 83).

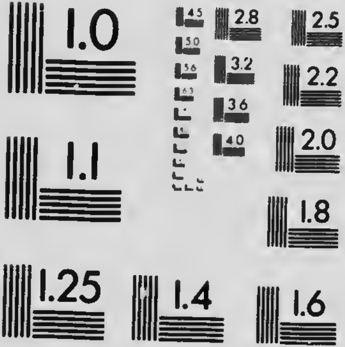
No structural relations between the Metchosin and Vancouver volcanics could be determined, since in the southeastern part of the island, in Esquimalt district, which is the only place where they are not separated by the Leech River formation, the contact is covered by the thick deposit of sand and gravel of the Colwood delta. The two volcanic formations are unlike petrographically, and the Vancouver volcanics are very much more metamorphosed. It is strongly suggested, therefore, that the Vancouver volcanics are older than the Metchosin volcanics. It has been thought best, however, to place the Metchosin volcanics provisionally with the Vancouver group, but they are almost assuredly not conformable with the Vancouver volcanics.

Relation to older formations.—To the south of the Vancouver volcanics in the east central part, from Goldstream river to San Juan river, is the Leech River formation. In the western part, the contact is a supposed fault, which occurs along the northern slope of the upper part of the San Juan valley. Along the eastern part of the contact from Goldstream river to west of Jordan meadows, the

[1] See pages 49 and 50.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



rocks to the north of the Leech River formation are the schistose varieties, whose relation with the normal meta-andesites is doubtful. Their relation with the Leech River formation is also indefinite. In the vicinity of Jordan meadows they appear to be infolded with the Leech River slates, without any apparent faulting or unconformity, as is true farther east also, although there, no infolds were observed. At present, since the schistose volcanics are closely related lithologically and structurally to the Vancouver volcanics, which appear on the whole to be younger than the Leech River formation, it seems best to consider the schistose volcanics and the Leech River formation as belonging to different groups, the schistose volcanics being the younger.

Relation to younger formations.—The Saanich granodiorite and its related plutonic rocks are clearly intrusive into the Vancouver volcanics. The plutonic rocks occur chiefly in irregularly outlined, small batholiths, which have been erupted along two main axes, a southern and a northern, the southern batholiths being intrusive into Vancouver volcanics only in the southeastern part of the island. Small stocks and bosses also occur between these main axes. Diorite is sometimes the contact phase of the intrusive batholiths, but more commonly it is a quartz diorite or granodiorite; so that the volcanics do not appear to have affected the invading magmas as the Nitinat limestones have. At the contacts, intrusive porphyrites, quartz-feldspar or granodiorite porphyrite predominating, occur as irregular dykes in the invaded volcanic rocks. The batholiths have greatly affected the invaded volcanics, metamorphosing them to schistose, silicified, and mineralized varieties, and also to amphibolites.

The sedimentary rocks of the Cowichan group which are seen in contact with the Vancouver volcanics are probably of the Nanaimo formation. They are unconformable upon the volcanics and coarse basal conglomerates occur, made up largely from detritus of the rocks of the Vancouver group.

The mode of origin and age and correlation of the Vancouver volcanics is so closely associated with that of the intercalated Sutton limestones, that it is discussed in connexion with the origin and age and correlation of the Sutton formation in the following section.

SUTTON FORMATION.

Intercalated with the Vancouver volcanics are numerous lenses of crystalline limestones or marble. From one of the lenses, exposed on the south shore of Cowichan lake, 3 miles west of Sutton creek, determinable fossils were collected. The fauna has been determined as lower Jurassic, and the beds in which the fossils occur have been named, from Sutton creek, the Sutton formation. It is probable that the other limestone lenses of southern Vancouver island are of the same or nearly the same age, and the Sutton formation is extended provisionally to include all of the intercalated limestones in the Vancouver volcanics of southern Vancouver island.

Distribution.—The limestone lenses constituting the Sutton formation have a wide distribution throughout the belt of Vancouver volcanics, except in the northeastern part, to the west of Nanaimo and Ladysmith, where no limestones were observed. They are especially well developed to the west of Esquimalt harbour, and extend from the vicinity of Esquimalt and Victoria to Alberni canal. Richardson[1] records similar fossiliferous limestones to the north of Alberni, and in the vicinity of Horne lake, 8 miles northeast of Alberni. The lenses are numerous, but small. There are only 34 lenses shown on the accompanying map, but in southern Vancouver island there are probably well over 100 lenses which are 50 feet or more in width, and besides these larger lenses there are in the volcanic and intrusive plutonic rocks many more smaller ones, some mere fragments, a foot or more in diameter. The greater number of the lenses as mapped are exaggerated in size, as they are only a few hundred feet in width, and one-quarter to one-half a mile in length. The largest mass that was measured is over a quarter of a mile in width and a mile and a half in length, and extends west from Esquimalt harbour to Colwood plain. Another mass probably as large, but which was observed only at a distance, forms the larger part of Limestone mountain, situated at the headwaters of Franklin river, 7 miles west of Alberni canal.

Lithological characters.—The limestones of the Sutton formation are all crystalline. They are chiefly grey to greyish blue, more rarely white, compact to fine grained marbles. At one locality, that

[1] James Richardson. Coal-fields of Vancouver and Queen Charlotte islands. Rept. of Progress, 1872-73, Geological Survey of Canada, pp. 52-56.

where the fossils were found, on the south shore of Cowichan lake, 3 miles west of Sutton creek, the original character of the limestone is still preserved. There, two beds occur which are formed entirely of corals, and are doubtless old coral reefs. Between the coral beds are strata composed almost entirely of small fragments of calcareous organisms, that is, typical calcarenites. Interstratified with the calcarenites are beds, one very thick, composed chiefly of pelecypod shells, which form a veritable coquina. The limestones weather characteristically, developing solution hollows with smooth surfaces, and small knob-like protuberances. They are very frequently brecciated, apparently by dynamic forces, and recemented by calcite veinlets.

Microscopic.—They are seen on microscopic examination to consist essentially of calcite, or magnesian calcite, in small grains, sometimes microscopic in size and firmly cemented together. Accessory or secondary constituents are, in many of the limestones, virtually absent. In others, small amounts of argillaceous and carbonaceous matter occur, and frequently a small amount of pyrite in minute cubical grains is present.

Near the contacts with the intrusive plutonic rocks the marbles are coarser grained and correspondingly lighter coloured. Calcite is still the only essential mineral, and the grains are always firmly cemented. Pyrite is more abundant and occurs in larger grains up to 2 or 3 mm. in diameter. At times light coloured, coarser grained lenses and zones occur in the darker, more compact marble. Where still more affected by contact metamorphism small diopside grains occur, that frequently have been altered to a white weathering opaque serpentine; and the original argillaceous matter has been recrystallized to sericite. Magnetite as well as pyrite is usually present in these varieties.

The following analysis is furnished by Mr. Adolph Neu, chemist with the Vancouver Portland Cement Company, and is an average analysis of the purer limestones from the quarry at Tod inlet:—

Calcium carbonate, $CaCO_3$	97·5 per cent.
Silica, SiO_2	1·1 "
Iron oxide, Fe_2O_3	0·8 "
Magnesia, MgO	trace
Specific gravity	ca. 2·6

Two other analyses of the Sutton limestones and one of the Nitinat limestone, for comparison, are given below:

	I.	II.	III.
Calcium carbonate, $CaCO_3$	95·35	86·29	96·89
Magnesium carbonate, $MgCO_3$	2·[illegible]5	0·42	0·42
Ferric oxide and alumina, Al_2O_3 and Fe_2O_3	·	1·40	0.40
Insoluble mineral matter	1·95	11·88	2·64
Sulphur, S	trace	0·42	0.01
Phosphorus, P	trace	0.02	trace
	100·31	100·43	100.36

I. Sutton formation, Rosebank Lime Company's quarry, one-half mile west of Esquimalt harbour.

II. Sutton formation, south shore of Cowichan lake, interbedded with fossiliferous beds.

III. Nitinat formation, west shore, southern end of Nitinat lake, northeast of Indian reservation.

F. G. Wait, Analyst; Chemist, Mines Branch, Dept. of Mines.

Metamorphism.—Diopside-epidote varieties. The dynamic metamorphism that the Sutton limestones have undergone has only served to crystallize them into marbles, but near the intrusive granitic rocks their mineral and chemical composition has been greatly changed, and they pass from the slightly contact metamorphosed varieties described above, to rocks composed chiefly of diopside and garnet; which in turn have sometimes been replaced by quartz and feldspar, or sheared and impregnated, and more or less replaced by metallic minerals. The least altered limestones consist of coarsely crystalline calcite, with irregular streaks of fine grained greenish silicates, which are seen microscopically to be diopside, epidote, and quartz, usually with some calcite. These pass into varieties in which the calcite has been entirely replaced. They are dense, light green rocks, locally called felsite, and consist chiefly of diopside, in small, sometimes sub-fibrous grains, with a little interstitial quartz and calcite, although varieties occur in which diopside is virtually the only mineral present. These types are usually cut by veinlets of quartz, sericite, and calcite, and in some instances by brown massive garnet. More rarely types of similar megascopic appearance occur, which are seen on microscopic examination to consist chiefly of epidote, irregularly intergrown with quartz and calcite.

'Garnetite.' The most common type of contact metamorphosed limestone is the so-called 'garnetite,' which is very commonly associated with the contact deposits of metallic minerals. It is a massive rock, consisting of a fine grained aggregate of light green silicates, diopside, and epidote, with calcite, sericite, and quartz, and light brown to greenish brown massive garnet, cut by veinlets of quartz and calcite. Actinolite is more rarely present. The garnet as determined by qualitative analyses is andradite, the iron-calcium garnet, although alumina and magnesia were detected in some cases. The garnet, though usually granular, also occurs in small dodecahedral crystals, showing microscopically a zonal growth and anomalous birefringence. The more common massive garnet is invariably isotropic, except where it has been subjected to dynamic stresses. Serpentine, probably derived from the diopside, is frequently present.

QUARTZOSE AND FELDSPATHIC VARIETIES AND AMPHIBOLITES.

In some instances the above mentioned contact metamorphosed varieties are largely replaced by quartz and feldspar. This phase is usually a dense, green rock resembling the diopside varieties, but contains patches of the unreplaced diopside, epidote, and garnet. Amphibolites, similar to those of the Nitinat formation, occur, but only rarely, and in most cases cannot be distinguished from those formed by the metamorphism of the associated volcanic rocks.

Mineralization.—Virtually all of the contact metamorphosed limestones have been impregnated, and more or less replaced, by metallic minerals. The more richly mineralized varieties have been sheared, and in these occur actinolite, serpentine, and chlorite, derived chiefly from diopside. The impregnating minerals occur in disseminated grains and are the following: magnetite, pyrite and chalcopyrite, and more rarely sphalerite and galena. They also occur in veinlets and irregular replacements, pyrrhotite being an important constituent of the larger masses.

Structural relations.—The general structure of the Sutton formation is virtually identical with that of the Vancouver vol-

Conformable contact of Sutton limestone with coarsely vesicular andesite of the Vancouver volcanics. South shore of Cowichan lake, to the west of the fossil beds.

canics, since the two formations are so intimately related. The formation has, therefore, a general strike of N 55° to 65° W, with steep dips; with large variations such as occur south of Cowichan lake, where the beds have a northeast-southwest strike. In common with the Vancouver volcanics, it has been closely folded into large rather than small folds. Small folds occur such as that exposed along the western contact of the fossil-bearing beds with the overlying volcanic rocks. The fold is a closed syncline, pitching steeply to the north. The Sutton limestones have been similarly jointed, faulted and sheared, although they have yielded by brecciation to a greater extent than the volcanic rocks.

The Sutton formation has also been intruded by the granitic rocks, the Wark diorite and quartz diorite gneiss, and the Saanich granodiorite. Invariably, as is also true of the Nitinat formation, the granitic rocks are in actual contact with metamorphosed phases of the limestone. As in the case of the Nitinat limestones, the Sutton limestones have apparently affected the composition of the granitic rocks along the contacts, developing more basic and hybrid types, some of them monzonitic in character.

No actual fragments of the Sutton limestones were noted in overlying and unconformable sediments of the Cowichan group, but many of the lower members of the group are highly calcareous, suggesting that they may have been formed in part from the detritus of the Sutton limestones.

Relation to Vancouver volcanics.—The Sutton formation, as already described, occurs as limestone lenses in the Vancouver volcanics. The two formations are considered to be contemporaneous in general, although their contacts are usually intrusive. The contemporaneity of the two formations is well shown on the south shore of Cowichan lake, where the fossil-bearing limestones are in contact with effusive volcanics, which apparently flowed over an old limestone surface. Here the volcanics which overlie the limestone occur to the west. They include both flow and fragmental types and the bedding is clearly shown. The beds correspond closely to those of the underlying limestones, striking about N 35° E, with a dip of 50° to 70° to the northwest. At the actual contact the andesite is interbedded with a stratum of white, compact, crystalline limestone, 12 to 18 inches thick, which is separated by 3 feet of andesite from an underlying stratum of blue, compact, crystalline limestone, 18 to 21 inches thick. This lower limestone is also underlain by several feet of andesite, to the south of which, beyond a small creek, 75 feet wide at its mouth, occur the fossiliferous beds, some 100 feet in thickness. The contacts of the andesite and the interbedded limestones, although as a whole conformable, are in detail extremely irregular; as tongues of lava protrude into the thin limestone beds and fragments of the limestone are included in the andesite. The andesite here is also extremely vesicular, much more so than was noted elsewhere. The limestone fragments occur in the enclosing lavas for some distance, and have been rounded by solution, and now have peculiar concretionary like forms. The contact is broken by normal dip faults, with a displacement of from 5 to 10 feet, and to the southwest the andesites and included limestone beds have been folded into a closed syncline, pitching steeply to the north.

If the andesites were sills intrusive into much older limestones, even at comparatively shallow depths, it seems probable that the contacts would be similar to those of the intrusive dykes in the limestone, that is sharp, and not marked by small apophyses of andesite. Neither are the dyke rocks vesicular along the contacts; and it is very doubtful if the andesites were sills, injected under considerable pressure, whether such large vesicles would be formed. These vesicles appear to have been formed by carbon dioxide liberated by the heating of the limestones, thus bloating the andesite into an extremely coarse pumice. It is also doubtful if carbon dioxide would be liberated if the andesites were sills.[1] The limestones cannot be an older folded formation, since they are interbedded and closely folded with the andesites. It is also probable that if the andesites were sills injected into a flat-lying horizon of limestones, separating them into layers less than 2 feet thick, more regular dykes, instead of extremely irregular tongue-like masses, would have broken across the thin limestone beds. Another proof of the effusive origin of the andesites is the interbeds of fragmental volcanics. A further support to the conclusion that the limestones and volcanic rocks are contemporaneous is given by Dawson,[2] who records in northern Vancouver island intercalations in the Vancouver volcanics of limestones and other sedimentary rocks which contain a fauna of Triassic age, showing that volcanic activity was in progress

[1] Cf. J. Barrell. The Physical Effects of Contact Metamorphism. Am. Journ. Sci. 4th ser., Vol. 13, 1902, p. 285, and p. 293.
[2] G. M. Dawson. Ann. Report Geological Survey of Canada, 1887, p. 91B

[illegible] Sutton formation was deposited, and might readily have continued on into the time of the laying down of the Sutton formation.

The intrusive contacts between the other lenses of the Sutton formation and the Vancouver volcanics appear to be due [illegible] to the injection of dykes of andesite porphyrite, which cut the [illegible]sive andesites as well as the limestones. The contacts have also [illegible] greatly obscured by dynamic and contact metamorphism and faulting, and the intrusive nature may in some instances be more apparent than real. However, intrusive types doubtless occur [illegible] intermingled with the limestones as well as with one another; [illegible] is not probable, as one is led to believe by the prevalence of intrusive contacts, that the Sutton formation [illegible]ars necessarily near the base of the Vancouver volcanics.

Mr. Allan records a very small limestone lens 25 feet long and 10 feet wide on Mount Brenton, which is apparently intercalated with tufaceous volcanics of the Sicker series. This is the only limestone, as far as known, which occurs with rocks of the Sicker series.

MODES OF ORIGIN OF VANCOUVER VOLCANICS AND SUTTON FORMATION.

At the type locality of the Sutton formation the limestones were evidently formed by the accumulation of marine organisms. It is also probable that the other limestones are of a similar origin, and indeed, in a few instances, fragments of poorly preserved fossils have been found, but the larger part of the limestones have 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 volcanic r[illegible] were [illegible]ly submarine; and the comparative rarity of tuffs and brecci[illegible] of [illegible]terbeds of terrestrial material adds weight to this conclus[illegible]. The occurrence of angular and unstratified tuffs sugges[illegible] [illegible]e of the old vents were above sea-level, forming islands. T[illegible] [illegible] volcanics a few conglomerates composed [illegible] [illegible]canic fragments, so that it appears as if these vol[illegible] [illegible]ad been subjected to marine erosion on the shores of [illegible] islands. Only one such occurrence has been noted in the [illegible]aver volcanics, exposed in the bed of Koksilah river north of [illegible] lake, but the conglomerates are more common in the Metchosin volcanics. Similar conglomerates probably occur with the typical Vancouver volcanics, but have not been observed. It was on these supposed volcanic islands that the organisms which built the coral reefs and coquina beds lived. The fauna of the Sutton limestones is very provincial, having no or few affinities, as far as known in North America, and the rarity of cephalapods is a notable feature; and, since no interbeds of sedimentary material other than limestone occur with the Vancouver volcanics, it is probable that the volcanic islands were far from the mainland, to the east.

Age and correlation of the Vancouver volcanics and Sutton formation.—From purely structural evidence the age of the Vancouver volcanics and the intercalated limestones cannot be determined definitely. They are pre-batholithic, that is, pre-upper Jurassic, and probably are younger than the Leech River formation, which is considered to be Carboniferous. From the above evidence the Vancouver volcanics and Sutton formation would be placed in the lower Mesozoic; a conclusion that is supported by the character of the fauna of the Sutton limestone, which fixes the age of the Sutton formation more definitely and specifically as lowermost Jurassic.

The fauna as determined proves to be unique, with few or no affinities, so far as known in North America, and since all the species are new, the determination of age must rest upon comparison with the nearest related species. This comparison is summarized in the following table prepared by Professor H. W. Shimer:—

TABLE NO. 2

Choristoceras suttonensis (r)	C. subrhacticum*	Rhaetic	Europe	Slightly more primitive
	Polycyclus nodifer	Upper Trias	California	
Myophoria suttonensis (C)	M. goldfussi*	Upper Trias thro' Rhaetic	Centr. Europe	Slightly more primitive
Terebratula suttonensis (R)	T. globata	Lower Middle Jura	England	Less primitive
	T. phillipsi*	Middle Jura	Europe	
	T. hypsogonia*	Lower [illegible] Jura	India	Slightly more primitive
Isastrea vancouverensis (C).	I. oblonga	Upper Jura	England	Less primitive
I. cowichanensis (r)	I. parva*	Upper Middle Jura	India	Less primitive
	I. richardsoni*	Lower Middle Jura	England	Less primitive
I. whiteavesi (r).	I. oblonga	Upper Jura	England	Less primitive
Calamophyllia suttonensis (C).	C. clathrata*	Rhaetic	Centr. Europe	More primitive
C. dawsoni (C).	C. delicatula	Rhaetic	Centr. Europe	

*Comparison indicates a fairly close relationship with the Sutton species.

C = very common; c = common; r = rare, [illegible] very rare.

The conclusions as to age reached by Professor Shimer and the present writer are given in the following quotation:—[1]

'The closest comparison of species is thus (as shown in the table) with the uppermost Triassic (Rhætic) and the middle and upper Jurassic. All of the Jurassic species, with one possible exception, show less primitive characteristics when compared with the Sutton species, or the Sutton species are more primitive, indicating an age prior to that of middle and upper Jurassic. All of the Rhætic species are slightly more primitive than those from the Sutton formation, indicating for the latter less primitive forms a later period of development. This would place the age in the lower part of the lower Jurassic or lower Liassic.

'The rarity of cephalapods is a notable feature of the fauna. The absence of such characteristic west coast pelecypods as *Daonella lommeli, Halobia superba,* and *Pseudomonotis subcircularis* would make its reference to any portion of the Triassic exceedingly improbable: similarly none of the cephalapods so abundant in the western Triassic was found here.'

That the Sutton formation continues to the northwest is shown by the occurrence of what appear to be similar or identical fossils in the limestones comprising Mount Mark, north of Horne lake. These fossils were collected by Richardson in 1872. They were poorly preserved, and could not be definitely determined, and Billings supposed them to be corals, crinoids, polyzoa, and brachiopods of Permian or Carboniferous age.[2]

A similar conclusion was reached in 1908 from the first collection of fossils from Cowichan lake, apparently the same genera being recognized as the Mount Mark fossils were thought to be. It is probable, therefore, that the Mount Mark fossils belong to the Sutton Jurassic.

In northern Vancouver island Dawson[3] finds similar volcanic rocks with intercalated limestones and argillites, which contain fossils referable to the Alpine Trias. The group as a whole he believed to be of very great thickness and of wide distribution. As a distinctive name for the whole, he employed the term Vancouver

[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 '38.

[2] James Richardson. Rept. of Progress. 1872-73. Geol. Survey of Canada, p. 54.

[3] G. M. Dawson. Ann. Rept. Geol. Survey of Canada for 1886, pp. 7B-11B

group, including under that name all of the sub-Cretaceous volcanic rocks, and the intercalated limestones and other sediments. He states that if the great mass of rocks should eventually prove separable into Triassic and Carboniferous portions, the name Vancouver group should be retained for the former. It is seen that a portion of the allied volcanic rocks and limestones of southern Vancouver island are lowermost Jurassic in age, but it is probable that some Triassic members occur, either in the typical Vancouver volcanics, or in one of the allied volcanic series in southern Vancouver island. It is perhaps impossible to distinguish between the Jurassic and Triassic members in southern Vancouver island, as they are probably conformable, and as fossils are rare. Since the Jurassic rocks are largely of volcanic accumulation, sub-Cretaceous and prebatholithic in age, they are members of the Vancouver group as originally defined. The occurrence, however, of both Jurassic and Triassic members in the group should be emphasized.

SICKER SERIES.

Underlying the east central part of the belt of Vancouver volcanics is a series of metamorphic, chiefly schisto-sedimentary and volcanic rocks, with intrusive porphyrites. The rocks of the series, although varied, are very characteristic, and may be correlated over large areas, with a great deal of assurance; and, therefore, have been mapped separately, although they are a part of the Vancouver group, and probably are conformable with the Vancouver volcanics. This separate grouping is also advisable, since the series is especially important economically, as it is the country rock for various copper deposits, the largest and best known of which is the Tyee ore body, now largely worked out. The series was first met by the writer in 1908 on Mount Sicker, and was called the Mount Sicker series, which may be more conveniently written Sicker series. Since the various rocks making up the series cannot be mapped separately on the accompanying map, they are considered in this report as constituting a series rather than one or more formations, although the Sicker and Sansum formations have been previously distinguished.[1]

As mentioned under Vancouver volcanics, the Sicker series as mapped includes some volcanic rocks which are typical of the Van-

[1] C. H. Clapp. Summary Report, Geol. Surv., Can., 1909, pp. 88-89. J. A. Allan. Summary Report Geol. Surv. Can., 1909, p. 99

couver volcanics; and in the region between the headwaters of Chemainus river and Alberni, which is mapped as being chiefly occupied by Vancouver volcanics, rocks typical of the Sicker series occur. The Sicker series is sharply defined from the other groups except at one locality, in the vicinity of Chemainus river, south of Mount Sicker. At this locality there is a transition between greatly metamorphosed, schistose sediments and unmetamorphosed sediments. The unmetamorphosed sediments, shales, and sandstones cannot be distinguished lithologically, nor at present can they be distinguished structurally from the shales and sandstones of the Nanaimo formation, and, therefore, have been grouped with them provisionally under the Cowichan group, which includes all of the unmetamorphosed sedimentary rocks of Mesozoic age.

Distribution.—The area underlain by the Sicker series is 6 to 8 miles wide in the eastern part, interrupted, however, by areas of intrusive plutonic rocks and unconformably overlying sediments. The easternmost exposures are found on Moresby, Portland, and Saltspring islands. The series may be traced northwestward fairly continuously to north of Cowichan lake, a distance of about 40 miles. Rocks referable to the Sicker series continue still farther northwest to near Alberni, but they are so intimately related to the Vancouver volcanics that at present they cannot be mapped separately.

The boundaries with the Vancouver volcanics are very indefinite and have been drawn where large rock bodies typical of the Sicker series, that is schists and porphyrites, are in contact with large areas of meta-andesites typical of the Vancouver volcanics. The boundaries with the intrusive Saanich granodiorite and overlying sediments of the Cowichan group are, for the larger part, well located.

The rocks of the series are well exposed, since they form a range of subdued mountains, with the wide, subsequent Cowichan valley to the south, and the east coast lowland to the north. Another subsequent valley, not occupied by a single stream, has been developed on an infolded or downfaulted area of the overlying sediments of the Cowichan group, and nearly separates the Sicker series into two parallel belts, of which the southern is interrupted where the subsequent valley in its central portion becomes confluent with the Cowichan valley.

Lithological characters.—The rocks of the Sicker series are varied in character and origin, and include volcanic rocks, both flow and fragmental types, sedimentary rocks, many of which are probably tuffaceous, and intrusive porphyrites of a wide range in composition. All of the types have been metamorphosed, many of them greatly, so that they pass into various types of schists. The origin of the schists is doubtful in many instances, on account of the extreme metamorphism. In the following lithological description, the volcanic rocks and their more metamorphosed phases are first described; then the stratified fragmental rocks, both sedimentary and, probably, tufaceous, with their probable metamorphic phases; and lastly the intrusive acid and basic porphyrites, and their metamorphic phases; followed by a short note on the mineralization.

Volcanic rocks.—Meta-andesites.—The rocks of the Sicker series that are clearly of volcanic origin, are largely, if not entirely, andesites. They are very similar in character to the andesites of the Vancouver group, and both flow and fragmental types occur. As already mentioned, the porphyritic augite andesite, a characteristic type of the Vancouver volcanics, occurs interbedded with the Sicker series. The normal andesites are green, aphanitic to fine grained rocks, sometimes porphyritic with phenocrysts of hornblende and feldspar. The andesites have been sheared and altered and are commonly cut by epidote veinlets. Commonly epidote and quartz also occur as roundish, yellowish-green nodules, up to a foot in diameter; and although these nodules are very numerous, the rock mass is usually dominant. These nodular andesites resemble fragmental agglomerates.[1]

Microscopic.—The groundmass is seen to consist, on microscopic examination, of fine feldspathic and amphibole needles. The feldspar is probably andesine, and the amphibole uralite and actinolite, alteration products of common hornblende. The minerals have a subparallel arrangement and form an interwoven mat. Magnetite is the only important accessory. The feldspar phenocrysts are oligoclase-andesine. The hornblende phenocrysts are now largely altered to uralite and epidote. Epidote also has replaced to some extent the minerals of the groundmass, and the feldspar phenocrysts. Other secondary minerals are chlorite, sericite, calcite, and quartz.

[1] Cf. Nodular porphyrites from Texada island. R. G. McConnell Summary Report, Geol. Survey Canada, for 1909, p. 70.

Metamorphic phases.—Chlorite schists. The meta-andesites pass into dark green, schistose rocks, consisting chiefly of green chloritic mica and altered feldspar, commonly mineralized and cut by veins of quartz and calcite. The original porphyritic texture in the less altered varieties is readily detected microscopically. The feldspar phenocrysts have been broken, but not decomposed, although sometimes replaced metasomatically by calcite, and occur in a chloritic and ferruginous groundmass. The hornblende has been entirely converted into chlorite and a weakly bi-refringent uralite, and more rarely near intrusive rocks, to biotite. Other secondary minerals are epidote, sericite, and muscovite.

In the more completely metamorphosed andesites evidences of an original porphyritic texture are entirely destroyed, and only traces of feldspar remain, as it has been completely sericitized. Secondary quartz, calcite, and magnetite are present, as well as the normal alteration products.

Amphibolites.—More rarely amphibolites similar to those of the Vancouver volcanics have been developed near intrusive granodiorite.

Stratified rocks.—Tufaceous slate.—Stratified rocks are especially well developed in the southernmost of the two belts underlain by the Sicker series. One of the most common types is a grey, fine grained slaty rock, often laminated in colour and texture.

Microscopic.—The essential constituents are seen microscopically to be quartz in fine sub-angular grains, average about 0·2 mm. in diameter, and carbonaceous, quartzose, and argillaceous material. Plagioclase feldspar is always present in small angular grains and is sometimes an essential constituent. Accessory and secondary minerals cannot be readily distinguished from each other. They include yellowish-green biotite, chlorite, and epidote. It appears as if the secondary minerals were derived from original femic minerals. Sericite and limonite are also secondary products. The presence of so much feldspar and secondary femic minerals suggests that the rocks are partly of volcanic origin.

Conglomerate.—On Chemainus river to the south of Mount Sicker, are exposed coarse grained fragmental rocks, metamorphosed, but clearly sedimentary in origin. Some of them have large rounded to sub-angular, water-worn fragments up to 3 inches in diameter. The fragments are chiefly quartzite, but some are apparently an acid porphyry. The matrix, which composes the whole rock in some of the beds, is arenaceous, greenish-grey in colour, and on microscopic examination is seen to consist of angular fragments of quartz and plagioclase, with chlorite, epidote, and calcite. The rocks have been more or less recrystallized and sheared, and cut by veinlets of calcite.

Metamorphic phases.—Schistose varieties.—The tufaceous slates pass into schistose varieties, which are lighter coloured, since the carbonaceous matter has been destroyed. They contain a larger amount of secondary minerals, especially sericite and light greenish brown mica. On the west shore of Sansum narrows, 2 miles north of Cowichan harbour, is exposed a schistose variety which resembles a 'knotenschiefer.'

Microscopic.—Microscopically, the knots are seen to consist of quartz and plagioclase feldspar. The groundmass is a schistose aggregate of quartz and feldspar, with secondary actinolite and epidote.

Silicified varieties.—'Cherts.' One of the most common varieties of the stratified rocks is a dark to light grey, sometimes laminated and thin-bedded rock, which is very dense, and cherty in appearance, breaking with a conchoidal fracture. Some varieties are even white and translucent.

Microscopic.—The cherty appearance is retained microscopically, the rock consisting essentially of quartz and sometimes feldspar, of very fine grain, which ranges from sub-microscopic to an average diameter of about 0·05 mm., and the grains are irregular and interlocking. Feldspar, an acid plagioclase, and possible orthoclase, is always present, if not as an essential, as an important accessory mineral, and sometimes occurs in larger angular grains. Other accessory constituents are very fine amphibole needles, chlorite, rarely epidote, sericite, and magnetite. Pyrite is virtually always present in very small grains, and has altered more or less to limonite. In the darker coloured varieties fine clouds, apparently of graphitic material, are present. The rock is sometimes schistose, and is commonly fractured and cut by veinlets of quartz and calcite. The origin of these cherty rocks is very indefinite, but as they are clearly stratified, and associated with the tufaceous slates, they are assumed to be silicified varieties of the tufaceous slates.

Quartz-talc schists.—White or light greenish schists, with a talcose feel, consisting chiefly of quartz and talc occur, and apparently have been derived from the stratified rocks, although they cannot always be distinguished from the schistose varieties of the quartz-feldspar porphyrite.

Microscopic.—Microscopically, they are seen to consist of finely granulated quartz intergrown with talc and probably sericite. Feldspar is sometimes present in clear, recrystallized grains. Epidote, chlorite, and calcite are present also.

Graphitic schists.—Interbedded with the talc-quartz and chlorite schists are graphitic schists which are apparently sedimentary, the best known example occurring as the wall-rock of the Tyee ore body. They are black, lustrous schists, commonly cut by veinlets of quartz and calcite.

Microscopic.—They are seen microscopically to consist almost entirely of quartz and calcite clouded with graphite. These graphitic schists closely resemble certain metamorphosed carbonaceous shales, exposed in the bed of Chemainus river south of Mount Sicker, which are transitional into the unmetamorphosed shales of the Cowichan group. The resemblance strongly supports the conclusion that the schists are sedimentary in origin.[1]

Jaspery-magnetite schists.—Associated with the other types of schist are dark red, fine grained, jaspery schists. They consist of very fine, irregular and intergrown grains of quartz, with fine grained magnetite sometimes in large amounts, up to 10 to 15 per cent. The magnetite occurs in roughly parallel streaks and lens-like masses, and occasionally in well defined veinlets; and has partially altered to hematite, which gives the schists their red colour. Iron claims have been taken up on these schists on Mount Sullivan

[1] E. H. Adye, in a quotation given by W. H. Weed, Notes on the Tyee Copper Mine, Eng. and Min. Journ. Jan. 25, 1908, p. 200, states unhesitatingly that the rock is sedimentary.

Saltspring island, and on the northeast slope of Mount Brenton. The origin of the original schists is uncertain, since the present minerals are largely secondary.

Biotite schists.—Dark reddish brown, to green, fine grained schists occur rather rarely. They are composed essentially of quartz, plagioclase feldspar, and light greenish brown biotite; with lesser amounts of calcite, epidote, sericite, pyrite, hematite, and kaolin. The origin of the biotite schists is indefinite.

'Garnetite.'—On the divide between Chemainus river and Cottonwood creek, to the north of Cowichan lake, certain beds of the silicified tufaceous slates of the Sicker series have, near the contact with intrusive granodiorite, been replaced chiefly by andradite garnet and metallic minerals; so that they resemble the 'garnetite' phases of contact metamorphosed limestones. The garnet occurs in brown, fine to medium grained masses, associated with actinolite, sericite, and quartz, and large amounts of metallic minerals, chiefly magnetite. The origin[1] of the garnet masses is indefinite. They may represent interbedded limestones, which were similar to the small mass noted by Mr. Allen on Mount Brenton,[2] but of which no traces remain at present; or they may be beds in the slaty series, replaced perhaps on account of their greater porosity.

Intrusive types.—Quartz-feldspar porphyrite.—Intrusive into the Sicker series, very abundant in many instances, and usually conformable to the bedding or schistosity, are quartz-feldspar porphyrites, which are identical lithologically with the quartz-feldspar or granodiorite porphyrites which are associated with the plutonic rocks along all of their contacts. The porphyrites of the Sicker series are presumably related to the plutonic rocks, but their great number, conformability, and frequent schistosity make them virtually one of the rock types of the Sicker series, with which they have been mapped.

The less schistose varieties are light coloured, usually slightly greenish, with an aphanitic and apparently siliceous groundmass, and frequent phenocrysts of feldspar and quartz, often of relatively large size. Megascopically, the rock usually looks to be very much sheared, but microscopically, little evidence is found of pronounced shearing.

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[1] More fully discussed under copper deposits, see pages 168-169.
[2] See page 67.

Microscopic. The groundmass is very fine, and is composed essentially of angular grains of feldspar and quartz. The feldspar predominates and is entirely plagioclase. The feldspar phenocrysts are also plagioclase, apparently in most instances albite-oligoclase, although at times they are replaced by epidote and calcite, suggesting that more basic plagioclase is sometimes present. The quartz phenocrysts are but slightly broken, and their wavy extinction is not as pronounced as one would expect from the appearance of the hand specimen. The only accessory mineral was probably hornblende, and it formed in most cases but a small percentage of the rock, and is now completely altered to uralite and epidote. Muscovite is the only other secondary mineral.

Schistose varieties. The above types pass into light green schistose varieties, cut by quartz veinlets and often greatly mineralized.

Microscopic. Microscopically, the phenocrysts are seen to be crushed, but not altered to any great extent, the quartz forming lens-shaped mosaics. In the groundmass the schistose texture is made evident by the parallelly elongated actinolite. Chlorite is also a pronounced accessory mineral.

The schistose varieties grade into quartz-chlorite-sericite or talc schists in which the original porphyritic texture has been obliterated; and which cannot be distinguished from quartz-talc schists probably derived from stratified rocks.

Gabbro-diorite porphyrites.—All of the above types have been intruded by numerous large masses of basic porphyrites. They were, for the greater part, intruded after the folding, since many of them are unsheared. Schistose varieties occur, however, which may have been intruded during or before the folding. The porphyrites occur in small stocks, dykes, and sills; many of the dykes and sills being very large but conformable to the bedding or schistosity. They range in composition from diorite to gabbro porphyrites, the feldspar varying from basic andesine to acid labradorite, although hornblende is virtually always the chief femic constituent. They are all clearly related, and best designated as a whole by the name, gabbro-diorite-porphyrite.

Diorite porphyrite.—Macroscopic.—The principal variety, a diorite porphyrite, is a dark green, holocrystalline rock of rather fine grained groundmass. The phenocrysts are principally feldspar, although phenocrysts of altered hornblende also occur. Magnetite or, as it is shown microscopically, ilmenite, is readily detected megascopically; and quartz also is sometimes seen.

Microscopic.—The rock consists essentially of lath-shaped feldspars, a characteristic hornblende, and micropegmatite of quartz and albite or microcline. The feldspar is andesine Ab. 50 An. 50 to Ab. 60 An. 40. The hornblende is of the common variety, with a nearly colourless to bluish green to yellowish green pleochroism. The micropegmatite which is rather unusual in that quartz is the host for the feldspar. The micropegmatite occurs interstitial to the andesine and hornblende, and sometimes entirely surrounds the andesine phenocrysts. Rarely, quartz is in very small amount or absent. Ilmenite is virtually the only accessory, but has been present in rather large amounts.

Alteration and metamorphism.—The rock is usually greatly altered and sheared. The feldspar has been saussuritized, and the hornblende has gone over to a fibrous uralite and chlorite. The ilmenite is always surrounded by a thick layer of leucoxene and has sometimes been completely replaced. Epidote is a very common secondary mineral and occurs in replacements and veinlets.

In the more sheared varieties, the rock resembles a dark greenish schist. The porphyritic and igneous character of the rock is, however, usually preserved. Calcite veinlets are usually very numerous. The feldspars have been twisted and broken, their edges frayed, and have been replaced by epidote and calcite. Recrystallized feldspars are also common. The alteration of the hornblende is similar to that described above, except that chlorite is more abundant. Even in the most altered varieties micropegmatite and leucoxene are present, and they furnish convenient earmarks for distinguishing the sheared diorite porphyrite from the sheared andesite.

Fine grained phases.—The smaller dykes of diorite porphyrite, and the contact phases of the larger bodies are very fine grained, and they resemble megascopically andesite porphyrites. The porphyritic character is more pronounced in the finer grained rocks, but otherwise they are identical with the normal varieties.

Coarser grained phases.—In the larger stocks such as occur in southern Saltspring island the rock is coarser grained than in the normal variety, and the porphyritic texture at times is undeveloped. The mineral composition is similar to that of the normal diorite porphyrite, but the coarser grained phases vary in chemical composition, developing feldspathic and hornblendic facies; the latter sometimes being composed almost entirely of coarse bladed hornblende, up to 2 cm. in diameter.

