GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 68-50

GEOLOGY AND MINERAL DEPOSITS OF ALBERNI MAP-AREA, BRITISH COLUMBIA (92 F)

(Report, 3 figures and P.S. Map 17-1968)

J. E. Muller and D. J. T. Carson

Price, $1.50

1969
Reprinted 1970

CANADA

GEOLOGICAL SURVEY

OF CANADA

PAPER 68-50

GEOLOGY AND MINERAL DEPOSITS OF ALBERNI MAP-AREA, BRITISH COLUMBIA (92 F)

J. E. Muller and D. J. T. Carson

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Available by mail from the Queen's Printer, Ottawa

from the Geological Survey of Canada
601 Booth St., Ottawa

and

Canadian Government bookshops in
HALIFAX - 1735 Barrington Street
MONTREAL - 1182 St. Catherine Street West
OTTAWA - Corner Mackenzie and Rideau
TORONTO - 221 Yonge Street
WINNIPEG - 499 Portage Avenue
VANCOUVER - 657 Granville Street
or through your bookseller

Price: $1.50 Catalogue No. M44-68-50

Price subject to change without notice

Queen's Printer for Canada
Ottawa
1969
1970

CONTENTS

Illustrations

ABSTRACT

This paper presents the results of a geological reconnaissance of the Alberni map-area, central Vancouver Island. The Sicker Group, which includes the oldest known rocks of the region, consists of a 10,000-foot basal section dominated by greenstone and greenschist derived from pyroclastic rocks of intermediate composition. Locally, these are overlain by a few thousand feet of Pennsylvanian greywacke, argillite, and conglomerate and, at the top of the group, as much as 1,000 feet of Lower Permian limestone (Buttle Lake Formation). The group is commonly intruded by basic sills, some several hundred feet thick, perhaps related to the younger Karmutsen basalt. At the base of the overlying Vancouver Group is the Karmutsen Formation consisting of 7,000 to 20,000 feet of pillow-basalt, pillow-breccia, and basalt flows of sub-greenschist metamorphic rank. Early Upper Triassic (Upper Karnian) limestone, up to 30 feet thick, is interbedded with the lavas about 1,000 feet below the top of the formation. The immediately overlying unit is the Upper Karnian Quatsino Limestone, 500 to 2,000 feet thick and this is succeeded by the uppermost division of the group, the Bonanza Subgroup. The latter consists of a few thousand feet of Upper Triassic (Norian) and Lower Jurassic thin-bedded limestone and argillite overlain by mainly pyroclastic rocks of intermediate composition.

The Sicker and Vancouver Groups are invaded by Middle to Upper Jurassic granodiorite and quartz monzonite batholiths of the Island Intrusions that are radiometrically (K-Ar) dated at 160 m.y. The crystalline complex on the west coast contains metamorphic and migmatized rocks subdivided into the following units: diorite and agmatite; amphibolite and hornblende-plagioclase gneiss; recrystallized basic and ultrabasic rocks; and homogeneous, slightly foliated quartz diorite. The complex was probably derived from the Sicker and Vancouver Groups during the Jurassic plutonic phase. A well-marked nonconformity separates all these plutonic rocks from Upper Jurassic and later sedimentary strata.

Near Tofino on the west coast a sequence composed of argillite, greywacke, and conglomerate contains reworked material of the older rocks and is perhaps of Late Jurassic-Early Cretaceous age. The Nanaimo Group near the east coast is epieugeosynclinal and contains 6,000 feet or more of mainly marine sandstone, shale, conglomerate, and coal. of Late Cretaceous (Santonian to Maestrichtian) age. It is divisible into at least four transgressive sedimentation cycles, well-dated by ammonite and <u>Inoceramus</u> faunas. Sills and stocks of dacite porphyry and quartz diorite, dated by the K-Ar method at 35 to 60 m.y., intrude the Nanaimo Group and older rocks. Ignimbrite, tuff, and breccia southeast of Kennedy Lake are the only known volcanic rocks of probable Tertiary age in the map-area.

The oldest structures recognized are north-northwesterly trending uplifts, partly fault-bounded, that expose Sicker Group rocks; these are Buttle Lake Axis, the Cowichan-Horne Lake Axis, and the Nanoose-Texada Uplift. Facies changes and unconformities indicate uplift of these axes before Late Cretaceous, and possibly before Mesozoic time. Folding appears to be restricted to fault zones. Sicker Group rocks commonly dip steeply and in places are isoclinally folded with development of axial-plane cleavage and associated lineations. The more competent Karmutsen volcanic rocks, however, are only warped whereas Quatsino and Bonanza bedded rocks, nearly flat-lying in most places, are locally intensely folded. The folds probably developed mainly during the mid-Mesozoic orogeny and accompanying plutonism. An earlier folding, however, may have occurred between deposition of Sicker and Vancouver Groups. Tertiary movement was characterized mainly by block faulting and tilting. Northwest-striking normal faults commonly separate northeastwardly tilted blocks and

in the Nanaimo Group such faults form imbricate zones of steep faults and folds. In places these faults are offset by northeasterly trending cross-faults.

Mineral deposits of the area are divided into several classes according to characteristic host rock, related intrusions (if any), age, and mineral composition. Most prominent are massive zinc-copper-lead sulphides associated with Sicker volcanic rocks; copper and iron-bearing skarns at the contacts of granite with limestone, mainly of the Quatsino Formation; and gold-quartz veins probably related to small intrusives of Tertiary age.

GEOLOGY AND MINERAL DEPOSITS OF ALBERNI MAP-AREA, BRITISH COLUMBIA (92 F)

INTRODUCTION

LOCATION AND ACCESS

Alberni map-area (lat. 49°-50° N., long. 124°-126° W.) occupies a central part of Vancouver Island, extends from west to east coast, and includes also Denman, Hornby, Lasqueti and Texada Islands in the Strait of Georgia. A small part of the mainland coast in the northeast corner of the map-area is outside the scope of this report. On the other hand the southwest corner of the Vancouver map-area, with a part of Vancouver Island and some of the Gulf Islands was included in the area mapped and the geology of this region is shown in Figure 1.

Access by motor vehicle is good in the eastern part of the area by means of the Island Highway along the east coast, the Parksville-Alberni highway, and numerous private logging roads.

Few roads are available in the western part, an area roughly bounded by a line following Alberni Canal, Alberni Valley and thence northwesterly to Upper Campbell Lake. The west coast may be reached by the roads from Alberni to Tofino and from Campbell River to Gold River. Between these roads access by way of the large lakes and the many tidal inlets is good. Helicopter landing sites are good above timberline, at about 3,500 feet, except in some areas of serrated granitic ridges.

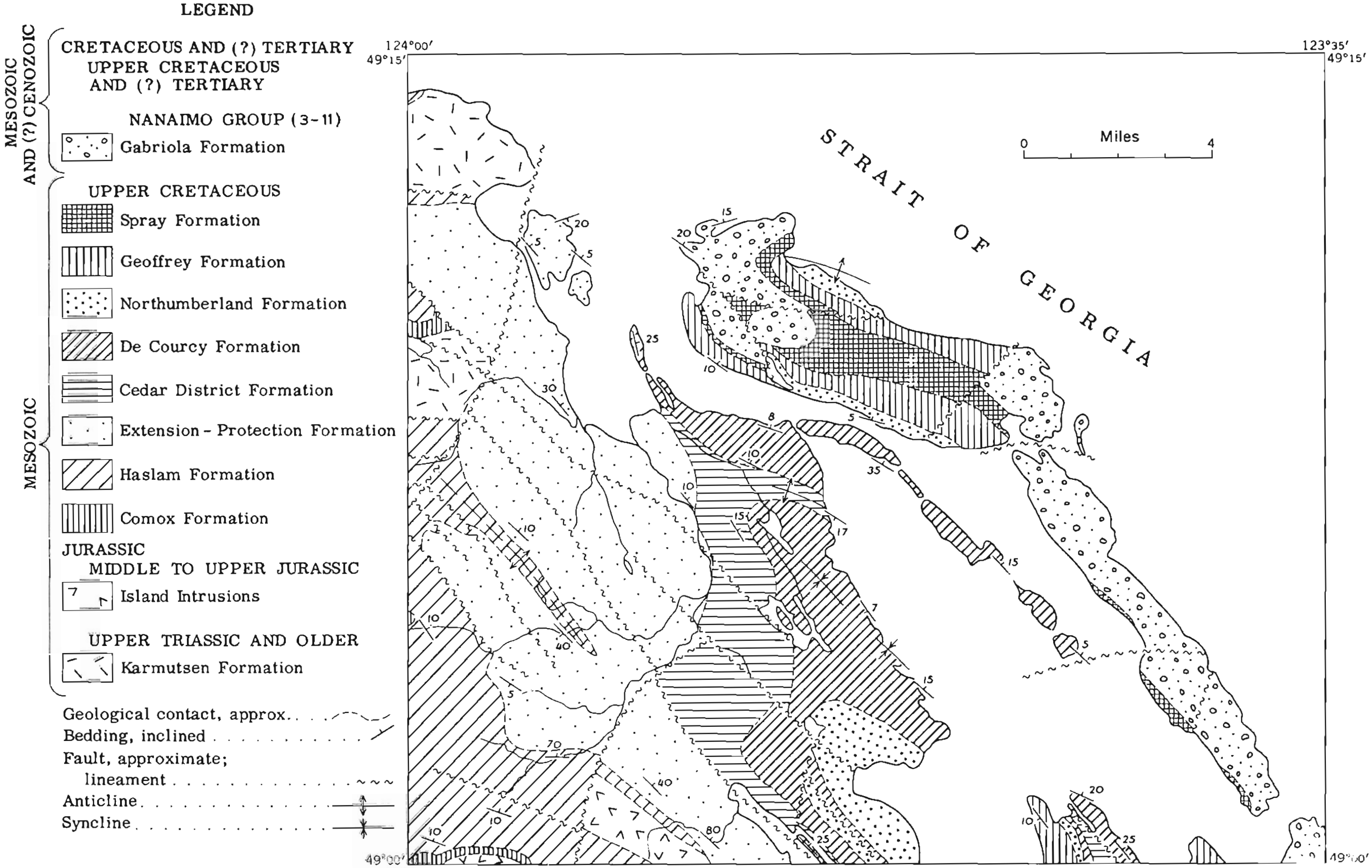
FIELDWORK AND ACKNOWLEDGMENTS

The area exhibits most of the geological units as well as important representatives of most types of mineral deposits of Vancouver Island and thus provides a good sample of the island's regional and economic geology.

A geological reconnaissance was undertaken in the summers of 1963 to 1966 and a few weeks in 1967 as the initial phase of the mapping of Vancouver Island. A special study of the Upper Cretaceous Nanaimo Group of Vancouver Island was carried out concurrently and will be reported elsewhere (Muller and Jeletzky, 1967; and in preparation).

Thanks for able assistance in the field are due to R. N. McNeely, L. G. Bryck, G. D. Bysouth and G. M. Leary in 1963; K. J. Roy, A. C. Gorveatt, B. A. McQuillan and D. J. Putt in 1964; M. E. Atchison, J. P. Chubb, and P. C. Jackson in 1965; P. C. Jackson, J. R. McLean, J. M. Carefoot, C. Dauncey, and P. Greengrass in 1966, and G. M. Dobson in 1967.

The largest part of this report was prepared by J. E. Muller, but the section on metalliferous deposits and Tables 3 and 4 are a contribution by D. J. T. Carson, hereby gratefully acknowledged by the senior author. In 1964 and 1965 Carson made a comprehensive study of the metalliferous deposits of Vancouver Island as a thesis project for Carleton University, sponsored by the Geological Survey of Canada. He was able to classify them according to mineral content, host rocks, related intrusions (if any) and age and most types of deposits are well represented in the map-area.



Refer to Map 17-1968, "Alberni", for lithologic descriptions.

Figure 1. Geology of map-sheet 92 G/4.

GSC

Of those rendering effective cooperation as helicopter pilots the late G. Fitzgerald is especially remembered. Courteous cooperation by many officials of logging and mining companies operating in the area is also gratefully acknowledged.

SUMMARY OF PHYSIOGRAPHY AND GLACIATION

The map-area lies within two major physiographic subdivisions, proposed by Holland (1964); the Coastal Trough and the Outer Mountain Area. The former is represented by the Georgia Depression, including the Strait of Georgia with Denman, Hornby, Lasqueti, Texada, and the southern Gulf Islands; and also the 'Nanaimo Lowlands' along the east coast of Vancouver Island. The Outer Mountain Area consists of the Vancouver Island Mountains, divided from east to west in the Beaufort Range, widening northward in Forbidden Plateau (at heights up to nearly 7,000 feet); the Alberni Basin; the Vancouver Island Ranges (in the map-area up to the 7,219 foot elevation of Golden Hinde); and the Estevan Coastal Plain along the west coast.

At the maximum of the last glaciation the area was nearly fully covered by ice. The sculpture of the interior mountains, ice-worn to about 5,500 feet, indicates that only peaks above that level projected above the ice as nunataks. At that stage the ice was probably continuous with the mainland cordilleran ice cap, but in the initial and final stages of glaciation a separate ice cap existed in the highest regions of the island and valley glaciers issued from it carving many U-shaped valleys.

Detailed recent studies by Fyles (1963) and Halstead in the eastern part of the map-area have revealed two glacial till-sheets, underlain, separated, and overlain by nonglacial deposits of nonmarine and marine origin.

PREVIOUS WORK

A considerable body of earlier geological work in the area is available and will be referred to in this report. The most important reports and papers containing detailed geological maps of parts of the map-area or introducing and discussing specific rock units are listed in chronological order, with reference to author, year of publication, and main topics (see bibliography for titles).

J.S. Richardson:(1872, 1873, 1878) Upper Cretaceous of Comox and Nanaimo coal basins; first reference to Carboniferous or Permian fossils.

G.M. Dawson: (1887) Northeast coast Texada and Lasqueti Islands, naming of Vancouver Group; (1890) naming of Nanaimo Group.

A. Webster: (1903) Survey of West Coast.

C.H. Clapp: (1908) Naming of "Sicker Series"; (1912, 1913, 1914, 1917). Detailed mapping of Vancouver Island east of lat. 124°, just east of area of this report, coal mines of Nanaimo area, naming of many formations of Nanaimo Group.

R.G. McConnell: (1914) Texada Island, Fe and Cu - Fe - Au - Ag - Mo deposits.

V. Dolmage: (1919) Naming of Quatsino Limestone; (1921) survey of part of west coast.

J.D. MacKenzie: (1922) Cumberland coal measures; (1923) Alberni valley area.

T. B. Williams: (1924) Comox coal basin, naming of some Nanaimo Group subdivisions.

H. C. Gunning: (1931) Buttle Lake area, Paleozoic limestone named Buttle Lake Formation; Cu - Zn - Ag deposits; (1932) naming of Karmutsen volcanics and Bonanza Group.

H. Sargent: (1940, 1941) Bedwell River area, gold-silver deposits.

J. S. Stevenson: (1945) China Creek area, Au - Ag deposits.

A. F. Buckham: (1947a, b) Nanaimo area, coal deposits.

W. H. Mathews: (1947) Limestone deposits.

J. A. Jeletzky: (1950, 1954) Mesozoic and Tertiary stratigraphy on west coast.

J. L. Usher: (1952) Nanaimo Group stratigraphy and paleontology; some new formation names.

J. T. Fyles: (1955) Cowichan Lake area.

W. A. Bell: (1957) Flora of Nanaimo Group, stratigraphic conclusions.

D. J. T. Carson: (1960) Mount Washington area, Tertiary intrusions and related Cu - Mo - Au - As mineralization.

A. McGugan: (1962) Micropaleontology and stratigraphy of Nanaimo Group.

D. Carlisle: (1963) Pillow lavas and pillow breccias of Karmutsen volcanics; (1965 with T. Susuki) Upper Triassic stratigraphy and structure.