Gabbro porphyrite.—On Maple mountain north of Maple bay, in Comiaken district, the porphyrite is more basic, the feldspar being labradorite Ab. 40 An. 60, and augite as well as hornblende is an essential constituent. The texture is coarser grained than in the normal diorite porphyrite, and is sometimes, in the finer grained phases, diabasic. Otherwise in mineral composition and alteration the gabbro porphyrite is similar to the diorite porphyrite.

'Rosette' gabbro porphyrite.—Another peculiar variety of the porphyrite occurs, which has been conveniently designated as 'rosette' gabbro porphyrite. It is best developed near the top of Mount Brenton, but even the diorite porphyrite in other places has commonly 'rosette' tendencies.

Macroscopic.—The rock is holocrystalline, and consists essentially of plagioclase and hornblede. Plagioclase has crystallized first in large but narrow rectangular or tapering crystals up to 2 cm. in length, averaging about 1·5 cm. These crystals or phenocrysts radiate from a common centre, and the groups resemble large spherulites. On exposed surfaces the plagioclase has weathered white, so that the groups form conspicuous rosettes, which, as they are very numerous, and arranged in parallel planes, give the rock a most peculiar appearance (see Plate VIII).

Microscopic.—The rock consists essentially of plagioclase, augite, and hornblende. The plagioclase forms about 60 per cent of the rock. It has a zonal structure, and ranges from acid labradorite to basic andesine, the average being somewhat more basic than Ab. 50, An. 50. It is fresh and unaltered, and usually occurs in lath-shaped crystals, and forms besides the 'rosettes,' small laths in the more finely crystallized groundmass. Hornblende is the principal femic mineral. It is in part original, and in part surrounds the augite, suggesting that it is secondary. It is the same variety of hornblende that occurs in the diorite porphyrites. Some of the hornblende is

"Ross Ho.. gabbro porphyrite of the Sicker series, ... nt ... Ch ... di... Pl...

Contortion in the stratified rocks of the Sicker series, south shore, Saltspring island.

contemporaneous with the feldspar, but the larger part is intersertal or interstitial. The augite is commonly intersertal, and even includes the smaller feldspars ophitically. Ilmenite is the only accessory, and forms fully 5 per cent of the rock.

Alteration.—The femic minerals have been sheared and altered slightly. The edges of the grains are usually marked by a growth of actinolite needles. The augite is sometimes granulated and is altering to uralite, and the hornblende is altering to light brown biotite.

Basalt or andesite porphyrite.—Intrusive into the silicified tufaceous slates, which occur on the divide between Chemainus river and Cottonwood creek, north of Cowichan lake, are altered porphyrites which are not clearly related to the gabbro-diorite porphyrites. They are greyish-green rocks with an aphanitic groundmass, and numerous fairly large phenocrysts of white weathering feldspar, which cannot be definitely determined microscopically, but is plagioclase, probably labradorite or andesine. The groundmass consists of altered plagioclase with secondary femic minerals, uralite, light brownish-green mica, and accessory magnetite or ilmenite, and titanite. Quartz is present but may be secondary. Other secondary minerals are sericite, kaolin, pyrite, and limonite.

Mineralization.—All of the rocks of the Sicker series are more or less 'mineralized,' the chief metallic minerals being magnetite, pyrite, chalcopyrite, and pyrrhotite, in relative abundance about in the order named. In the sheared and schistose varieties, especially near the intrusive porphyrites, the mineralization is especially rich, and certain of the impregnated and replaced schists have been prospected slightly in the search for copper ore. Pyrite and chalcopyrite bearing quartz and calcite veins are very common, and on Mount Sicker the Tyee ore body was developed in a syncline of the graphitic schists, near a dyke of diorite porphyrite.

Structural relations.—*Internal.*—The volcanic and stratified rocks of the Sicker series have been closely folded; and many small folds and contortions occur, especially prominent in the stratified rocks of southern Saltspring island. The strike of the folds averages about N 70° W and varies but slightly. The dips are chiefly steep, and to the southwest, the closed folds being slightly overturned.

The series has also been faulted extensively. On Mount Sicker the faults are strike, and probably compression or reversed faults; due to the close folding and injection of thick masses of diorite porphyrite. In most instances it is impossible to determine the amount of displacement of the faults; but it is probable that the total displacement is not proportional to the amount of movement which has taken place, which must have been at times, to judge from the amount of slickensiding and shearing, very great. Transverse faults also occur, well exposed in the tufaceous slates north of Cowichan bay. They are in part, and may be entirely reversed faults. They are numerous, but usually of small displacement, seldom more than a few feet, and are not marked by extensive shear zones, although the strata near the faults have frequently been bent by the drag and friction of the walls as they moved over each other. Besides the above faults, large boundary faults occur which bring the rocks of the Sicker series and Cowichan group into conjunction with each other. These are discussed under the structural relations to the Cowichan group.

The structure of the series is so complicated that the folds have not been correlated over very large areas, and the stratigraphic succession of the volcanic and stratified rocks has not yet been determined. Since the stratified rocks, which are dominant in the southern belt of the Sicker series, grade in one instance, along the Chemainus river south of mount Sicker, into relatively unmetamorphosed sedimentary rocks, it is probable that the series dips as a whole to the south, the volcanic rocks grading in general upward into stratified rocks, although the two are also clearly interbedded. If the stratified rocks are the younger, the infolds of quartz-talc and graphitic schists which occur on mount Sicker are synclinal, and this has been proved to be true by Mr. J. W. Bryant, of the Tyee Copper Company,[1] in the case of the relatively narrow fold in which the Tyee ore body occurs.

The quartz-feldspar and gabbro-diorite porphyrites are clearly intrusive bodies, injected in most, if not in all instances, and are not true stocks or batholiths, that is, are not subjacent. With the exception of the stocks of coarser grained gabbro-diorite porphyrite, the porphyrites have been injected largely parallel to the strike, so that they are conformable to the bedding or schistosity. They have also suffered in some degree from the folding and faulting which

[1] Shown in the figures published with W. H. Weed's article on the Tyee mine. Eng. and Min. Journ. Jan. 25, 1908, pp. 199-201.

has so greatly disturbed the volcanic and stratified rocks. The quartz-feldspar porphyrites, which are the older, since they are intruded by the gabbro-diorite porphyrites, have been the more affected by the dynamic movements, although no distinct folds in them were observed.

External.—Relation to other members of the Vancouver group.— The volcanic and stratified members of the Sicker series are conformable with the Vancouver volcanics, since in many instances, especially in the northern belt of the Sicker series, they are interbedded and apparently interfolded with typical Vancouver volcanics. Their position in the Vancouver group is not known. It is suggested, by the gradation of the stratified members of the Sicker series upward into unmetamorphosed sediments, that the series is near the upper part of the Vancouver group. North of Cowichan lake, however, the tufaceous slates of the Sicker series apparently dip under Vancouver volcanics; and Dawson[1] in northern Vancouver island found Triassic fossils in somewhat similar rocks older than the Sutton formation and a large part of the Vancouver volcanics, which are lower Jurassic in age.

On Mount Brenton, Mr. Allan found a very small (10 by 25 feet) inclusion, or intercalated lens of limestone, similar to that of the Sutton formation, in the volcanic rocks of the Sicker series.

Relation to younger formations.—The Saanich granodiorite is clearly intrusive into all the rocks of the Sicker series, with the exception of the gabbro-diorite porphyrite. With the gabbro-diorite porphyrite it does not come in contact, and either rock may be the younger. McConnell[2] notes what appears to be similar diorite porphyrites on Texada island which are younger than the quartz diorite, typical of the upper Jurassic batholiths; he states, however, that the porphyrites are related to the quartz diorites. If this be true on Vancouver island, the apparent restriction of the gabbro-diorite porphyrites to the Sicker series is remarkable. It is possible, however, that two occurrences of gabbro, observed in the Highland and Malahat districts, are related to the gabbro porphyrite of the Sicker series. The gabbro-diorite porphyrite is also younger than the quartz-feldspar porphyrites, which are identical lithologically with the

[1] G. M. Dawson. Ann. Rept. 1886, Geol. Survey Canada, pp. 9B-10B.
[2] R. G. McConnell. Summary Report Can. Geol. Survey for 1909, pp 70-71.

quartz-feldspar or granodiorite porphyrites characteristic of the granodiorite contacts.

The larger part of the sediments of the Cowichan group are unconformable upon the Sicker series, basal conglomerates resting in many occurrences on erosion surfaces of low to moderate relief developed by a pre-upper-Cretaceous erosion cycle. Unconformities of this character are well exposed on Mount Tzouhalem north of Cowichan bay, on the mountains of central Saltspring island, and on the northern slopes of Mount Richards and Mount Sicker. The southern contacts of the northern and southern belts of the Sicker series, which are with the sediments of the Cowichan group, are in the eastern part overthrust faults. They have a general strike parallel to the strike of the series, that is about N 65° to 70° W, and the upthrow side is to the north,[1] and the vertical displacement or throw has been in each case considerable, at least 2,000 feet. The westward extension of the two faults beyond Cowichan and Comiaken districts is not known.

To the west of Comiaken district, the southern contact of the northern belt of the Sicker series with the sediments of the Cowichan group is well exposed in the bed of Chemainus river south of Mount Sicker, and appears to be transitional. The contact is with the schistose sedimentary rocks of the Sicker series, notably the schistose conglomerate described above.[2] The conglomerate grades southward into greenish-grey quartzose sandstones, which consist of fine angular to sub-angular quartz grains in a carbonaceous and argillaceous matrix. They have been somewhat metamorphosed and silicified, secondary minerals being very abundant. Farther to the south occur slaty shales with thin interbeds, about a foot thick, of quartzose sandstones similar to those described. The shales are black, somewhat slaty and schistose, but are clearly altered carbonaceous shales. They grade rapidly southward into concentric weathering carbonaceous sandy shales, with thin interbeds of sandstone, which cannot be distinguished lithologically from similar rocks in the Nanaimo formation. The exposures are continuous and the beds all conformable, having a strike of about N 60° W, with nearly vertical dips; or overturned slightly, so as to have a steep dip to the north. Three to four miles to the southeast on Mount Prevost the steeply dipping shales

[1] The evidence of faulting is discussed more fully under Cowichan group, page 129.
[2] See page 74

are overlain by gently dipping conglomerates, apparently of the Nanaimo formation, and the contact, though not actually exposed, is almost certainly an unconformity. The sedimentary rocks of the Sicker series are, therefore, without much doubt conformable with lower horizons in the Cowichan group, although as stated, the larger part of the Cowichan group, that is, the Nanaimo formation, is clearly unconformable upon them.

Mode of origin.—The Sicker series have been seen to consist of volcanic rocks, largely andesitic, with interbeds of stratified rocks, which grow more numerous upwards, apparently, until they predominate. The stratified rocks are in large part sedimentary, but are probably mixed with more or less tufaceous material. The rocks have been closely folded, greatly metamorphosed, and injected by quartz-feldspar and gabbro-diorite porphyrites. The metamorphism has been in part regional, but the extreme metamorphism, especially that noted in the northern belt, between Maple bay and Mount Brenton, has been probably due in large measure to contact and thermal agencies, active during the injection of the gabbro-diorite porphyrites. It is remarkable that the intrusions and extreme metamorphism should have been confined to such a relatively narrow belt. It is even more remarkable that these metamorphosed rocks should, in less than a quarter of a mile, grade into virtually unmetamorphosed, although closely folded, sediments.

Age and correlation.—The rocks of the Sicker series are all pre-upper-Cretaceous, since the Nanaimo formation rests unconformably upon them. With the exception of the porphyrites, the rocks are all pre-batholithic, that is, pre-upper Jurassic. The volcanic and stratified rocks are conformable with the Vancouver volcanics, and are, therefore, one of the members making up the Vancouver group. As already mentioned, the position of the volcanic and stratified rocks of the Sicker series in the Vancouver group is entirely doubtful; although it has been suggested, but with objections, that they form one of the higher members. If they are one of the higher formations, they are probably lower or middle Jurassic in age; if not, they may be either Triassic or Jurassic. From the close lithological similarity of the quartz-feldspar porphyrites and the contact porphyrites of the Saanich granodiorite, it is presumed that they were injected during the general period of intrusion of the

Saanich granodiorite, that is in upper Jurassic times. The gabbro-diorite porphyrites are certainly younger than the quartz-feldspar porphyrites, and may be younger than the Saanich granodiorite. If so, they may with more assurance be correlated with the diorites and diorite porphyrites noted by McConnell[1] on Texada island, which he classifies as lower Cretaceous or upper Jurassic.

SUMMARY OF INTERNAL RELATIONS OF VANCOUVER GROUP.

It is seen that the above mentioned formations: Nitinat formation, Vancouver volcanics, Sutton formation, and surface members of the Sicker series, compose what is apparently a great conformable group, all having the same structural relations, and occurring contiguous to one another. The thickness of this great group cannot be even estimated with any degree of accuracy. It is certainly very thick. Dawson's[2] estimation of the corresponding group in the interior of British Columbia, the Nicola group, is 13,500 feet, but it seems as if the Vancouver group must be at least 20,000 feet thick, and may be very much more.

METCHOSIN VOLCANICS.

The volcanic rocks of the southernmost part of the island have been briefly described by Dawson in his report on Leech river and vicinity[3], and have been called by him the Sooke series. The name Sooke has also been used as the specific geographic term, designating the Tertiary beds exposed on the Sooke river and along the shore of Sooke harbour,[4] and this use as a formation name has been listed in the dictionary of formation names compiled by the United States Geological Survey.[5] As the volcanic rocks are well exposed in the district of Metchosin, and underlie nearly the entire district, in order to avoid confusion of names it has been thought best to designate the volcanic series as the Metchosin volcanics.

[1] R. G. McConnell. Summary Report. Geol. Survey Canada, for 1909, pp. 69-71.

[2] G. M. Dawson. Bull. Geol. Soc. Am., Vol 12, 1901, p. 62.

[3] G. M. Dawson. Geol. Survey of Canada. Rept. of Progress, 1876-77, p. 95.

[4] J. C. Merriam. Bull. Univ. Cal. Geology, Vol. 2, No. 3, 1896, p. 101.

[5] U. S. Geol. Survey. Bull. 191, 1902.

Distribution.—The Metchosin volcanics form a broad belt, 5 to 7 miles wide, which is nearly parallel to the southwest coast. They extend from Royal Roads to the west coast near the mouth of Sombrio river. The rocks of the formation are well exposed. The country they underlie is rugged and of the plateau type, with low rounded, bare peaks rising above the general level. The coast is bold and rocky, and affords excellent exposures.

The southern boundary in the eastern part has been fairly well located. The northern boundary, which is a fault and therefore presumably regular, has been located at a number of places; and as it follows a very pronounced east-west valley, it is probably shown with a considerable degree of accuracy.

The various types of volcanic rocks and their relations are very well exposed on Albert head. This head is only about a mile and a half long and half a mile across, and is easily accessible from Victoria.

Lithological characters.—The rocks of this series are all basic, principally basalt, but some augite andesites also occur, and there are many intrusive bodies of diabase. Texturally and structurally they vary widely, from coarsely porphyritic and ophitic basalts to amygdaloidals, from fine to coarse grained tuffs, and from injected dykes of diabase to pipes of agglomerate.

Basalt.—Macroscopic.—The most abundant rock is an aphanitic basalt, more or less porphyritic. The finer grained non-porphyritic rock is dark greenish-grey in colour, having a purplish tint where more affected by surface alteration and oxidation, as on exposed surfaces and along the numerous joint cracks. The component minerals, except for a few phenocrysts of feldspar and disseminated pyrite, are not recognizable in the hand specimen, although an occasional flash of light from the cleavage surfaces of the plagioclase needles is seen, and on some of the smooth surfaces tiny lath-shaped feldspars in a dark matrix can be detected on close examination. In the groundmass spots of green alteration products occur; and there are, in the more sheared rocks, calcite veinlets.

Microscopic.—The groundmass on microscopic examination is seen to consist of essential plagioclase and augite with an intersertal texture. The feldspar has been formed first, and occurs in small needles, which have a tendency to form radiating groups. The augite occurs intergrown with, and to some extent is interstitial to the feldspar, and also occurs in small grains. There are occasional small phenocrysts of plagioclase, which is labradorite, Ab. 35, An. 65. The smaller feldspar grains of the groundmass are of about the same composition, perhaps slightly more acid. Magnetite is the only accessory mineral, although pyrite is usually present, but it is probably secondary.

Alteration.—The feldspar is unaltered in the normal rock. The augite has, however, altered more or less to a fibrous, light green, pleochroic serpentine, the variety bastite. Sometimes the bastite occurs in rather large masses as if it had replaced an augite phenocryst. It is these masses that give the spotted appearance to the hand specimen.

Porphyritic varieties.—The porphyritic varieties are similar, except for the larger and more abundant phenocrysts of plagioclase and smaller ones of augite. The phenocrysts average 2 or 3 mm. in diameter, and are sometimes as large as 1 cm. The groundmass is aphanitic, and may even be amygdaloidal.

Microscopic.—The porphyritic feldspars are usually fresh and unaltered, although in some rocks they have been clouded with saussurite and sericite. The phenocrysts are labradorite, Ab. 40, An. 60. The original augite phenocrysts were less abundant and are now almost completely altered to serpentine. The serpentine alteration suggests the presence of original olivine, but no definite proof of its existence in the basalt has been seen. The groundmass consists of a fine grained mat of plagioclase needles and augite, clouded with dust-like magnetite. In the more coarsely crystalline rocks the groundmass is distinctly diabasic in texture. The augite of the groundmass is altering to a fibrous amphibole and chlorite. Other secondary minerals are a brown chloritic mica, which gives the altered rock a peculiar bronze-like lustre, and a red chloritic mineral, iddingsite, is a frequent but not abundant alteration product.

Amygdaloids.—The amygdaloidal basalt is similar in composition. The amygdules are commonly of calcite and more rarely of quartz and epidote. They are seldom large, averaging 1 or 2 mm. in diameter. Under the microscope the amygdules are seen to be vesicles filled with radial groups of calcite, which sometimes show concentric growth lines.

Taxitic varieties.—Other types of flows are banded and brecciated, the banding being very evident in the hand specimens on account of differences in colour, which are due primarily to a difference of texture. One band may be very fine grained and even amygdaloidal, while the contiguous one may be much coarser grained, or porphyritic.

Some of the basalts include small square shaped fragments of material exactly similar to that of the enclosing rock. These inclusions are at times very abundant. This feature is most strikingly seen on the weathered surface, the little blocks being in slight relief.

Fragmental varieties.—Other surface volcanics are fragmental in character, tuffs and agglomerates. These are fairly numerous, and there must be several horizons, since they are not confined, as far as known, to any particular portion of the formation. These fragmental members range from fine tuffs, consolidated ash-beds, to very coarse agglomerates.

The tuffs are dark green, fine grained fragmental rocks, and are often stratified. They are seen under the microscope to consist entirely of minerals similar to those of the normal basalt. They are usually altered to serpentine and calcite. Calcite also occurs in veinlets.

The fragments in the agglomerates have a maximum diameter of about 6 feet. Some of the agglomerates, notably the coarser ones, are not stratified and the fragments are angular to sub-angular. The stratified agglomerates seldom contain fragments of over 6 inches in diameter. The fragments are rounded to sub-angular, and many appear to be water-worn. They are all of volcanic rocks, of a basaltic composition, and are clearly related to the neighbouring basalts. The fragments range in texture from amygdaloid to porphyritic. The matrix is virtually a fine grained, basic tuff, now largely altered to serpentine, chlorite, and some calcite.

Diabase dykes.—Intrusive into the Metchosin volcanics are numerous dykes of a rather typical diabase. They are fine to medium grained, with a decided ophitic and intersertal texture, dark green on fresh fracture, but weathering into rounded masses of a brown colour. The essential minerals are labradorite and augite. The minerals are fairly fresh, but the groundmass is altering to chlorite, and there are also patches of serpentine, in some cases in irregular fibrous masses.

and again in radial aggregates. There is a possibility that some of the serpentine was derived from original olivine, but none has been seen in the rocks. Magnetite and pyrite are the chief accessories, and sometimes form from 5 to 10 per cent of the rock.

Augite andesite.—On Sheringham point, near Coal creek, is a dyke of a purplish aphanitic rock, with small porphyritic crystals of altered feldspar and a conchoidal fracture.

Microscopic.—Microscopically, the groundmass is seen to consist of needle-shaped microlites of feldspar which is plagioclase, probably basic andesine; with leucoxite, chlorite, and secondary minerals of the epidote group. There are few phenocrysts of basic andesine or acid labradorite. Augite occurs sparingly in small phenocrysts which sometimes surround and include the feldspar. Since the feldspar is apparently andesine, the rock is best classed as an aphanitic augite andesite.

Metamorphism.—The basalts have not suffered from as great metamorphism as would at first be thought. They have been largely altered to greenstones, the femic minerals having gone over to a greater or less extent to chlorite and serpentine. The feldspars are, however, usually unaltered, only the more decomposed surface rock showing much of any clouding of the feldspars by secondary minerals. The character of the alterations is such as would be produced by aqueous solutions under surface conditions of low temperature and pressure.

In many places, however, the basalt and diabase have been sheared to a very considerable extent. In these sheared rocks the augite has gone over to uralitic hornblende, and the feldspar has been clouded with saussuritic minerals, principally epidote. Where the shearing has been more intense the plagioclases have been bent and distorted, and sometimes even granulated and recrystallized. They have also separated along their cleavage planes, and the fine grained groundmass has fingered into the crystals along these cracks. This phenomenon may in part be due to a shearing while the rock was in a semimolten condition, thus developing a true protoclastic structure. Along the shear planes the femic minerals have altered to serpentine, and the serpentine alteration has apparently spread to the augite minerals of the groundmass and less sheared portions of the rock, so that quite large masses of serpentine are formed.

Along the shear zones in particular, the volcanics are cut by veins of epidote and quartz. These veins occur as irregular ramifications and networks of intersecting veins and veinlets. These are never of any great lateral or vertical extent. In a few places pyrite and chalcopyrite occur disseminated through these zones.

Near the contact with the Sooke gabbro, which is intrusive into the volcanic rocks, there is a change in the character of the alteration. Epidote is more abundant, and compact, poikilitic hornblendes occur, which are apparently secondary. This type of alteration has doubtless taken place at high temperatures.

Structural relations.—Internal.—The whole formation has the appearance of being made up of several flows, as contacts of slightly different types of rocks are often seen. These contacts are, however, very obscure and seldom traceable.

One clear proof of explosive action is revealed on the southern shore of Albert head, near the small point of land which separates the lagoon from the main body of water. There is here exposed a roughly circular mass of coarse agglomerate about 100 yards in diameter, which consists of angular to sub-angular fragments of volcanic rocks up to 6 feet in diameter, imbedded in a green, slaty matrix. Surrounding this rock is a fine slaty looking, banded tuff which dips in toward the agglomerate. Beyond the fine tuff is a much coarser tuff or stratified agglomerate, which is 200 yards from the central agglomerate. The outer agglomerate contains fragments of volcanic material up to 4 inches in diameter. They are, however, sub-angular to rounded, and some of them appear to be waterworn. The central mass of agglomerate most probably represents the neck or pipe of a small ancient volcano; and the inward dipping tuffs, the ash-beds which surrounded it. Farther from the neck are tho bedded agglomerates. It is possible that the volcano just protruded above the water level and that the fragments of the outer agglomerates were truly waterworn. The volcano was subsequently buried beneath a thick mass of lava and was thus protected from erosion.

Doubtless the large majority of eruptions were of the quiet sort, which resulted in the pouring out of thick sheets of molten rock. The channels for these eruptions were most probably fissures, which are now represented by the diabase dykes so abundant throughout the series, and which although clearly related to the basaltic flows, cut them. These dykes are often very irregular, varying greatly in width and in strike. The tracing of these dykes for any considerable distance is rendered difficult or impossible by the subsequent deformation of the series. The largest dyke noted was 35 feet wide, on Albert head. There are many others ranging from 2 feet to 20 feet in width.

The volcanic rocks evidently suffered considerable deformation. In many cases, particularly in the tuffs and agglomerates, direct evidence of folding is seen in the inclination and contortion of the beds. It is very difficult to determine with any assurance the strikes and dips of the beds and thus work out the structure due to folding, and to calculate accurately the thickness of the formation. The formation has a general northwest strike. The strikes observed range from N 15° W to N 85° W, and average about N 70° W. The dips seem to be mainly to the northeast and are quite steep, 20° to 80° averaging ca. 60°. A very few dips were noted to the southwest. It is probable that the rocks did not bend into close folds, or possibly even into more open ones, but yielded to the compressive forces by shearing and faulting.

Shear zones are very common throughout the whole belt of volcanic rocks. They are often wide, and the walls are slickensided. On account of the great uniformity of the entire formation, and the similarity of the two walls of the faults, it is virtually impossible to determine the amount and the direction of displacement which produced these shear zones.

An accurate determination of the thickness of the formation is not possible. The rocks are exposed through a vertical distance of about 2,200 feet; and this certainly does not represent the entire thickness. The thickness may safely be estimated provisionally, as 5,000 feet. Throughout the entire formation no truly sedimentary rocks are exposed; and with the exception of the augite andesite dyke, which cuts basalt on Sheringham point, the rocks are very similar in composition.

External.—Relation to older formations.—To the north of the Metchosin volcanics, except in the extreme eastern part, occurs the Leech River formation. In the eastern part the relation of the volcanics with the crystalline rocks to the north is obscured by the thick deposit of sand and gravel of the Colwood delta. The actual contact with the Leech River formation is not exposed, but from Goldstream west it may be located within a few hundred feet. The contact follows the very pronounced Leech River valley, which extends from Goldstream to the west coast, near the mouth of Sombrio river; and which is now occupied, as already described (see page 22), by several rivers and creeks. In the beds of the various streams occur the slates and schists of the Leech River formation. On going southward one climbs up a steep slope, on which the slates are more or less continuously exposed, to an elevation of 300 to 500 feet above the streams. Then for a few hundred feet one crosses a drift covered slope of low grade and no exposures. Beyond are high bold ledges of basalt, which rapidly obtain an elevation of 1,500 to over 2,000 feet above sea-level.

The basalts along the contact are massive, although they have been sheared, and their altitude is difficult of determination. They have a general strike of N 75° to 85° W, and a steep dip to the northward. This strike is at a slight angle to the strike of the contact, which in the eastern part is N 70° W and in the western part very nearly east and west. The strike of the rocks of the Leech River formation is more variable, but corresponds in general with that of the southern contact. The angles of dips of the formation are usually steep to the north.

All of the evidence which has been obtained goes to prove that the contact is a fault.[1] The fault is very persistent, and is doubtless of considerable throw.

There is little doubt as to the relative ages of the two formations. The Metchosin volcanics are not so much deformed. They have the appearance, even in the field, of being less metamorphosed than the Leech River slates and schists, and this difference in metamorphism and alteration is shown by petrographic study to be very great. In most cases the Metchosin volcanics have suffered only slight regional, and relatively slight contact metamorphism. The alteration is that produced by circulating waters under surface conditions, or those of moderate temperature and pressure. The Leech River formation has, on the other hand, suffered from intense regional metamorphism. The Metchosin volcanics are, therefore, younger than the Leech River formation.

Relation to younger formations. Along the southern boundary the basalts are in contact with two distinct formations, both of

[1] This explanation was preferred by Dawson. Geol. Survey of Canada, Rep. of Progress, 1876-77, p. 97.

which are clearly younger. One, the Sooke gabbro, is intrusive into the Metchosin volcanics. The other, the Sooke and Carmanah, occurs in small basins along the west coast, and the basal member is a coarse conglomerate with included cobbles of the basaltic rocks. The actual contact is exposed in many places, the basal conglomerate resting directly on an eroded surface of the volcanic rocks. A marked unconformity, therefore, separates the two formations.

Mode of origin.—The Metchosin volcanics were formed by the accumulation of successive basaltic flows. The eruptions were probably for the greater part of a quiet nature, and 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 neck and part of the cone exposed on Albert head, and by the bedded agglomerates and tuffs.

The base of the formation is not exposed, so that it is impossible to tell over what kind of a surface the basalt flowed. The entire absence of sediments suggests that they were built up in deep water, far removed from any continental mass. The existence of such cones as that exposed on Albert head, with the surrounding agglomerates, which contain fragments that are probably waterworn, indicates that enough lava was erupted to form a thick platform which reached nearly to the surface of the water, on which were built the cones which actually projected above the surface. The probable conditions existing at the time of formation were therefore similar to those existing during the formation of the greater part of the volcanic rocks of the Vancouver group.

Age and correlation.—The only definite evidence as to the age of the Metchosin volcanics is that they are much older than the Sooke and Carmanah formations, and are, therefore, pre-Tertiary. If the Sooke gabbro is correctly correlated with the upper Jurassic batholiths, then the volcanics are certainly either Triassic or Jurassic in age, since they are hardly older than volcanic rocks of the Vancouver group. They appear to be younger, as they are much less altered and metamorphosed than the greater part of the Vancouver volcanics, but are provisionally placed, however, in the Vancouver group. They are also very different in their lithological characters, and another striking difference is the absence of interbedded limestones in the Metchosin volcanics.

The Metchosin ophitic basalts are similar structurally and petrographically to some of the volcanics of the main coast of British Columbia, occurring to the north of Powell river, seen in the laboratory by the writer and described to him by Mr. J. Austen Bancroft.[1] Mr. Bancroft has determined the age of some of his volcanic rocks by the fossils included in interbedded sedimentary deposits, to be upper Triassic in age, and considers all the volcanics to belong to one group. The Metchosin basalts are correlated in a general manner with the ophitic basalts of the coast region and are, therefore, considered as upper Triassic or lower Jurassic in age. They are, therefore, included in the Vancouver group. They are either one of the youngest members of the group, or else have escaped from the general metamorphism, possibly largely contact metamorphism, which has affected the greater portion of the volcanic rocks of the Vancouver group.

BATHOLITHIC AND DYKE INTRUSIVES.

Intrusive into the Leech River slates and the Vancouver group, with the exception of the Metchosin volcanics, are large masses of plutonic rocks and their accompanying dykes. It is probable that all the plutonic rocks were erupted during one general period of batholithic intrusion, but in detail they may be divided into the three main types which were erupted in a definite sequence. The three types are, in the probable order of their eruption: Wark diorite and quartz diorite gneisses, Beale diorite, and Saanich granodiorite and quartz diorite. Besides the three main types which occur in large batholithic masses, dykes of basic porphyrites, and dykes and small intrusive bodies of acid porphyrites occur. The gabbro-diorite porphyrites of the Sicker series may be related to the main batholithic rocks, but as they are restricted to and mapped with the Sicker series, they have already been described under the Sicker series. Two occurrences of a rather similar gabbro have been observed in the Highland and Malahat districts, and are described under this section. Intrusive into the Metchosin volcanics are small stocks of a very characteristic gabbro, which has been called the Sooke gabbro.

In the following description the distribution and lithological characters of the three main batholithic types are first described;

[1] See J. Austen Bancroft, Geol. Survey Canada, Summary Report, 1907, p. 16.

followed by a description of the intrusive masses of acid porphyrites and dykes of basic porphyrites. Then the structural relations, mode of origin, and correlation of the igneous rocks are considered as a whole. The Sooke gabbro, which is isolated from the other plutonic rocks, is described and discussed separately.

WARK DIORITE AND QUARTZ DIORITE GNEISSES.

Distribution.—The Wark diorite and quartz diorite gneisses form virtually a single batholith, although the quartz diorite gneiss is intrusive into the diorite gneiss, often brecciating it, along the contacts; but the two types cannot be mapped separately on the accompanying small scale map, and are, therefore, considered together. The batholith that the two types compose extends in a northwest direction from the vicinity of Victoria, the easternmost exposures occurring on the small islands in Haro strait to near Jordan meadows, a distance of 30 miles. Its greatest width occurs in the eastern part of Malahat district, and is about 10 miles.

The gneisses are well exposed for the greater part, forming monadnocks, which surmount the lowland developed by the pre-Glacial cycle in the southeastern part of Vancouver island: such as mount Wark in the Highland district, where the diorite gneiss is typically exposed; and Wark has, therefore, been chosen as the distinctive geographic term to designate the gneisses. On detailed mapping the diorite and quartz diorite gneisses will be separated and the quartz diorite given a distinctive geographic name. The boundaries of the batholith have been well located in the eastern part, where detailed mapping has been done, and fairly well located in the western part.

Lithological characters.—*Diorite gneisses.*—*Normal.*—The normal Wark diorite gneiss is a rather dark greenish coloured, holocrystalline rock, of medium to coarse grain, and of gneissic texture. The essential minerals are andesine feldspar, and green hornblende, and the accessory minerals, quartz, magnetite, and titanite. The development of the gneissic texture has destroyed the original texture, but it appears that the andesine occurred in euhedral grains.

Secondary minerals, sericite, muscovite, biotite, chlorite, serpentine, saussurite, and limonite are numerous, as the alteration has been fairly large. The gneiss is commonly cut by quartz veinlets, and impregnated with pyrite.

Fine grained phases. Fine grained phases occur especially near the intrusive quartz diorite gneiss, and quartz diorite and granodiorite of the Saanich type. In them, fibrous amphiboles and secondary feldspar, probably albite, have been developed in addition to the other secondary minerals.

Femic facies. Associated with the fine grained phases near contacts with intrusive rocks are hornblende rich facies. These facies are commonly fine grained, and almost schistose. They are similar in composition to the normal diorite gneiss, but are much richer in hornblende.

Coarse grained femic facies occur in which the hornblende has been more or less recrystallized. It forms large euhedral crystals in a rather fine grained altered feldspathic groundmass. Epidote is a very common alteration product in these partially recrystallized phases, and occurs in the groundmass with the altered andesine feldspar. Secondary quartz is, as a rule, more abundant in these phases.

A diorite which is virtually identical with this type occurs near the contact of the Saanich granodiorite and the Sicker series on the ridge north of the east end of Cowichan lake. There is not, however, any large body of it, and it cannot be mapped separately from the Saanich granodiorite.

Poikilitic phases. A peculiar phase of the diorite with recrystallized hornblendes is fairly common. The hornblende of this phase forms large crystals, which include the older minerals, especially the altered feldspar, poikilitically. The poikilitic hornblendes are sometimes very large, as in the diorite exposed near Millstream road in the Highland district, south of Lost lake, in which the hornblendes are 6 to 8 cm. in diameter.

Hornblendites.—Rarely coarse grained phases occur, composed almost entirely of secondary hornblende of coarse grain, similar to the hornblendite zones in the metamorphosed quartz diorite gneiss.

Augite diorite gneiss.—Exposed on the high ridges to the north east of Jordan meadows is a gneissic rock, similar in appearance to the normal diorite gneiss and apparently related to it, which contains essential augite besides essential hornblende and basic andesine.

Gabbro.—Two occurrences of a gabbro are known. In both cases it is closely associated with the diorite gneiss, with which it has been mapped. One occurrence is in the Highland district to the northeast of Thetis lake, and the other in Malahat district, exposed in a cut on the Esquimalt and Nanaimo railway, on the west slope of the valley of Finlayson arm of Saanich inlet, where the gabbro is intrusive in the dacite tuffs of the Vancouver volcanics. The gabbros are medium to coarse grained, and consist essentially of labradorite and augite. They are not gneissic, and are only slightly to moderately altered.

Alteration and metamorphism.—The diorite gneisses are usually, as noted, moderately altered; and they are often altered very greatly, passing into schistose varieties composed almost entirely of secondary minerals such as uralite, chlorite, epidote, and sericite, with replacements and veinlets of quartz and calcite.

Quartz diorite gneiss. Normal. The normal quartz diorite gneiss is a grey, holocrystalline rock of medium grain and gneissic texture. It consists essentially of oligoclase-andesine, quartz, and green hornblende, with accessory biotite, magnetite, and more rarely titanite. It has been moderately altered to sericite, sometimes saussuritic minerals, and chlorite, and is commonly cut by veinlets of quartz and epidote.

S[illegible] facies. In the metamorphism of the quartz diorite it has been [illegible]llized, and the salic and femic minerals have been segreg[illegible]d separate zones, from a fraction of an inch up to several feet in width, so that the gneiss has usually a characteristic banded appearance. The salic facies are light coloured, medium grained, and gneissic to schistose in texture, and consist essentially of feldspar and quartz.

Microscopic.—The feldspar is an acid plagioclase, probably albite-oligoclase, and is usually in larger amounts than the quartz. Hornblende is accessory, but usually present in small amounts, and has altered extensively to chlorite and epidote. The feldspar as a rule is more altered than in the normal quartz-diorite gneiss, altering chiefly to sericite, although it sometimes occurs with quartz in crushed, interlocking, clear grains. Biotite is a relatively rare secondary mineral. Calcite and quartz commonly occur in veinlets.

and pyrite occurs as disseminated grains, and has usually been somewhat altered to limonite.

Femic facies (hornblendite).—Associated with the salic facies are the complementary femic facies. They are dark green, fine to coarse grained, the larger zones being virtually always coarse grained, and consist essentially of hornblende, with accessory magnetite. The hornblende is usually of two generations, a primary hornblende and a light coloured, somewhat foliated or fibrous, secondary hornblende.

Apophysal phases. Cutting the diorite gneiss are apophyses, which are doubtless related to the quartz diorite gneiss. They are light coloured, sometimes white, fine grained, gneissic rocks, consisting essentially of quartz and feldspar. The feldspar, which predominates, is chiefly plagioclase, probably albite-oligoclase, with some microperthite. The accessory minerals are hornblende, magnetite, and titanite. The alteration has usually been large, forming sericite, chlorite, and epidote. Pyrite is nearly always present, and weathering to limonite, has stained the exposed surfaces brown. These brown stained apophyses have been mistaken for quartz veins, and, in the vicinity of Victoria, have been frequently prospected.

BEALE DIORITE.

Distribution.—Closely associated with the granodiorite, of the Saanich type, which is intrusive into the Nitinat formation, are marginal facies of diorite. Although doubtless restricted to the margin or periphery of the granodiorite batholith, the diorite occurs in large masses, which can, for the greater part, be mapped separately, as the boundaries where located are very definite, the granodiorite being intrusive into the diorite. The diorite is typically developed at Cape Beale, and is very well exposed along the shore in that vicinity, so that Beale is used as a distinctive geographic term for the diorite. The diorite is also well developed and exposed in the vicinity of Gordon river, forming the highest mountain in Renfrew district, Mount Edinburgh, which is about 3,700 feet high.

Diorite similar to the Beale diorite sometimes occurs near the contacts of the Saanich granodiorite with the Vancouver volcanics and Sutton limestones; but is not in sufficient amount to map separately.

Lithological characters.—Quartz bearing diorite.—The normal Beale diorite is a medium to light coloured holocrystalline rock, of fine to medium grain.

Microscopic.—It consists essentially of andesine feldspar, about Ab. 60, An. 40, and common green hornblende. Quartz is present, and is sometimes an essential constituent. The accessory minerals include biotite, magnetite, [illegible], apatite, and titanite. The texture is subhedral, with euhedral andesine and hornblende, and interstitial quartz. The hornblende at times includes the andesine poikilitically. Two or three different hornblende individuals are sometimes poikilitically intergrown; and it seems as if the pleochrism of the hornblende were more or less compensated by the irregular intergrowth, so that many hornblende grains occur which have nearly colourless centres and strongly pleochroic rims. This phenomenon may be due in part to alteration, but no other evidences of alteration are always present. The diorite is slightly to moderately altered, the secondary minerals being uralite or actinolite, biotite, chlorite, epidote, and sericite.