G. E. P. Eastwood: (1963) Kennedy Lake area, Fe deposits.

J. G. Fyles: (1963) Pleistocene geology of Horne Lake area.

W. G. Jeffery: (1963, 1965) Buttle Lake area, Au - Ag - Cu - Pb - Zn deposits.

R. W. Yole: (1965) Faunas and stratigraphy of Permian limestones.

A. Sutherland Brown: (1966) Tectonics of Insular Belt.

Most of these authors are or were at the time of the investigations staff members of either the Geological Survey of Canada or the British Columbia Department of Mines and Petroleum Resources.

GENERAL GEOLOGY

by J. E. Muller

Vancouver Island is underlain by two major groups of eugeosynclinal, volcanic and sedimentary rocks that are respectively upper Paleozoic and lower Mesozoic in age. These are unconformably overlain by two major groups of clastic sediments laid down in shallow marine or continental basins, one of late Mesozoic and one of Tertiary age. The latter group also contains volcanic rocks.

Granitic rocks, formed during at least two separate plutonic events in Middle to Late Jurassic and in Tertiary time, outcrop throughout the island.

Most rock units of the island, with a few important exceptions, are represented in the map-area, and all units of the map-area are shown on the Table of Formations.

The structure is one of tilted fault blocks bounded by steep faults exhibiting at least three principal sets of trends. Strata are complexly folded and faulted along some major fault zones; elsewhere they are generally tilted at angles up to 30 degrees in Triassic and up to 10 degrees in Upper Cretaceous rocks. Even the isoclinal folding and conversion to schists of Paleozoic rocks appear to be confined to wide fault or flexure zones.

SICKER GROUP

Rocks of the Sicker Group are the oldest known on Vancouver Island. The name 'Mount Sicker Series' was introduced by C. H. Clapp (1909) for a tightly folded sequence of slate, greywacke, and conglomerate together with mainly andesitic volcanic rocks. These rocks were in part metamorphosed to chlorite schist, talc schist, and 'amphibole gneisses'. They appear to extend from Chemainus River to Alberni and were best known at Mount Sicker as the country rock of copper ores.

Fyles (1955) changed the name to 'Sicker Group' and extended the group to include limestone with Permian fossils occurring at Cowichan Lake.

The group is divided into a lower part of mainly pyroclastic rocks of intermediate composition, changed to greenstone, a middle part of greywacke, argillite and minor conglomerate, and an upper part of limestone with chert.

Lower (volcanic) part of Sicker Group

The lower, metavolcanic part of the Sicker Group is far more extensive than the upper sedimentary parts and presumably much thicker. It occurs in two separate uplifts. The larger of these is a northwest trending belt, broken by many cross-faults, and extending from Saltspring Island along the north side of Cowichan Lake to Horne Lake. The other underlies a north-northwesterly elongated area south and west of Buttle Lake. A third area of probable Sicker volcanic rocks outcrops on the west coast between Herbert Inlet and Clayoquot Arm.

In most places the thickness of the sequence cannot be determined due to intense folding. Jeffery, who examined the area west of Buttle Lake in more detail than the writer, estimated a total thickness of at least 10,000 feet, "provided there is no repetition by undetected faults".

In outcrop and hand specimen Sicker volcanic rocks are generally massive greenstones but in many places they have been converted to schists and phyllites. The massive rocks are dark green, brown or maroon, either fine and coarse breccia or laminated tuff, that weather light green, light brown, or rarely reddish brown. The angular breccia fragments, in places to one foot in size, are best seen on well-weathered surfaces, but may be invisible on a fresh surface of the same exposure.

Medium- to coarse-grained porphyritic greenstones with conspicuous black mafic phenocrysts to 1/4 inch in size and white feldspars are common as breccia fragments and also occur in many places as sills and dykes.

Thin sections commonly show aggregates of apparent pyroclastic origin with plagioclase, generally albitized or saussuritized, colourless and unaltered

TABLE OF FORMATIONS

Era	Period or Epoch	Group and formation	Map-unit	Lithology	Thickness (feet)
Cenozoic	Pleistocene and Recent		23	Till, gravel, sand, silt	
	Unconformity				
			22	Rhyolitic to dacitic tuff, breccia, ignimbrite	
	Relation unknown, perhaps coeval				
			21	Hornblende quartz diorite, quartz monzonite, porphyritic dacite, breccia	
	Relations unknown				
Mesozoic and Cenozoic	Cretaceous or Tertiary		20	Sandstone, conglomerate (may be younger than Ti, Tv)	
	Upper Cretaceous and (?) Tertiary	Nanaimo Group			6,000-8,000
		Gabriola Formation	19	Sandstone, conglomerate, shale	800-1,400
	Upper Cretaceous	Spray Formation	18	Siltstone, shale, fine sandstone	225-950
		Geoffrey Formation	17	Conglomerate, sandstone	400-700
		Northumberland Formation	16	Siltstone, shale, fine sandstone	500-1,000
		DeCourcy Formation	15	Conglomerate, sandstone	800-1,400
		Cedar District Formation	14	Shale, siltstone, fine sandstone	1,000±
		Extension-Protection	13	Sandstone, conglomerate, shale, coal	0-1,900
		Haslam Formation	12	Shale, siltstone, fine sandstone	280-1,000
		Comox Formation	11	Sandstone, shale, coal Benson member, mainly conglomerate	300-2,000
	Not known to be in contact				
Mesozoic	Upper Jurassic and/or Lower Cretaceous	'Tofino Area Greywacke Unit'	10	Greywacke, argillite, conglomerate	several thousand
	Nonconformity (also with Nanaimo Group)				
	Middle to Upper Jurassic	Island Intrusions	9	Biotite-hornblende granodiorite, quartz diorite	
	Intrusive contact				

TABLE OF FORMATIONS (continued)

Era	Period or Epoch	Group and formation	Map-unit	Lithology	Thickness (feet)
Mesozoic		Vancouver Group			
		Bonanza Subgroup			
	Lower Jurassic and Upper Triassic	Volcanic division	8	Andesitic to dacitic breccia, tuff lava; minor argillite, siltstone	1,000?
		Sedimentary division	7	Limestone and argillite, thin-bedded, carbonaceous, silty	
	Upper Triassic	Quatsino Formation	6	Limestone, mainly massive to thick-bedded, minor thin-bedded	500-2,000
	Upper Triassic and older	Karmutsen Formation	5	Pillow-basalt and pillow-breccia basaltic lava, minor tuff	7,000-19,000
	T 1 and ib may be comagmatic				
			4	Diabase, gabbro, peridotite	to 500
	Intrusive contact; unconformity with Vancouver Group				
Paleozoic		Sicker Group			
	Lower Permian	Buttle Lake Formation	3	Limestone, chert	0-1,000
		Unconformity			
	Middle Pennsylvanian		2	Argillite, greywacke, conglomerate, minor limestone	0-2,000
	Pennsylvanian and older		1	Volcanic breccia, tuff, argillite; greenschist, andesite porphyry	to 10,000?
	Um, Umi, Ui, probably metamorphosed and migmatized Sicker and Vancouver Group rocks: Uib probably metamorphosed diabase (ib)				
		'Westcoast Crystalline Complex'			
		'Basic Rocks'	D	Gabbro, peridotite	
		'Tofino Inlet Pluton'	C	Hornblende-biotite quartz diorite granodiorite	
		'Westcoast Diorites'	B	Hybrid hornblende diorite, quartz diorite, agmatite	
		'Westcoast Gneiss Complex'	A	Hornblende-plagioclase gneiss, amphibolite	

pyroxene and trachytic textured volcanic fragments. The matrix consists of chlorite, epidote, prehnite, and carbonate. Banded tuffs exhibit more or less graded layers with light plagioclase-rich and dark pyroxene-rich bands. The schistose rocks contain the same minerals with subparallel foliae of chlorite. The porphyries have phenocrysts of dark green to dark brown pleochroic hornblende containing inclusions of plagioclase. The hornblende, in part altered to chlorite and epidote, together with partly unaltered plagioclase of An_{50} to An_{60} composition, is contained in a chlorite-epidote-quartz-opaque matrix.

In the west coast area Sicker Group rocks are mainly metamorphosed tuffs and greywackes with minor argillite and thin-bedded silty limestone in the upper part of the sequence. Unlike in the areas farther east the sedimentary part of the group is not everywhere a separately mappable unit. It contains dark and light green to grey massive rocks only locally showing distinct colour banding and in many places converted to finely lineated greenschists.

Some thin sections show the clastic nature and layering of the original rocks; the light coloured layers consist mainly of actinolite fibres and sodic plagioclase, the darker layers are actinolite, epidote and opaque matter. Lighter coloured rocks contain mainly sodic plagioclase, sericite and quartz. Dykes and sills have relict ophitic or porphyritic texture and show pseudomorphs of actinolite after either pyroxene or amphibole, and plagioclase converted to saussurite, albite, or prehnite.

The grade of metamorphism of the Sicker Group in the west coast area is apparently of the low muscovite-chlorite greenschist facies. In the eastern areas where actinolite is not a common mineral, the lower zeolite or pumpellyite facies may be represented, although no distinctive minerals of that facies have yet been found.

The age of Sicker volcanic rocks is determined only by the Middle Pennsylvanian and Early Permian age of overlying sediments and may be Pennsylvanian or older. The rocks are apparently correlative with volcanic rocks of the Cache Creek Group of the British Columbia mainland and Yukon.

No fossils are known from Sicker Group rocks on the west coast. However, approximate correlation with dated Sicker rocks is confirmed on Herbert Inlet. There pillow lavas of the Karmutsen Formation overlie the Sicker Group assemblage of metavolcanic rocks, greywacke, and limestone.

Middle (clastic) part of Sicker Group

A sequence of greywacke and dark coloured, banded argillite and minor light green banded tuff overlies Sicker volcanic rocks in scattered areas and has been mapped separately in the Nanoose area, on Ballenas and Texada Islands, and in a small area east of Buttle Lake. The thickness is variable and probably nowhere more than 2,000 feet.

The beds form a typical turbidite sequence, with graded and laminated units 1/4 inch to 6 inches thick that show intraformational slumping.

In many places Buttle Lake limestone directly overlies the volcanic lower part of the Sicker Group and the middle part is missing.

Exposures on the Ballenas and adjacent islands and on Texada Island contain interbeds or lenses of clastic limestone, commonly less than 6 inches thick. On Ballenas Islands fine-grained limestone was found to contain an estimated 10 per cent of angular grains of albite, and some lenses contain brachiopod shells and fusulinids. Metamorphism of these rocks is generally confined to silicification and, in areas of strong deformation, to development of slaty cleavage. At intrusive contacts hornfels has been developed. So far as can be established the contact with the underlying volcanic rocks is gradational by a change from green and grey bedded tuffs to black and brown argillite and greywacke. The environment of deposition was a marine basin below wave-base, where turbid flows periodically introduced new layers of sediment.

The age of this sequence was established on the basis of fusulinids, determined by C.A. Ross of Western Washington State College and brachiopods, identified by E.W. Bamber:

GSC loc. 57588: Bay east of triangulation point, south shore of North Ballenas Island, lat. 49° 20'40" long. 124° 09'20"

Wedekindellina sp
Eoschubertella (?) sp

Age: middle Pennsylvanian, probably early Desmoinesian

Horn coral, unidentifiable
?*Horridonia* sp
?*Choristites soderberghi* Dunbar

Age: Pennsylvanian or Permian

Upper (carbonate) part of Sicker Group

The youngest part of the Sicker Group consists of bedded limestone, locally with chert.

The name 'Buttle Lake Group or Formation' was suggested by Gunning (1931, p. 59) for all or part of the assemblage of Paleozoic limestone and underlying sediments and volcanic rocks of the Buttle Lake area. Yole (1963, p. 142) recognized that as a group the rocks are equivalent to the Sicker Group and, as that name has priority (Clapp, 1909, p. 56) he suggested that the name Buttle Lake be restricted to the limestone. Although he refrained from officially introducing the name in his 1963 paper he will do so in a forthcoming publication (pers. comm.). The limestone formation as it occurs at Azure Lake west of Buttle Lake is the type occurrence described by Yole (1963) as formation 'B'.

Within the map-area the limestone intermittently marks the contact between Sicker volcanics and Karmutsen volcanics. North of Horne Lake and west of Buttle Lake it attains a thickness of 1,000 feet, elsewhere it is either a few hundred feet thick or missing.

The lithology, as described by Yole (1963, 1965) is dominantly medium- to coarse-grained, crinoidal, sparsely fossiliferous, light-coloured limestone. Beds are generally 6 inches to 2 feet thick and contain nodules and irregular bands of chert. The basal 10 feet at Buttle Lake consists of brown, thin-bedded, fine- to medium-grained fossiliferous calcareous greywacke and lenses with volcanic and cherty pebbles. The lower contact on volcanic rocks is sharp and gently undulating (Yole, 1965).

The relation between the middle clastic part of the Sicker Group and the Buttle Lake limestone is not fully established. One would judge that the basal greywacke of the Azure Lake section, though only 10 feet thick, could represent the middle clastic unit. The thickest sections of limestone occur on the plunging culminations of both Buttle Lake and Horne Lake uplifts, where the greywacke is thin or absent. Conversely the greywacke occurs mainly on the flanks and outside of these uplifts and is overlain by little or no limestone. Facies and age differences, somehow related to these uplifts, are indicated but their true meaning must await further detailed stratigraphic and paleontological work.

The age of the Buttle Lake Formation has been determined by Yole (1963, 1965) on the basis of a fauna consisting mainly of brachiopods and bryozoans. Foraminifera are apparently uncommon and not diagnostic of age. The faunal list of material, collected from the Azure Lake type section is reproduced here without change.

PARTIAL FAUNAL LIST BUTTLE LAKE FORMATION

Acanthocladia multipora Fritz
Clausotrypa spinosa Fritz
Fenestella basleoensis Bassler
F. parviuscula Bassler
F. cf. F. pulchradorsalis Bassler
F. cf. F. rottiensis Bassler
Goniocladia intermedia Fritz
Penniretepora grandis (Fritz)
Polypora consanguinea Bassler
P. elongata Fritz
P. cf. P. macrops Bassler
P. megastoma (Koninck)
P. sykesi (Koninck)
P. vancouverensia Fritz
Protoretepora cf. P. haimeans (Koninck)
Rhabdomeson sp.
Rhomboporea porifera Fritz
Stenopora prolifica (Fritz)
?Thamniscus unilateralis Fritz
Tetrataxis sp.
Fusulinids
Cladochonus? sp.
Caninia? sp.

Antiquitonia sulcata Cooper
Avonia ? sp.
Cleiothyridina cf. C. gerardi (Diener)
Echinoconchus inexpectatus Cooper
Horridonia sp. A
H. sp. B.

Hustedia cf. H. meekana (Shumard)
Kochiproductus n. sp.
Krotovia? sp.
Laevicamera n. sp.
Muirwoodia? sp.
Neospirifer? n. sp.
N. sp.

Rhyncopora cf. R. magna Cooper
"Spirifer" cf. S. ufensis (Tschern)
Spiriferella cf. S. saranae (de Verneuil)
Sqamularia cf. S. rostrata (Kutorga)
Parallelodon? sp.
Aviculopecten? sp.
Gastropods
Ostracods

Yole (1963, p. 143) mentions that Girty (in Gunning, 1931, p. 59), stated that the brachiopods indicate Late Pennsylvanian, rather than Permian age. But in Yole's opinion the present data suggest most probably Early Permian age.

DIABASE SILLS

The term diabase is used here to denote basic rocks occurring in dykes or sills of mainly gabbro and minor peridotite that are composed essentially of plagioclase, augite and minor magnetite and apatite, and that have a subophitic texture. Such tabular intrusions, in places 500 feet thick, are commonly exposed within the bedded rocks of the Sicker Group, especially the limestone and in limestone cliffs at Horne Lake and Buttle Lake such bodies are prominently displayed.

The rocks are fine to medium grained, and generally subophitic in texture. Plagioclase, where not altered to sericite, is labradorite. Augite appears to have been replaced partly or entirely by hornblende or actinolite, chlorite and magnetite.

The contacts of the intrusions are sharp and, though roughly parallel to enclosing strata, in places they diverge markedly from the bedding planes. No contact metamorphism has occurred beyond recrystallization and silicification of limestone within a few feet of the contact.

Although the intrusions are spatially exclusively related to the Sicker Group they are, like those described by Fyles (1955), most likely comagmatic with Karmutsen volcanic rocks.