Diorite.—Facies similar to the normal Beale diorite occur in which quartz is virtually absent, and which are, therefore, true diorites. These diorites, which sometimes have a porphyritic tendency, are richer in hornblende than the quartz bearing diorites.

Contact facies.—Femic.—Near the contacts with the Nitinat formation what appear to be hybrid types occur. Near the pure marbles femic facies invariably occur, while salic facies sometimes occur in contact with the amphibolites of the Nitinat formation. The femic facies are similar to the diorites, only finer grained and more basic, containing more hornblende and more basic feldspars, which occur in lath-shaped crystals. They are also more sheared and altered, but the alteration products are similar.

Salic facies.—The salic facies are lighter coloured, much finer grained rocks than the normal quartz bearing Beale diorite; and consist chiefly of andesine feldspar, with hornblende, biotite, and a colourless pyroxene, probably diopside. The texture of the groundmass is irregular, although sometimes euhedral feldspars occur, about 1 mm. in length, while the average grain is about 0·1 mm.

Segregations or inclusions. The Beale diorite, as well as the Saanich granodiorite, frequently, especially near its contacts, contains numerous rounded to subangular segregations or inclusions, of relatively small size, rarely more than a few inches in diameter. The segregations or inclusions in the Beale diorite closely resemble the diorite mineralogically, and are best classified as segregations. They are darker coloured and much finer grained than the diorite, sometimes with a larger percentage of femic minerals, and more altered. The feldspar commonly occurs in lath-shaped grains with diverse arrangement, and with intersertal hornblendes.

Alteration and metamorphism. Besides the ordinary alteration described above, the Beale diorite has occasionally, especially near the contact deposits of magnetite of the Nitinat formation and certain mineralized shear zones, been so greatly sheared and slickensided as to resemble a chlorite schist, but the originally granitic texture is seen if the rock is broken at right angles to the shear planes and smoothed or polished. On microscopic examination the feldspars are seen to be bent, and almost opaque with sericite. The hornblende has altered to uralite, and biotite. Other secondary minerals are chlorite, epidote, serpentine, and calcite, and veinlets of quartz and secondary feldspar occur.

SAANICH GRANODIORITE AND QUARTZ DIORITE.

The plutonic rocks of the Saanich type range from a granite to a quartz diorite. The Saanich type is transitional between a granodiorite and a quartz diorite, and cannot be definitely classified without a chemical analysis, but will be referred to ordinarily as a granodiorite.

Distribution. The Saanich granodiorite, which is the principal batholithic rock of southern Vancouver island, is widely distributed, but the larger batholiths are confined to two main but very broad axes, a southern and a northern. The southern axis extends from Saanich peninsula, where one of the larger individual batholiths occurs, westward to the Renfrew district, where again relatively large batholiths are exposed, and which doubtless continue, irregularly, but without complete interruption, to Barkley sound. Between Saanich and Renfrew districts small granodiorite stocks occur intrusive into the Wark diorite and quartz diorite gneisses, and Vancouver volcanics and Sutton limestones, and small stocks occur in Victoria and Esquimalt districts. Two areas of granodiorite are reported in the belt of the Leech River formation in Renfrew, and the western part of Malahat districts. The northern axis extends from Saltspring island, although a small stock occurs on Moresby island, northwest to Alberni canal. In the Somenos, Seymour, and larger part of Chemainus districts, there is, however, no granodiorite exposed. To the west of Chemainus district, irregular batholiths, probably more or less continuous, occur.

The Saanich granodiorite is fairly well exposed, especially well along the shore, and creek and river beds, and on the monadnocks which surmount both the pre-Glacial and Tertiary erosion surfaces. The northern and eastern part of the Saanich peninsula batholith is, however, almost entirely covered with drift. The contacts of the Saanich peninsula, Esquimalt and Victoria, and Saltspring island stocks and batholiths have been well located, but the contacts of the other stocks and batholiths have been determined only by traverses, and as the contacts are irregular, the widely separated, determined contacts cannot be extended to join each other with any great assurity; and little attempt has been made to do so on the accompanying map.

Lithological characters. Granodiorite and quartz diorite. Macroscopic.—The Saanich granodiorites and quartz diorites are light coloured, medium grained rocks, with a characteristic granitic, and frequently somewhat gneissic texture, which is rarely pronounced. The weathered surface is as a rule much lighter coloured than the freshly broken surface. They consist of feldspar and quartz, with essential hornblende, and with accessory biotite and magnetite. Pyrite is also common and is probably original. The feldspar at times weathers both pink and greenish white, the latter occurring in euhedral crystals. The hornblende sometimes occurs, especially near contacts, in large euhedral crystals, which give the rock a characteristic porphyritic or 'speckled' appearance.[1] The granodiorite usually contains numerous small, rounded segregations or inclusions of a darker colour.

Microscopic.—The essential minerals are plagioclase, orthoclase, frequently microperthite, and rarely microcline, quartz, and horn-

[1] James Richardson. Rept. of Progress, 1871-72. Geol. Survey, Canada, p. 90.

blende; the accessory minerals are biotite, magnetite, pyrite, and titanite; and the secondary minerals are biotite, chlorite, epidote, sericite, muscovite, limonite, and kaolin. The plagioclase is the chief feldspar, and occurs in euhedral grains. It is chiefly oligoclase-andesine, but varies in composition and is often zonal, ranging from Ab. 55, An. 45, to Ab. 90, An. 10. The quartz, orthoclase, microperthite, and where present microcline, are interstitial to the plagioclase and hornblende. The quartz and potash feldspars are sometimes graphically intergrown; and quartz more rarely occurs in large grains which include the plagioclase crystals. The quartz has a wavy extinction, and many of the quartz grains are greatly fractured. The microperthite when present is a very irregular intergrowth, probably of orthoclase and albite. It rarely occurs in large grains which include the earlier crystallized minerals. In some facies potash feldspar is in very small amount, or absent. The hornblende was of the common variety, but is now largely altered. The percentage amount of the essential minerals is approximately as follows:—

Oligoclase-andesine.	40 to 50 per cent.
Quartz.	20 " 35 "
Potash feldspar	0 " 15 "
Hornblende.	10 " 20 "

It is seen from the above description that the rock ranges from a typical granodiorite to a rather typical quartz diorite. It is probable, however, that even where the potash feldspar fails, that potash replaces soda in the plagioclase molecule isomorphously. The rock is, therefore, best classed as a granodiorite.

Alteration.—The granodiorite is usually altered and in the sheared varieties the alteration is large. The feldspar has altered to sericite, and epidote is sometimes an alteration product of the plagioclase feldspars. The hornblende is largely altered to brown biotite, chlorite, and an iron rich epidote. This alteration is very characteristic, not only of the granodiorites of Vancouver island, but of the Pacific Coast region.

Granite.—True granite facies are of very rare occurrence in the batholiths of Saanich granodiorite, and as far as known are restricted to batholiths intrusive into the Nitinat formation. They are very similar to the normal granodiorite in appearance, but are somewhat lighter coloured, and weather to a more reddish colour. The femic minerals are in smaller amount, and biotite predominates.

Microscopic.—Microscopically, the granite is seen to consist essentially of microperthite, albite-oligoclase, and quartz, with accessory biotite, and probably hornblende, now altered to biotite and epidote. The albite-oligoclase occurs in euhedral crystals, while the microperthite and quartz form a micrographic intergrowth. The feldspar is so largely alkaline that these facies are best classed as a calci-alkaline granite.

Apophysal phases.—Apophysal phases of the Saanich granodiorite are very similar in mineral composition to the granite described above; they are finer grained, and aplitic in texture. In certain related types, occurring near the contacts, feldspar is in great excess over the other constituents, chiefly quartz.

Segregations or inclusions.—Throughout the granodiorite, but more abundantly near the contacts, are numerous small, rounded, darker coloured segregations or inclusions. The contact between them and the granodiorite is sharp, although crystals of the one penetrate into the other. As the mineral composition is also related to the granodiorite, until they can be proved definitely to be inclusions they had best be considered as segregations. The segregations are fine grained, with a few small phenocrysts of feldspar and hornblende.

Microscopic.—The essential minerals are andesine-oligoclase, Ab. 60, An. 40, to Ab. 80, An. 20, hornblende, biotite, and sometimes quartz. Magnetite is sometimes present in large amounts, and other accessory minerals are titanite and apatite. The groundmass of the segregations has a rather characteristic texture, as it is composed of lath-shaped feldspars with prismatic hornblendes, with poikilitic biotite and interstitial quartz. The amount of the various minerals varies greatly, but hornblende and feldspar predominate. The alteration products are similar to those of the granodiorite, chiefly chlorite, epidote, and sericite.

Contact and hybrid phases.—Near the contacts, especially near limestone contacts, the granodiorite becomes more basic and passes into types in which quartz is absent or only an accessory, and which are therefore diorites. Orthoclase or microperthite is retained in these diorites, and occurs interstitial to euhedral oligoclase-andesine, rarely including them poikilitically; so that the contact diorites are monzonitic in composition and texture.

When in immediate contact with pure marbles or contact metamorphosed limestones the monzonitic diorite, and more rarely granodiorite, invariably contain pyroxene, sometimes augite, but usually diallage or diopside. Calcite is a common secondary mineral in these contact phases. It seems as if the pyroxene had been formed by the recrystallization of material derived by the assimilation of the limestones, and if so these facies are hybrid rocks.

Quartz gabbro.—Intrusive into the limestones, near the contact deposits of the King Solomon and Blue Bell mineral claims on Koksilah ridge in Helmcken district, and apparently associated with the Saanich granodiorite, is a quartz gabbro. It is a rather dark coloured, medium grained rock, consisting of lath-shaped labradorite, euhedral hornblendes, and interstitial quartz, the latter in small amount. The accessories are magnetite and pyrite. The relation of the quartz gabbro to the Saanich granodiorite is not known.

CONTACT, OR GRANODIORITE PORPHYRITES.

At the contacts of the granodiorite are frequently developed dyke-like and irregular masses of porphyritic rocks, which are sometimes intrusive into the granodiorite as well as into the intruded formation, but at other times they are not clearly intrusive into the granodiorite.

Quartz-feldspar porphyrite.—The most common type is a light greenish grey rock with an aphanitic to fine grained groundmass and medium sized phenocrysts of feldspar, quartz, and hornblende. The phenocrysts vary in number from very few into phases in which they are dominant.

Microscopic.—The feldspar phenocrysts are albite-oligoclase. The hornblende phenocrysts, where still preserved, have an olive to brownish green pleochroism, but are usually altered to biotite, chlorite, and epidote. The groundmass consists of very fine irregular grains, rarely intergrown micrographically, of albite-oligoclase, an untwinned feldspar, probably orthoclase, quartz, and hornblende, the hornblende usually accessory. Magnetite is the only other accessory mineral, although pyrite usually occurs in disseminated grains, but may be secondary.

Rounded segregations, similar to those in the granodiorite, are fairly frequent, especially in the coarser grained phases, in which the femic constituents and plagioclase are more abundant.

Alteration.—The porphyrites are slightly to greatly altered, the alteration being usually rather large. As mentioned the hornblende is usually replaced by biotite, chlorite, and epidote, and other secondary minerals are sericite, calcite, and limonite. The porphyrites have rather rarely, except when they are intrusive into the Sicker series, a schistose texture.

As may be seen from the lithological description, and as noted, the quartz-feldspar porphyrites are closely related to the similar porphyrites which are intrusive into the Sicker series in great numbers, and which have already been described.[1]

Feldspar porphyrite. Similar and transitional porphyrites occur in which quartz does not form phenocrysts. Otherwise, these types are similar to the quartz-feldspar porphyrites, although they are rather more basic, augite being present in some occurrences, and there is more variation in texture.

Both the quartz-feldspar and feldspar porphyrites are closely related to the granodiorite. Lithologically they are similar dellenite or dacite porphyrites, or as they are more commonly called quartz porphyrites. Their close relationship to the granodiorite may be indicated by calling them granodiorite porphyrites.

DYKES.

Augite bearing, andesite porphyrites. Distribution.—Confined for the greater part to the batholiths of Saanich granodiorite, and more numerous near the contacts of the granodiorite, are dykes of basic porphyrites. The dykes are seldom very numerous at any one locality. They are well defined, regular dykes, from a few inches up to 30 feet in width.

[1] See page 77.

Lithological characters. The principal dyke rock is an augite bearing, andesite porphyrite. Megascopically it is a greyish green porphyritic rock, with an aphanitic groundmass, and medium sized phenocrysts of feldspar, and smaller and finer phenocrysts of hornblende.

Microscopic. The phenocrysts are seen microscopically to be a basic andesine about Ab. 50, An. 50, hornblende, and augite. The groundmass consists essentially of a rather acid andesine, about Ab. 65, An. 35, which is in excess, and common green hornblende; and magnetite is the only important accessory mineral. The andesine of the groundmass occurs in lath-shaped crystals, and the hornblende is interstitial. The dyke rocks are usually considerably altered, the chief secondary minerals being epidote, chlorite, sericite, and quartz.

Andesite porphyrite. Intrusive into the Beale diorite, in the vicinity of Cape Beale, are a few dykes. One of these dykes, occurring on the east shore of Barkley sound, about 2 miles north of Cape Beale, 50 feet wide, and striking N 40° W, is an andesite porphyrite, but not of the augite bearing type. It is a dark grey aphanitic rock, with small but numerous phenocrysts of prismatic hornblende, which have a parallel arrangement.

Microscopic. The hornblende phenocrysts are seen on microscopic examination to be a light brown, common variety. The essentials of the groundmass are basic andesine, about Ab. 55, An. 45, and small grains of hornblende. The accessory minerals are quartz and magnetite, and possibly biotite, which may, however, be entirely secondary, although the rock is otherwise almost unaltered. The andesine of the groundmass occurs in lath-shaped crystals with a subparallel arrangement, often bent around the hornblende phenocrysts, which occasionally include the minerals of the groundmass.

STRUCTURAL RELATIONS OF THE BATHOLITHIC AND DYKE INTRUSIVES.

Internal—The plutonic rocks have all been subjected to more or less dynamo-metamorphism, which has produced a somewhat gneissic texture in the diorites and granodiorites of the Beale and Saanich types, and a pronounced gneissic texture in the diorites and quartz-diorites of the Wark type. All of the granitic rocks are commonly greatly jointed and fractured, with more regular large joints, and smaller irregular fractures. They have also been more or less sheared, often very greatly, developing wide shear zones. The fracturing and shearing has in most instances rendered the granitic rocks unfit for building purposes; although the granodiorite exposed on Alberni canal, near Franklin river, is in places regularly jointed, and nearly free from small fractures and shear zones, and would doubtless be suitable 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.

Relations of types to each other.—The Saanich granodiorite is clearly intrusive into the Wark diorite and quartz diorite gneisses and Beale diorite, brecciating them both along the contacts, and sending irregular, aplitic apophyses into them for long distances. The relation of the Wark and Beale diorites is not exposed, but the Wark diorites are, with considerable certainty, considered to be the older, since they are gneissic, and not so closely related lithologically and structurally to the Saanich granodiorite as the Beale diorite is. The probable sequence of eruption is, therefore, as given: Wark diorite and quartz diorite gneiss, Beale diorite, and Saanich granodiorite.

Although the Wark diorite and quartz diorite gneisses form virtually a single batholith, the quartz diorite is intrusive into the Wark diorite. Although relatively large masses of typical diorite gneiss occur, it is nearly everywhere cut by numerous apophyses of quartz diorite and aplitic gneisses, often forming a complex of diorite and quartz-diorite gneisses, that could not be mapped separately, even on large scale detailed mapping. The quartz diorite gneiss generally occurs in long lenticular masses, so that a series of alternating, irregular belts of the two rocks is formed. In the southeast portion of the batholith the series has a strike of N 50° W to N 60° W.

The relation of the gabbro noted in the Highland and Malahat districts with the Wark diorite is not known.

As described, the Beale diorite is usually the contact phase of the batholiths which are intrusive in the Nitinat formation, and which are composed chiefly of Saanich granodiorite. Since the two rocks are closely related lithologically, it is suggested that the Beale diorite is a marginal or peripheral differentiate of the Saanich granodiorite. The virtual restriction of the Beale diorite to the batholiths intrusive into the Nitinat formation is peculiar, and since it forms relatively large masses which are brecciated along the contact, showing that it must have been well crystallized when the granodiorite was intruded, and since there are no well marked transitional types, the Beale diorite and Saanich granodiorite may well be in detail separate intrusions.

The contact and hybrid facies of the Saanich granodiorite, best developed near the contact with the Sutton limestones, are cut by apophyses of granodiorite and aplite. Small and irregular aplite veins are also quite common throughout the granodiorite.

The granodiorite porphyrites are restricted in their occurrence to the vicinity of the contacts of the Saanich granodiorite with the invaded formations, other than the older plutonic rocks. They are, as stated, in some instances intrusive into the granodiorite, very frequently the relations are not clear. The quartz feldspar porphyrites, intrusive into the Sicker series, which on account of their lithological identity are almost assuredly one of the phases of the granodiorite porphyrites, are apparently older than the Saanich granodiorite.

As already discussed under Sicker series,[1] the relations of the Saanich granodiorite and the Sicker gabbro-diorite porphyrites are not known; but the gabbro-diorite porphyrites may be younger.

The dyke rocks, the augite bearing andesite porphyrite, and andesite porphyrite with the parallelly arranged phenocrysts of hornblende, are clearly later than the plutonic rocks, cutting the Beale diorite and Saanich granodiorite in well defined, regular dykes.

External. Relation to older formations.—The granitic rocks are, as stated, reported to be intrusive into the supposed oldest formation of southern Vancouver island, the Leech River slates; and the numerous quartz veins which occur in the slates may be referred to the after effects of the granitic intrusion.

The granitic rocks are intrusive into the formations of the Vancouver group, developing narrow zones of shatter breccias along the contacts, and sending apophyses and granodiorite porphyrite dykes into the invaded rocks. As stated, diorite or monzonitic diorite is

[1] See page 83.

virtually always the contact facies, even of the granodiorite batholiths, with limestone. The invaded rocks have been characteristically contact metamorphosed, and in some instances, notably near limestone contacts, deposits of metallic minerals have been formed. Inclusions or xenoliths occur in the granitic rocks, usually altered to amphibolites. The xenoliths are commonly angular and well defined, but occasionally they have indefinite boundaries, and are impregnated with material from the intrusive magma. Rarely hybrid types, such as those occurring near the Sutton limestone contacts, are developed.

Relations to younger formations.—The granitic rocks are unconformably overlain by the sediments of the Cowichan group and of the Sooke and Carmanah formations. The unconformity is usually marked by coarse basal conglomerates. In some instances[1] the contacts of the Saanich granodiorite and the Cowichan group are faults.

Mode of origin of batholithic and dyke intrusives.—The batholiths and dykes have been crystallized from a molten state under deep-seated conditions. They have been erupted into a great series of volcanic and sedimentary rocks, and now occupy a large volume formerly occupied by the invaded rocks. Little evidence is seen in the field as to the manner in which the batholiths have reached their present position. They have certainly replaced a very large mass of the country rock, apparently in a relatively quiet manner, without disturbing the strike and dips of the invaded formations. The invading batholiths, even during their last active stages, shattered the country rock along the contact into angular fragments. These fragments, which were 'stoped' off from the country rock, disappear within a few yards of the contact, and have either been shattered to smaller fragments and assimilated by the magma, of which there is some evidence in restricted localities, or else have sunk in the liquid magma to abyssal depths.[2]

The batholiths were erupted during two main periods, which we may call the Wark and Saanich periods. Each period was divided into two sub-periods, the first sub-period in each case being characterized by the eruption of more basic magma than that erupted during the second sub-period. The close lithological an

[1] See page 130.
[2] Cf. R. A. Daly Mechanics of Igneous Intrusion Three papers. Am. Journ. Sci., Vol. 15, 1903, p. 269; Vol. 16, 1903, p 107; Vol. 26, 1908, pp. 17-50

structural relationship of the basic and acid magmas erupted during the two sub-periods apparently shows that the two sub-magmas were differentiates of a common parent magma.

The Wark batholith, which was evidently erupted first, is closely related to the Saanich batholiths structurally. It is also, except that it is gneissic, very similar lithologically. We may, therefore, consider the Wark and Saanich magmas as differentiates of a common magma. As a whole the Wark magma was more basic than the Saanich magma.

The association of similar sub-alkaline rocks, exhibiting a similar sequence of eruption from basic to acid magmas, is very common, both in Europe and America.[1] The association and the sequence of eruption is very generally accepted to be due to magmatic differentiation. In the case of 'plutonic complexes,' such as that of Vancouver island, it has seldom or never been shown that the differentiation has been 'in place,' that is, 'laccolithic' in Brögger's[2] sense, but the various rock types have rather been separately intruded. The differentiation producing the various types has been, therefore, deep seated.[3] Consequently the differentiation cannot be easily studied, and has been but little discussed. A further discussion would be out of place in this report.

The close magmatic relation of the granodiorite porphyrites and Saanich granodiorite is clearly shown by the close similarity of their mineral, and presumably chemical, composition. The significant features of the granodiorite porphyrites are their restriction to the contacts, their long period of eruption, as some are probably older and some certainly younger than the granodiorite, and their texture, which shows that they crystallized more rapidly than the granodiorite. It seems most probable, therefore, that they are in a sense apophysal phases of the granodiorites which were erupted in part in advance of the main batholithic intrusion, and also after the batholith had begun to crystallize.

A very common feature of batholithic intrusion is the later intrusion of basic rocks usually as dykes or 'minor intrusions.'[4]

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[1] Cf. A. Harker. The Natural History of Igneous Rocks. Macmillan, 1909, pp. 125-131. A good example is the composite Okanagan batholith of the Cascade Mountain system. R. A. Daly, Bull. Geol. Soc. Am., Vol. 17, 1906, pp. 329-376.

[2] W. C. Brögger. Eruptivgestein des Kristianiagebietes, Vol. 1, 1894, pp. 178-179.

[3] Primary or "deep-magmatic" cf. Brogger Loc. cit.

[4] A. Harker. The Natural History of Igneous Rocks, Macmillan, 1909, p. 25.

and the basic dykes accompanying the Saanich batholiths are doubtless of this nature. It is possible that the gabbro-diorite porphyrites of the Sicker series also represent 'minor intrusions' accompanying the batholithic intrusion.

It may be well to emphasize here the conformity of the eruptive cycle represented by the igneous rocks of Vancouver island (in general, this is, the meta-andesites of the Vancouver group, the diorites and granodiorites of the batholithic intrusions, and the andesite and gabbro-diorite porphyrites of the dykes and minor intrusions) [illegible] general eruptive cycle, which has been firmly established by [illegible]tions all over the world and which has been recently emph[illegible]by Harker.[1] It consists of three phases of igneous activity in the following sequence, the volcanic phase, the batholithic phase, and the phase of minor intrusions.

The gneissic structure of the Wark batholith, and the virtual absence of pronounced gneissic structure in the Saanich batholiths, may be explained by supposing the Wark batholith to have been intruded during the orogenic movements, which generally accompany or precede batholithic intrusion. That the Wark batholith is somewhat older than the Saanich batholith has been clearly shown.

Both batholithic types have been dynamo-metamorphosed by later orogenic movements, probably during the Laramide revolution. The Wark batholith has not only been dynamo-metamorphosed, but since it has been intruded by the Saanich batholiths, also contact metamorphosed. This contact metamorphism has apparently caused the partial recrystallization of the diorite gneiss, and the segregation of the quartz diorite into salic and femic zones.

Mention has already been made of the types developed near limestone contacts. Their restriction to limestone contacts, and the presence of pyroxene, especially diopside, seems to show that they are hybrid rocks.

Age and correlation.—The batholiths are intrusive into lower Jurassic rocks, and upper Cretaceous sediments rest unconformably upon a subdued erosion surface of granitic rocks. They are, therefore, correlated with considerable certainty with the Coast Range batholith of British Columbia, which is composed of similar rocks, and which is considered to be upper Jurassic in age.

[1] A. Harker. The Natural History of Igneous Rocks, Macmillan, 1909, p. 95.

The Vancouver range differs from the Coast Range of British Columbia in that the granitic rocks of the Vancouver range do not, as exposed, occur in one large batholith, but occur in relatively small, irregularly outlined batholiths. In southern Vancouver island the batholiths, as noted under distribution, occur along the main axes, separated by a wide central area, in which few granitic rocks occur, and which may be synclinal. The great lithological and structural similarity of the individual stocks and batholiths, their very irregular outlines, and the occurrences, noted most clearly in Cowichan district along the Nanaimo, Chemainus, Robertson, and Koksilah rivers, of granitic rocks in valleys with mountains on either side capped by the invaded rocks, indicates that the granitic rocks form one or two large batholiths, not yet completely unroofed.

This hypothesis suggests a reason for the predominance of granitic rocks in the southeastern part of Vancouver island, where the pre-Glacial erosion cycle reached late maturity or old age, reducing the general level far below the Tertiary peneplain. The true difference, therefore, between the Vancouver and Coast ranges may be, that in the Coast range erosion has removed a large part of the roof of the batholith, so that the remaining sedimentary rocks are in a large sense mere 'roof pendants' and downfolds,[1] while the Vancouver range may be composed of a large Coast Range-like batholith, not yet largely unroofed, of which the exposed batholiths are mere protuberances or 'cupolas.'

SOOKE GABBRO.

Distribution.—Along the southwestern coast are two stocks of basic plutonic rocks, which are chiefly composed of gabbro. The larger stock underlies the greater part of the East Sooke peninsula. It is elipsoidal in form, the major axis being about 5 miles in length, and the minor axis a little more than 2 miles. The stock forms the country rock of the Sooke copper deposits, and the gabbro is, therefore, not only best developed on the Sooke peninsula, but is best known there. It seems advisable, therefore, to use the name Sooke as the distinctive geographic term for the gabbro. The smaller stock occurs on Rocky point, south of Pedder inlet. I[illegible] atest diameter is about 2 miles. Small isolated knobs or bosses also occur west of

[1] J. Austen Bancroft. Summary Report for 1907. Geol. Survey, Canada, pp. 16-17.

Sooke harbour along the coast, notably on Sheringham point, and between Jordan river and Boulder point.

The stocks and bosses are well exposed along the shore; and on the East Sooke peninsula the gabbro forms bold ridges and hills.

Lithological characters.—The rocks which compose the stocks are all closely related to the gabbro family, but otherwise vary considerably. They range from an augite-olivine gabbro to a salic gabbro, and even to a true anorthosite. The feldspathic types are confined to small bosses and veins. The principal rock body is a more or less gneissoid amphibole-augite gabbro, which resembles a basic diorite in the hand specimen. There are also apophysal types which range in composition from a hornblendite to a quartz diorite, and in rare cases to a quartz-feldspar pegmatite in which the feldspar greatly predominates.

Amphibole gabbro.—*Macroscopic.*—The amphibole gabbro is a greenish crystalline rock normally of rather coarse grain, usually with a gneissic texture, consisting of plagioclase feldspar and large bladed hornblendes. It varies in grain, however, to a medium, and in some cases, to a fine grained rock, which types appear to be truly transitional.

Microscopic.—Microscopically the rock is seen to consist essentially of plagioclase, hornblende, and augite. In the coarser grained varieties augite is less abundant and often lacking. The femic and salic minerals are present in about equal amounts. The feldspar is labradorite, Ab. 40, An. 60. The hornblende is a light green, weakly pleochroic variety of common hornblende. This hornblende is very characteristic of all the gabbroid rocks. It is seemingly an original constituent, the period of crystallization of the feldspar and the hornblende overlapping to some extent. Some of the amphibole in the rocks is a fibrous uralite which has been formed by the alteration of the original augite. Magnetite or ilmenite are the only important accessories, and are not commonly abundant.

Fine grained augite gabbro.—In some of the gabbros, notably the finer grained, hornblende, except as a secondary mineral, is only accessory or lacking. The feldspar in these rocks is more basic, Ab. 35, An. 65. The augite is sometimes light green and slightly pleochroic. The augite and plagioclase occur in about equal amounts and are more or less contemporaneous, although the feldspar is sometimes lath-shaped with inter-titial grains of augite.

Ophitic gabbro.—The fine grained, augite gabbro is transitional into a rock which has a true inter-ertal and ophitic texture. The ophitic gabbro also contains occasional phenocrysts of plagioclase in a finer grained crystalline groundmass. At times the ophitic gabbro contains olivine as a prominent accessory, which, however, rarely becomes an essential constituent. The olivine has been largely altered to serpentine and iddingsite. The augite gabbros are all more or less altered, the augite being chiefly affected, having altered to uralite. The feldspars are usually fresh and clear.

Columnar textured gabbro.—A very peculiar looking gabbro is found on Rocky point and also on Sheringham point. The rock is medium to coarsely crystalline, with an almost perfect euhedral texture. It consists of plagioclase and amphibole. The amphibole occurs in long columnar crystals, 10 mm. long by 1 to 2 mm. wide. The plagioclase also occurs in lath-shaped crystals. The two minerals form an interlacing mat, which gives the rock a very peculiar texture. This peculiar texture is especially striking on an unpolished weathered surface.

Microscopic.—The columnar mineral is seen under the microscope to be an intergrowth of light brownish green, weakly pleochroic hornblende with a diallagic augite. The feldspar is very basic, bytownite, Ab. 25, An. 75. The salic and femic minerals are in about equal proportions. They are nearly contemporaneous in their crystallization, but feldspar fills the interstitial spaces.

Apophysal phases.—The more basic varieties of the gabbro are cut by small bosses and dykes of a more salic gabbro, and by pegmatites and aplites, and also by dyke-like masses of almost pure hornblende.

Olivine anorthosite (allivalite).—The largest mass of salic gabbro occurs on the northwest slope of Mount Maguire, and is about 400 yards across. The rock is light coloured, coarsely crystalline, and of subhedral texture.

Microscopic.—It consists of about 85 per cent of a clear plagioclase, the variety bytownite, Ab. 35, An. 75, 10 per cent of olivine, and about 5 per cent of augite, with a very little magnetite. The bytownite occurs in large euhedral grains, the olivine usually in rounded grains, and the augite as small interstitial crystals. Magnetite is original, but also occurs with serpentine on the borders, and in the cracks of the olivine grains. The olivine as a whole is but slightly altered. The rock is clearly related to the gabbro, but is approaching an anorthosite. It closely resembles the olivine-anorthosite rocks described by Harker from the island of Rum, the feldspathic member of which he calls allivalite.[1]

Anorthosite.—Anorthositic rocks also occur as apophyses which cut the more normal femic gabbro. On Beechy head the feldspathic veins which brecciate the normal gabbro lose virtually all of their femic constituents. The vein rocks are light coloured, weathering greyish-white, of medium grain, and composed of about 95 per cent of feldspar and 5 per cent of augite, and a little magnetite. The feldspar is all basic, Ab. 25, An. 75, to Ab. 35, An. 65. The augite is interstitial, and is altering somewhat to amphibole. The rock is undoubtedly a derivative of the gabbro magma, but is nevertheless a true anorthosite.

Pegmatites.—Other types of apophyses are pegmatites. A common pegmatite is one consisting of coarsely crystallized feldspar and hornblende. The feldspar occurs in the central part of the vein, and the hornblende is more or less confined to the walls, although it frequently forms a band through the middle of the vein.

Microscopic.—The feldspar, which is the chief constituent, is unaltered labradorite, Ab. 30, An. 70. The hornblende is of the light coloured variety, and sometimes includes the feldspars, developing a poikilitic texture. A few grains of magnetite are also present. Epidote is a common secondary mineral and occurs replacing the plagioclase, and in veinlets.

Aplites.—The aplites are light coloured, fine grained holocrystalline rocks with an aplitic texture, and with large crystals of bladed hornblende. They are composed of quartz, orthoclase, and

[1] A. Harker. Geology of the Small Isles, Mem. Geol. Survey, 1908, pp. 69-77.

plagioclase, probably andesine, with small amounts of augite and hornblende. The large crystals of hornblende are of the characteristic light coloured variety.

Gabbro porphyrite. Another rock which occurs in distinct dykes, cutting both the gabbro and the feldspathic veins, appears to be related to the other gabbroid rocks. It is a gabbro porphyrite, and is exposed on Beechy head. It is a dark, finely crystalline rock of plagioclase and augite with a few phenocrysts of feldspar.

Microscopic.—It is seen microscopically to consist of a fine granular mixture of contemporaneous labradorite and augite. The plagioclase phenocrysts show zonal growth and range from Ab. 25, An. 75, to Ab. 40, An. 60. The augite occurs intergrown with and interstitial to the plagioclase. Magnetite and pyrite are accessories.

Diorites.—Midway between the mouth of Jordan river and Boulder point the Metchosin volcanics are cut by small irregular masses of diorite, which is apparently related to the Sooke gabbro. The diorite itself is brecciated by more acid, aplitic veins of quartz bearing diorite. The diorite is rather fine grained, and consists of hornblende and andesine feldspar with accessory magnetite and apatite. The texture is anhedral to subhedral, the feldspar and hornblende having crystallized nearly simultaneously. The rock is but slightly altered, the feldspar altering to sericite, and the hornblende to biotite.

In the more acid apophyses, the feldspar, which occurs in large euhedral crystals, predominates. It has a pronounced zonal growth, and ranges from andesine to oligoclase. The hornblende also occurs in euhedral crystals, while the interstices are filled with crushed grains of quartz. Magnetite is accessory, and biotite, epidote, and sericite are secondary products.

Metamorphism. The Sooke gabbro has suffered from considerable metamorphism, rendering the rock gneissic, and shearing it along well marked and often extensive zones. The original constituent minerals in these shear zones have undergone an almost complete change. The first step in the alteration is the formation of large poikilitic hornblendes. This hornblende is light greenish and weakly pleochroic, and has doubtless been formed from the original augite. It is very similar to the hornblende which in some instances appears to be original. The formation of this hornblende is characteristic even of the more altered rocks, and is in many cases an undoubted secondary mineral.

The more sheared rocks consist almost entirely of labradorite and the light yellowish green hornblende, the augite having been entirely replaced. Both of the essential minerals show the effects of movement. The feldspars have been broken, granulated, and even pulled out into veinlet-like forms, and to some extent recrystallized. Much of the hornblende has gone over to a fibrous amphibole, actinolite, or more likely to an aluminous amphibole such as strahlstein. The amphibole sometimes occurs in radiating groups, and veinlets of actinolite are also present. The amphibole has altered slightly to chlorite, and the feldspar is clouded somewhat, but otherwise is unaltered. The change is such as would take place only at high temperatures and pressures.

The more completely altered rock consists of a fine mat of small fibrous amphibole, weakly pleochroic, with larger needles of the light yellowish green hornblende. Scattered through the rock are patches and grains of a clouded feldspar, with a little secondary albite. Zeolites occur, filling minute cavities, and in veinlets. Disseminated through sheared rocks is very often found considerable amounts of magnetite and pyrrhotite.

Hornblendites.—The sheared meta-gabbros, described above, are closely related to and associated with masses composed almost entirely of amphibole. These amphibolites or hornblendites occur in shear zones. They are coarse grained, and consist of a bladed and a fibrous amphibole, with small segregations of feldspar and magnetite. The bladed amphibole is hornblende, and occurs chiefly in large irregular grains, massed closely together. The fibrous amphibole occurs in fine needles and in radiating groups. It is doubtless actinolite, and occurs in bands associated with the remaining 5 or 6 per cent of feldspar, and with magnetite.

Associated with the hornblendites is a light, greyish green rock, which consists of a fine grained, crystalline groundmass with narrow zones of actinolite or tremolite in divergent groups.

Microscopic.—Microscopically the rock is seen to consist almost entirely of amphibole and augite. The augite forms about 50 per cent of the whole rock and occurs in small irregular to prismatic grains. The amphibole is of two varieties, the characteristic light yellowish green hornblende, and a light green, weakly pleochroic actinolite. The actinolite was formed later than the more massive hornblende.

Associated with the last two types described, are the ores of the East Sooke peninsular. These ores are composed chiefly of chalcopyrite, which occurs as veinlets, although often of large size, 3 or 4 inches in width, in a matrix composed entirely of bladed and needle-like hornblendes. The chalcopyrite is clearly younger than the hornblende, and not only cuts the hornblende in veinlets, but has grown around the amphibole grains.

Structural relations. Internal.—The Sooke gabbro has suffered considerable dynamic metamorphism. The rock has yielded to some extent by folding, as is shown by its gneissic structure. The principal relief, however, has been by faulting and shearing. The abundant sheer zones doubtless represent a very considerable movement, as they are often very wide, having a maximum width of over 100 feet, and may be traced along the strike for considerable distances, in one case for nearly a mile. The rock is also slickensided, and has been altered and impregnated by ore-bearing solutions. It is impossible to tell, in any one case, just how much the displacement may have been, as there are no satisfactory means to correlate the rock on the opposite sides of the shear zone. Although the movement along these shear zones may have been very considerable, it is not probable that the actual displacement has been large. In the East Sooke stock there appear to be two, quite well developed, sets of shear zones, one having a strike near N 40° E and the other near N 75° E.

The joints in the Sooke gabbro are numerous and are related to the shear zones, and their strikes are approximately the same. They are doubtless due to the same causes, that is, to compressive forces.

The Sooke gabbro is cut by dykes of two kinds, one a diabase, and the other a gabbro porphyrite. The diabase is not closely related to the gabbro, and may represent igneous activity of a much later date. Only two dykes of this series were noted, one on Woodward point, 4 feet wide with a strike of N 15° W, and one 75 feet wide, exposed along the southern shore of the Sooke peninsula a mile west from Beechy head. The gabbro porphyrite is related petrographically to the gabbro, but is younger than the solidification of the gabbro and its accompanying salic veins and differentiates, as it cuts them all in well defined, narrow dykes. The dykes were only seen on Beechy head. There are three exposed there, respectively 2½, 1, and 1½ feet wide, the strike of all of them being about N 30° W.

Along the coast the dykes and shear zones have been eroded by the waves into narrow chasms. On the bold southwestern shore, where the rocks are subject to very powerful wave action, these chasms are very large, and form a striking feature of the coast.

As already noted, the gabbro shows a marked variation in composition and texture. One of the most common variations is that of grain. The gabbro is normally medium grained, but grades on one hand into a coarse grained rock, and on the other into a very fine grained, almost slaty material. These variations may all be found in the same outcrop, and occur in distinct narrow streaks, and thus accentuate the gneissic structure. These bands may have been produced by movement, with local shearing and recrystallization. As they also differ in composition, the finer grained containing more augite, it is more probable that they represent an original structure in the gabbro. Similar banding is a well recognized feature of gabbro.[1]

The more alkaline or salic types of gabbro and the pegmatitic and aplitic forms occur in distinctly intrusive dykes which cut the normal gabbro. The sequence of rocks is exposed in many places. On Rocky point, the peculiar gabbro with the columnar crystals is cut very irregularly by an intermediary rock, with over 50 per cent of feldspar. This in turn is included in and cut by a more acid, coarse grained pegmatite. All of these three varieties are intersected by aplitic veins. These various types are all consanguineous, but range from basic to acid, free quartz occurring in the aplites. The more acid types always cut the more basic. The contacts of the various types are not always sharp, but to some degree grade into each other, by the penetration of acid material into the basic, and the recrystallization of the included basic minerals in the acid magma.