VANCOUVER GROUP

The Vancouver Group is by far the largest major rock group of Vancouver Island. G. M. Dawson (1887, p. 103) introduced the name Vancouver Series for all volcanic and sedimentary rocks unconformably underlying the Cretaceous of Vancouver Island and the Queen Charlotte Islands. He suggested that if Triassic and Carboniferous rocks could eventually be separated the name should be retained for the former. The name 'Vancouver Group' is now well-established for all Triassic and Lower Jurassic (pre-intrusive) volcanic and sedimentary rocks of the Insular Belt. In this report the Karmutsen Formation, Quatsino Formation, and Bonanza Subgroup are included in the Vancouver Group.

Karmutsen Formation

The Karmutsen Formation is the oldest part of the Vancouver Group and is the thickest and most widespread formation of the island. The name 'Karmutsen Volcanics' was introduced by Gunning (1932, p. 234) for the volcanic rocks underlying Upper Triassic limestone of the Quatsino Formation. They are well-exposed along the Karmutsen Range just west of Nimpkish Lake.

Several other names have been introduced for the same rock group, but although some have priority on the basis of date of publication, 'Karmutsen' deserves preservation because it is well established on the north half of Vancouver Island and the Queen Charlotte Islands.

The other names omitted are: Valdes Group (Bancroft, 1913, p. 68); Texada Formation (McConnell, 1914, p. 21); Vancouver Volcanics (Clapp, 1913, p. 28; 1914, p. 36); Franklin Creek basalt (Stevenson, 1945a, p. 145; Fyles, 1955, p. 20).

Within the map-area, from east to west, the formation underlies most of Texada and Lasqueti Islands; the hills directly west of Nanaimo, a belt including Beaufort Range and continuing northward in the Forbidden Plateau; the mountains east and west of the north part of Buttle Lake; most of the area west of Alberni Canal and Alberni Valley, and smaller areas at the head of the inlets on the West Coast.

Only rough estimates of the thickness can be given. Gunning (1931, p. 61) gave a minimum of 5,000 feet west of Buttle Lake; Carlisle and Suzuki (1965, p. 452) found 7,700 feet on Quadra Island; Fyles (1955, p. 22) estimated 6,000 to 10,000 feet near Cowichan Lake. The writer (1965) calculated a thickness of 12,000 feet of pillow lavas and breccias and in addition a possible 7,000 feet of lava flows in the area west of Buttle and Upper Campbell Lakes, where the entire sequence is exposed in north-dipping successions.

Karmutsen basalt occurs in pillowed, brecciated or massive flows. The rocks are dark grey to black and weather dark reddish brown to brownish grey. They are commonly amygdaloidal and finely or, more rarely, coarsely porphyritic with single crystals or star-like clusters of white to light green feldspar in an aphanitic, dark coloured matrix.

The basal part of the formation consists of pillowed basalt, succeeded by various types of breccia. The many varieties of these intriguing volcanic rock structures as they occur on Quadra Island, just north of the map-area, have been described in detail by Carlisle (1963). Excellent examples also abound throughout the map-area. Briefly the following types are distinguished.

Pillow lava is most common in the lower part of the section. Pillows vary in shape from rough spheres, 6 inches to 1 foot in diameter, to irregular ellipsoids up to 4 feet in width and 1 foot to 2 feet high. Many pillows have chilled rims of aphanitic rock, about 1/4 to 1/2 inch thick, enveloping fine-grained, commonly porphyritic and amygdaloidal basalt. Typically the roughly tetrahedron-shaped open spaces between pillows are filled with quartz and epidote. Such quartz nests are in places the only indicators of pillow structure in otherwise massive-looking basaltic rock.

In pillow breccia, which commonly succeeded pillow lava, pillows are broken into angular fragments of diverse size, some showing parts of the original chilled rims. Carlisle (1963) distinguishes 'isolated-pillow breccias' with a few unbroken pillows between fragments and 'broken-pillow breccias' containing only broken pillows.

Pillows and breccia fragments carry white or light green plagioclase phenocrysts, singly or in clusters which in a few instances are as much as 4 mm in size. Amygdales occur throughout or are concentrated just inside the chilled rims and are filled with quartz and epidote. The matrix between breccia fragments contains finer fragmented material and green, lighter-rimmed glass globules that are detectable with the hand lens.

Thin sections of basalt from pillows and pillow fragments show plagioclase phenocrysts An_{60} to An_{85}, in part or entirely sericitized and albitized. Augite, in single or clustered equidimensional grains, is near-colourless or uralitized to green actinolitic hornblende. The matrix is brown devitrified glass, consisting of minute spherules and sheaves of a highly refractive and birefringent mineral and some microlites of plagioclase and augite. The pyroclastic matrix between pillow-fragments contains broken feldspar and augite, angular, partly devitrified shards, and flattened globules of chloritic material, quartz and carbonate.

Pillowed lavas and breccias are commonly succeeded by bedded lavas, well displayed, for instance, on Mount Flanigan, west of Upper Campbell Lake. Individual flows are clearly separated and on the average 5 to 10 feet thick. Amygdales are concentrated near the tops of flows and to a lesser extent at the bottoms. Thin sections of these rocks show ophitic assemblages of calcic plagioclase, up to An_{85}, or albite and augite, with interstitial devitrified glass and amygdales filled with quartz, carbonate, chlorite, and in many instances pumpellyite.

The metamorphism of Karmutsen rocks is evidently lower than that of Sicker rocks. They are generally massive and not to any extent converted to greenschist. However, partial albitization of plagioclase and the fairly common occurrence in amygdales of pumpellyite with quartz, carbonate and chlorite indicates the sub-greenschist pumpellyite facies of metamorphism. At granitic contacts the basaltic rocks are converted to massive dark coloured hornfels, consisting mainly of hornblende with minor plagioclase.

The basal contact of the Karmutsen is generally not exposed but is probably unconformable. West of Buttle Lake less than 50 feet of fine-grained clastic rocks intervene between Buttle Lake limestone and Karmutsen pillow lavas. On Ballenas Islands the Karmutsen lies on the Pennsylvanian greywacke-argillite sequence. There coarse volcanic conglomerate overlying jasperoid tuff and breccia underlies basal pillow lavas. Schistose greywacke and coarse conglomerate with clasts of Sicker volcanics and crinoidal limestone are also exposed on the Texada Island coast, north-west of Anderson Bay, apparently at the Sicker-Karmutsen contact. Jasperoid tuff and breccia are also common at the contact in the Nitinat-Horne Lake belt. Perhaps these red clastic rocks mark the erosional interval between the Sicker and Vancouver Groups.

The unconformity may be angular as Sicker rocks are, at least locally, highly folded whereas Karmutsen rocks occur most commonly in thick, unfolded, evenly dipping sequences. However, no visible angular unconformity has actually been found and the difference in degree of disturbance could be due to the far greater competency of the massive basaltic rocks.

The attitude of Karmutsen rocks is in many instances readily seen on mountain sides a few miles distant, but is difficult to determine in individual outcrops, especially in road-cuts and quarries for road-metal. In pillow lavas the shape and alignment of the pillows may be helpful; in the bedded lavas bottoms and tops of flows may be distinguished by concentration and alignment of amygdales or feldspar phenocrysts. In breccias the attitude is generally not detectable. The formation exhibits mainly gently tilted, broadly undulating sequences, separated by narrow fault zones of fractured rocks.

The basal succession of pillow lavas and breccias was probably the result of submarine outpouring of lava; the overlying bedded flows may have been formed when the volcanic pile had been built up above sea level.

The age of Karmutsen rocks is determined by the Early Permian age of underlying Buttle Lake Limestone and the early Late Triassic (Karnian) age of overlying Quatsino Limestone. A thin band of intervolcanic limestone, interbedded in the Karmutsen several hundred feet below the top also carries early Late Triassic fossils.

Correlatives of the Karmutsen on the mainland are parts of the Takla and Nicola Groups in British Columbia and the Mush Lake Group in southwest Yukon.

Intervolcanic Limestone Member

A sequence of limestone beds generally less than 30 feet thick, has been found in several places between lavas of the upper part of the Karmutsen Formation, but is not shown as a separate unit on the geological map. The distance from the top of the formation has not been established in any well-exposed section but is probably several hundred feet. It occurs on the west coast of Texada Island south of Favada Point and near the point at the south end of Mouat Bay (Mathews and McCammon, 1957, p. 36) and west of Upper Campbell Lake (Givens and Suzuki, 1964). It is perhaps correlative to the Open Bay limestone of Quadra Island, recently described in detail by Carlisle and Suzuki (1965)[1]. On Texada Island the limestone is lenticular, up to 10 feet thick, and irregularly bedded. The bottom part is microcrystalline and contains siliceous nodules, the top part is crinoidal. It overlies amygdaloidal porphyritic basalt on a smooth contact and is overlain by pillow lava.

Compressed ammonites, collected by the writer, were identified by E. T. Tozer.

GSC loc. 79255
49°45'25"N., 124°37'40"W. Texada Island, south of Crescent Beach

Shastites cf. aff. *S. compressus* Hyatt and Smith
Discotropites? sp.

Age: Upper Karnian, probably Dilleri Zone

---

[1] D. Carlisle (pers. comm.) believes the Open Bay Formation is equivalent to the Quatsino Formation.

GSC loc. 79257
49° 37'02" N., 124° 25'40"W. Texada Island - between Mouat and Davie Bay

Shastites sp. aff. S. compressus Hyatt and Smith
Paratropites? sp.

Age: Upper Karnian, probably Dilleri Zone

The Open Bay limestone fauna of Quadra Island and the 'interlava sediments' on the east side of Buttle Lake are according to Tozer (1967, pp. 82, 83) also clearly of the Dilleri Zone. It is apparent that in the region between Texada Island, Buttle Lake and Quadra Island deposition of carbonate shelf deposits occurred simultaneously in a short period of volcanic quiescence.

Quatsino Formation

The name Quatsino was first used by Dolmage (1919, p. 52) and later by Gunning (1932, p. 23) for the limestone formation outcropping on the east side of the southeast arm of Quatsino Sound. The formation is thickest and most prominent in northwestern Vancouver Island. In the map-area it occurs along Iron River, south of Sproat Lake, along part of the shore at the south ends of Alberni Canal and Henderson Lake and on a few mountain tops east and west of Kennedy River. The maximum thickness of the limestone is roughly 500 feet. The Marble Bay Formation of Texada Island (McConnell, 1914) is provisionally equated with the Quatsino. Mathews and McCammon (1957, p. 54) divide that formation into three members with an apparent total thickness of more than 2,000 feet. In view of possible duplication by faulting and uncertain correlation between measured partial sections, the true thickness may be somewhat less. The maximum thickness of flat-lying limestone, recently obtained in drilling by a cement company in the south part of the limestone belt is 640 feet.

The limestone is mainly massive or in beds several feet thick; in a minor part of the formation beds are a few inches thick and separated by thin shale and siltstone laminations. It is fine grained to microcrystalline with a black to dark grey fresh surface and weathers bluish grey. Many analyses of Texada Island limestone (Mathews and McCammon, 1957) show, even in 'black limestone', less than one per cent of insoluble matter, presumably mainly pyrite, clay, and silt, and only 0.1 per cent carbon. The lower part of the formation on Texada Island generally contains less than one per cent MgO, certain beds of the thick middle unit yielded up to 17 per cent MgO, and in the upper part dolomitic limestone predominates.

In many places the limestone is cut by dykes and sills of medium green hornblende-plagioclase porphyry, of andesitic to dacitic composition.

Near intrusive contacts the limestone is converted to coarsely crystalline marble and in many instances into skarn with economic magnetite and chalcopyrite deposits. The basal contact of Quatsino (and Marble Bay) limestone on Karmutsen volcanic rocks is rarely well exposed. On the northeast coast of Texada Island it is an even surface, offset by small faults.

The structure of the limestone is undisturbed over large areas, where the beds are horizontal or gently dipping. In contrast intense disturbance, commonly with isoclinal folds a few feet in amplitude, is found in faulted zones up to a mile in width and also along some intrusive contacts. Thus flat-lying limestone is exposed in the Ideal Cement quarry and at Limekiln Bay, both at the southwest side of the 'lime belt' of Texada Island, yet complexly folded limestone outcrops along the northeast coast, from Blubber Bay to Vananda Bay. In this instance the folds may be the result of fault movement between Texada Island and the mainland. Similar local differences in structure appear to be present on Vancouver Island.

Andesitic dykes, in many instances following normal faults, are common in the Quatsino Limestone and are well-exposed in Texada Island quarries. There many faults and dykes exhibit trends 10 to 20 degrees west of north and steep to vertical dips. These are offset and disturbed by a later set of faults and dykes, trending 60 to 75 degrees west. The latter dykes are commonly undisturbed, less altered, and more resistant to erosion than the earlier set.

Deposition of the Quatsino Limestone appears to have taken place on an offshore shelf that was probably some distance from the shore as indicated by the absence of volcanic debris and the rare faunas of only ammonites.

The age of the Quatsino, according to Tozer (1967), is Upper Karnian, and includes both Tropites welleri and Tropites dilleri faunal zones. Collections by the writer from south of Sproat Lake (GSC loc. 57066, 78442) include

Juvavites (Anatomites) sp.
Discotropites smithi Kutassi
Tropites sp.
Trachysagenites sp.
Halobia cf. H. superba Mojsisovics

These indicate the Welleri zone of the Upper Karnian.

The Welleri zone succeeds the Dilleri zone of the Upper Karnian stage (early Late Triassic) that characterizes the Intervolcanic Limestone Member. Within the map-area there is therefore a clear biostratigraphic distinction between the Intervolcanic Limestone and the Quatsino Limestone.

Correlative to the Quatsino is the limestone member of the Kunga Formation (Sutherland Brown, 1966, 1968). Other Welleri zone faunas cited by Tozer (1967, p. 82) from northern and interior British Columbia appear to have been collected from clastic and volcanic rocks and the overlying limestone is there generally of Norian age.

Bonanza Subgroup

The name Bonanza Group was introduced by Gunning (1932, p. 23A) for the assemblage of sedimentary and volcanic rocks exposed above the Quatsino Formation, on the upper slopes west of Bonanza Lake. He further suggested that the name be retained for the beds immediately overlying the Quatsino in the event of further subdivision of the Bonanza. Hoadley (1953) and Jeletzky (1954a) divided the group into a lower Sedimentary Division and an upper Volcanic Division. With more detailed work in the north part of Vancouver Island the Bonanza Group will no doubt be subdivided into formations, but as it is part of the Vancouver Group it should properly be called Bonanza Subgroup. For the present it will, in the sense of Gunning, include all post-Quatsino volcanic and sedimentary rocks.

Within the map-area the Bonanza caps Quatsino Limestone at the head of Museum Creek, south of Sproat Lake, and on several mountains east and west of Kennedy River. In the Quinsam-Iron River area it also overlies Quatsino Limestone. It occurs with less clearly defined stratigraphic relationships in several areas near the south edge of the map-area between Alberni Canal and Kennedy Lake.

Bonanza Sedimentary Division

Carlisle and coworkers (Surdam et al., 1963 and pers. comm.) measured on Iron River over 1,000 feet of black carbonaceous thin-bedded to fissile limestone overlying about 500 feet of grey, massive to thick-bedded limestone. They included all these rocks tentatively in the Quatsino Formation. However, for mapping purposes it is preferable to restrict the name Quatsino to the distinctive massive or thick-bedded, grey-weathering limestone and to group thin-bedded or fissile black limestone and calcareous shale with similar beds of Early Jurassic age in the Sedimentary Division of the Bonanza Subgroup. Along Iron River Bonanza sediments consist of a lower part of black thin-bedded limestone with Discophyllites, Placites and Juvavites, a middle part of black, very fissile limestone with Halobia and Monotis, and an upper part of argillite, minor limestone and tuff.

South of Sproat Lake and also at the south end of Effingham Inlet less than 100 feet of calcareous black shale containing fragments of Halobia occur between grey Quatsino Limestone and Bonanza volcanic rocks. Quatsino Limestone in the range west of Kennedy River is directly overlain by Bonanza volcanic rocks.