The only large mass of anorthositic gabbro is found, as already described, on the northwest slope of Mount Maguire. It is intrusive into the more femic gabbro and even brecciates it along the

[1] Geikie and Teall. Banded Igneous Rocks of Skye. Quart. Jour. Geol. Soc., Vol. 50, 1894, p. 645.

contact. A contact breccia of this nature is also well exposed on Beechy head. The gabbro is here brecciated in very similar manner to that characteristic of plutonic contacts, by material ranging from an almost pure hornblende to a true anorthosite, the more feldspathic veins always cutting the more hornblendic. The contacts of the veins here, are sharp.

Pegmatite veins are very common throughout the gabbro. The veins are never very large or extensive or the crystallization very coarse. They are essentially feldspathic, although hornblende is often present. In most of the veins quartz is lacking, but in a few it occurs. These veins are composed chiefly of feldspar, but in the central part are lenses, more or less disconnected, of a pure white quartz.

The relation of the hornblende veins and the large masses of hornblendite to the normal gabbro is not clear. They are, of course, younger than the gabbro, since they cut it. The smaller irregular veins often form a network intersecting the gabbro. The hornblende of these veins occurs in large bladed crystals, up to 6 inches in length. These veins are cut by the more acid, feldspathic pegmatites and aplites. They appear themselves to be intrusive, and are most probably basic pegmatites formed by the differentiation of the original magma. The larger masses of coarse grained hornblendite, such as occur in the shear zones, do not, however, appear to be intrusive. They are very large, and are only rarely cut by feldspathic veins, although they are cut by numerous quartz veins and veinlets. The hornblende seems to be largely secondary, the material having been derived from the sheared gabbro.

External.—Relations to older formations. The Sooke gabbro and its related rocks are intrusive into the Metchosin volcanics. The relation is shown along the southern shore of Sooke harbour. On Mill head the contact is exposed, but the relation is somewhat obscured by abundant, minute faulting. In places the gabbro penetrates the volcanics in small apophyses, which pinch out as they go away from the contact. A flow structure has been developed in the gabbro near the contact and parallel to it. Farther to the west along the coast a few inclusions of greenstone are to be found in the gabbro. The general contact can be readily traced eastward, even at a distance, by the difference in appearance of the weathered surfaces and ledges of the two rocks. The gabbro forms rounded, massive ledges while the greenstone ledges are rougher and more angular, and the rock has been more sheared. The actual contact, however is not again exposed on the peninsula. It is marked by a valley which is filled with drift, forming at the shore a pebbly beach. The boundary extends eastward along a narrow, although deep valley, having a trend of about N 60° W for a mile from the shore. It then follows a much larger valley, with a strike of N 30° W, for a mile and a half to Becher bay. Another similar valley, having nearly the same trend, marks the western contact of the Rocky Point stock. The gabbro and volcanics occur on opposite sides of these depressions at the same elevations, which are considerable, about 800 feet on the Sooke peninsula. The width of the unexposed zone on Rocky point is only a few yards. These facts suggest that contact occurs along a fault. This is almost to be expected since both formations have been faulted and sheared to such a large extent.

On Sheringham point a little boss of gabbro is exposed which is intrusive into the basalt, with the usual contact features such as is shown on the shore of Sooke harbour.

The diorite masses exposed along the coast between Jordan river and Boulder point are also clearly intrusive into the Metchosin volcanics.

Relation to younger formations. Diabase dykes, which are apparently unrelated to the gabbro, are intrusive into it. It is at present impossible to correlate these dykes definitely.

On Sheringham point the little boss of gabbro has been eroded, and is overlain by the conglomerate of the Sooke formation. This conglomerate contains large boulders of the gabbro, and is clearly younger than and unconformable upon it.

Mode of origin. The Sooke gabbro and related rocks, except as they have been the result of secondary processes, have all been crystallized from a molten state under plutonic conditions. As a whole the rocks form small stocks and bosses, which may or may not be protuberances of a larger body of gabbro which underlies the southern part of the district.

The various types are due principally to magmatic differentiation. The original magma was doubtless basic, and gave on solidification the normal, fine to medium grained, augite gabbro, sometimes olivine bearing. The apophysal types, which cut the normal gabbro, grow in general more sodic in successive intrusions. This is due to the separation of the femic minerals, and a consequent enrichment of the magma in salic constituents. The original salic mineral being a basic plagioclase, the salic differentiate was an anorthosite. The separated femic pole may be represented in part by the hornblende veins and by the gabbro porphyrite dykes.

The hornblendites of the shear zones, as was suggested, appear to have been formed by the recrystallization of the femic constituents of the sheared gabbro. The production of large hornblende crystals shows that this recrystallization must have taken place under conditions of very high temperature and pressure. The occurrence of aplitic veins and numerous quartz veins cutting the shear zones, and the fact that the hornblende is similar or identical to that which is characteristic of the amphibole gabbro, suggest that the hornblendites were formed directly following the solidification of the gabbro. Hot solutions, liquid or gaseous, penetrated the shear zones, removed the feldspar more or less completely and recrystallized the femic constituents into hornblende. The same solutions appear to have introduced the metallic minerals, which have been formed nearly contemporaneously with the large hornblende crystals. It is also possible that through the influence of the same solutions, the hornblendes of the amphibole gabbro, especially the large poikilitic hornblendes, were formed by the alteration of original augite.

An alternative hypothesis is that the hornblendites are truly hornblende pegmatite veins, similar to the smaller, irregular hornblende veins which cut the gabbro throughout the stock. The objections to this hypothesis are the large size of the hornblendites, and their restriction to nearly straight shear zones.

Age and correlation.—The only definite evidence as to the age of the Sooke gabbro is that it is much older than the Sooke and Carmanah formations, and is, therefore, pre-Tertiary. It is intrusive into the Metchosin volcanics, which have been correlated with the Vancouver group, and is, therefore, probably later than lower Jurassic in age. The other batholithic rocks of southern Vancouver island are all clearly related, and are almost definitely correlated with the Coast Range batholith of British Columbia, which is considered by most geologists to have been intruded in late Jurassic

[1] Cf. W. H. [illegible] Minerals [illegible] Economic Geology, V [illegible]

time. This batholith, although chiefly composed of more acid types, contains gabbros;[1] although none have been described which are identical with the Sooke gabbro. The diorites of the Sooke type, especially those which occur along the coast between Jordan river and Boulder point, have some lithological similarities with the other basic plutonic rocks of southern Vancouver island. From a consideration of the data above given, the intrusion of the Sooke gabbro is best correlated, in a general way, with the upper Jurassic period of batholithic intrusion.

COWICHAN GROUP.

The unmetamorphosed sedimentary rocks of Mesozoic, and possibly lower Cenozoic (Eocene) age in southern Vancouver island, belonging to at least two unconformable formations, cannot be distinguished lithologically, or at present structurally, and are, therefore, grouped together provisionally under the general name of Cowichan group.[2] The larger part of the group doubtless belongs to the Nanaimo formation or series as defined by Richardson, Whiteaves and Dawson.[3]

Distribution.—The Cowichan group occurs in three principal areas and basins, which were outlined by Richardson,[4] and called by him the Comox, Nanaimo, and Cowichan basins. The boundaries of the Comox and Nanaimo basins are about as Richardson describes, and in mapping the southern part of the Comox and northern part of the Nanaimo basins, Richardson's boundaries have been used with minor modifications. The Cowichan basin is much larger than Richardson supposed, as he did not trace it inland. All three basins occur along the east coast of Vancouver island. The Comox basin is the northern one, and only the southern portion is shown on the accompanying map. The Nanaimo basin is separated from the Comox basin by an axis of Vancouver volcanics which occur to the

[1] See O. E. Le Roy. Preliminary Report on a portion of the Main Coast of British Columbia and Adjacent Islands. Geol. Survey of Canada. Publication No 996. 1908. pp. 17-22.

[2] C. H. Clapp. Summary Report, 1909, Geol. Survey, Canada, p. 89.

[3] James Richardson. Report on the Coal Fields of Nanaimo, Comox, Cowichan, Burrard inlet, and Sooke, B.C. Rept. of Progress, 1876-77, Geol. Survey, Canada, pp. 160-192.

J.F. Whiteaves. Mesozoic Fossils, Vol. 1, Part 2, Geol. Survey, Canada, 1879, pp. 93-190.

G. M. Dawson. The Nanaimo group. Am. Journ. Sci., Vol. 39, 1890, pp. 180-183.

[4] Ibid.

north and south of Nanoose harbour. The Nanaimo basin on Vancouver island extends southeast from Departure bay, north of Nanaimo, to Crofton, a distance of about 30 miles. Its greatest inland extent, south of Nanaimo, is about 10 miles. It extends, however, much farther east and southeast, comprising the northern part of Saltspring island, and the islands to the east and north; extending still farther southeast to the islands of the State of Washington. Its greatest exposed length and width in Canadian territory is 55 and 15 miles respectively. The Cowichan basin occurs to the south of the Nanaimo basin, being separated from it by a narrow axis of crystalline rocks of the Sicker series, south of Crofton; and extends northwest from the east coast at Cowichan bay, where the basin is 8 miles wide, to the west end of Cowichan lake, a distance of about 40 miles. In the western portion it is divided into two parts by an axis of the underlying rocks forming a ridge between the Cowichan and Chemainus valleys. The Cowichan basin extends some 20 miles to the southeast from Cowichan bay, being exposed on the northern end of Saanich peninsula, and on several of the small islands between Saanich peninsula and the islands of the State of Washington.

A small basin occurs in the upper portion of Kokasilah valley, 10 miles west of Shawnigan lake, in the Malahat district; and a much larger basin, separated from the Comox basin, to the east, by a wide axis of Vancouver volcanics, occurs in the vicinity of Alberni, underlying the wide Alberni valley.

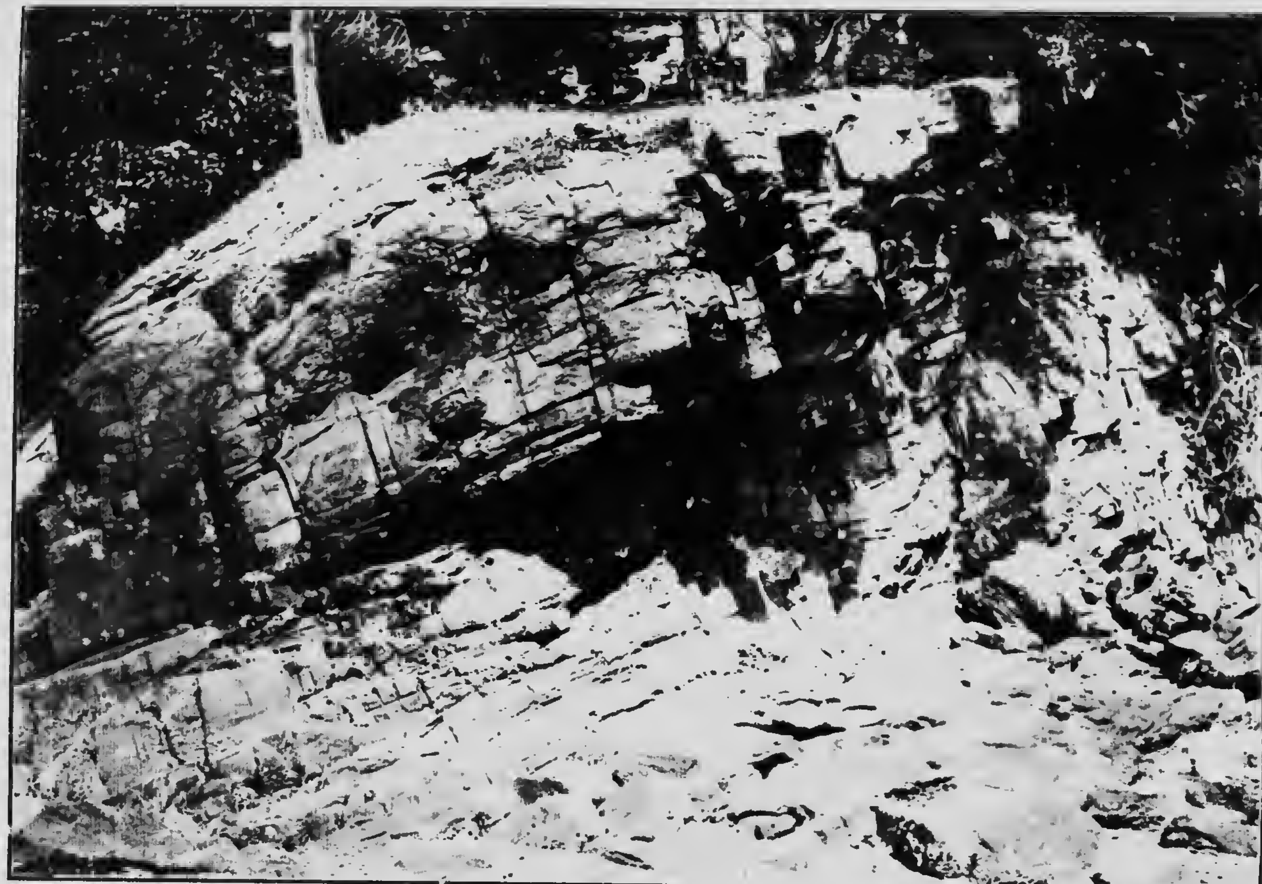
The rocks of the Cowichan group, being less resistant than the underlying crystalline rocks, were, as described under topography, greatly eroded by the pre-Glacial cycle, and lowlands have been developed on them. These lowlands were covered by drift during the Pleistocene period, and the rocks are, therefore, rather poorly exposed, except along the shore, and river beds. North of Cowichan bay and Cowichan valley, and on Saltspring island, thick, gently northeastward dipping basal conglomerates form low mountains with steep obsequent scarps, such as Mount Prevost in Somenos district, and Mount Tzouhalem in Cowichan district. Since the boundaries of the Cowichan group follow closely the boundaries of the pre-Glacial lowland, they have been located with considerable accuracy, with the exception of the interior boundaries of the northern Nanaimo and southern Comox basins, which, as mentioned, have been modified from those drawn by Richardson.

Lithological characters.—The rocks of the Cowichan group consist of conglomerates, sandstones, and shales, the sandstones predominating near the coast, and the shales in the interior. The shales are arenaceous, and many of them carbonaceous, especially in the lower part of the group; and coal occurs near the base of the Nanaimo formation. Distinctly calcareous rocks are rare.

The conglomerates usually consist of fairly well rounded, water-worn fragments of the underlying crystalline rocks of the vicinity, in a sandy matrix. They range from very coarse basal conglomerates to fine grained phases, and from phases in which there is very little matrix, to those in which the matrix is dominant. The conglomerates of the farther inland portions of the Cowichan basin are commonly green coloured, and consist almost entirely, both fragments and matrix, of detritus of the volcanic rocks of the Vancouver group; which detritus has apparently been formed by mechanical rather than chemical disintegration. More rarely, as on the south slope of Mount Sicker, the conglomerates consist of angular to sub-angular fragments, which are not clearly stratified.

The sandstones are yellowish (especially the upper members of the Nanaimo basin) to grey or greyish green in colour, and many of the sandstones of the Cowichan basin are dark olive green. Quartz is the most abundant constituent, and occurs with other mineral and even small rock fragments, in angular to sub-angular grains with an argillaceous matrix. The other minerals present are, in about the order of their relative abundance, feldspar, chiefly plagioclase, muscovite, biotite, chlorite, epidote, and more rarely serpentine, magnetite, and other iron oxides, and calcite. Ilmenite altering to leucoxene occurs in the sandstones near the gabbro-diorite porphyrites of the Sicker series.

The sandstones are commonly massive, forming with conglomerates thick bedded strata. They grade into arenaceous shales through thin bedded shaly sandstones, and the arenaceous shales are very commonly interbedded with thin beds of sandstones, a few inches thick, which are very numerous, seldom more than a foot or two apart. Fine grained, laminated sandstones occur, but as a rule the ordinary sandstones are quite uniform in composition, and no colour lamination is seen. The sandstones are commonly concretionary, the numerous concretions ranging from an inch to several feet in



Concretionary sandstone of the Nanaimo formation, Coal point, North Saanich district.

diameter. The cement of the concretions is ferruginous and calcareous. Sun cracks and ripple marks are rarely seen.

The shales are commonly dark, olive grey or drab coloured, seen on microscopic examination to consist of small angular quartz grains in a fine argillaceous groundmass, which is brown from the presence of carbonaceous matter. The carbonaceous matter occurs in microscopic, rounded clouds, which are darker near the centre. Calcite is frequently present, sometimes as veinlets, although rarely in large amounts. Muscovite occurs in small quantities.

The shales have very seldom a well developed shaly parting, but are relatively massive; although the finer grained, less arenaceous shales weather into small flakes. The shales, far more commonly, weather concentrically; and where calcite is fairly abundant in the groundmass, rapidly, to a light brown clay. Sandstone concretions are very numerous, and in the fine grained shales, associated with the coal, small rounded calcareous concretions also occur.

In the small basin of the upper portion of Kokasilah river, associated with an argillaceous sandstone, is a dark coloured, almost black, homogeneous rock, which consists of fine, rounded calcite or limestone grains in a carbonaceous and argillaceous matrix. Other calcareous rocks, which are, however, highly fossiliferous, occur near the base of the Nanaimo formation, in the northern part of the Nanaimo basin.[1]

Metamorphism.—The rocks are not commonly metamorphosed, although they have been extensively folded. As described under Sicker series, along the Chemainus river south of Mount Sicker, unmetamorphosed shales grade northward into the metamorphosed rocks of the Sicker series. At Cowichan lake, the steeply dipping rocks along the northern side of the basin are somewhat metamorphosed, and are sheared to some extent, and cut by quartz veinlets.

Structural relations. Internal. The rocks of the Cowichan group have been folded and faulted rather extensively, and the present basins in which the rocks occur are in general synclinal, with minor folds, and sometimes boundary faults. The correlation of single horizons in the Cowichan group over wide areas is at present impossible, and exact correlations may be impossible even on

[1] James Richardson, Rept. of Progress, 1876-79, Geol. Survey, Canada, p. 172.

detailed work on account of the apparent large vertical distribution of identical fossils, and the rapid variation in the lithological characters of the beds in both vertical and lateral directions. The present investigation has also been confined largely to the Cowichan basin, so that a discussion of the stratigraphy is necessarily very incomplete.

Stratigraphy.—The rocks of the Comox and Nanaimo basins, which are all, as far as known, members of the Nanaimo or higher formations, have been subdivided by Richardson[1] on lithological grounds, as follows:

Comox Basin—

G. Upper conglomerate	320 feet.
F. Upper shales	776 "
E. Middle conglomerate	1,100 "
D. Middle shales	76 "
C. Lower conglomerate	900 "
B. Lower shales	1,000 "
A. Productive Coal Measures	739 "
Total	4,972 "

Nanaimo Basin—

G to C. Sandstones, conglomerates and shales	3,290 feet.
B. Shales	660 "
A. Productive Coal Measures	1,366 "
Total	5,266 "

The Cowichan basin cannot at present be subdivided lithologically into general divisions, as it consists of rapidly alternating beds of conglomerates, sandstones, and shales which, as mentioned, grade laterally as well as vertically into beds of different texture, the individual beds being, therefore, lens-like in shape; and it also contains at least two unconformable formations, which have not as yet been distinguished. The lower formation where recognized consists chiefly

[1] James Richardson, Rept. of Progress, 1876-77, Geol. Survey, Canada, p. 162, p. 172, and p. 186.

of shales and sandstones. In the upper formation, which is largely or entirely part of the Nanaimo formation, there is a tendency for the rocks to grow finer grained upwards, and the basal conglomerate is, in places, very thick. No estimate as to the thickness of the lower formation can be made, but the upper formation is at least 6,000 feet thick. The Nanaimo basin is more extensive than was thought by Richardson, and the thickness of the sediments of the Nanaimo basin is probably near 10,000 feet.

Folding and faulting.—Comox basin.—The folding and faulting of the rocks of the Cowichan group is best taken up by discussing the various basins individually. The Comox basin is mapped by Richardson[1] as a simple open syncline, with a few minor rol.- between Vancouver island and Texada island. The southwest flank of the syncline rests on Vancouver island, and forms virtually a simple monocline, dipping to the northeast at relatively small angles. Only the southern part of this basin is shown on the map accompanying this report. Richardson[2] records only one fault, a strike fault, in the Comox basin.

Nanaimo basin.—The northern part of the Nanaimo basin is mapped by Richardson[3] as a simple open syncline, with a northwest-southeast strike, the axis of which occurs on Gabriola island, but farther to the southeast occurs under the Strait of Georgia. Strike and dip faults of small displacement are known to occur.

In the southern part of the Nanaimo basin there are closed folds, some of which are overturned to the southwest; and it is probable that there are a few strike faults of considerable displacement. The lower members of the Nanaimo basin, near the southern boundary, conform more or less closely with the uneven surface upon which they were laid down, and have in general dips of about 30° away from the basal contact.

Cowichan basin.—The apparent structure of the eastern part of the Cowichan basin is shown in figure 2; which represents a diagrammatic section across the Cowichan basin in the vicinity of

[1] James Richardson. Rept. of Progress, 1876-77. Geol. Survey, Canada. pp. 160-192.

[2] James Richardson, Rept. of Progress, 1872-73. Geol. Survey, Canada. p. 13.

[3] James Richardson, Rept. of Progress, 1876-77. Geol. Survey, Canada. pp. 160-192.

Cowichan and Maple bays. The structure is, briefly, a southern close-folded syncline, with a strike of N 70° W, which is slightly overturned to the southwest, with the northern limb broken by an overthrust fault, which brings up the underlying Sicker series against the folded rocks of the Nanaimo formation. The Sicker series are overlain by the basal members of the Nanaimo formation which form the southern limb of another parallel syncline, which also is broken by an overthrust fault—the northern boundary of the basin.

The evidence upon which this structure is based is fairly complete. From the southern contact, which at the northern end of Saanich peninsula is complicated by smaller infolds to the south and by some faulting, the rocks of the southern syncline may be traced northward with increasing northward dip, which, in the central part of the supposed syncline, becomes nearly vertical. On southern Saltspring island the beds which are exposed dip to the north against the Sicker series, but are apparently again the lower beds of the syncline, since they contain conglomerates with coarse, angular fragments of the underlying rocks of the Sicker series. To the west, at the head of Cowichan bay, similar sediments are exposed, whose attitude is undetermined, north of which occurs the Sicker series exposed on the south slope of Mount Tzouhalem. Mount Tzouhalem is capped with basal conglomerates of the Nanaimo formation resting unconformably on the Sicker series. The conglomerates have a northerly dip, which increases to the northward, the conglomerates grading upward into predominating sandstones, which in turn grade upward into predominating shales. Near the northwest shore of Maple bay, where they have a dip of about 70° to the north, the shales are terminated abruptly by the underlying Sicker series.

The southern syncline extends west to Cowichan lake, apparently preserving its structure, for at Cowichan lake a similar faulted syncline is observed, although the upthrown southern limb of the northern syncline is absent. Conglomerates and sandstones occur along the southern contact, unconformable upon the Vancouver volcanics, although along the actual contact some faulting has taken place. The conglomerates and sandstones have dips of about 40° to the north. The dips increase northward, and along the northern contact with Vancouver volcanics are shales with nearly vertical dips. The contact is, therefore, a fault, probably an overthrust fault.

with the upthrow side to the north. On the high ridge composed of the volcanic rocks, north of the east end of the lake, are remnant patches of the unconformable conglomerate, at elevations of 1,000 to 1,500 feet above the lake. The fault, which forms the northern boundary of the syncline in the eastern part of the basin, has not been traced across the low, drift-covered area to the northwest of Cowichan bay in Quamichan, Sahtlam, Somenos, and Seymour districts, but presumably it does extend across the low area to join with the fault described above as occurring in the upper part of Cowichan valley.

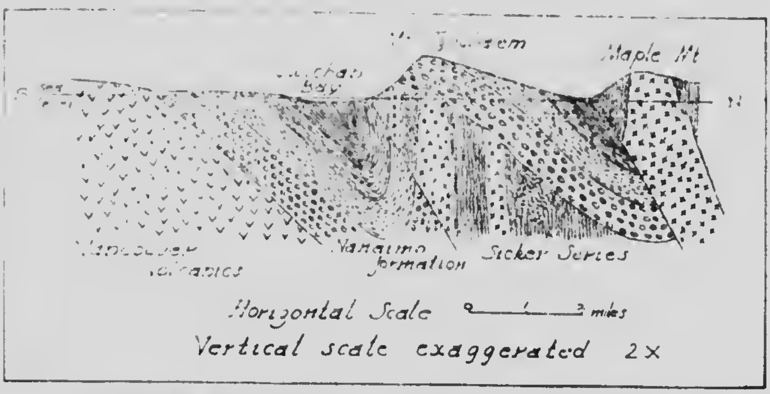


FIG. 2.—Diagrammatic structure section of the eastern portion of the Cowichan basin.

The north boundary fault of the Cowichan basin, which interrupts the northern syncline, may be traced westward from Maple bay across Comaiken district for about 4 miles. Then in Somenos and Seymour districts there are vertically dipping shales and thin beds of sandstones which are apparently transitional into the Sicker series, but definitely transitional in part, as along the Chemainus river south of Mount Sicker.[1] These vertically dipping shales are overlain on Mount Prevost by conglomerates which have a northward dip of only 30°, similar to those of Mount Tzouhalem. The contact between the shales and the conglomerates is not exposed, but may be located within 100 or 200 feet, and both horizons preserve their characteristic attitude as far as seen and show no evidence of overthrust faulting which might explain the structural relations. Since the shales in the one instance are transitional into known older

[1] See pages 84-85.

rocks, it is virtually assured that the conglomerates are unconformable on the lower shales. The lower shales, as stated, cannot be distinguished lithologically from the shales of the Nanaimo formation, and since the structure has not yet been worked out in the low drift-covered region to the northwest of Cowichan bay, the two formations cannot be mapped separately at present. The middle part of the Chemainus valley is underlain by sediments apparently of the Nanaimo formation, which have a dip of about 30° to the north and which form a part of the southern limb of the northern syncline of the Cowichan basin. Evidences of an unconformity between these greatly dipping sediments and the steeply dipping lower shales of the Cowichan group, have been noted.

Besides the two major folds, minor folds occur and, doubtless, there are also many smaller faults, most of them probably strike and thrust faults.

Minor basins.—A small basin occurs in the upper part of the Chemainus valley, and it seems as if it was originally a part of the southern limb of the northern syncline of the Cowichan basin, once continuous with the easterly portions, but now separated by erosion.

A similar area occurs in the upper part of the Kokasilah valley: but in this instance all other evidence of a large downfold to the south of Cowichan valley has been removed by erosion.

The Alberni basin has not been examined, except along the contacts with the underlying crystalline rocks. The dips are low, about 10°, and away from the contacts, so that it appears as if the basin were an open syncline.

External.—Relation to older formations.—The lowest horizon of the Cowichan group is apparently conformable with the Sicker series and another horizon of the Cowichan group appears to be unconformable upon it. The overlying horizon, the conglomerates of Mount Prevost, is similar to the lower horizons of the Nanaimo formation, which formation, with conformable overlying formations makes up the larger part of the Cowichan group. The Nanaimo formation is clearly unconformable upon the rocks of the Vancouver group and upon the igneous rocks of the batholithic and dyke intrusions, since the base is marked by coarse basal conglomerates.

The Nanaimo formation was deposited on a subdued erosion surface, which, however, was one of considerable relief. Small irregularities are directly observed in some instances in the exposed unconformity, as on Mount Tzouhalem and on Tongue point in Nanoose district.[1] It is also found that the contacts of the Nanaimo formation with the underlying rocks, where not disturbed by intense folding and faulting, follow the contours of the present elevations very closely in a manner otherwise unexplainable except by far more irregular and complex folding than is elsewhere observed. The best example of such a contact occurs west of Crofton, around the northern slopes of Mount Richards and Mount Sicker, and is shown in figure 3. It is also found (shown diagrammatically in figure 3), that the sediments occur in bays in the softer underlying rocks, while

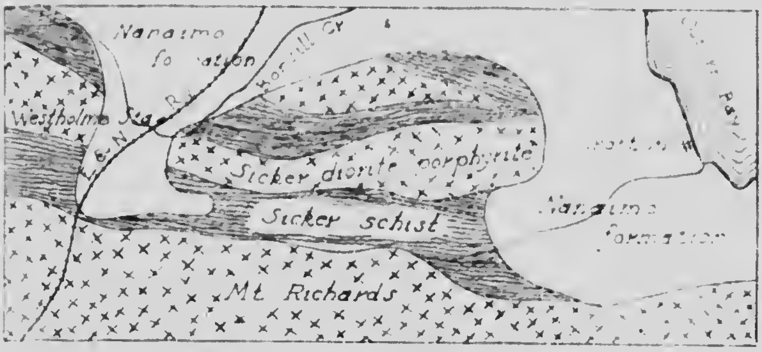


Fig. 3. Contact of Nanaimo formation with underlying Sicker series, west of Crofton Contact mapped by J. A. Allan. Geology of Sicker series, diagrammatic.

the harder rocks evidently formed monadnocks as they do at present. The basal sediments near the old monadnocks are coarser grained, the fragments are more angular, and the matrix as well as the fragments are composed of undecomposed and unsorted detritus of the underlying rocks. The amount of relief in the unconformable surface is, at present, doubtful; but to judge from the contacts around Mount Sicker, the maximum relief may have been as much as 1,000 feet.

Mode of origin.—The Nanaimo formation, shown by its fauna, is in large part of marine origin[2]; and since it was deposited on a

[1] James Richardson. Rept. of Progress, 1876-77. Geol. Survey, Canada, p. 67.

[2] J. F. Whiteaves. Mesozoic Fossils, Vol. I. Geol. Survey, Canada. Part V, 1903, p. 312.

surface of considerable relief and under varying conditions, shown by the rapid lateral and vertical gradation of the sediments, is probably of estuarine origin. It also contains land plants and coal, which are most probably of fresh water accumulation so that conditions of brackish or fresh water alternated with marine conditions. The upper part of the Nanaimo formation or the conformably overlying horizons contain few or no marine organisms, the only fossils being a few obscure plants, so that it is possible that varying marine and terrestrial conditions recorded in the lower part of the Nanaimo formation were finally replaced entirely by terrestrial conditions. The lithological character of the sediments, the sandstones being composed of angular to sub-angular fragments, and a large percentage of easily decomposed minerals such as feldspar, indicates a very rapid accumulation and deposition in relatively small basins where the detritus was not subject to severe wave action.

The conditions under which the lower beds of the Cowichan group were deposited are at present unknown.

Age and correlation.—The known fossiliferous horizons of the Cowichan group, which include the four lower subdivisions of the Comox basin and the two lower subdivisions of the Nanaimo basin, as subdivided by Richardson, have been grouped together by G. M. Dawson[2] and designated the Nanaimo group. But since the fauna is identical throughout, the strata are best considered as belonging to one formation, the Nanaimo formation. This formation is correlated with the Chico of the California Cretaceous, and approximately with the Pierre of the Great Plains.

The upper horizons of the eastern part of the Cowichan group contain a fauna identical with that of the Nanaimo formation. The following fossils have been identified:—

Tellina sp.—North shore, Saanich peninsula.

Trigonia, cf. *evansana*, Meek—Moresby island.

Trigonia tryoniana, Gabb—Mount Tzouhalem.

Axinea veatchii, Gabb—Head of Cowichan bay.

Inoceramus sagensis, Owen—Piers island.

Inoceramus cf. *barabini*—Piers island and north shore of Saanich peninsula.

[1] See page 128.

[2] G. M. Dawson. The Nanaimo Group. Am. Journ. Sci. 3rd series, Vol. 39, 1890, pp. 180-183.

They are, therefore, definitely upper Cretaceous in age and are members of the Nanaimo formation.

The lower horizons of the eastern Cowichan basin are unconformably below the Nanaimo formation and are apparently conformable with the Sicker series. They are, therefore, presumably of Triassic or more probably Jurassic age.

It has been suggested that the interior basins of Vancouver island, the western part of the Cowichan basin and the Alberni basin, are also unconformably below the Nanaimo formation, and if so, since they rest unconformably upon the Vancouver group and batholithic intrusives, should be lower Cretaceous or Comanchic in age. The reason for this suggestion has been the appearance of greater metamorphism of the rocks, and the virtual absence, as far as known, of coal. However, the rocks of the western part of the Cowichan basin appear to be continuous and conformable with the upper horizons of the eastern part, which, as shown above are members of the Nanaimo formation. Indications of coal are found in the Alberni basin and the rocks are not greatly disturbed or more metamorphosed than the rocks of the Comox and Nanaimo basins. They are, therefore, best correlated, provisionally, with the Nanaimo formation or at least considered as upper Cretaceous in age.

The upper horizons of the Comox and Nanaimo basins are conformable with the Nanaimo formation but are virtually unfossiliferous. It has been suggested by Dawson[1] that these upper horizons may be correlated with the Eocene, Puget formation of Washington[2] and the mainland of British Columbia in the vicinity of the Fraser River delta.[3] It is probable, however, that the rocks of the Nanaimo formation were folded during the Laramide revolution, at the close of the upper Cretaceous, since at least the lower members apparently have been folded to a greater extent than the rocks of the Puget formation. This conclusion is supported by the occurrence of a widespread unconformity between the Eocene and the Cretaceous on the Pacific coast of North America.[4] But, as Arnold points out,[5] the unconformity between the Eocene and Cretaceous is not

[1] G. M. Dawson. Am. Journ. Sci. 3rd ser. Vol. 39, 1890, pp. 180-183; and Bull. Geol. Soc. Am., Vol. 12, 1901, p. 79.

[2] Bailey Willis, Tacoma Folio, No. 54, U.S. Geol. Survey, 1899.

[3] O. E. LeRoy. Publication No. 996. Geol. Survey, Canada, pp. 23-24.

[4] Ralph Arnold. Tertiary faunas of the Pacific Coast. Journ. of Geol. Vol. 17, 1909, p. 512.

[5] Loc. cit.

always angular, and with one exception, at San Diego, California, the Eocene beds rest upon the Chico, which is equivalent to the Nanaimo, without an angular unconformity. He also states that as far as the stratigraphic evidence goes, the two formations represent an apparently uninterrupted period of sedimentation. It is, therefore, from analogy perhaps possible, as far as the geological history of the Pacific Coast region is known, for the uppermost members of the rocks mapped as belonging to the Cowichan group, apparently conformable with the Nanaimo formation, to be Eocene in age.

CARMANAH AND SOOKE FORMATIONS.

Fringing the west coast of Vancouver island is a group of marine sediments of Tertiary age. This group has been subdivided by Merriam[1] on palæontological evidence into the Carmanah and Sooke formations. The two formations cannot be subdivided on lithological or structural evidence, and as the fossils collected by the writer have not yet been determined, the two formations are mapped and described as one in this report.

Distribution.—The Tertiary sediments occur in small, isolated basins, which fringe the west coast, between Pachena bay to the northwest and Becher bay to the southeast. They underlie relatively low, flat areas, 150 to 200 feet above the present sea-level. The larger basins extend for several miles parallel to the coast, but rarely extend inland for much over a mile. Besides the larger basins, there are a great number of very small basins, a few of which are shown on the map, which occur between promontories of the underlying crystalline rocks.

The sediments are fairly well exposed along the shore, where they usually form a young cliff 100 to 150 feet high. The larger basins are partially covered with stratified drift, exposed at the shore in steep, wave-cut cliffs, except where eroded to the present sea-level by the larger streams, where coarse boulder beaches occur. The sediments, except in one or two instances, were not traced inland, but their inner boundary can be located fairly well from the shore as the underlying crystalline rocks surmount steeply the low areas underlain by the relatively soft sediments.

[1] J. C. Merriam. Bull. Univ. Cal. Geol., Vol. 2, No. 3, pp. 101-108, 1896.

PLATE XII.

West coast of Vancouver island, near Border point, Renfrew district, showing rapid disintegration of uplifted Tertiary sandstones, forming caves and arches.

Lithological characters. The Sooke and Carmanah formations consist chiefly of sandstone and conglomerate, with thin beds of sandy shale and marl. There is very little difference lithologically between the two formations, but the sandstones of the northwestern basins are seemingly more indurated than those of the southeastern basins.

The sandstones are yellow to grey in colour, more rarely darker coloured from included carbonaceous matter, usually rather coarse grained, the fragments being sub-angular to angular, and have a calcareous cement. The fragments are essentially of quartz and plagioclase feldspar. The accessories are numerous and in large amount, and include brown stained mica, hornblende, epidote, magnetite, chlorite, serpentine, sericite, and limonite. Small rock fragments also occur, and the sandstones pass rapidly from pebbly sandstones into coarse conglomerates. The sandstones are sometimes cross bedded, and are frequently, especially in the northwestern basins, concretionary. The concretions consist essentially of the same material as the matrix, but have been cemented more firmly. In certain horizons fossils, composed of their original material, are very abundant.

The conglomerates are as a rule coarse, the included fragments predominating over the matrix. The basal conglomerates are often exceptionally coarse, containing fragments up to 30 feet in diameter. The fragments are rounded to sub-angular, and consist almost entirely of the immediately underlying crystalline rocks, that is Leech River slates and schists, Metchosin meta-basalt, Saanich granodiorite, Beale diorite, and Sooke gabbro. The matrix is similar to the sandstone, and also has a calcareous cement. The conglomerates are also fossiliferous, rather more so than the sandstones, although the greater number of the fossil shells are broken.

In the southeastern basins there are frequent beds and lenses in which there is considerable argillaceous material, but there is very little true shale, as all of the argillaceous beds contain a great deal of sand. In certain of the more argillaceous beds the fossils are so abundant as to form an indurated marl. In certain sandstones lignite occurs in thin layers seldom more than 1 to 2 inches thick, and also in thin, cigar-shaped lenses.

The sandstones and conglomerates usually alternate rather rapidly. A conception of the character of the sedimentation may be gained from type sections exposed along the coast. The sediments of the basin at Sooke harbour have been described by Richardson,[1] and he also gives a section exposed at Parsons point, with a drill record obtained while prospecting for coal. The upper member of Richardson's column is of Pleistocene age.

The following section is exposed near the mouth of Coal creek, and is representative of the basin between Otter and Sheringham points:—

20 feet unconsolidated, stratified sand and gravel. (Pleistocene.)

10 " sandstone, soft, ferruginous, banded yellow and red, and concretionary.

5 " conglomerate, fossiliferous.

65 " sandstone, coarse to medium grained, buff coloured, cross-bedded, and concretionary.

4 " sandstone, argillaceous, grey, and fossiliferous.

10 " alternating soft sandstone and marl.

Higher beds are exposed on the east bank of Coal creek above Kirby's ranch. The exposed section is 70 feet thick, and consists chiefly of conglomerate and yellow ferruginous sandstone. There are also two thin beds of sandy shale which contain a large amount of pyrite and limonite, and thin lenses of a poor lignite.[2]

The following section of the Jordan river basin is exposed at the shore near the northwestern boundary:—

Stratified Pleistocene deposits—

40 feet sandstone, few thin pebbly layers and lenses of marl, and lignite ½ inch thick. Sandstone chiefly yellow and ferruginous, but some of it is dark and carbonaceous.

6 " sandstone, yellow and cross-bedded.

25 " sandstone, yellow, with thin lenses of pebbly marl, consisting of broken pelecypod shells.

Exposed 100 yards to the west, on the western and upthrow side of a transverse fault, are the following lower beds:—

[1] James Richardson. Geol. Survey of Canada. Rept. of Progress, 1876-77, pp. 190-191.

[2] The section is continued downward for about 300 feet in a drill hole, but it has not been possible to obtain a record of the bore.

10 feet sandstone, yellow ferruginous.
20 " basal conglomerate, containing large sub-angular to angular boulders of the underlying meta-basalt.

The sediments of the large Carmanah basin consist almost entirely of yellow, concretionary sandstones, with three or four pebbly layers, which contain broken shells. There are occasional interbeds of conglomerate, and a basal conglomerate 0 to 50 feet in thickness.

Structural relations.—Internal.—The rocks of the Carmanah and Sooke formations are not greatly disturbed. They have a general strike parallel to the shore, that is about N 70° W, and low dips to the southwest, usually under 10°, probably averaging less than 5°. The rocks of the northwestern basins have a slightly higher dip than those of the southeastern. The individual basins have a broad synclinal structure, the average dip toward the centre of the basin being about 2° or less, and there are also low undulations in the larger basins. The beds have been broken by faults, usually normal faults of slight displacement, seldom more than 10 to 15 feet in amount. The boundaries of the larger basins are sometimes faults and it is probable that they are of greater although not of large displacement.

Since the maximum inland extent of the largest basins is about 8,000 feet, and the average dip about 5°, the thickness of the sediments in any one basin is not more than 700 feet, and probably not more than 500 feet. However, since the sediments of the southeastern basins contain a stratigraphically higher fauna than those of the northwestern basins, the total thickness of the Carmanah and Sooke formations is unquestionably more than 500 feet.

External.—Relation to older formations.—The Carmanah and Sooke formations are clearly unconformable upon the Leech River formation, the Metchosin volcanics, the Saanich granodiorite, Beale diorite, and the Sooke gabbro, the unconformity being well exposed in many places. The basal conglomerate not only contains boulders of the underlying rocks, but rests on an eroded surface. The character of this surface shows clearly that it has been formed by marine erosion. Under the conglomerate are exposed rounded, wave-polished ledges of the crystalline rocks, and old dyke or shear-zone chasms occur filled with sandstone and conglomerate, which resemble dykes of sedimentary material. What were seemingly small coves and bays in the Tertiary shore also occur, filled with coarse conglomerate and sandstone. The ridges intervening between the smaller basins, and probably to some extent between the larger basins, are not upfolds, but hold promontories which projected into the Tertiary ocean. Near these promontories the sediments are composed of large angular boulders with a sandy matrix, the initial dip of which, away from the promontory, is very steep; so that they resemble modified talus deposits.

The underlying crystalline rocks steeply surmount the basins of relatively soft Tertiary sediments to an elevation of at least 1,000 to 2,000 feet. Since the Carmanah and Sooke formations are relatively thin, and as no remnants of Tertiary sediments have been found inland, it is very probable that the Tertiary sediments never extended inland over the present upland.

Relation to younger formations.—The Carmanah and Sooke formations are overlain by stratified, unconsolidated or only partially consolidated gravels, sands, and clays. The overlying sediments are sometimes conformable with the Tertiary sediments, but their difference in age is always shown by the relative amount of consolidation. Pleistocene fossils are also found in the overlying sediments.

Mode of origin.—The sediments of the Carmanah and Sooke formations are shown by their character and enclosed fauna to be of marine origin. They were laid down on an eroded surface of the crystalline rocks, which formed the mountainous coast of the Tertiary ocean. The present young coast with its bold promontories, the large angular and sub-angular boulders of the modern beaches, and the characteristic wave-worn dyke and joint chasms of to-day filled with sand and coarse gravel, are strikingly parelleled in the unconformity and basal conglomerate of the Tertiary sediments. The thin layers of lignite have been formed by the accumulation of carbonaceous matter along the coast, and it is very probable that the thin, cigar-shaped lenses and cylindrical masses of lignite were drift logs which were buried by the Tertiary sands and have been converted, more or less completely, into lignite.

Age and correlation.—The Carmanah and Sooke formations are of Tertiary age. Merriam[1] after listing the fossils collected from

[1] J. C. Merriam. Bull. Univ. Cal. Dept. of Geol., Vol. 2, pp. 101-108, 1896.

Old dyke chasm of the Tertiary coast, filled with the basal conglomerate of the Sooke formation, Sheringham point, Renfrew district.

the Carmanah basin and from the Coal Creek basin, and correlating the respective fauna, arrives at the conclusion that the sediments of the former basin are best correlated with those of Miocene age in the vicinity of Astoria, Oregon, as interpreted by Conrad; while those of the latter basin are of middle Neocene age, that is, upper Miocene or lower Pliocene, and that the time of their deposition was considerably later than that of the sediments of the Carmanah basin. Upon this palæontological evidence, therefore, the Tertiary sediments are divided into two formations, those of the northwestern basins belonging to the Carmanah formation, and those of the southeastern basins belonging to the Sooke formation. As stated, there is no apparent structural unconformity. The sediments to the northwest of Port San Juan are more indurated than those to the southeast, and massive, thick bedded sandstones are more prevalent. Their further separation must depend, however, solely on their included fauna.[1] It is probable that the Carmanah formation should be correlated with part of the thick series of Tertiary sediments, exposed along the southern shore of the Strait of Juan de Fuca, the Clallam formation, which Arnold[2] considers as Oligocene-Miocene, stating that the basal portion of the series is possibly Oligocene in age, while the upper part is certainly Miocene. Arnold[3] places the Sooke formation in the upper Miocene, separated from the lower Miocene, by an unconformity, which appears to be the best determination of age, since no other Pliocene sediments are recorded in western Washington.

SUPERFICIAL DEPOSITS.

The greater part of southern Vancouver island is covered with drift. The drift is varied in character, and has been deposited in its present condition by various agencies, but by far the larger part is primarily of glacial origin; for during the Glacial period Vancouver island was covered by an ice cap, and valley glaciers filled the larger valleys. The original glacial till has, however, been modified by sliding on the steep slopes, and in the larger valleys and on the low areas in the vicinity of the coast glacial detritus has been deposited by river, lake, and marine agencies.

[1] The collections of fossils made by the writer have not yet been worked up.

[2] Ralph Arnold, Geological Reconnaissance of the Coast of the Olympic Peninsula, Washington. Bull. Geol. Soc. Am., Vol. 17, p. 406, 1906.

[3] Ralph Arnold. Tertiary Faunas of the Pacific Coast. Journ. of Geology, Vol. 17, 1909, pp. 509-533. Table of correlations.

Character of deposits.—Unmodified glacial till is for the greater part restricted to the upland of Vancouver island. The character of the till and the form of the till deposits are usually obscured by heavy timber and thick underbrush. Deposits with a simple constructional form are rarely seen. Where the timber has been burned, and especially near the heads of the larger valleys, as at the head of San Juan valley, ground moraines, in certain instances esker-like in form, are seen, and along the sides of the valleys, well shown along the north side of Cowichan valley, what appear to be lateral moraines occur. On the steep slopes the till, which is often composed of sub-angular to angular fragments, is rudely stratified as if modified slightly by sliding and the removal by the run-off of its finer grained material.

The superficial deposits of the lowland areas of the east and west coasts and in the vicinity of Victoria, although composed of glacial detritus, are largely stratified. Stratified deposits also occur in the larger inland valleys. For the greater part the stratified deposits occur at elevations less than 400 feet above sea-level, well exposed along the coast in steep, wave-cut cliffs, although in the interior they occur at much higher elevations. The stratified deposits are of two chief types, estuarine and lake deposits, and river and delta deposits. The estuarine deposits consist largely of stratified clay, sand, and gravel; the deposits in a general way growing coarser grained upwards. Irregularly distributed through the deposits are glacial boulders, varying from small pebbles to boulders 10 feet in diameter. The deposits often rest directly upon the glaciated surface of the underlying crystalline rocks, and sometimes, as noted by Dawson,[1] upon a hard, stony boulder clay, which occurs wedged into the crevices of the glaciated rocks. The presence of marine organisms in many of the deposits shows that they were formed under marine conditions, and since the deposits occur between ridges of crystalline rocks they were probably formed in estuaries. It is, however, probable that some of the higher, but similar deposits, now covered with a thin layer of silt, such as occur in the larger valleys of the interior and in the large basins such as Jordan meadows, were deposited in lakes. Also, bog deposits, such as occur in Sooke district along Deman[illegible] river to the south of Young lake, give evidence of deposition in transient lakes in post-Glacial time.

[1] G. M. Dawson. On the Superficial Geology of British Columbia. Quart. Journ. Geol. Soc. Vol. 31. 1878. p. 95.

The river and delta deposits consist chiefly of stratified sand and gravel, often showing cross bedding, contemporaneous erosion and deposition, and other structures characteristic of deposition in currents; and the delta deposits have top-set and fore-set beds. One of the best examples of the river and delta deposits occurs in Esquimalt district, where the deposit forms a broad plain, known as Colwood plain, with two well-marked longitudinal terraces about 10 feet in height. A gold-bearing deposit of stratified sand and gravel, apparently a river or delta deposit, occurs along the west coast near the mouth of Sombrio river.

The above deposits are largely of Pleistocene age, since they are commonly strewn with large glacial erratic boulders, and in a few instances are overlain by unstratified glacial till, which shows also that they were deposited before a second period of glaciation. Besides the above deposits, delta and river deposits occur which have been deposited by existing rivers, and many of the smaller lakes and ponds, whose waters collected in the undrained hollows of the drift mantle, have been filled up in recent time with alluvium.

Mode of origin. From the character of the deposits described above, it is seen that they are in large part glacial detritus, so that a discussion of their origin is closely linked with the Glacial history of Vancouver island. From the widespread distribution of the glacial till, even on the upland, and from the severe glaciation of the upland, mountains nearly 5,000 feet high having been glaciated, it is seen that southern Vancouver island was at some time during the Glacial period nearly smothered by a thick ice-cap. Although rounded and smoothed glaciated outlines still remain, striations are seldom observed on the higher mountains, on account of the rapid scaling off of the exposed rock surfaces, owing in several instances to abnormal heating of the rock during forest fires. Local mountain glaciers occurred in the valley heads of the higher peaks, and excavated small cirques; while relatively rapid moving valley glaciers filled the larger valleys, widening and deepening them by glacial scour. Their presence is shown by polished roche moutonées, and deep, sometimes undercut, grooves. The great glacier, described by Dawson,[1] which filled the Strait of Georgia, evidently flowed west-

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

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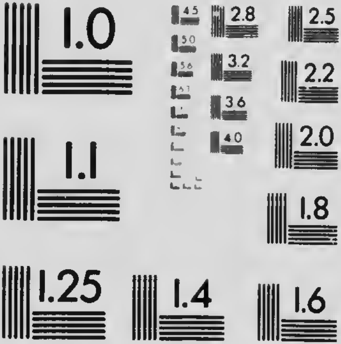

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ward through the Strait of Juan de Fuca, for traces of glaciation are evident along the coast of Vancouver island as far west as the entrance to Nitinat lake. But since there is little evidence of glaciation still farther to the west at Cape Beale, it is to be presumed that the farthest advance of the great Juan de Fuca glacier was to a short distance east of Cape Beale. However, marine erosion has been progressing very rapidly near Cape Beale, and the traces of glaciation may have been destroyed even on the crystalline rocks, as they have been farther to the east where the Tertiary sandstones are exposed to marine erosion.

On the retreat of the earliest and largest glaciers, the land stood some 200 to 400 feet lower than it is at present, and in the lowland developed by the pre-Glacial erosion cycle, estuarine sediments were deposited, while large rivers flowing from the retreating glaciers formed the river and delta deposits. A second glacial advance, which has also been noted by several observers, Dawson,[1] Willis,[2] LeRoy,[3] and others, is recorded by the till overlying the stratified deposits. This second period of glaciation was far less intense than the first period and eroded merely portions of the stratified deposits. The drift in the lea of the monadnocks on the lowland of southeastern Vancouver island was protected by the monadnocks from erosion, and now extends southward from them in long, ridge-like trains. Other similar drift ridges, esker-like in form, which are from 100 to 200 feet high, ¼ of a mile wide and 2 to 4 miles long, and almost straight, with their axes parallel to the glacial movement, have also, for some reason, escaped erosion.

A comparatively recent uplift of some 250 to 400 feet has taken place, possibly before the retreat of the second glacier, since the till which overlies the stratified drift is unmodified even at a few feet above the present sea-level. The uplifted stratified drift deposits have been retrograded during the present marine cycle, resulting in steep, wave-cut cliffs. Also many of the present rivers in the large drift-filled valleys have cut deeply into the Pleistocene stratified deposits.

[1] G. M. Dawson. Trans. Royal Soc. Canada, Vol. 8, 1890, sec. 4, pp. 43-44.

[2] Bailey Willis, Drift phenomena in Puget Sound. Bull. Geol. Soc. Amer. Vol. IX, 1898, pp. 112-162.

[3] O. LeRoy. Geological Survey of Canada, Pub. 996, 1908, p. 27.

STRUCTURAL GEOLOGY.

In the present attitude of the rocks of southern Vancouver island evidences are recorded of two periods of pronounced deformation, of large uplifts of an epeirogenic character unaccompanied by folding, and of lesser movements. The result of all these, especially of the first, has been to form a series of roughly parallel belts, which have a strike conforming in general to that of the whole island. In the southern portion of the island the strike is about N 65° W, or more nearly due west. The oldest formations, the Leech River formation and the Vancouver group, have been closely folded and dynamometamorphosed throughout their entire extent. The general strike of the Vancouver group is from N 55° W to N 65° W, but of the Leech River formation and Metchosin volcanics the strike is more nearly east-west, about N 80° W. The dips of these formations are all steep, and generally to the northeast in the southern part of the island and to the southwest in the northern part.

The non-conformity of the Leech River formation and the Metchosin volcanics with the Vancouver group cannot be satisfactorily explained, for the structural relations are obscured by later boundary faults of the Leech River formation. In the eastern portion of its northern contact the Leech River formation is apparently interfolded with the Vancouver group. Farther west, the two formations are separated by an extensive fault, which is parallel to the strike of the Leech River formation, but which is transverse to the strike of the Vancouver group. The character of the fault is unknown, but if the Leech River formation is, as supposed, the older, the upthrow side is to the south. The southern boundary of the Leech River formation, with the Metchosin volcanics, is also an extensive fault. It is approximately parallel to the north boundary fault, but with the apparent upthrow to the north, the Metchosin volcanics being the younger. The character of this fault also is unknown. Although its date is unknown the faulting may have taken place during the second period of deformation or at some time between the first and second periods.

The date of the first period of deformation is probably upper Jurassic, as it can be correlated with considerable certainty with the great deformation which outlined the Pacific Coast ranges. It is generally considered that in the northern portion of the Coast region this great deformation took place in the uppermost Jurassic, while in the southern portion it seems to have occurred in the lowermost Cretaceous.

Accompanying the deformation or closely following it, the granitic rocks were erupted, and they replaced large masses of the folded rocks, apparently without disturbing them noticeably. These granitic rocks now occur in small stocks and batholiths, which may be mere protuberances of one or more much larger batholiths.

Unconformable upon the folded and granitic rocks are the upper horizons of the Cowichan group, which were involved in the second period of deformation. They were apparently first deposited in a basin of deformation off the east coast of Vancouver island, which basin was formed during the first period of deformation, and which is a part of the great marginal downfold of North America, known as the Pacific Coast downfold. At the time of their deformation the sediments of the Cowichan group extended far inland over the denuded older rocks, but whether they covered the greater part of the island or were restricted to large depressions is not known. Presumably they covered the greater part of the northeastern portion of southern Vancouver island. During the deformation, which cannot be dated very closely since the age of the uppermost beds involved in the folding is doubtful, but which is best correlated with the very general and widespread Laramide revolution, the sediments of the Cowichan group were extensively folded and faulted. In the northeastern portion of southern Vancouver island they were deformed into rather broad open folds in a major syncline, but in the central portion of the island, in the southern part of the sedimentary basin, they were closely folded and even overturned and overthrust. The axes of the open folding correspond in general with the strike of the island, and the dip of the sediments is in general to the northeast. The axis of the major syncline occurs below the waters of the Strait of Georgia. The axes of the closed folds strike more nearly east and west, about N 70° W. These folds are overturned and overthrust to the southwest, which fact indicates that the forces causing the deformation acted from the northeast and probably had their origin below the basin between Vancouver island and the mainland. The pre-Cretaceous rocks were involved in the deformation, being overthrust against the Cretaceous or sedimentary rocks. It is possible, as indicated above, that the boundary faults of the Leech

River formation, which correspond roughly in strike with the axes of close folding and overthrust faulting, were formed at this time. The great downfold separating Vancouver island and the Olympic mountains of Washington, now occupied by the Strait of Juan de Fuca, corresponds in strike with the closed folds and was probably first depressed during this period.

Sediments were deposited in the Juan de Fuca basin of deformation and along the west coast in Tertiary time, forming the Tertiary coastal plain, which was uplifted with very little folding but with rather extensive minor and usually normal faulting. The recent uplift of 200 to 400 feet appears to have been nearly uniform throughout southern Vancouver island; although there may have been a slight tilting to the west, since the uplift appears to have been more on the east coast than on the west coast.

HISTORICAL GEOLOGY.

The oldest rocks of southern Vancouver island, the Leech River formation, are a series of what were originally shales and shaly sandstones, chiefly quartzose; and since the series is very thick and lithologically uniform throughout, it must have been deposited under uniform conditions which prevailed for a long time and which were, therefore, probably marine. The time of deposition is supposed to have been Carboniferous.

It is probable that at the close of their deposition the rocks of the Leech River formation were folded, since they appear to have suffered greater dynamo-metamorphism than any of the other rocks of southern Vancouver island. It is certain that a pronounced change of conditions took place in Mesozoic time, for during the Triassic and Jurassic the rocks comprising the Vancouver group were formed. They consist chiefly of volcanic rocks, mainly andesites with both flow and fragmental types, the flow types predominating. With the exception of a rather limited series of rocks, the Sicker series, partly of sedimentary origin, possibly occurring in the upper part of the Vancouver group, the volcanic rocks are exceptionally free from sedimentary rocks other than limestones. These limestones usually occur in relatively small intercalated lenses. They were formed largely by the accumulation of marine organisms, which were, as far as determined, of lowermost Jurassic age, and provincial since they have apparently nothing in common with the other known lower Jurassic faunas of North America. Since the organisms are marine, it is to be presumed that the volcanic rocks were largely submarine, and the comparative rarity of tuffs and agglomerates and of interbeds of terrestrial material supports this conclusion. It is probable that some of the old vents were above sea-level since fragmental varieties and a few conglomerates composed of rounded volcanic fragments interstratified with tuffs are known. The old vents were probably islands, and it was on these volcanic islands, far removed from the mainland to the east, that the provincial organisms lived.

Following a very thick accumulation of the volcanic rocks, perhaps marked by a transitional period in which terrestrial material was deposited with the volcanics, the entire group was greatly deformed, probably during upper Jurassic time, the main axes of deformation corresponding roughly with the present trend of the island. Batholithic rocks were then intruded, penetrating far into the roof along two main axes, a southern and a northern, separated in the central part of the island by a wide, possibly synclinal, area. The batholithic rocks were subsequently exposed by the erosion cycle initiated by the mountain-building deformation, since boulders and pebbles of them occur in the unconformably overlying sediments. Although further exposed by later erosion cycles, the batholithic rocks as exposed to-day, do not form large, uniform bodies of regular outline, such as are characteristic of the Coast Range batholith of the mainland of British Columbia. On the contrary they occur in relatively small masses, which are, however, very numerous, especially along the two main axes mentioned above. Hence it appears as if erosion if carried somewhat deeper would expose one or more very large and continuous bodies of plutonic rocks similar to the Coast Range batholith. If so, the masses exposed to-day on Vancouver island are merely protuberances, or as Professor R. A. Daly calls them, 'cupolas.'

The erosion cycle initiated by the upper Jurassic deformation, although exposing the granitic rocks, did not reduce the area to a lowland, since the surface upon which the sediments of Cretaceous, the upper members of the Cowichan group, were deposited was one of considerable relief, varying in elevation to more than 1,000 feet. It is at present impossible to state whether or not the sedimentation represented by the upper members of the Cowichan group began in upper Cretaceous time, since there is a possibility that some of the sediments are of lower Cretaceous or Comanche age, having been formed at the same time as similar rocks on Queen Charlotte islands. It appears, however, as if the greater part of the sedimentation began in upper Cretaceous time, at a stage corresponding with the Chico, or the Pierre, and it looks as if the sediments were first deposited in a marine basin between the mainland and Vancouver island, which basin was probably one of deformation and was depressed at least as early as the upper Jurassic folding. In the process of sedimentation the marine conditions alternated with those of brackish water and were finally replaced by terrestrial conditions, since the lower beds of the group are fossiliferous, above which is a horizon in which coal is found, which in turn is overlain by very thick, unfossiliferous deposits of coarse sandstone and conglomerates, with a few beds of sandy shale. The different beds vary rapidly in both vertical and lateral directions, indicating a great variation in the conditions of deposition. During the deposition, the sedimentation transgressed inland, at first filling up the irregularities of the pre-upper Cretaceous erosion surface, and then covering the higher residual elevations. The total thickness of the Cretaceous deposits, which may include some of Eocene age, was, toward the close of their deposition, probably near 10,000 feet. At this time they extended far inland over the denuded crystalline rocks, perhaps covering the greater part of the island, or perhaps restricted to large depressions.

They were later subjected to great orogenic movements, which cannot be dated very definitely, but which probably occurred during the very general and widespread Laramide revolution. The orogenic movements warped the sediments into broad open folds in the northeastern part of the basin, but in the southern part into closed, overturned folds, broken by overthrust faults. It is also probable that the Juan de Fuca downfold, separating Vancouver island from the Olympic mountains to the south, was depressed at this time.

A new erosion cycle, which has been called the Tertiary cycle, was initiated by the revolution described above, and the detritus from the eroded deformed rocks was deposited under marine conditions to the west and south off a mountainous region. Since there is no evidence that the Tertiary deposits extended inland over the underlying crystalline rocks, this mountainous region must have been exposed to erosion. As erosion and deposition continued, the region as a whole was probably depressed, until at the end of the cycle, a coastal plain had been built up against a submerged mountainous slope. It seems as if this coastal plain formed a virtually continuous plain with the old age surface developed during the erosion cycle on the deformed rocks. This erosion surface was a peneplain in the southern part and subdued in the northern part, with, however, high residuals and residual divides.

The first Tertiary sedimentation recorded on Vancouver island (the Carmanah formation) is of Oligocene or more probably lower Miocene age. Also Arnold[1] states that there were probably no high mountains in the Pacific Coast region, except in a few localities, in Oligocene time. It is possible, therefore, that the peneplain was formed during an early Tertiary cycle. If so, in Oligocene time it was uplifted and retrograded, forming a steep mountainous coast, against which the Miocene sediments were deposited. It seems probable, therefore, that if such an early Tertiary peneplain was uplifted, it would have been again peneplained by the close of the deposition in late Miocene or early Pliocene times. The steep, mountainous coast against which the Miocene sediments were deposited, must have been protected from erosion, since it is now exposed, apparently, in almost its original steepness; and it is most reasonable to suppose that it was protected by depression and sedimentation against it. The net result would be the same, therefore, as if there had been only one period of peneplanation, the deformed rocks having been subject to erosion throughout the lower and middle Tertiary, [illegible]ubtless with changes of level. The peneplanation woul[illegible] been completed in the upper Miocene or Pliocene times, [illegible]e it is probable, as stated above, that the peneplain and th[illegible]al plain formed a virtually continuous surface. Arnold[2] believes that the peneplain of the Klamath and Sierra Nevada was also completed in upper Miocene time; and Willis and Smith[3] date the peneplain of the Cascade mountains of Washington as Pliocene.

The uplift of the Tertiary peneplain probably took place during the Pliocene and possibly the early Pleistocene.[4] Before the Glacial

[1] Ralph Arnold. Tertiary Fauna of the Pacific Coast. Journ. of Geol., Vol. 17, 1909, p. 518.

[2] Ralph Arnold Journ. of Geol., Vol. 7, 1909, pp. 526-527.

[3] G. O. Smith and Bailey Willis. Contributions to the Geology of Washington. Professional Paper, No. 19, U.S. Geol. Survey, 1903.

[4] Cf. Ralph Arnold. Journ. of Geology, Vol. 17, 1909, pp. 528-531.

period it was maturely dissected, and along the east and west coasts, where underlain by soft rocks, was reduced to a lowland. An old-age surface was also developed on the crystalline rocks in the extreme southeastern portion. Following mature dissection, the region was apparently depressed, at least in the eastern and southeastern portion, forming the drowned shore-line characteristic of that portion of southern Vancouver island.

During the Glacial period Vancouver island was covered by an ice-cap, and valley glaciers flowed west into the Pacific ocean and east into the Piedmont glacier, which flowed southward through the Strait of Georgia, overriding the southeastern lowland of Vancouver island, and then westward to the Pacific ocean through the Strait of Juan de Fuca.

On the retreat of the earliest and largest glaciers, the land stood some 200 to 400 feet lower than at present, and on the lowlands developed by the pre-Glacial erosion cycle, marine sediments were deposited, while large rivers flowing from the retreating glaciers formed extensive fluviatile and delta deposits. A second period of glaciation is recorded by the till overlying these deposits, but it was far less intense than the first period, and merely eroded portions of the stratified deposits. Soon after, or possibly before the retreat of the later glaciers, an uplift of some 200 to 400 feet took place, uplifting the stratified deposits, which have been sub-maturely retrograded during the present marine cycle.

CORRELATION.

The supposed oldest rocks of southern Vancouver island, the Leech River formation, are correlated with the lower part of the Cache Creek group of British Columbia and with the Peshastin formation of Washington, and are, therefore, considered to be of Carboniferous age. This correlation rests chiefly on the facts that the Leech River formation is apparently older than the known Mesozoic rocks of southern Vancouver island, being more dynamo-metamorphosed, and that it is similar lithologically and structurally to the slaty rocks of Carboniferous age, which have a very wide distribution in the Pacific Coast region. It has also been suggested that the Nitinat marbles, since they are not definitely conformable with the Vancouver group and are apparently more metamorphosed than the

Sutton limestones, may be correlated with the upper part of the Cache Creek group, the Marble Canyon limestones. However, it has seemed best to consider them provisionally as members of the Vancouver group.

It has been generally supposed that the Mesozoic volcanic rocks of the Coast region of British Columbia were involved not only with slaty rocks, such as the Leech River formation of Palæozoic age, but also with metamorphosed volcanic rocks and limestones of Palæozoic age.[1] The reason for this supposition was chiefly the occurrence of fossils in the limestones intercalated with the volcanic rocks, which although undeterminable resembled Palæozoic forms. The fossils collected by the writer in 1908 at Cowichan Lake, were collected rather hurriedly, and the fauna represented by the imperfect collection was determined at first as Devonian, then as probably Devonian. On the strength of this determination, and from the occurrence of supposed Palæozoic fossils in the limestones in the vicinity of Victoria, farther north in Vancouver island, and on Texada island, and in the neighbouring coast region, a group was erected embracing the metamorphic volcanic rocks and coarsely crystalline marbles in the southeastern portion of the island, and called, using a term earlier employed by Dawson for the same rocks, the Victoria group.[2] A much more complete and more perfect collection of fossils from Cowichan lake has shown that the fauna is lowermost Jurassic. Obscure fossils in other of the limestone lenses intercalated with the volcanic rocks resemble the Sutton fauna, and are presumably, therefore, of Jurassic age. The volcanic rocks in which the Jurassic limestones occur are virtually continuous and are all apparently conformable, and are, therefore, considered with a good deal of certainty to be Jurassic or possibly Triassic in age, and to be members of the Vancouver group as defined by Dawson. Dawson[3] maps all of the pre-Cretaceous rocks of Vancouver and Queen Charlotte islands and of the neighbouring portion of the Coast range as the Vancouver group. On the evidence of the obscure Palæozoic fossils, LeRoy and

[1] G. M. Dawson. Bull. Geol. Soc. Am., Vol. 2, 1901, p. 72.
O. E. LeRoy. Publication No. 996. Geol. Survey, Canada, 1908, pp 12-17.
R. G. McConnell. Summary Report for 1909. Geol. Survey, Canada, pp. 69-70.
C. H. Clapp, Summary Report for 1908. Geol. Survey, Canada, pp 54-56. Summary Report for 1909. Geol. Survey, Canada, pp. 87-89.
[2] C. H. Clapp. Summary Report for 1908. Geol. Survey, Canada, p. 55
[3] G. M. Dawson. Northern Vancouver island and adjacent coasts. Ann. Report, 1886, Part B. Geol. Survey, Canada.

McConnell subdivide these rocks into Paleozoic and Mesozoic members. It seems most probable, however, since the rocks mapped as Paleozoic are identical in appearance, and as far as known, in structure, with those of the Vancouver group on Vancouver island, that the obscure fossils are Mesozoic. If so, the great bulk of the pre-Cretaceous rocks of the Coast region are Mesozoic, with occasional infolds of Paleozoic rocks, such as the Leech River formation and possibly the Nitinat formation appear to be.

The correlation of the younger formations on Vancouver island has been generally accepted for some time, and the present investigation has merely served to add details and corroborate the earlier investigations.

ECONOMIC GEOLOGY.

Groups of deposits.—There are in southern Vancouver island mineral deposits valuable, or possibly valuable, for gold, copper, iron, fluxes, and pigment; also important structural materials including lime and cement, clay, sand and gravel, and stone. The various deposits are grouped on an economic or metallurgical basis, that is, according to the product for which they are valuable. This classification also serves fairly well to group together those deposits which are of like origin. In some instances, however, deposits valuable for different metals are of identical origin. Under copper deposits are also described certain deposits which contain silver bearing galena and sphalerite, but these minerals are usually subordinate to copper bearing minerals. The deposits chiefly valuable for metals are first described in the following order: gold, copper, and iron. Under each of these divisions the deposits are subdivided according to their origin. Some of these deposits are possibly valuable for sulphur and are briefly considered from this standpoint. The non-metallic resources are then considered in the following order: fuels, including coal and oil, lime, cement and fluxes, pigments, clays, sand and gravel, and stone.

GOLD.

Placer deposits.—Placer deposits are the chief source of gold in southern Vancouver island, and the only source which has produced gold in paying quantity. Gold is reported from a large number of rivers and creeks on southern Vancouver island, and 'colours' can doubtless be obtained by panning in most of the streams. With two or three exceptions, the principal deposits all occur, however, in the streams which flow for a considerable part of their course over the Leech River formation. The gravels and sands near the mouth of Sombrio river have been known as a source of gold since the Spaniards explored the Pacific coast in the latter part of the eighteenth century. In the sixties the deposits in the Leech and Jordan rivers were discovered and worked, the yield being estimated at from \$100,000 to \$200,000; and, somewhat later, coarse gold was found in the upper part of the San Juan river. For a number of years Chinamen have worked on Leech river, and one or two more extensive attempts have been made recently to obtain gold from Leech river and its north fork. At present, a partnership has been formed to work a large deposit of sand and gravel near the mouth of Sombrio river. Besides these deposits, which occur in the belt of the Leech River slates, small amounts of gold have been obtained from China creek and Franklin river, emptying into Alberni canal, and also from Nanaimo river.

Virtually all of the streams which occur in the belt underlain by the Leech River slates contain more or less coarse gold. With the exception of the two large valleys which occur along the northern and southern boundaries of the formation, the San Juan valley, and the valley which has been called Leech River valley (but which is occupied by several streams besides Leech river, notably Jordan river and its tributaries Bear creek and Y creek, and Lost river), the valleys are narrow and the grade steep. The amount of gravel in these streams is, therefore, small. It is very possible that relatively large amounts of auriferous gravel may be found on the wide, comparatively smooth, inter-stream areas. These inter-stream areas are as a rule drift covered, and heavily timbered, so that prospecting is carried on with considerable difficulty.

The amount of gravel, even in the Leech River valley, is not large throughout the greater part of its extent, but special conditions have existed in certain portions, which have caused its accumulation in large amounts. The conditions are not at present well understood. The largest known deposit occurs in the lower part of the valley, extending to the coast near the mouth of the Sombrio river. Lost river, which occupies the western part of the Leech River valley, does not cross these gravels, but turns abruptly to the south, over a mile from the shore, and finds its way to the sea through a narrow cañon. The gravels are underlain by Tertiary conglomerate and sandstone, which are exposed at the shore and at the bend of Lost river at 320 feet above sea-level. Near sea level the Tertiary rocks are directly overlain by a sandy clay of indefinite thickness, but probably not more than 10 or 15 feet, which contains marine Pleistocene fossils. The overlying sand and gravel is from 300 to 500 feet thick; and the deposit is ¼ to ½ mile wide, and extends inland beyond the bend of Lost river, for a distance reputed to be 2 miles. On top of the gravels is a yellow garnet-bearing sand, to 20 feet thick, occurring at elevations of from 450 to 500 feet above sea-level, although near the shore it occurs much lower, probably on account of local slips in the deposit. The sand consists largely of rounded quartz grains, and resembles a beach sand. Mr. R. S. Gallop, one of the partners who own the deposit, in a recent letter to the writer states that the mining engineers who have examined the deposit estimate the amount of gravel at 155,000,000 cubic yards, and the gold contents at 12 cents per yard.

The origin of the gravels is not at present clear. A large part of the gravel contains pebbles of many different rocks, and appears from its heterogeneous character to be composed of glacial detritus. It seems probable, therefore, that the gravel was deposited by a large, post-Glacial river flowing westward in the Leech River valley before the recent uplift. This uplift diverted the river into its present course, that of the Lost river. The gold, if deposited under these conditions, was probably derived from a much larger quantity of glacial gravels.

A large amount of gravel occurs also in San Juan valley, but is probably low grade, as it is chiefly of glacial origin, and any gold that it may contain does not appear to have been especially concentrated, except very locally.

The gold in the above mentioned gravel deposits has doubtless been derived from the quartz veins which occur in the Leech River slates.[1] These quartz veins, or more correctly small stringers and lenses, are very numerous, but they seldom attain any great size. The quartz of the veins is associated with a little albite, which in the

[1] See G. M. Dawson. Report of a Reconnaissance of Leech River and Vicinity. Geol. Survey of Canada, Rept. of Progress, 1876-77, p. 100.

sheared veins has altered to sericite. The only metallic minerals are a little pyrite or chalcopyrite, and free gold. The veins are, as far as known, very low grade, and are too small and too barren to be profitably mined, and all attempts which have been made to work the veins have been unsuccessful.

The only development of the gold deposits of the Leech River belt going on at the present time is that of the large deposit of sand and gravel occurring along the west coast near the mouth of Sombrio river. Messrs. R. S. Gallop, D. W. Hanbury, and W. H. Kirkbride have nearly finished the construction of a hydraulic plant to work these gravels. It is possible that other gravel deposits, sufficiently large to pay for the establishment of a plant, occur in other parts of the Leech River valley. As far as known these deposits are small, but the western portion of the valley has never been thoroughly explored. Although the deposits of the San Juan valley are low grade, thorough examination may reveal enough gravel to warrant the establishment of a plant designed to work large quantities of low grade material. More thorough prospecting of the gravels on the upland between the two major valleys is also advised.

The upper parts of the Franklin river, China creek, and Nanaimo river flow in a mountainous district formed of the Vancouver metavolcanics, with intercalated lenses of limestone, both of which have been invaded by large granitic batholiths. Considerable mineralization has taken place near the contacts, and it is probable that the small amount of gold in the above-named streams has been derived from mineral deposits of this character. As far as seen, the gravel deposits of these streams, which are likely to be gold bearing, are very bouldery and restricted in amount.

Along the west coast of Vancouver island, except where fringed by the Tertiary deposits, black sands which carry gold occur in the beaches. The gold, however, is quite flaky and would probably be saved only with considerable difficulty, as has proved to be the case farther north along the west coast of the island. The actual amount of black sand in the beaches of southern Vancouver island does not appear to be large. Mr. Gallop, who has prospected the gravels and sands in the vicinity of Sombrio river, reports the occurrence of native mercury in the sands. The mercury was probably derived from such deposits as are known to occur on Cinnabar creek, near Sechart, on the northwest side of Barkley sound.

Vein and impregnated deposits.—In the southeastern part of Vancouver island many of the quartz-feldspar veins, which were probably formed during the intrusion of the upper Jurassic granitic rocks, have been prospected for gold, entirely without success. The true nature of these veins, or apophyses, has apparently not been recognized. For since the feldspar has altered to sericite, it resembles on the weathered surface white milky quartz, and the veins have, therefore, the appearance of ordinary quartz veins. The veins also contain pyrite, which altering to limonite has stained the exposed surfaces, still further hiding the true character of the veins. On microscopic examination, feldspar is always seen to be present, and usually in excess. Such veins as these have not been shown elsewhere to be gold bearing, and it is not likely, therefore, that they contain gold in commercial quantities in southern Vancouver island, and their prospecting should be discouraged.

Mineralized shear zones occur throughout the limestones and meta-volcanics of the Vancouver group, but are best developed near the contacts with the intrusive granitic rocks. Similar mineralized shear zones also occur in the granitic rocks themselves, especially near the contacts. Deposits of this character are usually more important as possible sources of copper, but they also carry small amounts of gold. A typical example is the deposit on the Alfreda claim, situated on the east slope of Gordon River valley, 3 miles above the mouth. Here the diorite has been tremendously sheared, forming a shear zone about 25 feet in width, which strikes N 50° W. The sheared diorite has the appearance of a chloritic or amphibole schist, but its true nature is readily recognized on microscopic examination. Although traces of the original minerals and texture are retained, the sheared rock is composed chiefly of secondary minerals, which include sericite, uralite, biotite, muscovite, chlorite, and a little epidote. In the shear zone quartz lenses have been developed partly by replacement. The quartz of the lenses occurs in irregular, usually very small grains, up to 2 or 3 mm. in diameter. Associated with the quartz is a very little plagioclase feldspar and sericite. The quartz contains disseminated grains of pyrite and magnetite, which have altered somewhat to limonite, and is cut by later veinlets of quartz and calcite. The quartz rock is said by the owner of the claim, Mr. T. M. Baird, to assay $2 a ton in gold and 5 oz. of silver. Unless considerably larger bodies of higher grade are found, these deposits are of little or no commercial importance.

COPPER.