Halobia alaskana Smith from bedded shale overlying Quatsino Limestone of Welleri zone age (GSC loc. 57606, southeast of Two Rivers Arm of Sproat Lake) indicates according to E. T. Tozer, the Kerri Zone of the Lower Norian stage. On Iron River the section of black thin-bedded to fissile carbonaceous limestone studied by Carlisle (Surdam et al., 1963; Tozer, 1967, p. 81 and pers. comm.) yielded in succession the following fossils: 1) ?Indojuvavites suggesting Magnus zone, 2) Monotis cf. M. scutiformis pinensis Westermann indicating Columbianus zone of the Middle Norian stage, and 3) Monotis subcircularis Gabb, zone fossil of the Lower Suessi Zone of the Upper Norian.

A thin and entirely different sedimentary sequence occurs between Quatsino Limestone and Bonanza volcanic rocks on the east fork of St. Andrews Creek, south of Sproat Lake. It consists of greenish grey, brown weathering calcareous shale and greywacke containing fragments of plants and coaly material. The beds carry a pelecypod fauna of mainly Trigonia (s. lato) ex gr. costata Sowerby, indicating, according to H. Frebold and J. A. Jeletzky, Early to Middle Jurassic age. The contact relations between limestone and greywacke are not clear and could be disconformable. In the Kyuquot-Esperanza area north of the map-area, Jeletzky (1954) found the same fossil, but there the containing strata overlie Bonanza volcanic rocks. No definite correlation between the two areas can be made as yet but it may be that the volcanic rocks of Sproat Lake are younger than those occurring on the west coast.

The sparse occurrence of Bonanza sediments in the map-area conform approximately with the structure of underlying Quatsino Limestone but due to lack of competency of the thin-bedded sediments they are generally more disturbed.

The environment of deposition of these shaly limestones and calcareous shales containing ammonites and thin-shelled pelecypods, was probably rather deep water, but perhaps nearer to land than that of Quatsino Limestone.

Similar sediments of Norian age are known from the Queen Charlotte Islands (Kunga Formation), western British Columbia (Tyaughton Group, Takla Group, Sinwa Formation), northeastern British Columbia (Pardonet Formation) and Yukon (Lewes River and Mush Lake Groups).

Bonanza Volcanic Division

Volcanic rocks constitute the bulk of the Bonanza Subgroup which in the map-area probably does not exceed 1,000 feet in thickness. They are largely light coloured lava, tuff and breccia of intermediate latitic to andesitic composition. Areas containing a predominant volume of dykes of such rocks have also been mapped with the formation.

Outcrops are massive light coloured rocks that show tuff banding or breccia fragments only on some weathered surfaces. In several places it is not readily apparent in the outcrop whether the rock is intrusive, effusive, or pyroclastic. Hand specimens are light green to light brown, fine granular or aphanitic and in some phenocrysts of plagioclase and hornblende are visible. In places mafic minerals are concentrated in dark green clots that may be more than 1 inch in size.

Thin sections of flow rocks, dykes and sills show porphyritic or equigranular, commonly trachytic aggregates mainly of plagioclase of intermediate composition and minor hornblende needles, either as phenocrysts or in the matrix; a few contain augite and biotite. Tuffs are of similar mineral composition, but exhibit broken mineral and rock fragments, and pellets of devitrified glass in a very fine matrix. Many of all these rock types are altered to albite - chlorite - actinolite - epidote greenstones.

Breccias and tuffs south of Sproat Lake and in several other areas are distinguished by chocolate brown and light purple colours and are associated with coarsely amygdaloidal lavas. These rocks are generally much altered and owe their red colour to hematite and siderite. Some of the flow rocks contain large amygdales, filled with carbonate and chlorite that commonly weather out to open vesicles on the surface.

Bonanza volcanic rocks either conformably overlie Bonanza, Lower Jurassic sediments, or rest on Quatsino Limestone, perhaps disconformably. They are invaded by granodiorite but in places the contact between volcanic and intrusive rock is gradational. Conversely Jurassic granitic rocks are in some areas invaded by swarms of andesitic or more silicic dykes considered to be Bonanza volcanic rocks. In the Kyuquot-Esperanza area they are unconformably overlain by lowermost Upper Jurassic (Callovian) sediments. On the basis of these relationships their age is apparently Early to Middle Jurassic. The change from basaltic (Karmutsen) to andesitic and dacitic volcanism in this time may well be related to the onset of Jurassic plutonism.

ISLAND INTRUSIONS

Granitic intrusions are exposed along the length of Vancouver Island, and wherever their age has been established, the major batholithic bodies are Middle to early Late Jurassic in age. For this complex of granitic rocks the name 'Island Intrusions', used earlier by Eastwood (1965) is here adopted, in analogy to 'Coast Intrusions'. The latter name has been used by some authors for intrusions of Vancouver Island, but the writer suggests that its use be limited to mainland plutonic bodies.

Within the map-area the Island Intrusions have, next to the Karmutsen Formation, the greatest areal extent. They are several separate batholithic bodies: the Nanaimo batholith in the Nanaimo-Englishman River areas; the Quinsam Intrusions; the Alberni Inlet batholith east and west of that inlet; and the Bedwell batholith in the Great Central Lake – Bedwell River area. Smaller granitic bodies in the Kennedy Lake – Tofino area, though of more diverse composition, are also provisionally included.

The Nanaimo, Alberni Inlet and Bedwell rocks are mainly of granodioritic to quartz dioritic, and less commonly of quartz monzonitic composition. Thin sections exhibit quartz (15 - 40%), zoned plagioclase (An_{15} - An_{50}, 40 - 60%), green-brown pleochroic hornblende (1 - 24%) and biotite (0 - 8%). Quartz diorite carries the highest percentages of mafic minerals, including augite in a few instances; biotite is generally less abundant than hornblende. Up to 25 per cent potash feldspar is present in the quartz monzonites. In the Quinsam area this mineral, together with nuclei of micropegmatite, imparts to the rock a distinct pink colour. A large part of the Bedwell batholith is characterized by conspicuous dull grey quartz eyes on the weathered surface and a mafic mineral content of less than 5 per cent.

Contacts with Karmutsen volcanic and sedimentary rocks are generally sharp and well-defined. Steep contacts at the sides of the batholiths have in many places zones only a few feet wide of hornfelsic basalt and granitic rock with inclusions. The roof, as displayed in many peaks in the Bedwell batholith area, consists of several hundred feet of hornfelsic basalt riddled with granitic dykes and sills. Contacts with Sicker and Bonanza volcanic rocks are more commonly marked by transitional zones of gneissic rocks and migmatites, perhaps due to the similarity in composition of the volcanic and plutonic rocks. Skarn zones have developed along contacts with Quatsino Limestone, and less commonly with Buttle Lake and Bonanza carbonate sediments. Several of these carry economic deposits of magnetite and chalcopyrite. Within the map-area only Nanaimo Group sediments are known to overlie Island Intrusions nonconformably.

The age of the Island Intrusions is well defined. Within the area it is bracketed by the intrusive relationship with the Upper Triassic to Lower Jurassic Bonanza Group and the nonconformable superposition of the Upper Cretaceous Nanaimo Group. Elsewhere on Vancouver Island the time of intrusion is more closely defined between Lower Jurassic intruded rocks and Upper Jurassic superposed rocks (Jeletzky, 1954a, p. 14). Furthermore, several potassium-argon age determinations have confirmed the Jurassic age, determined by structure and stratigraphy. Within the area two samples from the north end of the Bedwell batholith, on Heber River and near Ucona River, yielded ages of 162 ± 9 m.y. and 166 ± 8 m.y. (Wanless et al., 1967) and another (Wanless et al. 1968) date from the Nanaimo batholith yielded 160 ± 8 m.y. Outside the map-area, four samples collected by D. J. T. Carson in the Zeballos and Nimpkish areas yielded ages ranging from 143 to 151 m.y. This indicates a Middle to early Late Jurassic age according to the currently accepted time scale.

WESTCOAST CRYSTALLINE COMPLEX

Crystalline rocks of the west coast and inlet areas differ markedly from those of the Island Intrusions. They range from fine-grained plagioclase amphibolite to hornblende-plagioclase gneiss, schlieren gneiss and schlieren diorite and massive faintly foliated biotite quartz diorite. These rocks have been subdivided into four map units: (1) the Westcoast Gneiss Complex, a metamorphic complex of amphibolite and hornblende-plagioclase gneiss; containing (2) the Tofino Inlet pluton, a core of hornblende quartz diorite; (3) the Westcoast Diorites, hybrid and gneissic diorite, quartz diorite, and granodiorite; and (4) the Westcoast Basic Rocks, a unit of amphibolized basic and ultrabasic rocks.

Westcoast Gneiss Complex

The name Westcoast Gneiss Complex is used provisionally for hornblende-plagioclase gneiss and amphibolite of the coastal inlet area between Kennedy Lake and Bedwell Sound. These rocks range from gneisses, exhibiting irregularly alternating light feldspathic and dark hornblendic bands or laminae, to massive amphibolites, commonly with distinct lineation. In thin section they exhibit more or less clearly foliated, commonly cataclastic to poikiloblastic textures. The following are mineral percentages of light and dark bands of the same outcrop, north of Grice Bay and minimum and maximum percentages of ten point-counts of scattered samples.

	Light band	Dark band	Maximum	Minimum
Plagioclase	44.1	49.7	66.1	21.0
K-Feldspar	0.1	0.4	3.5	0.0
Quartz	44.5	10.0	44.5	1.7
Hornblende	0.0	20.2	77.9	0.0
Biotite	1.0	0.1	7.4	0.1
Prehnite	8.9	18.2	18.2	0.0

Accessories, generally less than 1 per cent, are pyroxene, epidote, chlorite, rutile, apatite, zircon, sphene, and opaque minerals. Prehnite, abundant in several samples, occurs mainly as veinlets and clots.

The general presence of hornblende and intermediate plagioclase indicates the amphibolite facies of metamorphism. The albitization of plagioclase and the common presence of prehnite in plagioclase and biotite suggest a later phase of retrograde metamorphism to a subgreenschist facies.

The structure is highly complex and isoclinal folds with more or less pronounced fold axes and lineations are commonly detectable. The predominant trend of axes and lineations is north-northwest to north-northeast with slight northerly plunge.

Insofar as could be established contacts with low-grade metamorphic volcanic and sedimentary rocks of the ? Sicker Group and those with the Tofino Inlet pluton are gradational or faulted. This is in accordance with the probable genetic relationships of the units referred to in following sections. Contacts drawn on the geological map are rather arbitrary.

The gneiss complex may be equivalent to Clapp and Cooke's Wark gneiss of southern Vancouver Island, that according to the description (1917, p. 174) appears to be similar in composition and texture.

Tofino Inlet Pluton

The Westcoast Gneiss Complex contains a core of only slightly gneissic granitic rock extending from Clayoquot Arm to the east side of Meares Island, and named here Tofino Inlet pluton. The rocks are medium to coarse grained, light coloured, with conspicuous large biotite flakes that exhibit more or less pronounced northerly alignment parallel to the surrounding gneisses. They are quartz diorites with 40 to 70 per cent plagioclase, normally zoned from andesine to oligoclase, 20 to 52 per cent quartz, less than 5 per cent potash feldspar, 1 to 5 per cent biotite, little or no hornblende, and accessory sphene, opaque minerals, epidote, prehnite and chlorite. The contact of the pluton with surrounding metamorphic rocks of the gneiss complex is gradational but at the north end of Tofino Inlet the contact with greenstone of the ? Sicker Group appears to be sharp and truly intrusive. There a band of pink coloured fine-grained felsite, about 6 inches wide, separates granitic rock and hornfelsic sediments.

Westcoast Diorites

Dioritic rocks, commonly with irregular agmatitic or crudely gneissic texture, are the main plutonic rocks along the west coast. They are typically exposed on Effingham Inlet, Toquart Bay and southwest of Catface Range on Calmus Passage.

The rocks are similar in mineral composition to the Westcoast Gneisses but lack distinct continuous gneissic banding. Dark, well defined or ghost-like inclusions of angular, elongate or sinuous shape are present throughout this unit. Most rocks are dark coloured, medium grained hornblende diorite and quartz diorite with 40 to 65 per cent plagioclase, zoned from cores of An_{50} to nearly-pure albite rims, 15 to 45 per cent hornblende, 0 to 30 per cent quartz, and accessory biotite, sphene, apatite, epidote, chlorite, prehnite and opaque minerals. The texture is generally poikilitic with hornblende enclosing plagioclase and magnetite.

The Crystalline Complex between Toquart Bay and Kennedy Lake exhibits a greater range of rock types. They vary from light coloured quartz monzonite with 1 to 6 per cent combined hornblende and biotite via biotite-hornblende quartz diorite with 25 per cent mafic minerals to hypersthene-hornblende gabbro with 60 per cent combined mafic minerals.

Contacts with other rock units have not been observed but are inferred to be either gradational or faulted with all units up to Bonanza volcanic rocks.

Westcoast Basic Rocks

Small areas of metamorphosed gabbroic rock occur in a discontinuous belt from Kennedy Lake through the middle part of Meares Island to Cypress Bay. The rocks are similar to the darker coloured varieties of Westcoast Diorites and exhibit granitic, gneissic or granulitic textures. Thin sections of rocks from the coast and small islands of Lemmens Inlet exhibit the following mineral assemblages: hornblende-augite-hypersthene gabbro with 40 per cent zoned plagioclase (An_{80}); hornblende gabbro with all mafic minerals apparently converted to blue green to yellow green pleochroic hornblende (about 70 per cent of the rock); and a granulitic rock with a fine-grained heteromorphic assemblage of colourless plagioclase, augite, and serpentinized olivine, and large poikilitic porphyroblasts of brown hornblende including plagioclase and magnetite. A sample of light greenish grey anorthosite with a practically mono-mineralic assemblage of fractured and slightly prehnitized bytownite was collected on the southwest side of Kennedy Lake.

Origin and age of Westcoast Crystalline Complex

The derivation and age of metamorphism of the Crystalline Complex is not fully established. On the basis of apparent transition into metavolcanic and meta-sedimentary rocks that are provisionally assigned to the Sicker Group, they are considered to be mainly metamorphic equivalents of that group. Parts are probably also derived from rocks of the Vancouver Group and the Basic Rocks may well be metamorphosed equivalents of the basic sills that are common in the Sicker Group. In the absence of any datings by structural or isotopic methods one may speculate that the time of metamorphism and migmatization coincided with the emplacement of the Island Intrusions in Middle Jurassic time. The difference between the two types of crystalline rocks may be the result of greater mobilization and consequent 'homogenization' of the Island Intrusions. The latter were intruded upwards into rocks of the Vancouver Group whereas the Westcoast rocks remained at a lower level within Sicker Group rocks. The Tofino Inlet pluton may demonstrate the initial phase of movement in the Westcoast Complex. Although in general it exhibits foliation concordant with gradual transition to the enveloping gneisses, it has in places been intruded with sharp contact into non-migmatized ? Sicker Group rocks. An early phase of metamorphism may have occurred in the interval between Vancouver and Sicker Group time and the later phase of retrograde metamorphism in Tertiary time.

Sutherland Brown (1966 and in press) has described 'syntectonic batholiths' with aureoles of amphibolite and migmatite in the Queen Charlotte Islands. The 'syntectonic batholiths' would appear to be equivalent to the Westcoast Diorite. Because they are mainly surrounded by Karmutsen volcanic rocks Brown considers the amphibolites to be derived from these. There can be little doubt that as a metamorphic complex these rocks are correlative to the Westcoast Gneiss Complex, but in the latter the material was probably, in large part, derived from Sicker Group rocks.

TOFINO AREA GREYWACKE UNIT

A sequence of dark-coloured, partly conglomeratic greywacke with minor argillite occurs along the Pacific Coast and a few miles inland, from Vargas Island to the Ucluelet Peninsula south of the map-area. It is provisionally referred to as the Tofino Area Greywacke Unit.

The dark coloured, massive greywackes with indistinct bedding and incipient schistosity, have the superficial appearance of volcanic rocks. But the clastic nature is faintly visible in hand specimens; commonly they are greenish grey, fine-grained, well-indurated aggregates of chert, quartz, volcanic material, and argillaceous matter.