The copper deposits of southern Vancouver island, although rather varied in character, are all more or less closely connected with the igneous rocks erupted during the upper Jurassic period of batholithic and dyke intrusion. They were, however, deposited under different conditions in different kinds of rock, and may be subdivided into three main types, as follows: (1) contact deposits, (2) impregnated and replaced shear zones with accompanying quartz veins, under which is the special type occurring on the East Sooke peninsula, which has been called the Sooke type, and (3) a large lens of ore formed in a syncline in the Sicker schists on Mount Sicker, which has been called from the largest mine developed on the ore body, the Tyee type. The contact deposits, which are developed chiefly in metamorphic limestones near their contact with intrusive igneous rocks, are the more numerous, but oddly enough the Tyee ore body, which is the only example of the Tyee type known to occur on Vancouver island, is the only deposit from which there has been a commercial production. The contact deposits will be described first, then the impregnated and replaced shear zones, with a separate description of the special Sooke type, and lastly the Tyee type. Since there is at present no commercial production of copper from southern Vancouver island, a special description of mines and prospects is given only in special instances.

Contact Deposits.

The contact deposits as mentioned, have been developed in contact metamorphosed rocks, chiefly limestones, near intrusive granitic rocks. In a few instances limestone was not present, or was present in relatively small amounts, so that there is now little or no evidence of its original presence, the 'country rocks' being contact metamorphosed volcanics and tufaceous slates of the Vancouver group. The contact deposits developed in the limestones appear to be capable of subdivision into two sub-types, which, however, merge into each other They are those which occur at the contacts, and those which occur in the zone of contact metamorphism at some distance from the actual contact. The former are characterized by a higher percentage of magnetite and pyrrhotite, and the latter by a higher percentage of pyrite and chalcopyrite, these four minerals being the principal metallic minerals of the contact deposits. The deposits developed in the higher and lower zones of the contact metamorphosed limestones are first described separately. Following this is a description of the deposits apparently developed in contact metamorphosed volcanics and tufaceous slates of the Vancouver group. Finally, the genesis of the various types is considered.

Deposits developed in contact metamorphosed limestones at or near the intrusive granitic rocks. General character and distribution.—The deposits developed at or near the intrusive granitic rocks in the contact metamorphosed limestones are typically exposed on Mount Malahat, in the Malahat district. They occur in the metamorphosed Sutton limestones, which, on Mount Malahat, are little more than large inclusions in the intrusive Wark diorite gneiss, near later intrusions of Saanich granodiorite, which has monzonitic diorite facies near the contact. The deposits consist of irregular masses of magnetite, pyrrhotite, and pyrite, with disseminated grains and veinlets of chalcopyrite. Occasionally, as in the deposits exposed near the east fork of Robertson river in Cowichan Lake district, chalcopyrite occurs in fairly large masses. The deposits on the east fork of Robertson river also occur in the contact metamorphosed limestones of the Sutton formation near diopside-bearing granodiorites of the Saanich type. Similar deposits occur in the contact metamorphosed limestones of the Nitinat formation, near the intrusive Beale diorite on Santa Maria island in Numakamis bay of Barkley sound, and on the south bank of Sarita river, one mile from its mouth. All of these deposits have been opened up only by shallow pits, small shafts and short drifts. There has been no commercial production, but some of the deposits, such as those near the east fork of Robertson river, are of considerable prospective value.

Mineralogy.—The metallic minerals occurring in the deposits of this type, in the order of their relative abundance, are: pyrrhotite, magnetite, chalcopyrite, and pyrite. Oxidized minerals are not abundant, although limonite is virtually always present, and the exposed surfaces of the deposits are stained with malachite, and sometimes with the black, earthy, copper oxide, melaconite. The non-metallic gangue minerals are those derived by the contact metamorphism of the limestones,—garnet, diopside, and epidote, with secondary actinolite, serpentine, and kaolin: and those of later introduction feldspar, quartz, and calcite.

Chalcopyrite is virtually the only copper-bearing mineral. It is massive and occurs in disseminated grains or small lenses and veinlets in the other metallic minerals and in the contact metamorphosed limestone. It is sometimes irregularly intergrown with pyrrhotite. But more rarely, as mentioned, it occurs in relatively pure and large masses, 1 to 10 feet in width, one of which is exposed near the discovery post on the Alpha claim, near the east fork of Robertson river. Chalcopyrite is usually the last of the metallic minerals to have crystallized, and when large masses of pyrrhotite and chalcopyrite are seen replacing older minerals of the contact metamorphosed limestones (see Plate 11) it is usually closely associated with the inclusions of the older minerals, penetrating them in small veinlets. The chalcopyrite has altered somewhat to limonite, and more rarely to malachite and melaconite, which form merely surface stains.

Pyrrhotite is usually the most abundant of the metallic minerals. It is massive, and occurs in relatively large, irregular masses, replacing the 'contact rock.'

Magnetite is usually present, and is one of the most abundant minerals. It is more or less complementary to pyrrhotite, for where either one is the chief mineral the other occurs in rather small quantities. It is finely granular to massive, usually occurring, where present in large quantities, in fairly large, irregular masses, which may contain only a small amount of the sulphide minerals, grading toward the magnetite type of contact deposits of the Nitinat formation, exploited as sources of iron.[1]

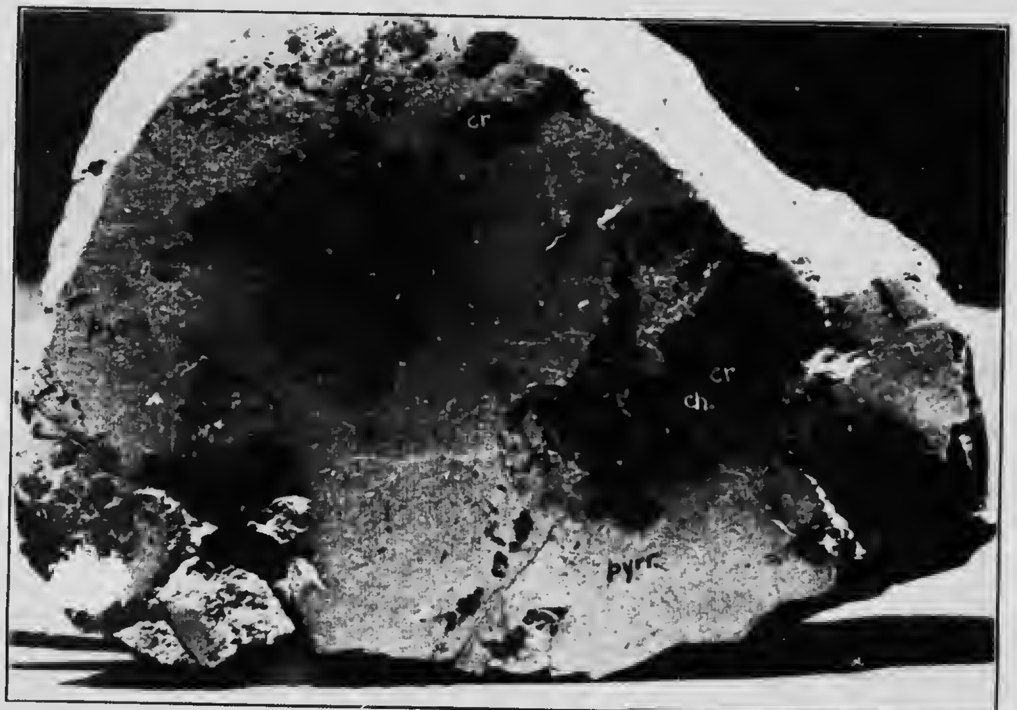
Pyrite occurs in small amounts, either intergrown and associated with pyrrhotite and chalcopyrite, or in later veinlets cutting the magnetite and pyrrhotite, and at times the chalcopyrite.

The character of the contact metamorphosed limestones and the occurrence of the minerals comprising them has already been given.[2] Quartz, epidote, and calcite also occur as veinlets cutting the gangue and metallic minerals.

Texture and paragenesis.—It may be well to emphasize characteristic textures more fully than has been done in the description of the minerals, especially those textures shown on polished

[1] See page 187.
[2] Pages 63-64.

PLATE XIV.



Pyrrhotite (pyrr) and chalcopyrite (ch) replacing contact rock (cr). Mt. Malahat. (Specimen 381) 1¼x.

ore surfaces, which indicate the probable paragenesis of the minerals comprising the ores or which throw light on the origin of the ores. Where pyrrhotite is the principal metallic mineral, chalcopyrite is usually associated with it in lens-like masses, varying from almost microscopic size to 8 inches, the greatest width noticed. These two minerals are commonly seen including fragments of the contact metamorphosed limestone, or as it may be conveniently called, 'contact rock.' As seen on the polished surfaces, the sulphides appear to be replacing the rounded and irregular inclusions of 'contact rock' apparently by impregnating along the contacts, and by penetrating them in tiny irregular apophyses and veinlets. The veinlets of chalcopyrite in the pyrrhotite are more abundant near the inclusions, which the chalcopyrite penetrates and impregnates more freely than does the pyrrhotite (Plate 14). A polished sample from the deposit on the south bank of Sarita river, a mile from its mouth, shows the silicates of the 'contact rock' in irregular grains, and secondary quartz in elongate, irregular masses, intergrown with and possibly replaced by chalcopyrite and pyrrhotite. The pyrrhotite occurs bordering the included quartz masses, also in grains included in the chalcopyrite, so that it looks as if it had entered with the chalcopyrite solutions but had crystallized first, and then had been eliminated in part from the chalcopyrite during the crystallization of the chalcopyrite, thus forming the border zones. In this instance both the pyrrhotite and the chalcopyrite are cut by later veinlets of pyrite, probably along incipient fractures. These veinlets cut abruptly across the inclusions of 'contact rock' also.

In the samples from the deposits near the east fork of Robertson river the relation of the metallic minerals to the garnet is shown. The garnet occurs massive and in relatively coarse grained dodecahedral crystals, probably of two generations. In the massive garnet are irregular patches of coarse grained garnet, magnetite, and chalcopyrite. The chalcopyrite cuts the massive garnet in veinlets and occurs in the interstices between the garnet crystals. The magnetite has apparently replaced the massive garnet, forming irregular vein-like masses, in which garnet crystals occur in such a manner as to suggest that they crystallized somewhat later than the magnetite.

The paragenesis of the metallic minerals is apparently magnetite, pyrrhotite (the relations between magnetite and pyrrhotite not being clearly shown), pyrite, and chalcopyrite, although pyrite occurs also, as described, in later veinlets. The minerals of the contact metamorphosed limestones are all earlier, with the exception of the well crystallized garnets, which appear to be of a later generation, and to have crystallized after or with the magnetite, occurring in well formed crystals possibly because of their greater power of crystallization; but even the recrystallized garnets appear to be older than the chalcopyrite. The veinlets of quartz, epidote, and calcite may be of several generations, but are found cutting all the other minerals.

Character of deposits.—The exact shape and size of any single ore body has never been determined. The bodies appear to be irregular masses, usually more or less elongate and rudely lenticular, probably vertically as well as laterally. As far as they have been examined they are not more than 8 or 10 feet wide, and are usually less. In general the percentage of chalcopyrite is low and the deposits of very low grade.

As noted, they occur in contact metamorphosed limestones, near intrusive granitic rocks, the mineralization usually being greater along shear zones. They are virtually restricted to the contact metamorphosed limestones of the so-called 'garnetite' variety, and this variety is usually in close association with relatively pure, unaltered limestones. The mineralization of the amphibolites formed by the contact metamorphism of the limestones is very small.

Deposits developed in contact metamorphosed limestones at some distance from the intrusive granitic rocks. General character and distribution.—The deposits developed in contact metamorphosed limestones at some distance from the contact with the main body of the intrusive granitic rock are well exposed on Mount Gordon southwest of Cowichan Lake narrows, at the Gladys mine on the south slope of Alberni canal near the entrance, and at the King Solomon and Blue Bell mines on Kokasilah ridge in Helmcken district. They are all developed in small limestone lentils of the Sutton formation, greatly contact-metamorphosed and sheared, and so intimately associated with metamorphic and sheared volcanics that the two types of metamorphic rocks cannot always be distinguished. The deposits consist chiefly of impregnations of magnetite, pyrite, and chalcopyrite in the sheared metamorphic rocks. The metallic minerals occur also in small lenses and irregular shaped masses, as at the Gladys

PLATE XV.

Magnetite (mg) and pyrrhotite (pyrr) including and replacing "contact rock" (cr) and cut by irregular veinlets of pyrite (p). Mt. Malahat. (Specimen 377). 1½x.

mine. Quartz and calcite veinlets and lenses, up to 6 inches in width, frequently containing chalcopyrite, occur cutting the sheared rocks. The deposits at the Gladys mine and at the King Solomon and Blue Bell mines have been developed by shafts and drifts, but very little ore has been produced. The deposits on Mount Gordon have been opened up by drifts and shallow pits, but no ore has been produced. The deposits as a whole are low grade, but owing to the relative absence of magnetite and pyrrhotite, they are the most promising of the contact ore bodies.

Mineralogy. The metallic minerals occurring in the deposits of this type are, in the order of their relative abundance, pyrite, chalcopyrite, magnetite, and pyrrhotite, and more rarely, as in the King Solomon and Blue Bell deposits, sphalerite and galena. The first named minerals are very similar to the same minerals in the contact deposits developed near the intrusive granitic rocks, the chief difference between the two types being in the relative amounts of the different minerals. They occur more commonly as impregnating grains and small lenses in the sheared country rock, and less commonly as relatively large lenses composed almost entirely of metallic minerals. The sphalerite and galena occur in fine grains and irregular veinlets intimately associated with the pyrite and chalcopyrite.

The non-metallic minerals are those forming the contact metamorphosed limestones and volcanic rocks, and are virtually identical with those already described. At the Gladys mine there is a rather peculiar rock composed almost entirely of large-bladed actinolite in parallel arrangement. Chalcopyrite occurs in the interstices, in elongate grains parallel to the bladed texture, and the rock is cut by small quartz lenses.

Texture and paragenesis. The texture of the more massive ores is similar to the texture of those already described. The paragenesis is less readily determined, especially when the ore minerals occur disseminated through the sheared metamorphic rocks, but appears to be similar to that of the other types, that is, magnetite, pyrite, and chalcopyrite. The galena and sphalerite appear to be later than the chalcopyrite. The minerals of the metamorphic rocks are generally earlier than the metallic minerals, and are being replaced by the metallic minerals. The ores have been sheared and broken by post mineral movements, and recemented by calcite and quartz veinlets.

Character of the deposits.—As noted, the ore minerals occur chiefly as impregnations and replacements of sheared metamorphic limestones and volcanics, and are, therefore, of irregular and indefinite size and shape, following in a general way more or less well defined shear zones. As noted, the impregnated zones are relatively small, not more than 4 or 5 feet wide, and seldom traceable along the outcrop for more than 100 or 200 feet. Large masses of pure ore are not exposed, but a relatively large mass is said to have been mined out near the surface at the Gladys mine. The ores are low grade, but if larger masses were located they could doubtless be mined at a fair profit.

Although the country rocks have been metamorphosed by contact agencies, the granitic rocks in the immediate neighbourhood of the three deposits are confined to quartz-diorite porphyrite dykes and irregular masses. The larger batholiths of granodiorite are usually exposed at some distance from the deposit, commonly at a lower level, and doubtless occur directly below the deposits at no very great depth.

Deposits apparently developed in contact metamorphosed volcanic rocks.—Contact deposits very similar to those described above occur developed in contact metamorphosed rocks, also similar to those already described, near intrusive granitic rocks. The contact metamorphosed rocks are so intimately and irregularly associated with volcanic rocks, that it is supposed, since there is no direct evidence of the original presence of limestone, that the metamorphic rocks were derived by the contact metamorphism of original volcanic rocks.

General character and distribution.—The deposits which are developed in the contact metamorphosed volcanic rocks are similar in character to the contact deposits described above. They usually occur in silicified and sheared volcanics, near intrusive granitic rocks. Deposits of this character are generally small, of indefinite extent, and low grade, and are of scientific rather than commercial interest. They have been noted in the Penton mineral claim, one mile east of Tod inlet in South Saanich district, and on the Iron mask mineral claim on the south slope of Mill hill in Esquimalt district. A similar deposit occurs on the Sterling and Glen Apa claims, on the upper Koksilah river, in the southern part of Helmcken district, which appears to be related to the type developed at a distance from the actual contact, similar to that at the King Solomon and Blue Bell mines, since galena and sphalerite are among the principal metallic minerals. On the divide between Cottonwood creek and Chemainus river in Cowichan Lake district is a rather peculiar type developed in the silicified and tufaceous slates of the Sicker series.

Mineralogy.—The metallic minerals occurring in the deposits are similar to those in the limestone contact deposits. Chalcopyrite is the only copper-bearing mineral, other than the relatively unimportant oxidized minerals, and is associated with magnetite, pyrite, and pyrrhotite. More rarely, as in the deposits on the Sterling claim, galena and sphalerite occur, and molybdenite occurs in the quartz veins associated with the deposits on the divide between Cottonwood creek and Chemainus river. The occurrence of the minerals is similar to that of the limestone contact deposits. The gangue minerals are also similar to those of the limestone contact deposits, although epidote and chlorite, as well as secondary quartz, are more abundant. In the deposits of the Sterling claim galena and chalcopyrite, with a little sphalerite, occur, irregularly interbanded with a light brown, flat rhombohedral dolomite. All of the deposits are cut by veinlets and lenses of quartz, and of calcite, which carry chalcopyrite, and, as mentioned, in one instance, molybdenite.

Character of the deposits. The metallic minerals, as stated, occur chiefly as impregnations and replacements of sheared metamorphic rocks usually along fairly well defined but irregular shear zones. The shear zones are as a rule narrow and not extensive. The conditions prevailing on the divide between Cottonwood creek and Chemainus river are rather peculiar. There the silicified tufaceous slates of the Sicker series are cut by dykes of andesite or basalt porphyrite[1] and granodiorite porphyrite, near a large intrusive mass of granodiorite, which is exposed on the slope north to the Chemainus river, about 300 feet below the deposits. Irregularly interbedded with the tufaceous slates are beds which have been replaced almost

[1] See page 81.

entirely by andradite garnet associated with actinolite.[1] The alternation of beds is usually rapid, the individual beds ranging from 2 to 30 inches in thickness. They also thin out laterally in a short distance. The mineralization has been confined almost entirely to the garnetiferous beds. These are frequently replaced to such an extent as to form ore, which, though of a fair grade, is seldom in large amounts.

Genesis of the contact deposits.—From the occurrence of the deposits described above, it is clear that they are intimately connected with the granitic rocks which were erupted into the limestones and volcanics of the Vancouver group in upper Jurassic time. Similar deposits 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 metallic minerals also are those which characterize the Vancouver island deposits, chiefly magnetite, pyrrhotite, pyrite, and chalcopyrite. There can be little doubt, therefore, that the Vancouver island deposits are contact deposits.

There are two general hypotheses of the origin of the minerals of contact deposits. The first is that the garnet, diopside and other non-metallic minerals, and in part at least, the metallic minerals were derived from the recrystallization of an impure rock, usually a 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, which entered the limestones in hot gaseous solutions, well above the critical temperature of water, and metasomatically replaced them.

The limestones of southern Vancouver island were, to judge from the unaltered portions remaining to-day, very pure carbonates of lime with some magnesia, and were comparatively free from

[1] See page 77.

PLATE XVI.

"Contact rock" (cr) cut and brecciated by veins of magnetite (mg), which in turn are cut by veins of epidote (ep) and calcite (cal). Penton mineral claim, South Saanich district. (Specimen 225). 1⅓x.

9871 p. 166

sedimentary material other than organic fragments.[1] That they have been subject to very great alteration near the intrusive granitic rocks is shown by the universal occurrence of a metamorphosed zone in contact with the granitic rocks, which are never, except in small dykes, in direct contact with pure limestone or marble. The inference is, therefore, that additions of silica, iron, copper, and sulphur were received from solutions derived from the invading magma. The nature of the mineralization also supports this conclusion, as it is greatest where solutions would most easily circulate, that is, along shear zones, frequently being confined to them. Also in the magnetite type of contact deposits occurring in the Nitinat limestones, irregular, apophysal-like veins of magnetite cut and brecciate nearly pure marble, suggesting that they have been formed by the intrusion of very concentrated magnetite solutions.[2]

Some of the deposits also appear to have been developed in contact metamorphosed volcanic rocks, although the contact metamorphosed rocks are very similar to those derived from limestones. As noted, if limestone was originally present it has been entirely converted into metamorphic varieties. The metamorphic varieties are apparently confined to irregular shear zones in the recognizable volcanics near intrusive granitic rocks. They may represent old limestone inclusions, which are found in the volcanic rocks, and which have been sheared and completely metamorphosed. But since the shape of the metamorphic portions is very irregular, and since they are so intimately associated with the volcanics, it is strongly suggested that the metamorphic portions have been formed by the alteration of sheared volcanic rocks by solutions derived from the invading granitic magmas. The chemistry of the alteration cannot be satisfactorily discussed at present owing to lack of analyses. The chief difficulties appear to be the introduction of lime to form andradite garnet and a loss of alumina, which does not appear to be present in the garnet. If the contact zone as a whole is considered, there has probably not been any great loss in alumina, and possibly no very great gain in lime, as minerals such as epidote and chlorite are probably more abundant than garnet. The non-aluminous

[1] See page 67.
[2] See pages 192-193.

pyroxene, diopside, is not an abundant metamorphic product in the deposits of this type. In the metamorphism there appears to have been a general rearrangement of the minerals.

The production of andradite garnet by contact metamorphism in igneous rocks intruded by later eruptions is uncommon, but has been noted by Brock[1] in volcanic rocks, and even in granodiorite, which were intruded by younger granitic rocks. It appears that in this instance a large part of the constituents of the garnet was introduced by solutions derived from the younger, intrusive rocks. In the deposits on the divide between Cottonwood creek and Chemainus river the garnetiferous and mineralized beds occur interbedded with the tufaceous slates of the Sicker series, the two forming, as mentioned, a rapidly alternating series. Although a small inclusion or lentil of limestone was noted by Mr. Allan, associated with the rocks of the Sicker series on Mount Brenton,[2] in no instance has limestone been noted interbedded with the stratified rocks of the Sicker series, and it seems improbable that at the one locality limestone originally occurred in thin beds rapidly alternating with rocks identical with those exposed in several other parts of southern Vancouver island, and that it was entirely destroyed by contact metamorphism. It seems more probable that certain beds in the series consisting largely of stratified, tufaceous sediments were more porous or more readily altered than other beds, and that these were converted, by solutions uprising from the granitic magma below at the time of batholithic intrusion, into the garnetiferous and mineralized beds exposed to-day.

Further proof of deposition from solution is found in the rather definite order of crystallization of the metallic minerals and to a less extent of certain of the non-metallic minerals of the deposits. The earliest minerals appear in virtually all cases to have been those formed by the action of solutions on the original minerals of the invaded country rocks, notably diopside, epidote, and garnet. Garnet and, to a less extent, epidote also appear to have been formed later, after some mineralization had taken place. The order of crystallization, or paragenesis of the metallic minerals appears to have been magnetite, pyrrhotite, pyrite, and chalcopyrite. A similar paragenesis is of very general occurrence in all massive ores, and

[1] R. W. Brock. Preliminary Report on the Boundary Creek district, B.C. Summary Report for 1902. Geol. Survey, Canada, pp. 108A-109A.
[2] See page 83.

has been noted by many observers in many different ore deposits,[1] and is probably due to a definite order of crystallization from the metal-bearing solutions according to a definite solution law not at present well understood, since the various factors controlling the crystallization of these minerals from solution have not been determined. However, magnetite and pyrrhotite were deposited first, while pyrite and chalcopyrite were usually deposited later. This law appears to have been of considerable importance, not only in determining the texture of the ores, but in determining their character. Those near the sources of the solutions, that is near the contacts with the granitic rocks, which were formed during the early stages of deposition, were rich in magnetite and pyrrhotite: while those formed during the later stages of deposition, deposited from solutions enriched in pyrite and chalcopyrite through the loss of magnetite and pyrrhotite, usually at some distance from the source of the solutions, in the upper portions of the contact metamorphosed zones, were relatively rich in pyrite and chalcopyrite. A similar circulation of solutions has been emphasized by recent wri[illegible] Lindgren,[2] and explains most plausibly the zonal distribution of different types of ore deposits, ranging from those formed under igneous and deep-seated conditions to those formed under surface conditions.

Conclusions and classification.—The conclusions reached regarding the deposits are that they were deposited in contact metamorphosed and sheared limestones and volcanics of the Vancouver group from solutions emanating from the magmas erupted during the upper Jurassic period of batholithic intrusion. The solutions penetrated the contact metamorphosed rocks more readily along shear zones or more porous beds, and the metallic minerals, and to some extent garnet, actinolite, quartz, and calcite replaced the older metamorphic minerals. Near the intrusive igneous rocks and in the lime-

[1] W. Lindgren. The copper deposits of the Clifton-Morenci district, Arizona. Professional Paper No. 43, U.S. Geol. Survey, 1905, p. 194.
F. L. Ransome. Geology and ore deposits of the Bisbee quadrangle, Arizona. Professional Paper No. 21, U.S. Geol. Survey, 1904.
J. E. Spurr. The ore deposits of Monte Cristo, Wash. 22nd Ann. Rept. U.S. Geol. Survey, Part II 1901, p. 838.
R. W. Brock. Preliminary Report on the Boundary Creek district, B.C. Summary Report for 1902, Geol. Survey of Canada, p 107A.

[2] W. Lindgren. The relation of ore-deposition to physical conditions. Econ. Geology, Vol. 2, 1907, pp. 105-127
Present tendencies in the study of ore deposits. Econ. Geology, Vol. 2, 1907, pp. 743-762

stones, the replacements were largest. The metallic minerals first deposited were magnetite and pyrrhotite, so that the deposits found near the granitic rocks are not only larger but are characterized by a larger percentage of those two minerals. By the removal of magnetite and pyrrhotite the solutions were enriched in pyrite and chalcopyrite which deposited farther away from the actual contact with the granitic rocks, forming smaller deposits which are characterized by a higher percentage of pyrite and chalcopyrite, and occasionally by sphalerite and galena. The deposits thus formed have been fractured and recemented by quartz and calcite veinlets and lenses which frequently carry chalcopyrite. But there has been no notable rearrangement and enrichment of the original ores, and all oxidized ores if ever present were removed by the recent glacial abrasion during the Glacial period, so that no oxidized ores are exposed near the surface. As a whole the deposits are classified as belonging to the magnetite-pyrrhotite-chalcopyrite type of contact deposits, but the two sub-types should not be ignored.

General status and future possibilities.—There has been no commercial production from the contact deposits, and as a rule they are too small and too low grade to be probable sources of copper ore in the near future. They are very similar, as has been indicated, to a well recognized type of copper deposits which have been notable producers of copper ore. The productive deposits are much larger than the known deposits of southern Vancouver island, and in most cases they have been enriched by secondary processes forming higher grade copper minerals, bornite, and chalcocite. Except in rather rare instances the deposits of southern Vancouver island developed in the contact metamorphosed limestones near the granitic rocks are too high in magnetite and pyrrhotite, which could not be cheaply separated from the chalcopyrite, for them to be of any great value as sources of copper ore. The deposits in the metamorphic volcanic rocks are as a rule too small and irregular to be of value. The most promising type is that in which magnetite and pyrrhotite are subordinate to the pyrite and chalcopyrite, and which are normally developed in the contact metamorphosed limestones at some distance from the actual contact with the granitic rocks.

IMPREGNATED AND REPLACED SHEAR ZONES, WITH ACCOMPANYING QUARTZ VEINS.

General character and distribution.—Throughout the volcanic rocks of the Vancouver group are schistose or sheared zones which are more or less mineralized, chiefly with pyrite and chalcopyrite. Pyrrhotite and magnetite are frequently present, and more rarely bornite and chalcocite. Associated with the mineralized shear zones are small veins and lenses of quartz which frequently contain chalcopyrite and the other metallic minerals. Several claims have been taken up on these mineralized shear zones, and some of them appeared to be quite promising prospects, but in no instance has any large body of payable ore been located.

A large number of the deposits occur in the schistose rocks of the Sicker series, throughout the belt underlain by them. The principal deposits occur on Mount Sicker, Mount Richards, and Mount Brenton, and are more or less closely related to the Tyee ore body, which also occurs in the Sicker schists. The metallic minerals consist chiefly of chalcopyrite and pyrite, but bornite and chalcocite, as well as sphalerite occur sparingly. Pyrrhotite is frequently abundant, and magnetite is sometimes present. The gangue minerals are chiefly quartz, but barite also occurs, showing the relations of these deposits to that of the Tyee type.[1] The gabbro-diorite porphyrite which is intrusive into the schists of the Sicker series frequently contains finely disseminated grains of chalcopyrite, and possibly some chalcocite. A large area of the gabbro-diorite porphyrite—about 2 square miles—exposed on Mount Richards to the north of the Lenora railway is reported to assay as high as one per cent of copper.

Similar impregnated schists occur on the south slope of Mount Skirt, a mile to the northeast of Goldstream station, in the schistose phases of the Vancouver volcanics.[2] The mineralized zone is cut by small irregular lenses of quartz with more or less chalcopyrite and pyrrhotite. On the 'Brass' mineral claim of the Jubilee group, which is situated near the headwaters of Green river in Dunsmuir district, an impregnated shear zone in the Vancouver volcanics is cut by a quartz vein 18 inches wide, striking N 10° E and traceable

[1] See page 182.
[2] See page 56.

for about 50 feet along the outcrop. The vein carries pyrite and chalcopyrite, pyrite being greatly in excess.

Mineralized shear zones occur in the Vancouver volcanics, exposed along the upper part of the Gordon and Nitinat rivers, in which pyrite is the principal metallic mineral. The sheared rock is usually greatly altered, commonly to a fine grained aggregate of quartz and sericite. On the surface the whole impregnated zone weathers to deep reddish-brown, so that the mineralization appears superficially to be much more extensive than it really is.

In the Metchosin volcanics, shear zones with accompanying quartz stringers which carry metallic minerals occur, although they are not numerous except near the intrusive stocks of Sooke gabbro. Those which are apparently related to the Sooke gabbro are described under the special Sooke type. An example of the deposits which are not closely associated with the Sooke gabbro, is exposed on a small tributary which enters the Jordan river from the east about 3 miles from its mouth. Pyrite with some pyrrhotite and chalcopyrite occurs, impregnating, and to some extent replacing narrow shear zones, the strikes being N 25° E and N 60° W. The sheared rock consists chiefly of fine grained, prismatic uralite and chlorite, with very fine grains of quartz and clear, recrystallized feldspar. Cutting the shear zones are quartz stringers up to 4 inches wide, which carry small crystals of pyrite and chalcopyrite.

In the Sooke gabbro are wide shear zones which have been impregnated and partly replaced by chalcopyrite and other metallic minerals. The type has many characteristic features, and is more important than any of the other shear zone deposits, and is described separately as the Sooke type.

A large number of claims have been staked on a group of deposits near the headwaters of Franklin river and China creek, in Alberni, Dunsmuir, and Barkley districts. These claims were not visited, so that their character is not known. Some of them may be contact deposits, but it is probable that they are chiefly impregnated and partially replaced shear zones.

Genesis.—The association of metallic minerals and the character of the alteration of the original minerals of the sheared rocks indicate that the mineralization took place under conditions of high temperature and pressure. The date of the mineralization can be determined quite definitely since the rocks of the Vancouver group, in part of lower Jurassic age, are mineralized, and fragments of the mineralized rocks are found in the basal conglomerates of the Nanaimo formation of upper Cretaceous age. Hence, the mineralization is post-lower Jurassic and pre-upper Cretaceous. It is, therefore, more or less contemporaneous with the upper Jurassic and possibly lower Cretaceous period of batholithic and dyke intrusion, and since the mineralization took place at high temperature and pressure, it is almost certainly closely connected with the batholiths and dykes which are intrusive into the rocks of the Vancouver group. Doubtless the larger number of the deposits are related to the batholiths of the Wark, Beale, and Saanich types,[1] and since these batholiths are widespread and very numerous, the mineralization is correspondingly extensive. The deposits in the Sicker series are probably related to the gabbro-diorite porphyrite intrusions, which themselves contain such a notable percentage of metallic minerals. Since the mineralization of the Sicker series is greater than that of any other formation, and since it is characterized by the occasional presence of bornite and chalcocite and of barite, it is probably related not only to the gabbro-diorite porphyrites intrusive into the Sicker series,[2] but also to the Tyee ore deposit.

General status and future possibilities.—Although a great number of claims have been taken up on the shear zone deposits and some of them developed slightly, there has been, as mentioned, no commercial production, and no large persistent bodies of ore have been located. The low grade character of the ore, pyrite and pyrrhotite greatly predominating over the copper-bearing minerals, and the irregular character of the deposits, make them in most instances improbable sources of copper ore, and their future prospecting cannot be recommended. The presence of bornite and chalcocite in the sheared and schistose zones of the Sicker series, and the greater extent of the mineralization make the area underlain by the Sicker series more favourable prospecting. It is doubtful if ever the shear-zone type of deposit will be found of economic value, but further prospecting may lead to the discovery of another lens of ore of the Tyee type. The associated gabbro-diorite porphyrites with their small percentage of chalcopyrite and possibly chalcocite, are also a

[1] See page 95
[2] See page 78.

possible source of copper ore, for although the percentage of copper is small, yet the ore is of such a character as to be readily and cheaply concentrated by ore dressing.

SOOKE TYPE.

General character and distribution.—On the East Sooke peninsula, developed usually in shear zones of the Sooke gabbro and distributed throughout the gabbro stock, are deposits of low grade copper ores. The ore mineral is chalcopyrite. Associated with it are pyrite, pyrrhotite, and magnetite. Pyrite, pyrrhotite, and magnetite occur chiefly in large masses which are composed almost entirely of metallic minerals. Chalcopyrite occurs chiefly in wide shear zones, through which it is disseminated as small patches, lenses or veinlets. The only important gangue mineral is hornblende. Since the chalcopyrite is usually disseminated through wide zones of sheared rock, the deposits are low grade. The ore mineral could, however, be easily concentrated, hence the deposits are of great prospective value. At present but little development work has been done.

Mineralogy.—The metallic minerals present are chalcopyrite, magnetite, pyrrhotite, and pyrite, and native copper. The non-metallic, gangue minerals are amphibole, chlorite, feldspar, and quartz. Chalcopyrite is the only important copper-bearing mineral, as the iron sulphides probably do not contain any appreciable amount of copper. Chalcopyrite occurs in small disseminated grains, minute veinlets, and in larger veins and masses. In the shear zone deposits it is nearly free from the other sulphides, although magnetite is present. The chalcopyrite has crystallized later than the associated hornblende, cutting the hornblende in veinlets and also including it. It also includes grains of an untwinned feldspar, probably albite-oligoclase. The massive chalcopyrite was not assayed, but appears to be nearly pure. In the large masses of metallic minerals, chalcopyrite is very subordinate. It occurs in veinlets, cutting enclosed masses of hornblende, or disseminated through the massive magnetite and pyrrhotite. The chalcopyrite has crystallized later than the magnetite and pyrrhotite, and with the exception of quartz, has been the last mineral to form in both types of deposits.

A little native copper is occasionally found near the surface. No oxidized copper minerals are found to any great extent, although the green copper stain due to the carbonate is of common occurrence.

Fine granular to massive magnetite is of almost universal occurrence in the deposits. In the shear zone type, magnetite occurs in small, elongated segregations closely associated with feldspar. In the massive type of deposit, magnetite is one of the chief components, and has been one of the first of the metallic minerals to crystallize.

Pyrrhotite is common, but is present in large amounts only in the massive type of deposits of which it is the chief constituent. It is a yellowish bronze, finely granular variety. It occurs as irregular masses and also as veinlets cutting magnetite, pyrite, and the included silicates. The contact of the pyrrhotite and the included silicates is very irregular, tiny apophyses of the former entering the latter.

Pyrite is not abundant, and is found chiefly in the massive type of deposit closely associated with pyrrhotite.

The above metallic minerals are but slightly oxidized near the surface, and only a very small amount of gossan, composed largely of limonite is found. The apparent order of crystallization of the metallic minerals is magnetite, pyrite, pyrrhotite, and chalcopyrite.

The chief gangue is amphibole, which is of two varieties, a bladed, common green hornblende, and a fibrous or needle-shaped, slightly pleochroic variety. The hornblende occurs in large irregular grains, some of which are sheared and frayed on the edges. The fibrous amphibole occurs in radiating groups in narrow zones, and is closely associated with magnetite. Some of the amphibole is altered to chlorite. The amphiboles occur chiefly in the shear zones, so that the shear zones resemble coarse hornblendites. In the masses of nearly pure metallic minerals the amphibole has been reduced to a few included grains. In a few of the shear zones, augite in small irregular to prismatic grains is as abundant as the amphibole.

Other silicates in the shear zones are feldspar (probably albite-oligoclase), and zeolitic minerals. Feldspar forms only a small percentage of the rock, and is associated with the chalcopyrite and not with the large bladed hornblendes. Quartz occurs in small stringers throughout the shear zones, but is absent or insignificant in the massive type of deposits.

Character of deposits.—Relations to country rock.—The Sooke deposits are of two types, disseminated chalcopyrite in shear zones, and large irregular masses of metallic minerals. The former is of the greater importance. Most of the shear zones throughout the gabbro stock are more or less impregnated with chalcopyrite, but only the larger have any commercial importance. These are well defined, and vary in width from a few feet up to one which is at least 250 feet wide. They are 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 of the larger shear zones varies widely, but there are two principal sets, one having a strike near N 40° E and the other near N 75° E. There is every reason to believe that these shear zones extend to considerable depths. Erosion has progressed more rapidly along the shear zones so that they are marked by small valleys, and along the shore by narrow, wave-eroded chasms. This erosion is probably due more to the sheared character of the rock than to the presence of easily decomposed sulphides, so that shear-zone chasms cannot be taken as any indication of the presence of ore minerals.

Chalcopyrite occurs distributed throughout the entire shear zone, but the percentage in the whole shear zone is small, rarely more than 5 per cent. The amount of chalcopyrite varies greatly in different shear zones and different portions of the same zone. There appear to be better values, in most cases, near the walls. In only one case, on the Willow Grouse claim, was a specially enriched shoot noted. This shoot, as exposed by a small shaft and drift is about 7 feet wide, and carries a relatively high percentage of chalcopyrite. This enriched deposit occurs at the junction of two well defined shear zones. It also occurs near an intrusive mass of the olivine anorthosite.

Only two types of the massive type are known: one on a claim on section 83, and the other at Iron mountain (section 79), near O'Brien point. These two deposits have been supposed to be continuous, but this is very doubtful. At Iron mountain the metallic minerals have been developed in a shear zone, 30 to 40 feet wide, in a basic ophitic gabbro. Large bladed hornblendes are the only silicate minerals that are prominent, and these are included and are apparently being replaced by magnetite and pyrrhotite. This apparent replacement has gone on to such an extent that large masses of relatively pure metallic minerals occur.

In the shear zones of the Metchosin volcanics which are intruded by the Sooke gabbro, in the neighbourhood of the gabbro stock, deposits of disseminated sulphides of iron and copper also occur.