Angular to rounded fragments of green to grey volcanic rocks are scattered throughout or concentrated in irregular lenses, and in places granitic clasts are also common. Thin sections show assemblages of subangular grains of quartz, quartzite, plagioclase, hornblende, biotite, and epidote.

The rocks are well-indurated but unmetamorphosed and the occurrence of clastic epidote and hornblende suggests that epidote-amphibolite regional metamorphism preceded their deposition. Nor is there any albitization of the feldspars or other indication of later retrograde metamorphism. The beds are generally much disturbed and exhibit steep southwest dips. No structural relationships with other rock units could be established within the area, except that west of Tofino and on Stubbs and Felice Islands the unit is intruded by a stock of quartz monzonite of isotopically determined early Tertiary age.

Tentatively the unit may be correlated with clastic, in part conglomeratic, beds of Late Jurassic or Early Cretaceous age, recorded by Jeletzky (1950, 1954, a, b) farther north.

NANAIMO GROUP

The combined succession of Sicker and Vancouver Group rocks and the Island Intrusions are, in eastern Vancouver Island, unconformably overlain by a succession of clastic continental and marine rocks containing several economic coal seams. The geology and biostratigraphy of these rocks is treated in more detail in a report by the writer and J. A. Jeletzky (1967, and in preparation).

Due to their economic significance these beds have been studied by many geologists since 1857. The name Nanaimo Group was introduced by G. M. Dawson (1890) for the Upper Cretaceous beds of Vancouver Island.

In the map-area the group is exposed in the Nanaimo area ('Nanaimo Basin') with outliers in the upper Nanaimo River and Englishman River areas, in the Alberni Valley, in the Cumberland area ('Comox Basin'), on Denman, Hornby and Texada Islands, and in the Quinsam-Oyster River areas with outliers on Forbidden Plateau. Formations within the group have been named from time to time by various workers, as shown in Table 1. Separate sets of formational names have so far been used for the Nanaimo and Comox Basins. However, correlation between the two basins is now sufficiently established to use the same names throughout. Most of the names of the Nanaimo Group, established by Clapp in 1909 and later, have priority. A

TABLE 1. PRESENT AND EARLIER CORRELATIONS OF NANAIMO GROUP SUCCESSION IN COMOX AND NANAIMO BASINS

Richardson 1873	McKenzie Williams	Clapp 1912-1917	Buckham, 1947 Usher, 1952			McGugan, 1962 Williams-Burk, 1964			Muller - Jeletzky (this paper), 1968		
COMOX BASIN	COMOX BASIN	NANAIMO BASIN		COMOX BASIN	NANAIMO BASIN		COMOX BASIN	NANAIMO BASIN		VANCOUVER ISLAND AND GULF ISLANDS	
upper conglomerate	ST JOHN		MAESTRICHTIAN	HORNBY	GABRIOLA	MAESTRICHTIAN	HORNBY		MAES-TRICH-TIAN	GABRIOLA	
upper shales	TRIBUNE	GABRIOLA		SPRAY			SPRAY	GABRIOLA	CAMPANIAN	SPRAY	FOURTH CYCLE
middle conglomerate	HORNBY			GEOFFREY	NORTH-UMBERLAND		GEOFFREY			GEOFFREY	
							U. LAMBERT				
middle shales	LAMBERT	NORTH-UMBERLAND		LAMBERT		upper CAMPANIAN	L. LAMBERT	NORTH-UMBERLAND		NORTHUMBERLAND	THIRD CYCLE
lower conglomerate	DENMAN	DE COURCY	CAMPANIAN	DENMAN	DE COURCY		DENMAN	DE COURCY		DE COURCY	
lower shales	TRENT RIVER	CEDAR DISTRICT		TRENT RIVER	CEDAR DISTRICT		U. TRENT RIVER	CEDAR DISTRICT		CEDAR DISTRICT	SECOND CYCLE
coal-measures	COMOX	PROTECTION		COMOX	PROTECTION			PROTECTION		EXTENSION-PROTECTION	
		NEWCASTLE		QUALICUM	NEWCASTLE			NEWCASTLE			
		CRANBERRY	lower CAMPANIAN or ? SANTONIAN		CRANBERRY	CAMPANIAN TO SANTONIAN		CRANBERRY			
		EXTENSION			EXTENSION			EXTENSION			
		EAST-WELLINGTON			EAST-WELLINGTON			U. HASLAM		EAST WELLINGTON MEMBER	
		HASLAM			HASLAM		L. TRENT RIVER	L. HASLAM	SANTONIAN	HASLAM	FIRST CYCLE
		BENSON			BENSON		COMOX	BENSON		COMOX / BENSON	
							QUALICUM				

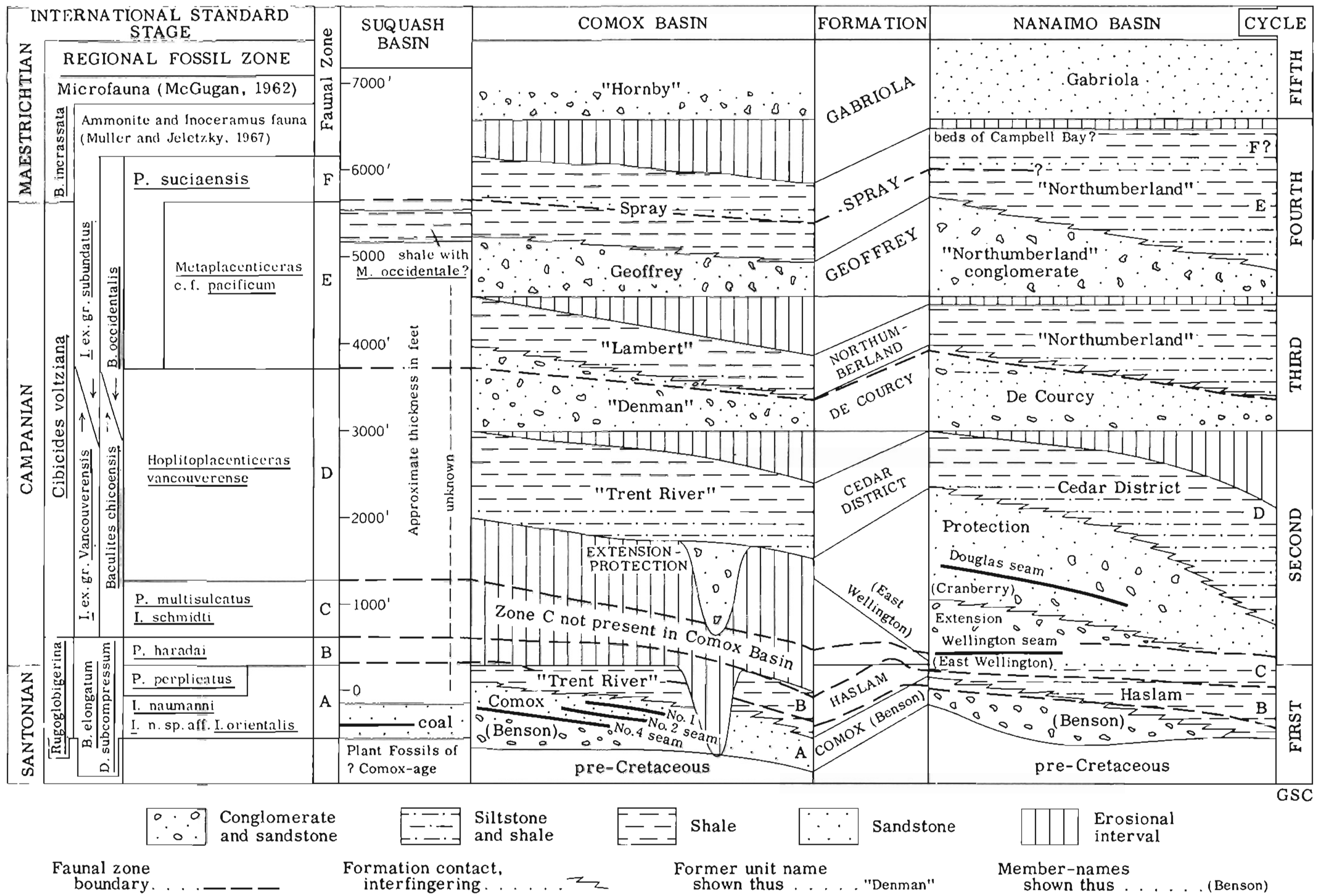


Figure 2. Biochronological and lithological subdivisions of Nanaimo Group.

correlation of the Nanaimo Group formations of the Nanaimo and Comox Basins, with newly proposed unified nomenclature, is shown on Figure 2. No complete sections are available anywhere, but the maximum thickness of the group at any point is estimated not to exceed 2,500 feet on Vancouver Island. It may reach a maximum of 6,000 feet below Hornby Island and 8,000 feet below Gabriola and other outer Gulf Islands.

The writer has distinguished four transgressive cycles, grading upward from nonmarine coarse clastic to marine fine clastic sediments and a fifth cycle with only nonmarine coarse clastics. A brief description of five main facies types will precede discussion of the successive formations.

The Benson-type facies are dark green and brown coloured, poorly bedded fanglomerates and associated greywackes occurring in irregular lenticular masses of small areal extent and extremely variable thickness. The components are unsorted subangular boulders, pebbles and grit, mainly of pre-Cretaceous volcanic material. Granitic clasts are rare even on a granitic substratum. The material has been transported over only a short distance and the deposits are probably basal conglomerates, formed along shoreline cliffs during transgression or in inshore valleys and canyons.

The Extension-type facies is another kind of coarse clastic facies where conglomerate, pebbly sandstone and arkosic sandstone are interbedded. The components are well-worn and well-sorted and consist mainly of resistant rock types like white quartz, black argillite and light green or grey chert. The sandstones are commonly crossbedded and consist mainly of quartz, feldspar, biotite and hornblende. It is suggested that the material was transported and reworked along beaches by marine currents and finally came to rest in an environment of deltas and shore bars. In several conglomerates, pebbles derived from distant sources are mixed with larger, more angular clasts, a few up to 6 feet diameter, of schist, volcanic and granitic rocks of nearby origin, and sandstone, shale and calcareous concretions from older Nanaimo Group units. The contrast between well-rounded quartz and chert and larger, subangular clasts of less resistant rocks is in many instances striking. The well-worn material was probably carried in by waves and currents along the shore, the angular boulders by local streams or by wave-erosion of seacliffs.

The Comox-type facies is a variant of the Extension-type facies. The clastic material is also quartzofeldspathic, but it generally lacks the conglomeratic phase. On the other hand it contains numerous intercalations of carbonaceous shale and coal, here and there carrying plant fossils. This facies, which contains the coal seams of the Nanaimo Group, is thought to have originated in lagoons and swamps, closed off from the sea by shore bars. These rather special conditions occurred only at one time interval in the Comox Basin and again at a later time in the Nanaimo Basin.

The Haslam-type facies, represented by the lower few hundred feet of the Haslam and Cedar District Formations is a littoral facies. The beds are massive, poorly bedded sandy shale and shaly sandstone with generally abundant fossils indicating nearshore deposition. These beds were laid down at shallow depths subject to disturbance by wave action.

The Cedar District-type facies exhibits thick successions of graded beds inferred to be turbidites. Much of the Cedar District, Northumberland and Spray Formations consist of such sequences. They are fine-grained sandstones, siltstones and shales in which individual graded units are 1/4 inch to 6 inches thick. Individual units commonly exhibit complex overturned slump-folds between undisturbed subjacent and superjacent units. The slumps which occur in units ranging in thickness from less than 1 inch to several feet reflect sliding of the upper layers of sediments down the ancient sea floor, and thus can be used to determine the direction of the paleoslope of the basin. Distance of movement of these 'dimunitive overthrusts' ranges from a few inches for thin units to as much as 10 feet for sandstone beds about one foot thick. Similar structures in the coal seams were described by Clapp (1914), who attributed them to local folding and faulting. Predominantly shaly sections are also layered in units, 3 inches to 2 feet thick, consisting mainly of massive shale, but with a bottom layer of fine sand and silt less than 1/4 inch thick. Fossils in these rocks are rare and are always found at the parting of two shale-siltstone layers. Calcareous concretions are locally common and may be products of diagenesis.

The Cedar District-type facies was deposited in deeper water than the Haslam facies, and was deposited below the wave base, where wave action could not destroy the fine laminations and intricate convolutions of the sediments. Each graded unit probably resulted from a flood of suspended material carried down the sea slope from the nearshore area, set in motion by a storm or similar trigger mechanism, and settling in ordered fashion according to the relative settling velocities. The rare remains of pelagic molluscs sank to the bottom in intervening times.

Though not all these facies may be found in one single section, the general progression from the shallower to the deeper facies may be recognized in each cycle. Slow subsidence of the basin was apparently not quite compensated for by sedimentation. Ultimately each cycle was ended by rapid re-emergence, not generally accompanied by sedimentation, and a new cycle followed. The lithological succession is schematically represented in Figure 2. Each cycle is shown with a horizontal base and with approximate thicknesses. Northeastward thinning of conglomerate-sandstone units coupled with thickening of siltstone-shale units is shown from left to right, but the apparent widening of the break between cycles in that direction is not truly representative; rather it is believed that the marine shale units may merge in the deepest part of the basin.

Comox Formation

The Comox Formation with basal Benson conglomerate is the lower part of the first depositional cycle. Clapp introduced the names in 1912 (a and b) for the coal-bearing sequence in the Comox Basin, and for basal conglomerate in the Nanaimo area. Due to erroneous correlation of the coal measures in the two basins he did not realize that the two formations are succeeding facies of the same stratigraphic unit. Comox sandstone and/or Benson conglomerate are present in most Nanaimo Group occurrences on Vancouver Island. The Benson conglomerate member is developed locally and may mark the site of emergent ridges in the early Nanaimo Sea. In the Comox Basin the formation contains several coal seams and four of them (Numbers 1, 2, 3 and 4 seams) have been mined. The thickness of the formation (inclusive of the Benson Member) as measured in boreholes and sections varies from 550 to 800 feet in the Cumberland area, to over 2,000 feet in the Oyster River area, and is 300 to 900 feet in the Nanaimo Basin. On Qualicum River no Comox is present between Haslam shale and granitic rock.

Bell, in a study of the existing fossil plant collections of the Nanaimo Group (1957, pp. 12-14) could not define the age closer than Santonian to Maestrichtian. But he concluded that the Comox was equal in age or older than the Extension Formation. At the time of his writing the Comox was still considered correlative to the Protection Formation.

Marine fossils from the upper part of the Comox and from basal Haslam ('Trent River') shale indicate according to Jeletzky (Muller and Jeletzky, 1967) the upper part of the Santonian stage (middle Late Cretaceous).

Haslam Formation

The Haslam Formation is the upper part of the first depositional cycle. It was named by Clapp (1912a, p. 97) and is exposed on Haslam Creek and other streams in the Nanaimo area. Thicknesses established in borings vary from 280 to more than 1,000 feet. In the Comox Basin the formation is represented by the lower part of what until now has been called Trent River Formation, with a subsurface thickness up to 460 feet. Correlation of the lower part of the 'Trent River' and 'Qualicum' Formations to the Haslam Formation has been established on the basis of microforaminifera (McGugan, 1962) and invertebrate fossils (Jeletzky, 1967; Muller and Jeletzky, 1967). It is here proposed to extend the name Haslam to correlative beds in the Comox Basin and other areas and to abandon the terms 'Trent River' and 'Qualicum'. Minor thicknesses of Haslam shale are also present on Forbidden Plateau and in Alberni Valley.

The formation occurs mainly in Haslam facies and according to Jeletzky it contains three successive faunal zones (A, B, and C, Figure 2; Table 2) of late Santonian and early Campanian (Late Cretaceous) age.

Extension-Protection Formation

The formation is the basal part of the second depositional cycle. Clapp (1912a, pp. 95-99) named a large number of formations within the coal measures of the Nanaimo area, from top to bottom.