Genesis. The association of minerals, especially the presence of the hornblendes, proves conclusively that the deposits were formed under conditions of high temperature and pressure. The disseminated chalcopyrite is so intimately connected with the large bladed and fibrous amphiboles of the shear zones that the two minerals have doubtless been formed by a similar and continuous process.

The conclusions reached regarding the origin of the 'hornblendites' of the shear zones[1] is that they were probably formed directly following the solidification of the gabbro, through the influence of hot solutions, either liquid or gaseous, acting on the sheared rock, recrystallizing the basic constituents into amphibole. Following or virtually contemporaneous with the above changes, solutions carrying magnetite and sulphides of iron and copper were introduced and their contents were deposited as disseminations through the shear zones. The metallic minerals may have been more abundant in the original gabbro along certain of these zones, formed by segregation in the primary gabbro magma. The only field evidence of such segregation or basification of the gabbro was noted in the neighbourhood of the Iron mountain deposit, and it is very possible that the massive type of deposit owes its existence in part to original segregation, but it also has doubtless been enriched in metallic minerals by subsequent processes.

Metasomatic replacement has gone on to a very considerable extent, as is shown by the silicates with jagged, irregular or obscure outlines, that are included in the metallic minerals, even in the massive chalcopyrite. The large masses of sulphides and magnetite have apparently been formed in part where this process has been most efficient. In the chalcopyrite deposits marked replacement of the hornblende has taken place only near the walls or at the intersection of two shear zones. Replacement of the feldspar has, however, gone on to a very considerable extent.

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[1] See origin of Sooke gabbro, page 122.

Even after the formation of the 'hornblendites' in the shear zones slipping has occurred, as is shown by the abundant slickensides. This movement continually opened up new passages for the solutions, so that the metallic minerals continually worked their way farther into the sheared rock, and more and more completely filled the small interstices between the hornblende crystals.

The paragenesis of the minerals of the deposits always shows chalcopyrite to have been formed last. This feature is not characteristic of the ores of this district only, but is of very general occurrence in similar ores,[1] and has been explained as due to a definite order of crystallization from metal-bearing solutions. On this assumption the most probable explanation of the shear-zone type, which is comparatively free of the valueless sulphides, pyrite, and pyrrhotite, appears to be as follows: The metal-bearing solutions deposited the greater part of their contents early in their progress upward through the sheared gabbro, or as they radiated out from segregated masses of metallic minerals, and replaced the silicates readily and formed such masses as that exposed on Iron mountain. The deposition of the iron minerals, and the replacement of the silicates, left the solutions enriched in copper and silica. These, penetrating farther into the shear zones, deposited nearly pure chalcopyrite and quartz. Where the solutions were especially vigorous in their action, along the main channels of circulation, that is near the walls of the shear zones, and along their intersections, replacement of the hornblende occurred and the enriched deposits of chalcopyrite were thus formed. Solutions of this same character seem to have penetrated also the shear zones in the overlying and invaded Metchosin basalts.

General status and future possibilities.—Several claims have been taken up on the Sooke deposits, and numerous prospect pits have been made, but no mining has been carried on, and only a very meagre amount of development work has been done. Ore from the Willow Grouse and Blue Bird claims has been tested in large quantities, and the results are said to be satisfactory. A few attempts have been made to mine the Iron mountain deposit, 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.

[1] See pages 168-169.

The 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 for 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. A suggestion is made under sulphur that the deposits may have some future value for the manufacture of sulphuric acid. Their chief value has been as an iron flux in copper smelting.

The shear-zone type of deposit, with the local enrichments, is of very great prospective value. The deposits as a whole are very low grade, but the chalcopyrite could easily be concentrated by ore-dressing machinery, without transportation of the low grade ore. Since the deposits are in such well defined shear zones, and are of deep-seated origin, there is every reason to believe that they are continuous in depth. There is, however, no reason for believing them to increase in value with depth. They will rather decrease gradually in value, and if the hypothesis suggested holds, the amount of pyrite and pyrrhotite will probably increase. The small amount of native copper found frequently at the surface is due to surface alteration, and cannot be expected more than a few feet from the surface.

Description of prospects.—The prospect on the Willow Grouse and Blue Bird claims is one of the two or three more important ones. It is situated on the northwest slope of Mount Maguire, on section 111. The ore is developed in a shear zone about 60 feet wide having a strike of N 40° E. An enriched body of chalcopyrite occurs at the junction of the wide shear zone with a narrow one having a strike of N 3° W and a dip of 80° W. The crossing of the shear zones, the large one being approximately vertical, has formed a so-called 'horse' of gabbro, which is exposed in the short drift. Directly to the south is a body of olivine anorthosite, about 400 yards across, which is intrusive into the normal gabbro.

The ore mineral is chalcopyrite and occurs disseminated through the wide shear zone, although best developed along the north wall. The enriched body, which occurs at the intersection of the two shear zones, is about 7 feet wide and follows the smaller zone.

It carries a good percentage of chalcopyrite, with vein-like masses of the pure mineral over a foot in width.

The deposit has been opened up by a shaft 40 feet deep, with a 40 foot drift running west across the body from the bottom of the shaft.

On the southern slope of Mount Maguire are three claims, the Margaret, Copper King, and Eureka, located on a wide shear zone some 200 feet wide, having a strike of N 43° E, which is traceable for the whole length of the three claims. As a rule, the metallic minerals, chiefly chalcopyrite, are disseminated through the entire shear zone, with the best values along the northwest wall. Occasionally the chalcopyrite occurs in small lenses and veins. Quartz stringers are very abundant. The deposit is opened only by four or five small pits or shafts.

Another prospect, half a mile northwest of the Willow Grouse claim, is on a small shear zone having a strike of N 80° W. Good ore is exposed close to the wall rock of gabbro.

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 N 15° W.

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 massive 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.[1]

TYEE TYPE.

General character and distribution.—The only copper deposit known of the Tyee type occurs at Mount Sicker. It is virtually a single lens of ore extending through three claims, from east to west, the Richard III, the Tyee, and the Lenora. The ore is chal-

[1] See E. Lindeman, Publication No. 47, Mines Branch, Department of Mines, Canada, 1910, p. 9.

copyrite associated with pyrite, sphalerite, and some galena, in a gangue consisting chiefly of barite, with some quartz and calcite. Outside of the lens are massive veins consisting chiefly of quartz and dolomite. The lens occurs in a synclinal trough of the quartz-talc and graphite schists of the Sicker series. The production from the deposit has been large, and during its activity the Tyee mine was the most important copper producer of the Coast region of British Columbia. At present the ore has been worked out and the mines are shut down. All of the three mines giving access to the ore-body are now, and were at the time of the writer's visit inaccessible, so that it has been impossible to make an examination underground. The Tyee Copper Company kept a very careful record of their regular development work, and by extensive diamond drilling and by sinking and drifting have gained a full knowledge of the extent of the ore-body and of the geological structure. Some of the results of their work have been made public in several papers, the most important of which are listed in the bibliography. With the exception of a few details concerning the character of the ore and the general geological relations, little can be added in the present instance to the already existing knowledge of the district. The writer has been compelled to draw his knowledge of the deposit from the already published accounts, and so a short summary is all that is advisable. The chief sources have been an article by Mr. W. H. Weed on the Tyee mine, published in the *Engineering and Mining Journal*, January 25, 1908, pp. 199-201, and one in the same magazine by Mr. Robert Musgrave, Vol. 78, 1904, pp. 673-674.

Mineralogy.—The number of minerals found in the ore is comparatively small. The complete list is:—

Metallic minerals.	Non-metallic minerals.	Oxidized minerals.
Chalcopyrite.	Quartz.	Limonite.
Pyrite.	Barite.	Turgite.
Sphalerite.	Calcite.	
Galena.	Albite.	
Pyrrhotite.	Dolomite.	

Chalcopyrite is the only copper-bearing mineral. It occurs massive and in small grains. It is sometimes intergrown with pyrrhotite, both minerals including small grains of pyrite. It is more rarely intimately intergrown with pyrite. Grains of chalcopyrite are commonly surrounded by sphalerite.

Pyrite usually occurs as small grains either with the gangue minerals or in the massive chalcopyrite. Sometimes the pyrite and chalcopyrite are finely disseminated one in the other.

The sphalerite, which is dark coloured and high in iron, is nearly always present in the ores in which the non-metallic minerals occur, which ores are usually banded, but in the massive sulphide portions it is less common or absent. It occurs as grains disseminated through the banded ore and also surrounds chalcopyrite in the more massive parts. In general, it has been one of the last minerals to crystallize, and sometimes occurs interstitial to calcite. Occasionally sphalerite extends through the ore, forming a sort of matrix for the other minerals, with the exception of quartz and calcite.

Galena is not very abundant, is not always present, and occurs as disseminated grains in the banded ore.

Pyrrhotite occurs intimately intergrown with massive chalcopyrite, and both minerals include small grains of pyrite.

Quartz is nearly always present, occurring intergrown with calcite and barite in the banded ores, and in veinlets cutting the massive sulphides. It also occurs in the veins outside of the Tyee ore-body.

Barite is the most abundant non-metallic mineral of the normal ore. It occurs with quartz in a fine grained mixture, apparently having crystallized first in small grains of rounded or crystalline outline.

Calcite occurs in veinlets cutting the massive sulphides, and also as one of the non-metallic constituents of the banded ore.

Albite, which is nearly always present although not in large amount, occurs with the other non-metallic minerals in the banded ores, in irregular grains. Some of the grains are broken, and are penetrated by veinlets of the metallic minerals, notably sphalerite.

Dolomite is confined to the quartz veins and occurs in rhombohedral crystals surrounded by the quartz. It is of a light yellowish colour and resembles ankerite, but contains scarcely more than a trace of iron. It is sometimes penetrated by little veinlets of chalcopyrite.

Tyee ore, massive chalcopyrrhotite and pyrrhotite including small grains of pyrite, brecciated and cut by veinlets of calcite and quartz. Tyee mine. (Specimen 432). 1¼ x.

Limonite and turgite occur in the gossan associated with residual sulphides. There are virtually no oxidized copper minerals present.

The ores of the lens may be considered as of two kinds, a banded ore consisting of both metallic and non-metallic minerals, and a massive ore consisting solely of metallic minerals, although brecciated by veinlets of quartz and calcite. The paragenesis of the banded ore appears to be albite, pyrite, barite, chalcopyrite and galena, sphalerite, quartz, and calcite. The relation of the metallic and non-metallic minerals is not always clear, but otherwise the paragenesis as given is fairly definite and holds generally. The banded ore is not crustified, and the minerals comprising it are virtually contemporaneous, the definite paragenesis apparently being due to a definite order of crystallization. The banding appears to be due in part to a slight crushing and movement after the minerals of the ore had been crystallized. The massive ore consists of chalcopyrite, some of which is intimately and irregularly intergrown with pyrrhotite, these minerals including pyrite. The ore is commonly broken and cut by veinlets of quartz and calcite. The paragenesis is, therefore, pyrite, pyrrhotite and chalcopyrite, quartz and calcite.

The composition of the ore is shown in the following table[1]:—

	I.	II.	III.
Copper	4·56	4·08	4·50
Iron	11·91	10·49	12·50
Zinc	6·60	7·36	7·00
Silica	13·50	13·48	12·50
Alumina	3·95	7·01	
Baryta	37·30	37·63	38·00
Lime	2·20	2·04	
Magnesia	trace	trace	
Sulphur	16·62	15·65	
Total	96·67	97·74	
Silver, oz. per ton	2·87	2·67	2·80
Gold, " "	0·14	0·13	

I. Average of analyses made by the company.
II. Average composition of the ore mined in 1905.
III. Average of 150,000 tons shipped up to the middle of 1905.

Character of deposit: relations to country rock.—Mr. Weed[2] describes the deposit as follows: 'The ore-body is a large but

[1] W. H. Weed. Notes on the Tyee copper mine. Eng. & Min. Journ., Jan. 25, 1908, p. 200.
[2] W. H. Weed. Notes on the Tyee copper mine. Eng. & Min. Journ., Jan. 25, 1908, p. 200.

irregular lens with a proved length of 2,800 feet, a mean width of 20 feet, and a depth of 150 feet. It is 40 to 50 feet wide in many places. In the Lenora and Tyee mines, where its limits are known, it contains in all over 300,000 tons of ore. Extensive cross-cutting, drifting and diamond drilling from the various levels of a shaft 1,200 feet deep show that the ore-body does not go down, but that the shear zone, with its peculiar barytic impregnation, extends through the folds, showing patches of low grade copper-bearing rock at one or two points in other and lower saddles.'

This lens has been developed in a closed syncline, striking about N 90° W, the north leg being the steeper, of graphitic, quartz-talc and quartzose schists in chloritic schists of the Sicker series. The syncline is about 100 yards wide, and can be traced along its axis for 2 miles. It widens toward the west and therefore apparently pitches in that direction.

The trough of schists is delimited on both sides by gabbro diorite porphyrite dykes. The southern wall is a very persistent strike fault. This fault is of post-mineral development, since it has broken and slightly displaced the lens of ore.

The main lens is located on the southern side of the trough adjacent to the talcose and graphitic schists. Another smaller body 'of low and very irregular grade' occurs along the northern side.

About 100 feet to the north of the main deposit is the vein mentioned above[2] of quartz and dolomite, carrying chalcopyrite.

The schistose zone or syncline is very generally impregnated with chalcopyrite and other sulphides. This is also true of a large number of other shear zones throughout the entire extent of the Sicker series.[1]

Weed states that in some places the copper content of the impregnated shear zones reaches 0.5 to 1 per cent. No other distinct lenses of the ore are known.

Genesis.—Mr. Weed's conclusion as to the origin of the ore-body is as follows: 'The Tyee ore-body resembles in features and occurrence the lenticular bodies of iron ore of the Lake Superior ranges, the origin of which has been so clearly disclosed by Van Hise, Leith, and others. The hypothesis that the copper is a concentration

[1] R. Musgrave. Copper Deposits of Mt. Sicker. Eng. & Min. Journ. Vol. 78, pp. 673-674, 1904.
[2] See page 171.

by shallow ground-water circulations of material extracted from sparsely disseminated particles of chalcopyrite and pyrite of the schists, liberated during gradual erosion of the country, gathered in shear zone cracks or trunk channels and precipitated by graphitic matter with coincident replacement of crushed material, appears at first sight to be an adequate explanation for this and many other deposits. The chief objection to this, and apparently an insuperable one, is the fact that the Tyee deposit consists largely of barium sulphate, while the surrounding rocks are entirely free from it: showing that lateral moving waters have not furnished the ore. It is, therefore, evident that we must look to deep-seated waters as the source of the ore in this deposit.'

The general impregnation of the schist with chalcopyrite and pyrite has certainly taken place during the metamorphism and alteration of the country rock. The alteration has been shown[1] to be due largely to contact and thermal agencies, which were active during the intrusion of the gabbro-diorite porphyrites. After the field examination the writer felt that 'shallow ground-water circulations' concentrating the material of the shear zone deposits was a sufficient explanation of the origin of the ore lens. The presence of barite is not a conclusive argument that the deposit was formed by deep-seated waters, since its absence in the surrounding rock might be explained by the thoroughness of the leaching. W. H. Emmons lists it as being characteristic of deposits of moderate depth,[2] and the chief barite deposits of the United States, which are those of the Mississippi valley, are commonly conceded by most geologists to have been formed by circulating meteoric waters at moderate or shallow depths. Furthermore, cases are known in Tennessee and Nova Scotia where barite is the product of surface decomposition. The presence of talcose schists, which were mapped by Mr. Livingston, the late manager of the Tyee Copper Company, as being the immediately adjacent country rock to the ore lens, also favours the hypothesis that it was formed at shallow depths, since talc is commonly, though not always, formed by surface weathering. The shallow depth to which the ore extends also favours this conclusion.

But what appears an insurmountable obstacle to the acceptance of the hypothesis of concentration by shallow circulating waters, is

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[1] See page 85.

[2] Genetic Classification of Minerals. Economic Geology, Vol. III, 1908, p. 618.

the massive character of the ore, the minerals of which have apparently formed more or less contemporaneously, crystallizing out of the solution in a definite order. The presence of pyrrhotite and albite, minerals characteristic of deposits formed in the deep zone, also argues strongly against the hypothesis. It seems, therefore, to the writer that it is very possible that the deposit was formed by deep-seated waters.

The shape of the ore-body is of great interest. It is suggested by Mr. Musgrave[1] that the ore was deposited in a pre-existing cavity formed by the dislocating forces which caused the intrusion of the gabbro-diorite porphyrite (diabase) dykes. He also states that metasomatism may have taken place to a small extent, but that no evidence has been noted. A definite amount of metasomatic replacement is seen in the shear zone deposits. The study made by the writer of the Tyee deposit has been under such unsatisfactory conditions that it would be very inadvisable to dispute Mr. Musgrave's statement. However, the banded character of the massive ore is perhaps explained in some degree by the replacement of an original banded rock.

If the hypothesis of concentration by shallow circulation be accepted, the graphitic schist offers a very convenient precipitating agent for the ore minerals. If the other hypothesis is granted, there is no need to search for a precipitating agent, since the change in physical conditions is sufficient to explain the deposition of the minerals.

General status and future possibilities.—At present the Tyee ore-body is apparently worked out. The very thorough prospecting of the Tyee Company virtually precludes the finding of any other lens in the trough in which the Tyee body is located. Possibly similar lenses occur in the Sicker series. The location of these bodies from the surface exposures is almost impossible. If it had not been for a happy accident, the Tyee ore-body might have remained undiscovered for a long time. Prospecting is also greatly hampered by the thick layer of drift and by the heavy forest. The only suggestion that can be given to aid the prospector is that he should pay special attention to the tight, infolded synclines of schists.

[1] R. Musgrave. Copper Deposits of Mt. Sicker. Eng. & Min. Journ., Vol. 78, p. 674, 1904

Description of mines and prospects.—Since the description of the only important mines is so bound up with the description already given of their deposits, and as the history and development of the district has been quite fully dealt with in several papers in various magazines and in the reports of the Minister of Mines of British Columbia, a further description need not be given here.

Production.—The production of the Tyee mine to April 30, 1907, after which time but little ore was shipped, is given[1] as 166,000 tons of ore carrying 11,715,336 pounds of copper, 115,116 ounces of silver, and about 26,000 ounces of gold. The production from the Lenora mine is estimated[2] as 80,000 tons of ore averaging 1.77 per cent copper; 3.28 ounces silver; and 0.188 ounces gold per ton. The production from the Richard III has been approximately 1,000 tons.

IRON.[3]

General character and distribution.—The iron ore deposits of southern Vancouver island are of four types, contact deposits, impregnated schists, replacement or segregation deposits in gabbro, and bog ore deposits. The contact deposits are most important, and will be taken up in more detail in the following sections. The other three types have little or no value as sources of iron in the near future, and may be briefly described here and then dismissed.

The only representative of the impregnated schist type examined is on Saltspring island;[4] but other deposits of the same type occur in the same belt of schist farther to the west, on the northeast slope of Mount Brenton, and probably elsewhere. The deposit on Saltspring island is developed in the Sicker schists, on the northwest slope of Mount Sullivan, opposite Sansum narrows, at an elevation of about 825 feet above sea-level. The unmineralized schists in the immediate neighbourhood of the deposit are quartz-chlorite and quartz-biotite schists, and have been intruded by large masses of gabbro-diorite porphyrite. The impregnated zone is about 100 feet wide and in places the ordinary schists have been converted into a

[1] Rept. on Mining and Metallurgical Industries of Canada. 1907-8 Dept. of Mines. Mines branch, p. 171.

[2] Ibid. p. 173.

[3] The iron deposits of Vancouver island are excellently treated by Mr. Einar Lindeman from a commercial rather than geological view point in a report published by the Department of Mines, Mines Branch, Publication No. 47, 1910, 29 p. with 5 maps, two of them magnetic surveys.

[4] The examination was made by Mr. J. A. Allan.

dark red, jaspery schist, consisting of very fine grains of quartz irregularly intergrown, of an average diameter of about 0·05 mm., with 10 to 15 per cent of magnetite, which occurs in small grains, rarely over 0·02 mm. in diameter. The magnetite is arranged in roughly parallel streaks and lens-like masses, with a few large grains, with crystal outlines, 0·1 mm. 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 in width, parallel to the schistosity, but sending tiny apophyses out into the jaspery schist. Quartz veinlets occur and appear to be later than the magnetite. Metallic sulphides are virtually absent. The deposit has apparently been formed by solutions of quartz and magnetite, derived from the neighbouring gabbro-diorite porphyrite intrusion, impregnating the schist and to a certain extent replacing it. The deposit is exposed in an open cut 75 feet long. The ore is of good grade in places, and much of the richer portions of the impregnated schist could be readily concentrated to a high grade product. It does not seem, however, that the deposit on Saltspring island is large enough to warrant an attempt at mining. Similar but larger deposits may occur elsewhere in the Sicker schists, so that the type is of great prospective value.

The replacement or segregation deposits which occur in the Sooke gabbro, and which consist of massive pyrrhotite, magnetite, pyrite, and chalcopyrite, with very little gangue, have been exploited as sources of iron ore. The only known examples of this type in southern Vancouver island occur on the East Sooke peninsula, and have been described already under the Sooke type of copper deposits.[1] The chief metallic mineral of these deposits is pyrrhotite, and although magnetite is present in considerable quantity, it could be concentrated only at a large expense, so that the deposits are unlikely sources of iron ore.

In the Sooke district, in the vicinity of Demaniel river occurs a deposit of yellow ochreous clay,[2] which is similar to the bog ore deposits occurring north of the West arm of Quatsino sound in the northern part of Vancouver island. In the Sooke deposit, the bog ore, limonite, is mixed with a large amount of clay, so that the iron content is only 15·5 per cent, which is too low grade for an iron ore.

[1] See pages 176-177.
[2] Described in more detail under Pigments. See page 198.
[3] See E. Lindeman. Publication No. 47, Mines Branch, 1910, pp. 17-18.

Contact deposits.—General character and distribution. Many of the southern Vancouver island contact deposits, that is, those deposits developed near the contact of granitic rocks with the invaded country rocks, usually limestone, contain notable amounts of magnetite; while the other metallic minerals, pyrrhotite, pyrite, and chalcopyrite, which are usually present, occur only in relatively small amounts. These deposits are, therefore of much more value as sources of iron than of copper. In all of the contact deposits of the southern part of the island, with the exception of the type developed in the higher zones of the contact metamorphosed limestones of the Sutton formation of the Vancouver group, magnetite is one of the principal metallic minerals. However, the deposits, in so far as they have been examined in southern Vancouver island, which occur in the Sutton limestones near the contact with the intrusive rocks, such as those on Mount Malahat, contain large amounts of pyrrhotite, are irregular in shape and of relatively small extent. They are not, therefore, probable sources of iron ore. Lindeman,[1] however, describes a fairly large deposit on the Darby and Joan mineral claims, situated a quarter of a mile from the east shore of Alberni canal, opposite the mouth of Nahmint river, which apparently occurs in one of the Sutton limestone lenses near an intrusive granodiorite contact, and which is composed chiefly of magnetite. The analysis of an average sample of the ore dump is given as:

Insoluble matter.	25.95	per cent.
Iron.	50.96	"
Phosphorus.	0.014	"
Sulphur.	0.083	"

In the central and northern parts of Vancouver island, large ore bodies also occur in the Sutton limestones, intercalated with volcanic rocks, such as those at Head bay, Nootka sound.

In the southern part of Vancouver island the largest bodies of magnetite occur in the Nitinat limestones; and the following discussion applies to these bodies rather than to those developed in the Sutton limestones, which have been described already under copper deposits.[2] The deposits of the Nitinat formation occur in the contact metamorphosed limestones at the contacts with intrusive

[1] Publication No. 47, Mines Branch, 1910 p. 11.
[2] See pages 158-170.

plutonic rocks, diorite always being the contacting phase of the eruptive bodies. The largest and best known deposits occur in the vicinity of Gordon river and its tributary, Bugaboo creek, which empties from the west into the main river, about 6 miles above the mouth; and also near Sarita river, a mile from the mouth of the river and a quarter of a mile to the south. These deposits have not been opened up to any great extent, but are apparently of good size and the ore is of fair grade.

Mineralogy.—The only ore mineral is magnetite, which is massive to finely granular. Closely associated with the magnetite occurs pyrrhotite, pyrite, and chalcopyrite. Pyrrhotite occurs as small, irregular grains interstitial to the magnetite, and as small stringers. The magnetite and pyrrhotite are commonly cut by veinlets of pyrite, with which is associated a little pyrrhotite and chalcopyrite. The veinlets sometimes occur in shear planes in the more massive magnetite and pyrite. Pyrite and chalcopyrite rarely occur as disseminated grains. Included grains of calcite and silicate minerals occur, and veinlets of calcite are quite frequent. The paragenesis of the above minerals appears to be fairly definite, but their respective periods of crystallization doubtless overlapped. The paragenesis is apparently, calcite and silicate minerals of the contact metamorphosed limestone, magnetite, pyrrhotite, pyrite, veinlets of pyrite, pyrrhotite and chalcopyrite, and veinlets of calcite. With the exception of the small amount of included calcite and silicates, and the calcite veinlets, the deposits consist almost entirely of metallic minerals, as can be seen from the following average of the three analyses of ores from the Gordan river district given by Lindeman[1]:—

Insoluble matter	7·30	per cent.
Iron	60·85	"
Sulphur	2·55	"
Phosphorus	0·048	"

Relations to country rock.—The metallic minerals occur usually in closest association with the sheared, contact metamorphosed limestone, in which are occasional lenses of residual marble. The marble is similar to that characteristic of the Nitinat formation, and is composed essentially of calcite, in medium to coarse grains. The

[1] Publication No. 47, Mines Branch, 1910, pp. 10-11.

marbles often contain irregular veinlets of quartz, sericite, biotite, and serpentine, especially near veins of magnetite, which occasionally cut nearly pure marbles. Pyrite is usually present in the marble as disseminated grains. The marble has been metamorphosed in places to a typical 'contact rock,' similar to those described under contact copper deposits, composed essentially of massive brown garnet, the variety andradite, and small grains of green diopside. More commonly the marble has been metamorphosed even more profoundly to amphibolites, dark green, fine grained, foliated rocks, composed of hornblende and feldspar, with accessory titanite and magnetite, and secondary minerals such as sericite and limonite. In most cases the amphibolites are clearly derived from the metamorphism of limestone,[1] but in a few cases, as exposed in the gorge of Bently creek, on the Conqueror claim, the nearly pure marble is cut by narrow dykes of amphibolite, in which are traces of an original porphyritic texture. The amphibolite dykes have probably been derived by the metamorphism of andesite or basalt porphyrite dykes, which were injected into the limestones before the granitic rocks.

The contact zone is cut rather rarely by small, irregular veins of quartz. On the Iron Master's claim, one of the more westerly claims on Bugaboo creek, there is a vein of a dense, reddish brown, siliceous looking rock, seen on microscopic examination to consist of very fine grained quartz and feldspar, and shreds of brown biotite, with accessory hornblende, and secondary sericite, and disseminated grains of pyrite. The vein is apparently related to the intrusive plutonic rocks in some such manner as are the granodiorite porphyrites which are characteristic of the contacts of the plutonic rocks.

The intrusive plutonic rocks are the Saanich granodiorite and the Beale diorite, the latter invariably forming the contacting phase against the limestone, although it is brecciated by apophyses of granodiorite. The diorite in the vicinity of the deposits is as a rule richer in hornblende and poorer in quartz, and is also more sheared and altered. Near the contact the diorite passes into hornblende rich phases, fine grained, and sometimes porphyritic in texture. These phases are very commonly sheared and slickensided to such an extent as to resemble a chlorite schist, which is often in direct contact with the magnetite body.

[1] See discussion under Nitinat formation, pages 46 and 49.

The contact of the granitic rocks and marbles is virtually always marked by more or less mineralization, but the greater number of magnetite bodies are small and irregular. The more promising deposits are apparently of fair size, although in no case has enough development work has been done to fully outline one of the larger bodies of magnetite. The largest known deposit of southern Vancouver island occurs in the Baden-Powell and Little Bobs mineral claims on the south side of the valley of Bugaboo creek. It is exposed along the outcrop for about 500 feet, and its width, as shown in the upper tunnel on the claim, is about 125 feet wide.

Genesis.—As the occurrence of the magnetite bodies is restricted to the contacts of the marble and the intrusive plutonic rocks, there can be little question that they owe their origin to the contact action of the plutonic rocks on the marble. This conclusion or theory has been substantiated by observations in many parts of the world. The original limestones, to judge from the residual lenses now remaining, and from the absence of other sedimentary rocks in the Nitinat formation, were comparatively pure carbonates of lime and magnesia. Although the Nitinat marbles have been invaded by the granitic rocks to such an extent that the present masses are virtually large 'roof pendants' in the batholiths, in no case do pure marbles occur in actual contact with the plutonic rocks. They must, therefore, have been subjected to profound alteration. The magnetite bodies are usually developed in the altered or metamorphosed marble, but are occasionally in contact with the basic and schistose diorite, and more rarely with the unaltered marble. An exceptionally good contact of the magnetite with pure marble occurs on the Conqueror claim on Bently creek (see Plate 18). There the magnetite body, which forms a cliff 30 to 40 feet high over which the creek falls, is in contact with a mass of white crystalline marble, at least 100 yards in width, which occurs down stream, that is to the north. Irregular magnetite veins or apophyses extend from the magnetite body into the pure marble, brecciating it and including blocks of marble much as apophyses of an igneous rock would brecciate and include fragments of an invaded formation.

From the above evidence,[1] it is seen that the magnetite deposits of the Nitinat formation not only owe their origin to the intrusion

[1] The origin of the contact deposits is more fully discussed under the contact copper deposits, see pages 166-169.

Magnetite veins brecciating marble, Conqueror claim, Bugaboo Creek district. Scale 1 inch = ca. 1 foot

of the plutonic rocks, but, since it seems as if the original limestones were pure, the minerals of the deposit have apparently been derived from the intruding batholith. After the limestones had been more or less contact metamorphosed, as inclusions of silicates occur in the magnetite, solutions of magnetite, with small amounts of sulphides, penetrated the contact zone, and replaced it in part. The solutions were apparently very concentrated, virtually magnetite magma, since they intruded and brecciated the sheared diorite and unaltered marbles in much the same manner as rock magma intrudes and brecciates. Very large deposits of magnetite supposed to have been formed in a similar manner, that is by the intrusion of concentrated magnetite solutions or magnetite magma, occur in Norway, the famous deposits at Kiirunavaara.[1] Similar contact deposits have been recognized by several observers, and in recent classifications of ore bodies have been made a separate type of contact deposits, the magnetite type.

General status and future possibilities.—The deposits on the Gordon river and Bugaboo creek, and those to the south of Sarita river, are the only ones on which any development work has been done. The development work to date has not been large, so that it is impossible to arrive at definite conclusions in regard to the economic value of the ore bodies. The more promising of the individual deposits have been described by Lindeman, so that the description need not be repeated here. It appears that the deposits are fairly large, but that a high percentage of sulphides will always be present. The percentage is not so high, according to Lindeman, as to render the ores unfit for smelting. Doubtless other similar deposits occur in the area underlain by the Nitinat formation and the intrusive granitic rocks. The greater part of the area has not been prospected at all thoroughly. In prospecting, the bodies of pure marble may be easily recognized, the contacts of which should be prospected thoroughly. Little attention need be given to the large areas underlain by the amphibolites and granitic rocks.

SULPHUR.

The large deposits of massive sulphides in gabbro, such as those which occur at Sooke, and the contact deposits which are rich in

[1] Per Geijer, Igneous Rocks and Iron Ores of Kiirunavaara, Luossavaara, and Tuolluvaara, Economic Geology, Vol. V, 1910, pp. 699-718.

sulphide minerals, especially pyrite and pyrrhotite, similar to those of Mount Malahat, are possible sources of sulphur. These deposits consist of large irregular masses of pyrrhotite, pyrite and magnetite, with small amounts of chalcopyrite. The only gangue minerals are the primary silicates, which the sulphides have more or less completely replaced, and a little secondary quartz. These deposits have been prospected for copper and iron, although they are too low grade for the one and too high in sulphur for the other. They have been described under copper deposits in some detail and so need not be redescribed here.

These deposits are possible but not probable sources of sulphur, since the sulphur content is low, and since the deposits are relatively small, and the contact deposits irregular in form. 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 if these deposits could compete with other deposits that are richer in copper or the precious metals.

FUELS: COAL AND OIL.

Coal at present is the chief source of mineral wealth of Vancouver island. The coal mined is a high grade bituminous variety, and is obtained near the base of the Nanaimo formation of the Cowichan group. It is mined in large amounts along the east coast from the northern part of the Nanaimo basin and from the Comox basin. These deposits were not examined during the present investigation and are not considered further.

Other basins of sedimentary rocks of the Cowichan group[1] have been considered as possible sources of coal, because of the frequent indications of coal which have been found, and on account of their proximity and lithological similarity to the coal-bearing measures of the Nanaimo and Comox basins. A large part of the rocks of the Cowichan group belong to the Nanaimo formation, but an exact correlation of the coal horizon in the various basins cannot be made at present. Although the rocks are well exposed, no thick or extensive seams are known; but small lens-like seams are exposed in the southern part of the Nanaimo basin and eastern part of the Cowichan basin. They are rarely more than a foot thick, although beds of impure, sandy and shaly coal occur from 3 to 6 feet thick. Fossil

[1] See pages 124-125.

coal plants and thin seams of coaly material, seldom more than one-quarter of an inch thick, are found in the western part of the Cowichan basin and in the minor basins exposed in the upper Chemainus and Kokasilah valleys. Thin seams of coal are reported to occur also in the Alberni basin.

The coal, so far as known, occurs near the base of the Nanaimo formation. Since it is known that the rocks of the Nanaimo formation were deposited on a surface of considerable relief,[1] and that sedimentation probably first began in the down-warped area off the east coast, it seems probable that part of the area now covered with the rocks of the Nanaimo formation was above the depositional level during the period of coal formation. The Nanaimo formation and conformably overlying formations are very thick—6,000 to 10,000 feet;[2] and since the rocks of the southern part of the Nanaimo basin and of the Cowichan basin have been closely folded, the coal horizon, occurring as mentioned near the base of the Nanaimo formation, must occur chiefly at great depths. The folding and faulting increases the difficulty of prospecting, and in the southern Nanaimo and Cowichan basins is so extensive as to preclude mining. As far as known the structural relations of the Alberni basin are not unfavourable to prospecting and mining.

Considerable prospecting has been done and some attempts at mining have been made, especially in the eastern portion of the Cowichan basin, as yet without success. The probability of finding coal which could be mined profitably, in the southern Nanaimo, Cowichan, and minor basins, with the exception of the Alberni basin, is slight.

The Carmanah and Sooke formations of the west coast have also been considered as possible sources of coal and oil, and have been prospected at Sooke, Muir creek, Coal creek, and Carmanah. The only indications of coal are thin seams of lignite and lignitic sandstones, with occasional cigar-shaped lenses and cylindrical masses of lignite. The Carmanah and Sooke formations consist largely of coarse detritus which was deposited off a mountainous coast under marine conditions.[3] The conditions were, therefore, very unfavourable for the formation of coal. It seems as if the carbonaceous matter present was of drift origin, that is, composed

[1] See pages 132-133.
[2] See pages 128-129.
[3] See page 140.

of logs and other vegetable waste, which accumulated along the shores of the Tertiary ocean during the deposition of the Carmanah and Sooke formations. No thick shale horizon occurs, rich in organic matter from which oil might have been derived, and since the beds are coarse grained and porous, without impervious layers, and are not folded, the structural conditions are unfavourable for the accumulation of oil. The rocks of the formations, which in any single basin are probably not more than 500 feet thick,[1] are well exposed, and no indications of coal and oil other than those which have been described are known. The formations are also broken by numerous small faults, which, although of small displacement, would interfere greatly with mining. It is, therefore, with considerable assurance that any attempt at mining or even prospecting for coal and oil in the Carmanah and Sooke formations is discouraged.

LIME, CEMENT, AND FLUXES.

The crystalline limestones of the Nitinat and Sutton formations are among the most valuable of the mineral resources of southern Vancouver island, since they furnish excellent material for the manufacture of lime and Portland cement, and for fluxing. They are rarely of value in southern Vancouver island as a building or ornamental stone. The large deposits of pyrrhotite and magnetite such as occur at Sooke, and of magnetite, the magnetite type of contact deposits, are also available as sources of iron flux in copper smelting.

The distribution and extent of the limestones has already been given,[2] and is shown on the accompanying map. The Sutton limestones occur as relatively small lentils in the Vancouver volcanics, and the majority are of little value on account of their small size, metamorphic character, or numerous porphyrite dykes, but the larger and purer lentils furnish abundant material for the establishment of a large industry, and are at present the bases of a considerable industry in the southeastern portion of the island. The limestones of the Nitinat formation are largely altered to amphibolites, but relatively large masses of pure marble occur, such as that exposed on the west shore of Nitinat lake near the southern end.

[1] See page 139.
[2] See pages 44 and 61.

As may be seen from the lithological descriptions and chemical analyses,[1] the purer limestones are largely of excellent material for the manufacture of lime and cement, and for flux in lead and iron smelting, even when it is proposed to utilize the slag for the manufacture of slag cement. They are as a rule 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, as may be seen from the analyses, is usually very low.

The limestones of the Sutton formation are, as mentioned, quarried extensively for the manufacture of lime in the southeastern portion of Vancouver island, near the west shore of Esquimalt harbour, by the Rosebank Lime Company, Thomas Atkins, and the Silica Brick and Lime Company, and on the west shore of Saanich inlet in Malahat district by Elford and Company. Lime has been manufactured in the Highland district also, but the cost of transportation to the railway and salt water was too large for the plants to compete successfully with those more favourably located. Limestone has been quarried in the western part of the district near Alberni canal, at Smiths landing, but apparently no lime was burned. The Silica Brick and Lime Company[2] also manufactures hydrated lime and sand-lime brick, the sand being obtained from the Colwood delta.

The Vancouver Portland Cement Company, whose plant is situated on Tod inlet, in South Saanich district, is the only company manufacturing Portland cement.[3] The limestone is obtained from one of the lentils of the Sutton formation, and the clay which is mixed with the limestone is obtained from the stratified superficial deposits on the same property. The capacity of the plant is about 300,000 barrels, and during 1909, 238,000 barrels were produced, valued at about $360,000.[4]

At present none of the limestones are used as a flux. On account of their comparative freedom from phosphorus and sulphur, and their low magnesia content, they are, as mentioned, of good quality for flux in both lead and iron smelting, and could be used even when it is intended to utilize the slag to manufacture slag

[1] See pages 45 and 62-63.
[2] For a description of the plant and character of the product, see Rept. Min. of Mines, B.C., for 1907, pp. L155-L157.
[3] For a description of the plant see Rept. Min. of Mines, B.C., for 1904, pp. G256-G260.
[4] Rept. Min. of Mines, B.C., for 1909, p. K25.

cement. The larger lentils afford an abundant supply, so that any demand for limestone flux could be readily supplied.

At present none of the deposits available as an iron flux in copper smelting are mined, but the massive type of deposit occurring at Sooke[1] has been utilized to some extent. If there is ever a demand for a flux of this nature, it can be supplied from the Sooke deposits and the magnetite type of contact deposits.