Protection Formation:	mainly sandstone
Douglas Seam:	coal
Newcastle Formation:	conglomerate, sandy shale
Newcastle Seam:	coal
Cranberry Formation:	sandstone, shale conglomerate
Extension Formation:	mainly conglomerate
Wellington Seam:	coal
East Wellington Formation:	sandstone

These formations cannot be distinguished beyond the coal mining area. In this report it is proposed to consider them as members of one single formation, to be named Extension-Protection Formation after the most prominent members.

The formation is best exposed in the area around Nanaimo and on Newcastle and Protection Islands. Its maximum thickness is estimated to be 1,900 feet. It contained the Wellington, Newcastle and Douglas seams that have yielded many million tons of coal.

In the Comox Basin the Comox Formation was formerly believed to be the equivalent of the Protection Formation. This correlation is now disproved by the faunal correlation of the Haslam with the lower part of the 'Trent River Formation' (see the foregoing section). But a sandstone-conglomerate unit overlying 'Trent River' (= Haslam) shales in many boreholes and exposed in low hills north of Trent River, north of Tsable River and on Bloedel Creek, is now taken to be the equivalent of the Extension-Protection Formation.

In Alberni Valley Extension-Protection sandstone overlies Haslam shale. The isolated conglomerate of Thunder Mountain is probably Extension-Protection equivalent because it carries clasts of limestone concretions presumably derived from Haslam shale.

On Texada Island basal conglomerate overlying Karmutsen Formation on Mouat and Cook Creeks represents Extension conglomerate of the second depositional cycle, as indicated by fossils in interbedded coquina on Cook Creek (*Inoceramus schmidti* of Faunal zone C, Fig. 2, Table 2).

TABLE 2. AMMONITE AND INOCERAMUS FAUNA OF NANAIMO GROUP

ZONES	A	B	C	D	E	F		A	B	C	D	E	F
Anisoceras cooperi Gabb	-	-	-	-	X	X	Inoceramus ex gr. vancouverensis Shumard	x	x	x	X	-	-
Baculites chicoensis Trask sensu Usher	x?	x	x	X	x	-	Metaplacenticeras cf. pacificum (Smith)	-	-	-	-	x	-
Baculites occidentalis Meek sensu Usher	-	-	-	x?	X	X	Neophylloceras ramosum Meek	-	-	-	-	X	X
Botrychoceras elongatum (Whiteaves)	X	X	-	-	-	-	Nostoceras hornbyense (Whiteaves)	-	-	-	-	-	x
Bostrychoceras sp.aff. B. otsukai (Yabe)	x	-	-	-	-	-	Pachydiscus binodatus Whiteaves	x?		-	†	-	-
Damesites damesi var. intermedius Matsumoto	X	X	X	-	-	-	Pachydiscus buckhami Usher	x	-	-	-	-	-
Diplomoceras notabile Whiteaves	-	-	-	-	x	-	Pachydiscus elkhornensis Usher	x	x	x?	-	-	-
Diplomoceras subcompressum (Forbes)	X	X	-	-	-	-	Pachydiscus (Eupachydiscus?) haradai sensu Usher	-	X	-	-	-	-
Diplomoceras? sp.	-	-	-	x	-	-	Pachydiscus jacquoti Seynes	-	-	-	x?	-	-
Epigonoceras epigonum (Kossmat)	X	X	X	x?	-	-	Pachydiscus (Canadoceras) multisulcatum (Whiteaves)	-	-	X	-	-	-
Gaudriceras denmanense Whiteaves	-	x	x	X	x	-	Pachydiscus neevesi Whiteaves	-	-	-	x	-	-
Gaudriceras sp.	x	-	-	-	x	-	Pachydiscus (Canadoceras) newberryanum (Meek)	-	-	x	X	-	-
Hauericeras gardeni (Baily)	X	X	-	-	-	-	Pachydiscus ootacodensis (Stoliczka)	-	-	-	-	X	X
Hoplitoplacenticeras cf. plasticum Paulke	-	-	-	x	-	-	Pachydiscus (Eupachydiscus) perplicatus Whiteaves	X	-	-	-	-	-
Hoplitoplacenticeras vancouverense (Meek)	-	-	-	x	-	-	Pachydiscus suciaensis (Meek)	-	-	-	-	X	X
Inoceramus ex gr. chicoensis Anderson	X	X	X	x	-	-	Pachydiscus (Canadoceras) yokoyamai (Jimbo)	-	-	X	x?	-	-
Inoceramus ex aff. cordiformis Sowerby	x	-	-	-	-	-	Puzosia (Parapuzosia) sp.	x	-	-	-	-	-
Inoceramus elegans Sokolov	-	-	X	-	-	-	Phyllopachyceras forbesianum d'Orbigny	-	-	-	-	-	x
Inoceramus ex aff. lobatus Goldfuss	X	-	-	-	-	-	Pseudobyloxeras cf. lineatum (Gabb)	x	x	x?	x?	-	-
Inoceramus naumanni Yokoyama	X	x	-	-	-	-	Pseudophyllites indra (Frobes)	-	-	-	-	X	X
Inoceramus orientalis Sokolov emend. Nagao and Matsumoto	x	X	x	-	-	-	Pseudoschloenbachia brannani Usher	-	x	-	-	-	-
Inoceramus orientalis var. ambiguus Nagao and Matsumoto	x	X	x	-	-	-	Pseudoschloenbachia cf. umbulazi Boyle	-	-	-	x?	-	-
Inoceramus n.sp.aff. orientalis	X	x	-	-	-	-	Ptychoceras vancouverense Whiteaves	X	-	-	-	-	-
Inoceramus sachalinensis	-	-	X	-	-	-	Ryugasella ryugasensis Wright and Matsumoto	x	x	-	x?	-	-
Inoceramus schmidti Michael s.str.	-	-	X	-	-	-	Schluteria selwyniana (Whiteaves)	x	x	x	x	-	-
Inoceramus ex gr. subundatus Meek	x	x	x	X	-	-							

- = no occurrence x = occasional occurrence X = general to mass occurrence x? occurrence in this zone uncertain

The lithology of the formation is in part Extension, in part Comox facies, and on Texada Island Benson facies. The lithologic similarity of the Comox and Protection Formations was the basis of their mistaken correlation by earlier workers. In the Nanaimo Basin the Wellington sandstone, overlain by Wellington seam, may be regarded as a regressional facies of the Haslam, from littoral sand to lagoon and coal swamp. The Extension conglomerate represents maximum regression and deltaic conditions, and the succeeding units represent alternating lagoonal and coal-swamp conditions. In the Comox Basin the formation occurs as shoestring conglomerate-sandstone bodies. Boring T.R. 40 on Langley Lake intersected more than 1,000 feet of sandstone and conglomerate but a few miles to the north on Trent River the unit is tentatively identified as a thin sandy layer with clay and woody material, apparently representing an erosional break with Trent River shale. Other borings show conglomerate and sandstone, alternately overlying a reduced section of Trent River shale, or a reduced section of Comox sandstone with the higher seams missing, or Karmutsen volcanic rocks.

Bell (1957) in his study of the available plants of Comox, Extension and Protection Formations defined the age between Santonian and Maestrichtian.

Marine fossils do not occur in the Nanaimo coal measures but were found at Blunden Point and Northwest Bay in silty and sandy shale of the East Wellington member, underlying the Wellington Seam (Jeletzky, 1967; Muller and Jeletzky, 1967). They also occur in the conglomerate on Cook Creek, Texada Island. Of these Inoceramus schmidti Michael is diagnostic of faunal Zone C, of lowermost Campanian age.

Cedar District Formation

This formation is the marine part of the second depositional cycle. It was named by Clapp (1912a, p. 99) and occurs southeast of Nanaimo in Cedar District. Best exposures in the map-area are on Nanaimo River and along the coast, south of Dodds Narrows where 1,010 feet of silty shale were measured. No diagnostic fossils were found in this section, and the base is not exposed. The basal part is exposed on the south shores of North Pender and Saturna Island, southeast of the map-area.

In the Comox Basin the formation is probably represented by the upper part of the Trent River Formation, exposed only on the lower part of Trent River and on the west side of Denman Island (Jeletzky, 1967). In the latter place a section of nearly 1,000 feet was measured. The formation is also exposed in Texada Island.

The lithology is mainly Cedar District facies and, on the better exposures of the Gulf Islands, upward transition from thickly interbedded fine-grained sandstone and siltstone to thinly interbedded siltstone and shale is common.

Outside the map-area, on North Pender and Saturna Islands, sandy beds of Haslam facies overlie Extension conglomerate. Fossils are rare or absent in the Cedar District facies except for local accumulations of Baculites and rare ammonites. Interbedded shale, siltstone and sandstone of Haslam facies overlying Extension conglomerate on North Pender and Saturna Islands have yielded a good ammonite and pelecypod fauna, regarded by Jeletzky as representing faunal zone D (Fig. 2 and Table 2), on Texada Island they may be from zone D or E.

De Courcy Formation

The formation is the lower coarse-clastic part of the third cycle of deposition. It was named by Clapp (1912a, p. 99) and is well exposed on the De Courcy Island group and in the area southeast of Nanaimo. No measured section is available but Clapp's estimated thickness of 800 to 1,400 is verifiable on the geological map.

In Comox Basin the formation is represented by interbedded sandstone and conglomerate, underlying most of Denman Island and named Denman Formation by Williams (1924) and Usher (1952). The thickness of 900 to 1,000 feet, estimated by these writers, appears entirely acceptable.

The lithology is Extension facies of pebbly sandstones with pea-size, black chert and white quartz pebbles. Conglomerates are commonly mixtures of well-worn small pebbles and larger angular blocks of Nanaimo and Vancouver Group rocks. The contact with Cedar District shale, exposed on the coast north of Boat Harbour is sharp but conformable, and the contact with overlying Northumberland shales is gradational. No fossils have been collected from De Courcy beds.

Northumberland Formation

The Northumberland Formation is the marine shaly part of the third depositional cycle. Clapp named it (1912a, p. 100) for the exposures on Gabriola Island off Northumberland Channel but included the overlying sequences of conglomerate, sandstone and shale. The formation is here redefined and restricted to the shale-siltstone unit, occurring below conglomerate exposed in the upper south and north slopes of Gabriola Island. At False Narrows between Mudge and Gabriola Islands the formation is about 1,000 feet thick. In the Comox Basin the redefined Northumberland Formation is represented by the lower part of the Lambert Formation of Williams (1924) and Usher (1952). It is exposed on the east shore of Denman Island above De Courcy (Denman) sandstone and near the south end of Hornby Island at Ford Cove. There the exposed thickness is less than 300 feet, and the total probably less than 500 feet.

The lithology is Cedar District facies and quite indistinguishable from that formation. Contacts with underlying De Courcy sandstone are gradational, whereas contacts with the overlying conglomerate are sharp, or in many places, bounded by faults. Jeletzky (in Muller and Jeletzky, 1967, p. 38) places the scarce marine fossils in the lowest part of zone E (Fig. 2 and Table 2) and dates the beds as Middle Campanian in age.

Geoffrey Formation

The Geoffrey Formation is a conglomerate-sandstone sequence in the lower part of the fourth depositional cycle. The name was introduced by Usher (1952, p. 28) in the Comox Basin for the exposures on Mount Geoffrey of Hornby Island. The formation underlies a large part of this island and is about 700 feet thick.

In the Nanaimo Basin the formation is exposed on the southwest coast of Gabriola Island and on its north and south slopes. It is also well-exposed outside the map-area on Galiano and Mayne Islands. There Clapp (1914, p. 67) and Usher (1952, p. 19) described a sandstone-conglomerate sequence in the middle part of the Northumberland Formation. As indicated in the previous section the writer proposes to limit the term Northumberland to the shales underlying the conglomerate sequence which is considered to represent the Geoffrey Formation. On Gabriola Island the thickness is about 400 feet.

Once again the lithology of the formation is Extension facies, with many granitic, volcanic and schist boulders of nearby origin mixed with well-worn quartz and chert pebbles in the conglomerates. The contact with underlying Northumberland shales is sharp, but commonly faulted or poorly exposed.

Spray Formation

The Spray Formation is a shale, siltstone and minor sandstone sequence forming the upper part of the fourth depositional cycle. It was named by Usher (1952, p. 29) for the succession that underlies a strip of Hornby Island and underlies Tribune Bay. The name is derived from 'Spray Point'[1], a low sandstone bluff in the middle of Tribune Bay.

The formation is only partly exposed on Tribune Bay, where it overlies the Geoffrey. Usher here measured 800 feet of shale; the writer's party estimated 950 feet of which more than 400 feet are concealed. In the writer's interpretation part of the same section occurs between Shingle Spit and Collishaw Point on the west coast of the island, and again west of Tralee Point.

In the Nanaimo Basin and within the map-area the formation is present only on Gabriola Island where it is probably exposed on Decanso Bay, Leboeuf Bay and Degnen Bay. Best exposures are found outside the map-area on Mayne Island in Miners Bay, Bennett Bay and Campbell Bay. Usher (1952) considered the Nanaimo Basin occurrences to be the upper part of the Northumberland Formation. The measured thickness at Decanso Bay is 225 feet, on Bennett and Campbell Bay it is 1,800 feet.

The lithology is Cedar District facies, but more shale in the upper part of the unit results in larger covered intervals in the sections. A sandstone member, forming Spray Point, and Manning Point (between Phipps and Collishaw Points) on Hornby Island separates the formation into two members.

No fossils have been found in the Spray Formation of Tribune Bay, but many have been collected in the section, formerly included in the Lambert Formation, between Phipps and Collishaw Points on Hornby Island. A few have also been found in the beds so far included in the Northumberland Formation of the Nanaimo Basin. On the basis of fossil collections, made by Usher (1952) and located with the use of his field notes, and also the microfaunas of McGugan (1962), likewise located with field notes kindly supplied by Dr. McGugan, it appears that the sandstone of Manning Point separates two faunas (E and F of Fig. 2 and Table 2). The upper fauna, carrying *Bolivina incrassata* is judged to be Maestrichtian in age, the lower one late Campanian.

Gabriola Formation

The highest formation of the Nanaimo Group is believed to contain only continental sandstone and conglomerate. It was named by Clapp(1912a, p. 100) for sandstone overlying the Spray (upper Northumberland) Formation and is exposed on the northwest and southeast ends of Gabriola Island. Clapp mentions a thickness of 1,400 feet on Gabriola Island, and like Usher (1952, p. 20), the writer adopts this estimate. On Hornby Island a sequence of conglomerate and sandstone at Flora Point, named 'Hornby Formation' by Usher (1952, pp. 29-30), and according to him about 800 feet thick, is believed to be correlative. Generally the formation is an Extension facies, but massive or heavily cross-bedded quartz-feldspar sandstone with minor shaly interbeds predominates on Gabriola Island. Shallow caves in a small bay southeast of Malaspina Point, formed by undercutting of sandstone ledges, have been described by Clapp (1914, p. 68) as Galiano (or Malaspina) Galleries. They are typical of the

---

[1] This geographic name is neither officially known, nor mentioned as such in Usher's report, but appears in his field notes. It has now been proposed to the Canadian Permanent Committee on Geographic Names.

formation, but similar though less spectacular erosional phenomena may be seen in some older sandstones. On Hornby Island the formation is predominantly conglomerate.

To the writer's knowledge no fossils have been found in the formation and the age is therefore known only to be younger than the Spray and is Maestrichtian or younger.

CRETACEOUS OR TERTIARY SEDIMENTS

Tertiary clastic sediments are abundant in the Sooke area to the south (Clapp and Cooke, 1917) and along the west coast north of the map-area (Jeletzky, 1954a). The only possible known representatives of such beds within the map-area are in the Strait of Georgia. On Sangster Island, south of Lasqueti Island, conglomerate carries cobbles of mainly volcanic and minor granitic rocks and quartzite, and also porphyry similar to that in early Tertiary sills and perhaps derived from these. Sandstone and lenses of shale breccia are interbedded. Some glauconitic and other yellowish white sandstones on the north side of Lasqueti Island are also possibly very late Cretaceous or early Tertiary. G. A. Rouse (pers. comm.) has recently found pollen of latest Cretaceous or Paleocene age in sandstone on a small island north of Lindbergh Island, in Scottie Bay, Lasqueti Island. These are younger than Gabriola Formation and appear to be coeval with the Chuckanut Formation of northwestern Washington.