PIGMENTS.

In the Sooke district there is exposed in the bed of Demaniel river, half a mile south of Young lake, a deposit of yellow ochreous clay, or impure bog iron ore. It is traceable for some distance, and has an exposed thickness of 4 feet. Mr. Dan. Campbell, who holds a claim on the deposit, states that it extends as far north as Young lake, and that he has bored through it 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 also occurs 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 the Demaniel river during times of high water, and they do not continue in depth. The material has been deposited during late Pleistocene or recent times in a bog which probably represented the second 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.[2]

There are two types of clay deposits in southern Vancouver island, the shales of the Nanaimo formation, and the clays of the

[1] See pages 176-177.

[2] The clay deposits and clay industry will be treated more fully in a report to be published shortly by the Geological Survey Branch on the clays of Western Canada, by Heinrich Ries. The clay industry is fully described by Herbert Carmichael, the Provincial Assayer, and analyses of ten glacial clays and one analysis of the Nanaimo clay shale are given in a report on the clay of the southern coast district of British Columbia, in the Report of the Minister of Mines of British Columbia for 1908, pages 182-188.

superficial deposits. The greater part of the shales of the Nanaimo formation are sandy and ferruginous, and frequently contain a high percentage of lime. They are also very commonly interbedded with thin layers of sandstone which average less than a foot apart. In the northern basins, in the vicinity of Nanaimo and Comox, there are, however, near the base of the deposit, and more or less closely associated with the coal seams, relatively thin beds of clay shale, up to 3 to 5 feet in thickness. The shale, although rather sandy, becomes fairly plastic when ground and pugged, and is moderately refractory. It is not, however, as it is often locally called, a fire-clay. Carmichael[1] gives an analysis of the shale from the Extension mine, as follows:—

Silica, SiO_2	59.4	per cent.
Alumina, Al_2O	19.7	"
Iron oxide, FeO	8.7	"
Lime, CaO	1.3	"
Magnesia, MgO	0.7	"
Water and loss	10.4	"
Fusibility	Seger cone 8, ca. 2350° F.	

These shales have been mined only by the coal companies where they occur in association with the coal. The entire product has, to the present date, been utilized by the British Columbia Pottery Company, whose plant is located in Victoria west. The shale is mixed with the clays of the superficial deposits to bring up the plasticity, and is manufactured chiefly into sewer pipe.

The clays of the superficial deposits occur chiefly in the stratified Pleistocene drift of lacustrine or estuarine origin. They usually occur near the base of these deposits and are found in beds up to 10 or 15 feet thick. The clays are chiefly sandy, but are fairly plastic. Fat blue clays also occur, especially underlying the sandy clays, and often resting directly upon glaciated rock surfaces. Disseminated through the clays are glaciated pebbles and boulders of crystalline rocks, rarely more than 2 or 3 feet in diameter. The clays are all of rather low fusibility. They are fairly uniform in character throughout the southern part of the island, and are also uniform in composition, as may be seen from the following analyses:—

[1] Herbert Carmichael, Rept. of Min. Mines, B.C. for 1908, p. 188.

TABLE No. 3

No.	Location.	Silica, SiO_2.	Alumina, Al_2O_3.	Iron Oxide, Fe_2O_3.	Lime, CaO.	Magnesia, MgO.	Alkalies Na_2O+K_2O	Water and Loss.	Fusibility, seger cone.	Specific gravity.
1	Brethour's Road, Sidney	60.0	20.8	7.6	4.6	0.7		5.4	3	
2	Sidney Brick and Tile Company's clay pits	60.2	15.5	9.4	5.3	1.5		6.8		
3	Atkin's lot, Esquimalt	63.6	19.0	7.6	3.6	0.[illegible]		6.0	3	
4	Duncan	67.6	13.6	8.8	3.6	0.2		5.6		
5	Roger creek, Alberni district	56.8	17.5	10.8	3.4	0.3		6.[illegible]		
6	Lot 7, Alberni district	57.5	22.8	9.2	4.0	0.5		[illegible].0		
7	Smiths Landing, Alberni district	57.5	20.2	9.2	7.0	3.2		2.9		
8	Vancouver Portland Cement Company's clay pits at Tod inlet, Saanich district	65.0	10.0	14.0	5	1.1	tr			2.4

Nos. 1-7 Herbert Carmichael and Herbert Carmichael Rept. Minister of Mines, B.C., for 1908, p. [illegible]
No. 8 furnished by Mr. Adolph Neu, chemist with the Vancouver Portland Cement Company.

The clays are used for the manufacture of common brick at Victoria, Sidney, Sidney island, and Somenos. At Sidney island the stiff-mud process is used, but at all the other plants the wet-mud process is used for the manufacture of the brick, although at Victoria drain-tile is moulded in an auger machine. The glacial clay is used by the Vancouver Portland Cement Company in the manufacture of Portland cement.

SAND AND GRAVEL.

Sand and gravel are quarried rather extensively from the upper portion of the Pleistocene estuarine deposits, and from the river and delta deposits; and the sand has been utilized by the Silica Brick Company in the manufacture of sand-lime brick. The largest amount of material is obtained from the Colwood delta. It is also quarried in northeast Victoria, south of Mount Tolmie in Victoria district, and on the west shore of Saanich inlet.

STONE.

The fractured and sheared character of the rocks of southern Vancouver island render most of them—with the exception of the sandstones of the Cowichan group occurring in the less folded basins—unfit for building purposes. A few of the marbles of the Nitinat formation, for example, those exposed on the west shore of Nitinat lake near the southern end, appear to be fairly free from large joints and shear zones, and although they are fractured considerably near the surface, blocks of fair size could apparently be obtained at shallow depths, and with increased depth the size and quality of the blocks would improve. As is shown by their lithological character and chemical analysis,[1] the quality of the marbles is excellent. Although the quality of the more compact, crystalline limestones or marbles of the Sutton formation is also of a fair grade, the small size of the individual deposits, their metamorphic and often greatly fractured and sheared character and the presence of porphyrite dykes, render the deposits of southern Vancouver island virtually useless. The granitic rocks are also broken not only by large joints, but by numerous irregular fractures, and are frequently sheared to a very great extent. Near the Alberni canal, to the north of Franklin river, the basic granite or granodiorite is

[1] See page [illegible]

fairly regularly jointed and comparatively free from small fractures, and moderately large and sound blocks could probably be quarried.

The sandstones of the Nanaimo basin have been quarried at Jack point near Nanaimo, near the Esquimalt and Nanaimo railway north of Cowichan station in Quamichan district, and at Maple bay, and also on Newcastle, Gabriola, and Saturna islands, and on Saltspring island at Vesuvius bay. Some of the sandstones of the more folded portions of the Nanaimo basin and of the Cowichan basin are of good grade but are more fractured. Furthermore, the steep dip of the beds makes the quarrying more difficult and causes great variation in the exposed stone.

The sandstones of the Carmanah and Sooke formations are as a rule of coarse and varying grain, very commonly concretionary, and rather greatly fractured, and are, therefore, unsuitable for building stone.

The volcanic rocks are too greatly fractured and too dark coloured to make desirable building stone, but the less altered and more basic varieties, especially the Metchosin volcanics, furnish excellent and plentiful material for crushed stone for road metal and concrete and for similar uses. The Metchosin volcanics are quarried at Albert head in Esquimalt district by the British Columbia Trap Rock Company. Crushed stone is obtained also near Victoria and within the city limits, the fine grained phases of the Wark diorite being quarried.

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DEPARTMENT OF MINES

GEOLOGICAL SURVEY BRANCH

HON. ROBERT ROGERS, MINISTER; A. P. LOW, DEPUTY MINISTER;
R. W. BROCK, DIRECTOR.

SELECTED LIST OF REPORTS AND MAPS

(SINCE 1885)

OF SPECIAL ECONOMIC INTEREST

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*972. Descriptive Catalogue of Minerals and Rocks, by R. A. A. Johnston and G. A. Young.
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941. Preliminary Geological Map of Rossland and vicinity, scale 1,600 ft. = 1 in.
987. Princeton coal basin and Copper Mountain Mining camp, scale 40 ch. = 1 in.
989. Telkwa river and vicinity, scale 2 m. = 1 in.
997. Nanaimo and New Westminster Mining division, scale 4 m. = 1 in.
1001. Special Map of Rossland. Topographical sheet. Scale 400 ft. = 1 in.
1002. Special Map of Rossland. Geological sheet. Scale 400 ft. = 1 in.
1003. Rossland Mining camp. Topographical sheet. Scale 1,200 ft. = 1 in.
1004. Rossland Mining camp. Geological sheet. Scale 1,200 ft. = 1 in.
1068. Sheep Creek Mining camp. Geological sheet. Scale 1 m. = 1 in.
1074. Sheep Creek Mining camp. Topographical sheet. Scale 1 m. = 1 in.
1095. 1A—Hedley Mining district. Topographical sheet. Scale 1,000 ft. = 1 in.
1096. 2A Hedley Mining district. Geological sheet. Scale 1,000 ft. = 1 in.
1105. 4A Golden Zone Mining camp. Scale 600 ft. = 1 in.
1106. 3A Mineral Claims on Henry creek. Scale 800 ft. = 1 in.
1123. 17A Reconnaissance geological map of southern Vancouver island. Scale 4 m. = 1 in.
1125. Hedley Mining district: Structure Sections. Scale 1,000 ft. = 1 in.
Deadwood Mining camp. Scale 400 ft. = 1 in. (Advance sheet.)
1164. 28A Portland Canal Mining district, scale 2 m. = 1 in.
Beaverdell sheet, Yale district, scale 1 m. = 1 in. (Advance sheet.)
Tulameen sheet, scale 1 m. = 1 in. (Advance sheet.)
1136. 16A Phoenix Boundary district. Geological sheet. Scale 400 ft. = 1 in.
1136. 16A Phoenix Boundary district. Geological sheet. Scale 400 ft. = 1 in.

ALBERTA.

594–596. Peace and Athabaska rivers, scale 10 m. = 1 in.
*808. Blairmore-Frank coal-fields, scale 180 ch. = 1 in.
892. Costigan coal basin, scale 40 ch. = 1 in.
929-936. Cascade coal basin. Scale 1 m. = 1 in.
963-966. Moose Mountain region. Coal Areas. Scale 2 m. = 1 in.
1010. Alberta, Saskatchewan, and Manitoba. Coal Areas. Scale 35 m. = 1 in.
1117. 5A Edmonton. (Topography). Scale ½ m. = 1 in.
1118. 6A Edmonton. (Clover Bar Coal Seam). Scale ½ m. = 1 in.
Portion of Jasper Park, scale 1 m. = 1 in. (Advance sheet.)
1132. 7A Bighorn coal-field. Scale 2 m. = 1 in.
1201. 51A Geological Map of Portions of Alberta, Saskatchewan, and Manitoba. Scale, 35 m. = 1 in.

SASKATCHEWAN.

1010. Alberta, Saskatchewan, and Manitoba. Coal Areas. Scale 35 m. = 1 in.
1201. 51A Geological Map of Portions of Alberta, Saskatchewan, and Manitoba. Scale, 35 m. = 1 in.

MANITOBA.

804. Part of Turtle mountain showing coal areas. Scale 1½ m. = 1 in.
1010. Alberta, Saskatchewan, and Manitoba. Coal Areas. Scale 35 m. = 1 in.

* Publications marked thus are out of print.

1201. 51A—Geological Map of Portions of Alberta, Saskatchewan, and Manitoba. Scale, 35 m. = 1 in.

NORTH WEST TERRITORIES.

1089. Explored routes on Albany, Severn, and Winisk rivers. Scale 8 m. = 1 in.
1099. Pelly, Ross, and Gravel rivers, Yukon and North West Territories Scale 8 m. = 1 in.

ONTARIO.

227. Lake of the Woods sheet, scale 2 m. = 1 in.
*283. Rainy Lake sheet, scale 4 m. = 1 in.
*312. Hunter Island sheet, scale 4 m. = 1 in.
343. Sudbury sheet, scale 4 m. = 1 in.
*373. Rainy River sheet, scale 2 m. = 1 in.
560. Seine River sheet, scale 4 m. = 1 in.
570. French River sheet, scale 4 m. = 1 in.
*589. Lake Shebandowan sheet, scale 4 m. = 1 in.
599. Timiskaming sheet, scale 4 m. = 1 in. (New Edition, 1907)
605. Manitoulin Island sheet, scale 4 m. = 1 in.
606. Nipissing sheet, scale 4 m. = 1 in. (New Edition, 1907).
660. Pembroke sheet, scale 4 m. = 1 in.
663. Ignace sheet, scale 4 m. = 1 in.
708. Haliburton sheet, scale 4 m. = 1 in.
720. Manitou Lake sheet, scale 4 m. = 1 in.
*750. Grenville sheet, scale 4 m. = 1 in.
770. Bancroft sheet, scale 2 m. = 1 in.
775. Sudbury district, Victoria mines, scale 1 m. = 1 in.
*789. Perth sheet, scale 4 m. = 1 in.
820. Sudbury district, Sudbury, scale 1 m. = 1 in.
824 825. Sudbury district, Copper Cliff mines, scale 400 ft. = 1 in.
852. Northeast Arm of Vermilion Iron ranges, Timagami, scale 40 ch. = 1 in.
864. Sudbury district, Elsie and Murray mines, scale 400 ft. = 1 in.
903. Ottawa and Cornwall sheet, scale 4 m. = 1 in.
944. Preliminary Map of Timagami and Rabbit lakes, scale 1 m. = 1 in
964. Geological Map of parts of Algoma and Thunder bay, scale 8 m. = 1 in.
1023. Corundum Bearing Rocks. Central Ontario. Scale 17½ m. = 1 in.
1076. Gowganda Mining Division, scale 1 m. = 1 in.
1090. Lake Nipigon, Thunder Bay district, scale 4 m. = 1 in.

QUEBEC.

*251. Sherbrooke sheet, Eastern Townships Map, scale 4 m. = 1 in.
287. Thetford and Coleraine Asbestos district, scale 40 ch. = 1 in.
375. Quebec sheet, Eastern Townships Map, scale 4 m. = 1 in.
*571. Montreal sheet, Eastern Townships Map, scale 4 m. = 1 in.
*665. Three Rivers sheet, Eastern Townships Map, scale 4 m. = 1 in.
667. Gold Areas in southeastern part, scale 8 m. = 1 in.
*668. Graphite district in Labelle county, scale 40 ch. = 1 in.
918. Chibougamau region, scale 4 m. = 1 in.
976. The Older Copper-bearing Rocks of the Eastern Townships, scale 8 m. = 1 in.
1007. Lake Timiskaming region, scale 2 m. = 1 in.
1029. Lake Megantic and vicinity, scale 2 m. = 1 in.
1066. Lake Timiskaming region. Scale 1 m. = 1 in.
1142. 12A—Vicinity of the National Transcontinental railway, Abitibi district, scale 4 m. = 1 in.
1151. 23A—Thetford-Black Lake Mining district, scale 1 m. = 1 in.
Larder lake and Opasatika lake, scale 2 m. = 1 in. (Advance sheet.)
Danville Mining district, scale 1 m. = 1 in. (Advance sheet.)

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NEW BRUNSWICK.

*675. Map of Principal Mineral Occurrences. Scale 10 m. = 1 in.
969. Map of Principal Mineral Localities. Scale 16 m. = 1 in.
1155. 24A Millstream Iron deposits, N.B., scale 400 ft. = 1 in.
1156. 25A—Nipisiguit Iron deposits, N.B., scale 400 ft. = 1 in.

NOVA SCOTIA.

*812. Preliminary Map of Springhill coal-field, scale 50 ch. = 1 in.
833. Pictou coal-field, scale 25 ch. = 1 in.
897. Preliminary Geological Plan of Nictaux and Torbrook Iron district, scale 25 ch. = 1 in.
927. General Map of Province showing gold districts, scale 12 m. 1 in.
937. Leipsigate Gold district, scale 500 ft. = 1 in.
945. Harrigan Gold district, scale 400 ft. = 1 in.
995. Malaga Gold district, scale 250 ft. = 1 in.
1012. Brookfield Gold district, scale 250 ft. = 1 in.
1019. Halifax Geological sheet. No. 68. Scale 1 m. = 1 in.
1025. Waverley Geological sheet. No. 67. Scale 1 m. = 1 in.
1036. St. Margaret Bay Geological sheet. No. 71. Scale 1 [illegible] = 1 in.
1037. Windsor Geological sheet. No. 73. Scale 1 m. = 1 in.
1043. Aspotogan Geological sheet. No. 70. Scale 1 m. = 1 in.
1153. 22A—Nova Scotia, scale 12 m. = 1 in.

NOTE.—Individual Maps or Reports will be furnished free to *bona fide* Canadian applicants.

Reports and Maps may be ordered by the number prefixed to titles.

Applications should be addressed to The Director, Geological Survey, Department of Mines, Ottawa.

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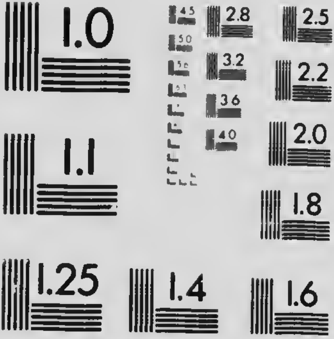
MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



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LEGEND

QUATERNARY		Q	Superficial deposits	
TERTIARY	OLIGOCENE-MIOCENE	T	Sooke and Carmanah formations *conglomerate sandstone*	
MESOZOIC	UPPER CRETACEOUS (IN PART)	K	Cowichan group *conglomerate sandstone shale with coal*	
	UPPER JURASSIC AND POSSIBLY LOWER CRETACEOUS		Anorthosite and Olivine Anorthosite	SOOKE GABBRO GROUP (AGE DOUBTFUL)
		4	Gabbro and Amphibole Gabbro, etc.	SOOKE GABBRO GROUP (AGE DOUBTFUL)
		3	Saanich Granodiorite	
			Beale Diorite	
		1	Wark Gneiss	
	JURASSIC(?)		Metchosin Volcanics *basalt, tuff etc.*	
	JURASSIC OR TRIASSIC	JT2	Sicker series *andesite flows tuff*	...UVER GROUP
	LOWER JURASSIC		Sutton formation	...UVER GROUP

GEOLOGICAL RECONNAISSANCE

Canada
Department of Mines

GEOLOGICAL SURVEY

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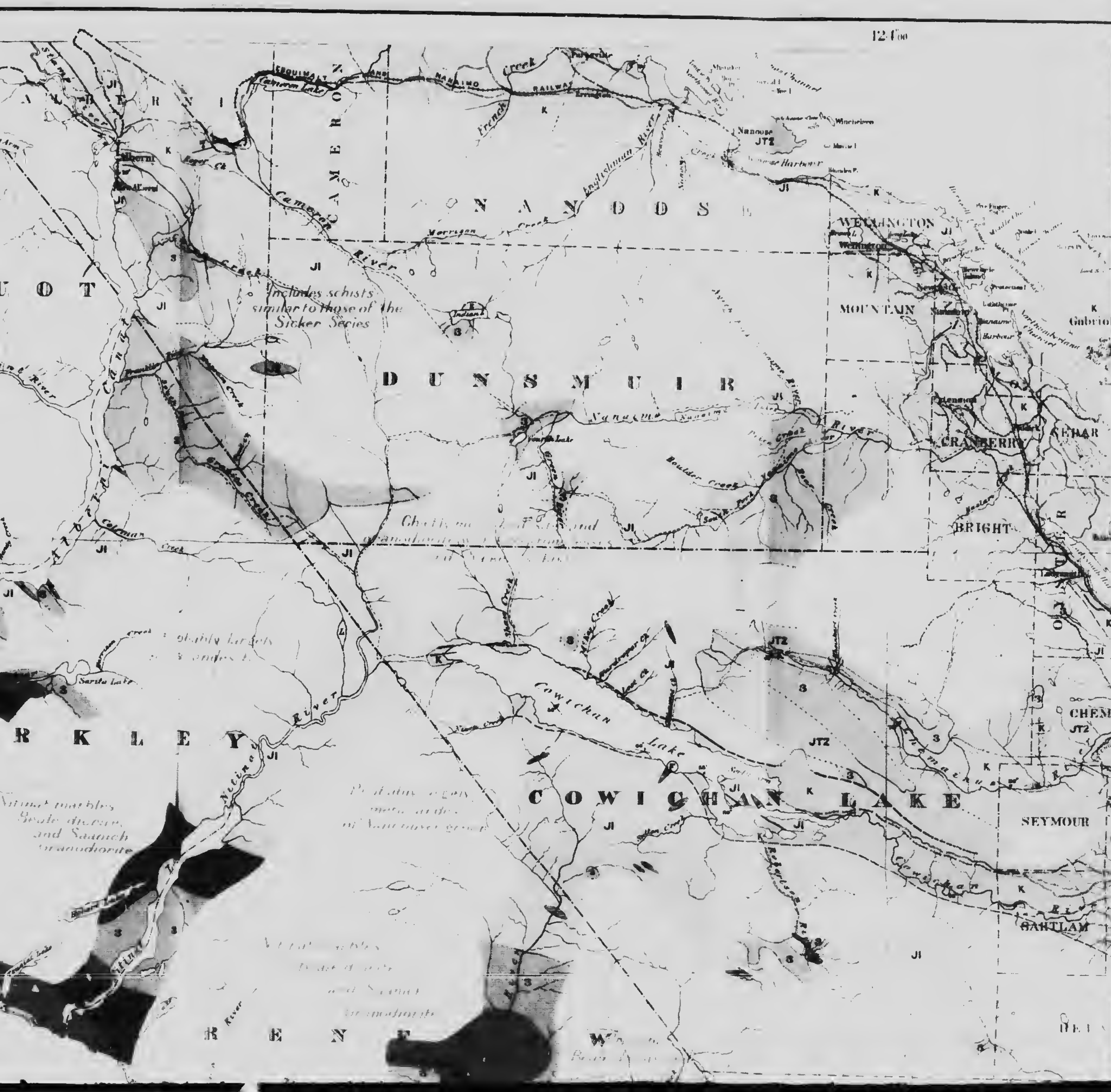
... DIRECTOR

1911



Canada
Department of Mines

GEOLOGICAL SURVEY

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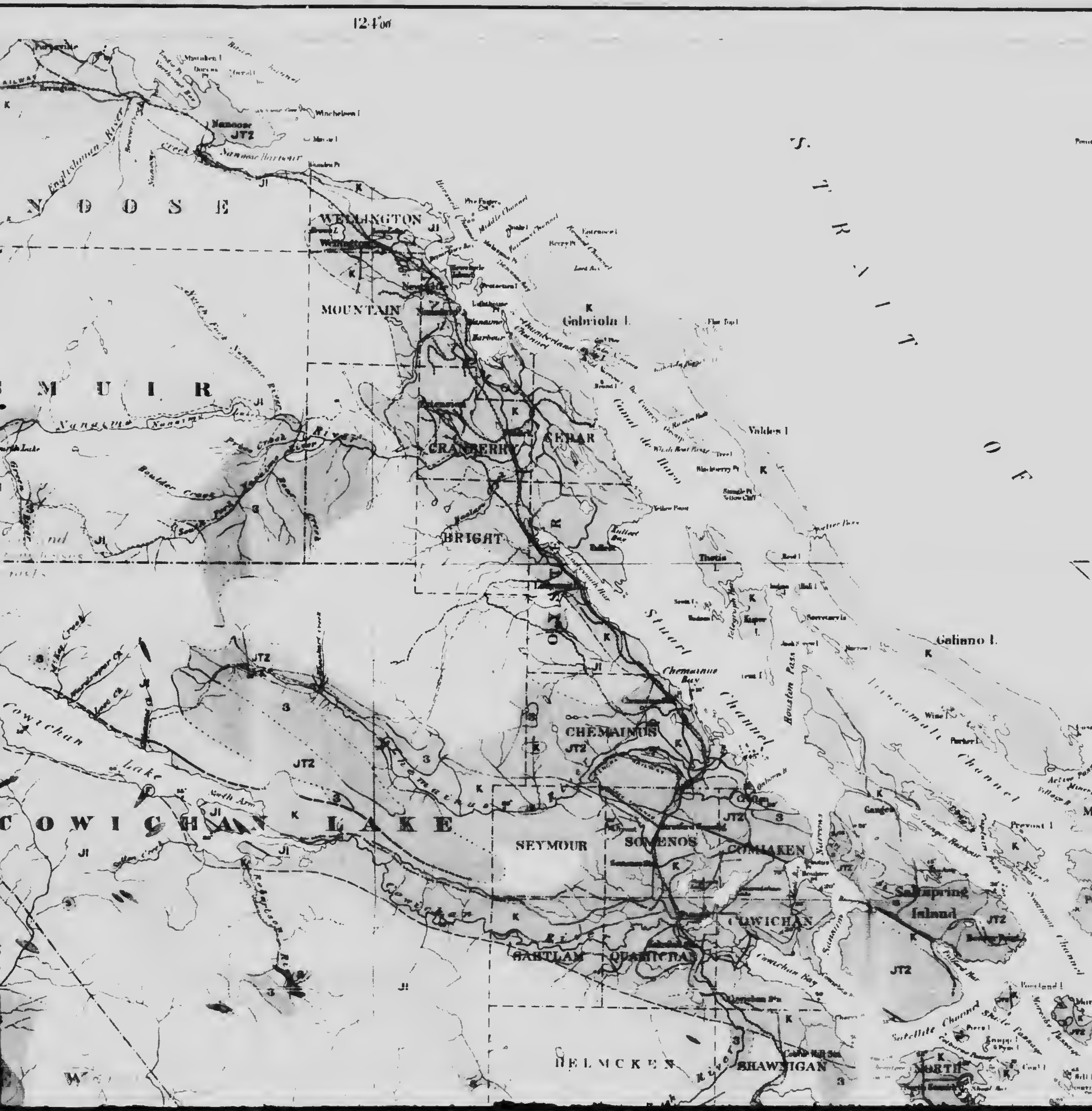
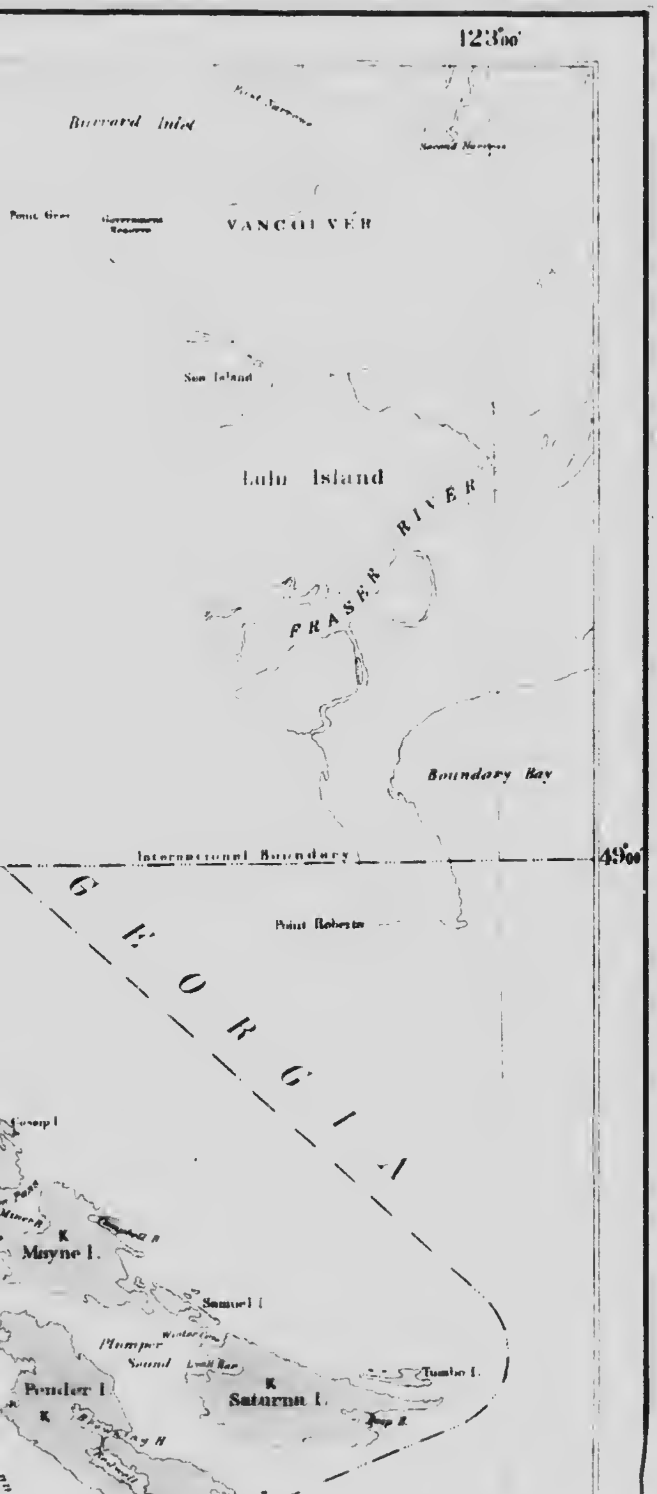
R. W. BROCK DIRECTOR

1911



BRITISH COLUMBIA



LEGEND

Symbols

Geological boundary
(position [illegible])

Geological boundary
(probable error in location less than half a mile)

Geological boundary
(probable error in location greater than half a mile)

Geological boundary
(position assumed)

Fault
(position determined)

Fault (?)
(probable error in location less than half a mile)

Fault (?)
(probable error in location greater than half a mile)

Dip and strike

Vertical strata

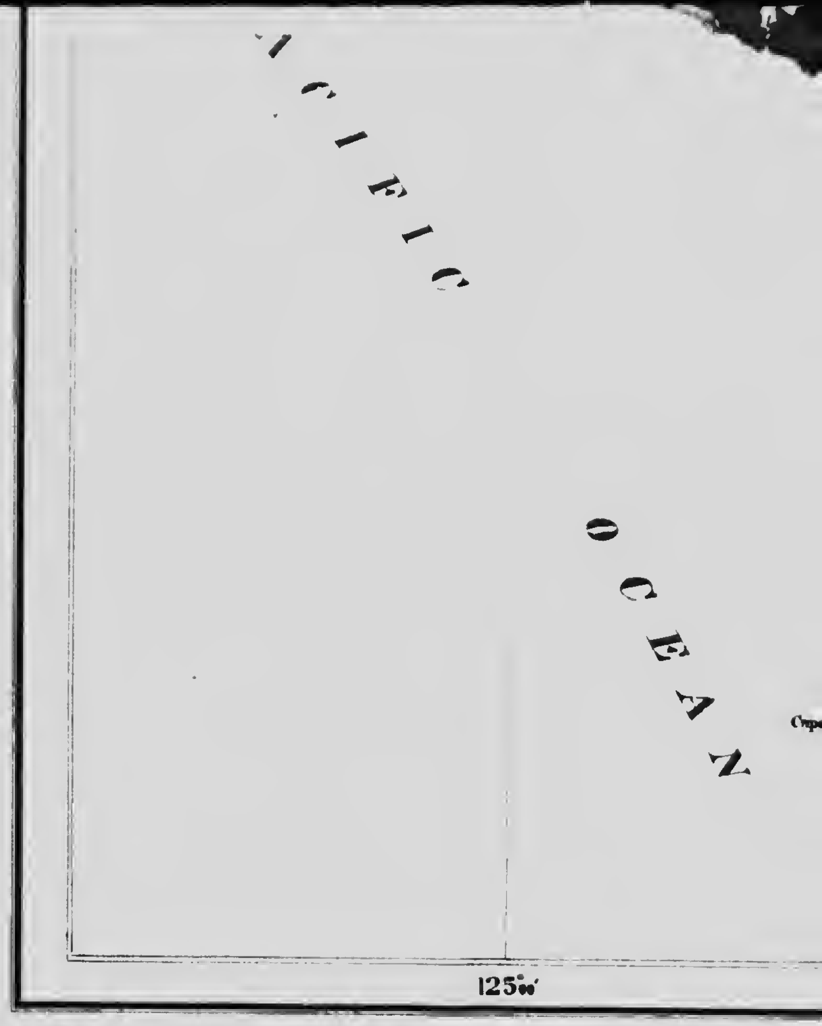
Fossil locality

Geological Notes

PALAEOZOIC

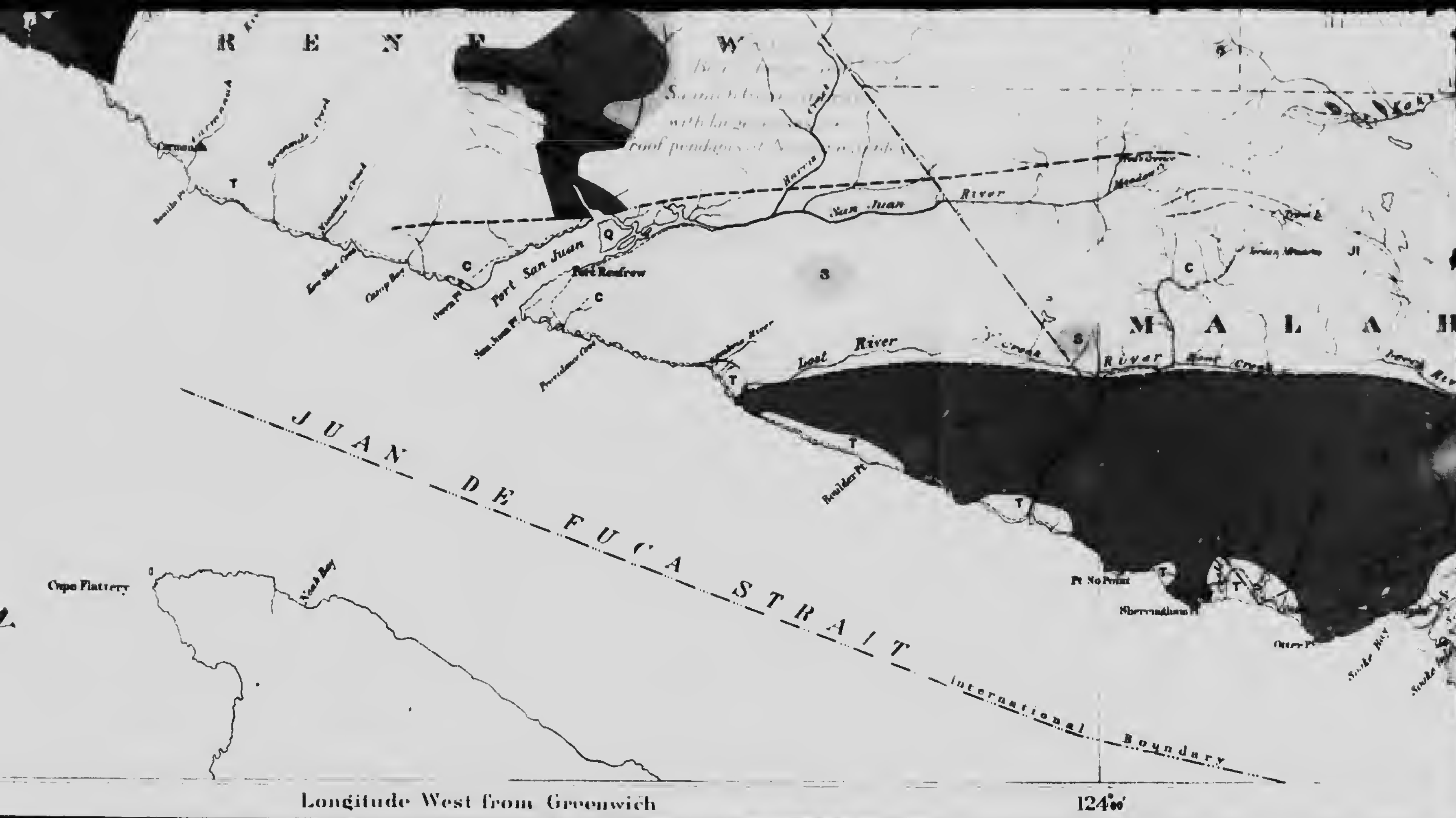
LOWER JURASSIC	J2	**Sutton formation** *crystalline limestone*
LOWER MESOZOIC POSSIBLY, IN PART, PALAEOZOIC	J1	**Vancouver Volcanics** *andesite, amygdaloid, porphyrites, tuff, etc.*
JURASSIC OR TRIASSIC ?		**Nitinat formation** *crystalline limestone*
CARBONIFEROUS ?	C	**Leech River formation** *(slate, schist, quartzite)*

VANCOUVER GR



C.O. Senécal, *Geographer and Chief Draughtsman*

GRAPHICAL BASE
ATED GRADE 3



MAP 17A

SOUTHERN VANCOUVER ISLAND

BRITISH COLUMBIA

Scale, $\frac{1}{380,160}$

Miles

Kilometres

6 MILES TO 1 INCH

MAP 17A

ERN VANCOUVER ISLAND

BRITISH COLUMBIA

Scale, $\frac{1}{380160}$

Miles

Kilometres

6 MILES TO 1 INCH

GEOLOGY

C.H. CLAPP, (IN CHARGE) 1908, 1909, 1910.
J.A. ALLAN, 1909.

TOPOGRAPHY

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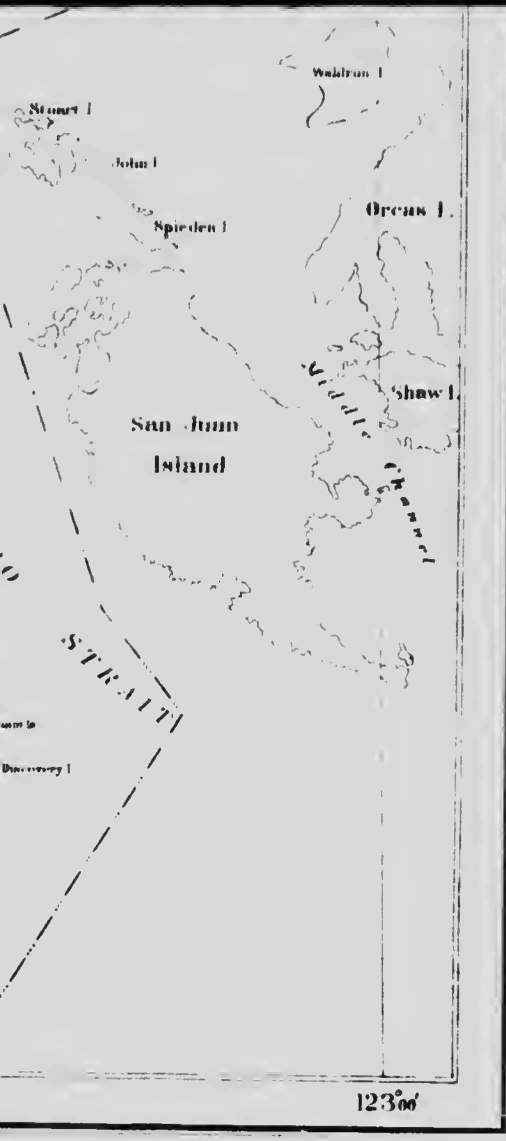

...910.

...AND UNPUBLISHED MAPS
...CHARTS
...MAP

To accompany Memoir No 1...