TERTIARY INTRUSIONS

Small stocks of granitic rocks with associated sills, dykes, and laccoliths of hornblende-feldspar porphyry intrude beds of the Nanaimo Group and older strata. They have not been named and will be referred to as Tertiary Intrusions. Best known is the Mount Washington quartz diorite stock, less than one mile in diameter, that has branched out into sills of porphyritic dacite. The sills are exposed on the same mountain, on Constitution Hill, and in other areas north of Comox Lake.

On Forbidden Plateau sills occur on Strata Mountain and Mount Brooks, and a small breccia pipe with associated intrusive rock occurs near Gem Lake. Farther south many sills, most of them several hundred feet thick, intrude Nanaimo Group rocks or overlie them on Patlicant Mountain, on the mountains west of Labour Day Lake, and on many hilltops in the headwater region of Englishman River. On the west coast Tertiary radiometric ages have been established for a stock exposed west of Tofino and on Stubbs and Felice Islands, for a northwesterly elongated intrusion extending from Catface Mountains to Lemmens Inlet, and for other bodies southeast, east and north of Kennedy Lake. Other possible Tertiary intrusions are exposed on Snowdon Island in Toquart Bay and on Vernon Bay, and more such plutons may well exist.

The geology of Mount Washington and its copper-gold deposits was studied in detail by Carson (1960, 1968) and has been explored by various mining companies. The copper-molybdenite occurrences on Catface Mountain are still under investigation by Falconbridge Exploration Company.

On Mount Washington the central stock consists of fine-grained biotite-hornblende quartz diorite. The sills, laccoliths and dykes surrounding the stock are mainly light coloured dacite porphyry, containing phenocrysts of zoned andesine and hornblende in a matrix of quartz, feldspar and chlorite. Along the edge of the stock, breccias occur, presumably in vertical sheet – or pipe-like bodies. Carson has distinguished two breccia types. The Murray breccia consists of subangular to well-rounded fragments, up to 6 inches in size, mainly of porphyry but with minor sandstone and shale. The margin of the breccia zone contains large fragments of the surrounding

Cretaceous rocks. The matrix consists of coarsely to finely comminuted angular and round fragments of porphyry and country rock.

The Washington breccia forms a steeply-dipping sheet-like mass and underlies one prominent topographic culmination. It consists of large angular fragments of porphyry and bleached sediments, some more than one foot in size, in a matrix of smaller fragments, commonly cemented by magnetite and actinolite. Many of the rocks contain biotite, apparently due to later biotitization.

Dacite porphyry and minor equigranular quartz diorite are the main rock types of the other Tertiary intrusions on the northeast side of the island.

The intrusions on the west coast are of more varied mineral composition. They are also mainly light coloured but commonly not strongly porphyritic. As potash feldspar is here either the minor or the predominant feldspar they vary from quartz diorite to leucoquartz monzonite. Mafic minerals are commonly biotite and/or hornblende, more rarely pyroxene and tourmaline. Micrographic or granophyric textures are not uncommon.

Isotopic datings (Wanless et al., 1967, 1968) gave 35 $\pm$ 6 m.y. for the Mount Washington stock; 39 $\pm$ 7 m.y. for the small intrusion of Faith Lake; 48 $\pm$ 12 m.y. for the Catface intrusion; 50 $\pm$ 5 m.y. for Stubbs Island and 59 $\pm$ 3 m.y. for the east slope of Mount Frederick, east of Kennedy Lake. These dates suggest a Paleocene to Eocene age for the west coast plutons and a slightly younger, Eocene to Oligocene age for those of the east coast. The writer believes that these small shallow intrusions are subsurface manifestations of volcanism that occurred at higher levels.

TERTIARY VOLCANIC ROCKS

Volcanic rocks of probable Tertiary age were discovered on Mount Frederick, south of Kennedy Lake, near and beyond the south border of the map-area. They are well exposed on logging spur 565 on the east side of Mount Frederick. The lower part of the sequence consists of massive to well laminated dark grey, bone-white weathering dacite-tuff exhibiting blocky fracture, and dipping about 20 degrees south. Thin-sections show many volcanic pellets and intermediate plagioclase with trachytic texture in a fine matrix of plagioclase, lepidomelane, chlorite, minor quartz and opaque minerals. The upper part, exposed near the top of the ridge, consists of tuff and ignimbrite. These dark grey to greenish grey rocks are roughly layered by flattened volcanic fragments, less than 1 inch thick and several inches long, in a similar looking matrix and are speckled with pinpoints of lustrous quartz. The thin-section shows resorbed, rounded and angular quartz, and angular fragments of finely recrystallized glass, in a fine-crystalline matrix. A lighter coloured rock shows quartz, zoned intermediate plagioclase, some K-feldspar, fragments containing plagioclase crystallites with trachytic texture, and epidotized volcanic rock in a very fine crystalline matrix, probably quartz, feldspar and epidote.

It is not known whether these rocks are intruded by or rest unconformably on the Paradise Creek quartz monzonite porphyry. In either case a genetic relationship is probable. They appear to be similar to rhyolitic ash flows of the Paleocene Masset Formation of the Queen Charlotte Islands (Sutherland Brown, 1966).

STRUCTURAL GEOLOGY

by J. E. Muller

PALEOZOIC ARCHES

The oldest structural elements in the area are several northerly trending axial uplifts. They may be called Buttle Lake Arch, Cowichan-Horne Lake Arch, and Nanoose Uplift. Each one has a core of Sicker Group volcanic and clastic rocks exhibiting in some areas shear folding and lineation with horizontal or gently plunging northerly trending axes. Fold axes and lineations of the Westcoast Gneiss Complex in the Tofino area have the same trend. The folding, apparently reflecting the trend of the arches, may have been connected directly with their uplift. Although detailed structural studies are lacking, it appears that intense folding is either confined to linear belts of steeply flexured beds or to stratigraphic intervals of incompetent bedded rocks.

An unconformity, perhaps angular, separates lower and middle parts of the Sicker Group (Middle Pennsylvanian and older) from overlying formations. In several places it is marked by conglomeratic beds and jasperoid layers and breccias, that overlie either the lower volcanic or middle clastic division of the Sicker Group and are succeeded by either Buttle Lake or Karmutsen Formation. Folding and uplift therefore occurred at the end of Paleozoic time.

As mentioned previously, relatively thick sections of Buttle Lake limestone coincide with the plunging culminations of Buttle Lake and Horne Lake Arches. They may indicate a facies difference, perhaps due to the rising of the arches as shallow submarine shelves where carbonate deposits could accumulate.

EARLY MESOZOIC STRUCTURES

Early Mesozoic structures can be identified in Triassic to Lower Jurassic Vancouver Group rocks that were folded and faulted prior to emplacement of Middle to Upper Jurassic Island Intrusions.

Carlisle (Carlisle and Suzuki, 1965) made a detailed study of Upper Triassic, Open Bay limestone on Quadra Island. The limestone has been compressed into "non-plane, noncylindrical folds from 200 to 500 feet across" and upon the larger folds are "many lesser folds, roughly 5 to 40 feet across having the appearance and orientation of drag folds and conforming generally in plunge with the larger folds". Axial surfaces are steep to vertical and curved. Andesitic dykes were, according to Carlisle and Suzuki, injected before, during, and after the folding. They conclude (1965, p. 472) that the main deformation was progressive and recurrent flexural-slip folding along a north-northwesterly trend. This folding phase preceded emplacement of the 'Main Coast Intrusives'. This writer believes that much of this folding was an indirect result of movements in steep fault zones.

Triassic Marble Bay limestone on Texada Island is also highly folded along the northeast coast but is essentially flat and undisturbed in quarries near the south-west coast. In the latter, two sets of vertical faults may be seen and many of these are intruded by diorite dykes. The oldest set of faults and dykes strikes 10 to 20 degrees west of north, shows evidence of movement after intrusion of the dykes, and is inferred to be older than the Island Intrusions.

Folding did not occur to a large extent in Karmutsen volcanic rocks. They reacted like a rigid shield, in places more than 10,000 feet thick.

Thus one early Mesozoic and possibly one late Paleozoic deformation preceded the main Middle Jurassic intrusions. The deformations are characterized by steep faults and by small-scale folds related to the fault-zones.

The Island Intrusions are marked by northwesterly trends contrasting with the northerly strikes of Paleozoic arches. The Bedwell batholith intersects the Buttle Lake Arch at a sharp angle and intrusions within and surrounding the Cowichan-Horne Lake Arch exhibit similar divergent trends. The northwesterly structural trend therefore appears to have been established first with the Island Intrusions in Middle Mesozoic time.

POST-BATHOLITHIC STRUCTURE

A major nonconformity separates the Island Intrusions, together with rocks of Sicker and Vancouver Groups, from Upper Jurassic and Cretaceous rocks. On the west coast of Vancouver Island the erosion surface is overlain by Upper Jurassic and Lower Cretaceous rocks in the Quatsino region. These rocks may be represented in the map-area by the Tofino Area Greywacke Unit. Along the east coast uplift and erosion continued until mid-Late Cretaceous, Santonian time, when first deposition of Nanaimo Group beds occurred. The region where the Upper Cretaceous sea encroached still had considerable relief. This is apparent from the uneven distribution of the lower Nanaimo Formations and on a small scale from exposures of rough unconformity surfaces with abrupt near-vertical scarps to about ten feet in height.

The old Paleozoic arches remained as active positive elements until Late Cretaceous time. At that time they had been uplifted and Sicker Group rocks laid bare after being stripped of many thousand feet of Vancouver Group rocks. In the Late Cretaceous they were emerging ridges, where conglomerates were deposited directly on these exposed Sicker rocks, whereas elsewhere marine shale was laid down in deeper water on (still preserved) Karmutsen volcanic rocks.

TERTIARY FAULTING

Much of the faulting that dominates the structure of Vancouver Island took place in Tertiary time as attested by large displacements of Nanaimo Group beds. The main fault system trends northwesterly in Strait of Georgia and adjacent regions and again along the Pacific Coast. In the central part of the island west-northwesterly to westerly trends prevail. Subsidiary faults strike northerly to northeasterly and in the Duncan area, south of the map-area, they clearly offset the northwesterly faults (Muller and Jeletzky, in preparation).

The most conspicuous fault, 45 miles in length, separates Alberni Valley, an asymmetric graben (<u>see</u> structural section on Map 17-1968) and Beaufort Range, extending from Alberni to Forbidden Plateau. The displacement of the top of the Karmutsen Formation is in the order of 5,000 feet. Clapp (1914, p. 72) notes a large fault in the Nanaimo area, southwest of Extension. It was cut by the tunnel of the Extension Collieries about 300 feet vertically below its outcrop and has a southwestward downthrow of about 500 feet.

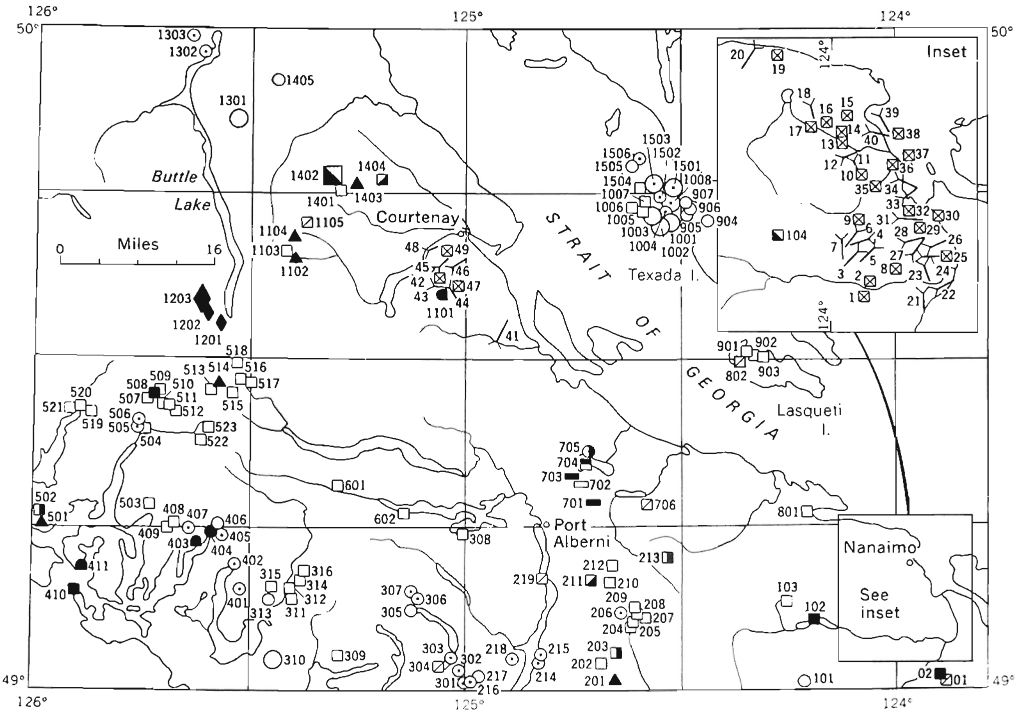
A large fault probably runs northwesterly in the Strait of Georgia between Hornby and Lasqueti Islands, and a major northwesterly fault-system skirts the southwest coast of Vancouver Island.

Latest movement in the panels between these longitudinal faults has generally been northeastward tilting. This is clearly expressed in northeastward dipping Nanaimo Group beds and also in beds of the Tofino Area Greywacke Unit.

Clapp (1914, p. 69) believed that the structural style of the Nanaimo Group is predominantly folded and subordinately faulted. Buckham (1947 a, b) emphasizes faulting rather than folding as the main structural element. The writer prefers the latter view. He believes that zones of steeply dipping or highly sheared and crumpled beds in the Nanaimo Group are imbricated vertical fault zones. Such a fault zone may be the near-surface expression of one single profound fault.

On Texada Island a younger set of faults and dykes trends north 70 degrees west. The dykes are altered less than those mentioned in the section on Mesozoic structures, and have not been disturbed by younger faults. These may be Tertiary structures.

Carlisle, in his work on Quadra Island (Carlisle and Suzuki, 1965) also distinguished later folds, superimposed on the pre-batholithic folds described in the section on early Mesozoic structures. They are gentle folds about near-horizontal east-west axes, expressed in undulations of lineations and axes of the first phase. A third type of deformation has caused "local folding about steep axes related to north-northwesterly fracture zones and shears, transecting the whole of Quadra Island". These structures are younger than the Coast Intrusions and this writer believes they may be related to faulting and tilting in Tertiary time.



METALLIFEROUS DEPOSITS

SYMBOL	CLASS	TYPE OF DEPOSIT
♦	A	Zn-Cu-Pb-Ag-Ba massive sulphide
▬	B1	Fe chert
▭	B2	Mn chert
	C	Cu in basic lava
	D	V in carbonaceous sediment (not in map-area)
	E	Ni in peridotite, gneiss complex
○	F1	Fe skarn
⊙	F2	Cu skarn
●	F3	Mo-Cu skarn
	F4	Zn skarn or replacement in limestone
	G1	Mo-quartz stockwork or vein
	G2	Cu-quartz stockwork or vein
	G3	Cu shear zone
	G4	Sb-quartz vein
	G5	W stockwork (not in map-area)
	G6	As-carbonate vein
	G7	Cu-As-quartz vein or breccia zone
□	G8	Au-quartz vein or fissure zone
▲	H	Cu porphyry

For list of mineral deposits, see Table IV. First digit(s) of numbers refer to subdivisions of N. T. S. map-areas. Thus 101 and 1001 are respectively in map-areas 92 F/1 and 92 F/10. But 01 and 02 are in 92 G/4. Large-size symbols are the most important past and present producing mines.

COAL MINES (all defunct)

Shaft mine . . . . . ⧗ Slope mine. . ≻—

For list of main coal mines see Table V

GS.

Figure 3. Index map of metal deposits and coal mines.

ECONOMIC GEOLOGY

METALLIFEROUS DEPOSITS

by D. J. T. Carson

Introduction

Table 3 presents a classification of the metalliferous deposits of the Alberni map-area. The deposits are listed in Table 4 and located on Figure 3. They are classified on the basis of their metal content as well as mineralogy, textures, type and alteration of host rock, structures, and where applicable, type of related intrusion. All deposits from small prospects to producing mines are included.

Important features of the various classes are discussed below. Reference is made to some Vancouver Island mineral deposits outside the map-area, which are pertinent to the discussion.

Much of the information in this section is taken from a doctoral thesis (Carson, 1968) sponsored by the Geological Survey of Canada and written at Carleton University, Ottawa. The writer is greatly indebted to J. E. Muller for geological information and logistic assistance in the field.

Zinc-copper-lead massive sulphide deposits (A)

The Lynx deposit of Western Mines Limited (Jeffery, 1965) is the largest of the zinc-copper-lead massive sulphide deposits on Vancouver Island. Reserves at Lynx (September 1966) were more than 2,000,000 tons averaging approximately 10 per cent zinc, 2 per cent copper, 1 per cent lead, 0.06 ounce gold and 2.6 ounces silver per ton. Present production is about 320,000 tons per year. Paramount and Price deposits, the other two in the Alberni map-area, have not been developed. The Twin "J" mine near Duncan (Stevenson, 1945b) is in the same class but is outside the map-area. It yielded substantial ore with metal content similar to but of lower grade than that of Lynx.

All deposits of this class occur in schists derived from cherty volcanic tuffs and breccias of the Sicker Group. They are in local discontinuous 'shear zones' which are probably tightly-folded incompetent tuffaceous horizons in which axial plane cleavage is highly developed and approximates schistosity. Faults cross the 'shear zones' and in some cases have displaced ore.

The sulphide bodies are lenses, irregular masses, and tabular bodies which vary from masses less than one foot in diameter to lenses several hundred feet long. The ore commonly consists of alternating bands of chalcopyrite and sphalerite with pyrite crystals strewn out in both minerals. Galena and tetrahedrite are less abundant and occur as blebs, generally concentrated in certain bands. Minor bornite may be present and pyrrhotite is rare. Distinguishing features of these deposits are pockets or lenses of barite, and absence of magnetite.

Structures in which the sulphides are localized include near-horizontal drag folds, bulges in the walls of the 'shear zones', the upper flanks of unsheared masses of rock which occur as isolated blocks in the 'shear zones', and faults.

Deposits of this class may be hydrothermal (Jeffery, 1965) and derived from intrusions (Stevenson, 1945a). However, their unique structural, mineralogical, and textural characteristics, restriction to the Sicker Group, and the lack of any obvious igneous source may indicate that the metals were deposited with their host rocks in the late Paleozoic and were in part, further concentrated by migration to favourable structures during subsequent periods of deformation.

Table 4. List of mineral deposits (see index map Fig. 3).

Number	Deposit	Class
01	Bush Creek	G3
02	Molly	G1
101	Jump Creek	F1
102	Moly	G1
103	Vulcan	G8
104	Macmillan	G7
201	Corrigan Creek (Andy, Pak)	H
202	WWW	G8
203	Mary	G2
204	Black Lion	G8
205	Black Panther	G8
206	Thistle	F2
207	B and K	G8
208	Golden Eagle	G8
209	Storm	G8
210	Regina	G8
211	Grizzly	G6
212	Vancouver Island Gold Mines	G8
213	Independent	G2
214	Island Copper (incl. Kitchener, Modoc)	F2
215	Darby and Joan Victoria and Canadian	F2
216	Sunshine	F2
217	Black Prince	F1
218	J. J. J.	F2
219	Dauntless	G3
301	Cascade	F2
302	Torse	F2
303	Rainy Day	F2
304	Big Bluff	G3
305	Magnetic No. 1	F1
306	OK	F2
307	Gretna Green	F2
308	Sproat Lake	G8
309	Toquart	G8
310	Brynnor Mines	F1
311	Leora	G8
312	Rose Marie	G8
313	Iron Mountain	F1
314	Jo Jo	G8
315	Bear Creek	G8
316	Tommy K	G8
401	O. K.	F2
402	Northern Crown	F2
403	Tofino Nickel	E
404	Sunwest	F3
405	Hetty Green	F2
406	Crow or Craigellachie	F1
407	B. C. Wonder	F2
408	Fandora	G8
409	Gold Flake	G8
410	"Tofino Molybdenite"	G1
411	Meares Nickel	E
501	Catface - Cliff, Hecate Bay	H
502	Catface - Irishman Creek	G2
503	Moscena	G8
504	Prosper	G8
505	Seattle	G8
506	Avon, Galena	G8
507	Noble	G8
508	Dry Gulch	G1
509	O. K.	G8
510	Joker	
511	Musketeer and Shamrock	G8
512	Buccaneer	G8
513	You	G8
514	Big I, Ptarmigan	H
515	Della	G8
516	Sherwood	G8
517	P. D. Q.	G8
518	Cream	G8
519	Abco (Mary McQuilton)	G8
520	Moyeha	G8
521	Big Boy	G8
522	Thunderbird	G8
523	Trophy	G6
601	Apex-Morning	G8
602	Murphy-Johnson	G8
701	Unnamed	B1
702	"Lacy Lake"	B2
703	Unnamed	B1
704	Silver Bell	G4
705	P. D.	F4
706	"Qualicum"	G3
801	Georgina	G8
802	Old Bill	G3
901	Juneau	G8
902	Venus	G8
903	St. Joseph	G8
904	Black Prince	F1
905	Cap Sheaf	F1
906	Malaspina	F1
907	Raven	F1

Table 4. List of mineral deposits (continued).

Number	Deposit	Class	Number	Deposit	Class
1001	Texada Mines, Lake	F1	1301	Argonaut	F1
1002	Texada Mines, Paxton	F1	1302	Sumpter	F2
1003	Texada Mines, Prescott	F1	1303	Big G.	F2
1004	Sentinel	F2			
1005	Copper King	G8	1401	Domineer	G8
1006	Silver Tip	G8	1402	Mt. Washington Copper	G7
1007	Victoria	G8	1403	Mt. Washington-Murex	H
1008	Cornell	F2	1404	Wolf Lake	G6
			1405	Iron River	F1
1101	"Coal Creek"	C			
1102	"Faith Copper"	H	1501	Little Billy	F2
1103	"Faith Lake"	G8	1502	Copper Queen	F2
1104	Gem Lake	H	1503	Marble Bay	F2
1105	Three Musketeers	G3	1504	Marjorie	G8
			1505	Paris Group	F1
1201	Price	A	1506	Loyal Lease	F2
1202	Paramount	A			
1203	Lynx	A			

Ferruginous and manganiferous cherts (B_1B_2)

Known deposits of these two classes in the Alberni map-area are small. However, larger but uncommercial ferruginous chert deposits (taconites) occur near Ladysmith (Bacon, 1957), and residual manganese oxide and gem quality rhodonite have been taken from the manganiferous cherts near Cowichan Lake (Fyles, 1955).

Known deposits of these classes are restricted to the upper Sicker Group but similar deposits may occur in the Bonanza Formation, parts of which are lithologically similar to the Sicker Group.

Copper in basic volcanic rocks (C)

The Coal Creek deposit is one of several copper deposits in basic volcanic rocks of the Bonanza and Karmutsen Formations of Vancouver Island. The copper is believed to be syngenetic but limited migration of sulphides to fractures may have occurred during diagensis or later periods of deformation.

Nickel-copper-bearing peridotite-gabbro (E)

The Meares Island nickel-copper deposit is of undetermined size. It occurs in a serpentinized ultrabasic sill (?) in the Westcoast Gneiss Complex. Muller (this paper) believes that the gneisses are mainly derived from Sicker Group rocks and that the sill (?) is equivalent to the basic sills contained in the Sicker Group at other localities on Vancouver Island. These sills are thought to be intrusive equivalents of Karmutsen basalts and are therefore probably Triassic.

Sulphides in the deposit are in veinlets or are interstitial to olivine and pyroxene. Siegenite is the only nickel-bearing mineral identified. It occurs in minor amounts as partly replaced crystals in pyrrhotite.

Nickel, copper, and palladium are reported to occur in a gneiss complex at Tofino Nickel deposit (Eastwood, 1964).

Iron and copper skarns (F1, F2)

Iron and copper skarn deposits (contact metasomatic deposits) are abundant in the map-area, and several have been mined. Their characteristics are given in Table 3. In the former, magnetite is the main economic mineral whereas in the latter it is chalcopyrite. Many deposits, especially copper skarns, contain appreciable gold and silver.

The only magnetite skarns being mined at present are the Prescott, Paxton, and Lake deposits of Texada Mines Limited. Present production is approximately 1,300,000 tons of ore per year and total production until 1966 from these and other nearby deposits was about 12,000,000 tons of ore. Some copper, gold and silver have been recovered. Past producers on Vancouver Island were Brynnor and Argonaut, each of which yielded approximately 5,000,000 tons of ore.

Copper skarns of the Alberni map-area are erratic. Most are probably uneconomic, and none is presently mined. Small amounts of ore have been shipped from several, but only Marble Bay, Vananda (Little Billy) and Cornell on Texada Island have produced significant amounts of copper. Their combined production was approximately 430,000 tons of ore yielding 10,000 tons of copper, 77,000 ounces of gold, and 515,000 ounces of silver. A present producer outside the map-area is Coast Copper Limited.

Both types of skarn deposits are associated with garnet-epidote-diopside-actinolite skarn zones within or in close proximity to limestone. At nearly all deposits the limestone overlies the Karmutsen Formation and is of late Triassic age (Quatsino Formation), or occurs slightly lower in the Karmutsen Formation – the older 'inter-volcanic limestone'. However, limestone of the Paleozoic Sicker Group occurs at the Thistle deposit (Stevenson, 1945a), and the 'Skarn' deposit near Nanaimo Lakes south of the map-area. Also, some skarn deposits near Tofino are in limestone which may belong to the Sicker Group.

Intrusive stocks and batholiths related to both the copper and iron skarn deposits of Vancouver Island vary in composition from gabbro such as the Coast Copper stock, to quartz monzonite such as the Nimpkish batholith. They appear to have caused intense local deformation, especially of limestone, during their emplacement, and many orebodies are located in the deformed host rocks near intrusive tongues and apophyses.

Brynnor iron deposit is probably of Jurassic age because pre-ore granodiorite and a post-ore dyke yield K-Ar ages of 167 and 121 million years respectively (Wanless et al., 1966). Iron Hill (Argonaut) and several other skarn deposits near Campbell Lake are related to the Jurassic (?) Quinsam granodiorite which is unconformably overlain by Upper Cretaceous sediments of the Nanaimo Group. Elsewhere on Vancouver Island, several skarn deposits are related to pre-Upper Cretaceous intrusions, some of which have been dated by K-Ar methods and yield ages of 151 - 166 million years (Wanless et al., 1967, 1968). Some small copper-bearing skarn deposits near Zeballos are related to the youngest major phase of the Zeballos batholith, which is a stock of Tertiary quartz diorite. However, phlogopite from the Zeballos FL orebody magnetite skarn which is related to older granodiorite or diorite has a K-Ar age of 148 million years (Wanless et al., 1967, 1968).

It appears that most of the iron and copper skarn deposits are related to the Middle to Upper Jurassic Island Intrusions, and a few are related to Tertiary stocks.

Molybdenum-copper skarn (F3)

Sun West molybdenite skarn at Tofino Inlet (Eastwood, 1964), is the only deposit of this class in the map-area. Erratic patches up to a few feet wide of molybdenite with some chalcopyrite occur in garnet-epidote-diopside-actinolite-wollastonite skarn in a zone of undetermined extent.

Zinc skarn or replacement in limestone (F4)

A 'vein' several feet wide containing sphalerite and arsenopyrite is reported to occur in Sicker Group limestone at PD deposit near Horne Lake (Minister of Mines, Province of British Columbia,Ann. Rept., 1927, p. c351). Little else is known of the deposit but it may be a siliceous replacement or skarn deposit similar to Danzig on Muchalat Arm (Minister of Mines, Province of British Columbia, Ann. Rept., 1949, p. 219) and the Alice Lake deposit on northern Vancouver Island (Gunning, 1930).

Molybdenum-bearing quartz veins and stockworks (G1)

Deposits of this class are related to the roof facies or porphyritic border zones of relatively potassic intrusions. The two deposits in the map-area, Dry Gulch and Tofino Molybdenite have not been developed. The Tofino occurrence consists of a small stockwork of quartz veinlets containing molybdenite, chalcopyrite and pyrite in a Tertiary granodiorite porphyry plug (50 million years, Wanless et al., 1968). Dry Gulch is reported to be a stockwork containing molybdenite with copper and gold (Bancroft, 1937).

A known Jurassic deposit of this class is Allies on Mount Buttle, south of the map-area (Fyles, 1955).

Copper-bearing quartz veins and stockworks (G2)

No deposit of this class in the map-area is known to be economic although the Mary deposit on Mount Spencer is extensive. However, the Rupert Arm deposit which is presently being explored by Utah Construction and Mining Company is of this type. It is reported to contain more than 180,000,000 tons grading in excess of 0.5 per cent copper and 0.025 per cent molybdenite (February, 1969).

Stockworks of this class are somewhat similar to porphyry copper deposits but are not within intrusive complexes. Most occur in the Karmutsen or Bonanza Formations.

Copper-bearing shear zones (G3)

Deposits of this class occur in narrow shear zones, generally in the Karmutsen Formation, in which silicification and carbonatization are absent or restricted to the shear zone. They show no relationship to intrusions and may represent a migrational stage intermediate between (syngenetic) copper in basic volcanics and copper-bearing quartz veins and stockworks. None has been proven to be economic.

Antimony-quartz vein (G4)

Silver Bell deposit near Horne Lake consists of a stibnite-quartz vein six inches wide by at least seventy feet long, and a smaller parallel vein. An old tunnel has been driven along the main vein.

The age of the deposit is unknown but because of the affinity of antimony for arsenic, and because arsenic veins and copper-arsenic veins of the Alberni map-area are Tertiary, the Silver Bell may also be of Tertiary age.

Arsenic veins (G6)

Grizzly deposit near Alberni consists of a steeply dipping vein containing native arsenic, arsenopyrite, carbonate and quartz which is up to two feet wide and 50 – 60 feet long. It occurs in sedimentary rocks of the Nanaimo Group. Some native arsenic has been taken from it for mineral collections.

Wolf Lake deposit (Hurst, 1927) is a steeply-dipping vein 2 – 12 feet wide and 250 feet long. It contains realgar, arsenopyrite, calcite, quartz, and minor native arsenic.

Both deposits occur in brecciated fault zones and have close spatial relationships with dacite porphyry sills or laccoliths intruding the Nanaimo Group.

Copper-arsenic vein and breccia zone (G7)

Mount Washington Copper deposit (Carson, 1960) is a nearly horizontal quartz-filled vein or sheeted zone 7 – 15 feet thick and 250 by 600 feet in area. Approximately 400,000 tons of ore containing 1.4 per cent copper, 0.015 ounce of gold and 1.2 ounces of silver per ton have been mined by open-pit methods but the mine is presently inactive. Chalcopyrite, pyrite, pyrrhotite, arsenopyrite, realgar, and orpiment are the main minerals. Bornite, molybdenite, tetrahedrite, chalcocite and magnetite are present in small amounts and twelve other metallic minerals including native arsenic, hessite, wehrlite, native gold and chalcostibite occur in very minor amounts.

The vein is in argillite and quartzite of the Nanaimo Group and Tertiary dacite porphyry, alongside the Mount Washington quartz diorite stock which yields a K-Ar date of 35 million years (Wanless et al., 1968). The argillite and quartzite are in a local metamorphic halo surrounding the stock.

Another deposit of this class is Macmillan near Nanaimo Lakes. It is a silicified breccia zone of unknown form in Karmutsen Formation volcanic rocks containing minor amounts of bornite, tetrahedrite, covellite, chalcocite and corynite (antimonial gersdorffite).

Both copper-arsenic deposits occur near the Nanaimo-Karmutsen unconformity, which may have been a zone of weakness near which the favourable structures were formed.

Gold-bearing-quartz veins, fissure zones (G8)

The chief characteristics of these deposits are given in Table 3. The main camps or areas of occurrence in the Alberni map-area are Bedwell River (Sargent, 1940, 1941), Herbert Arm and Kennedy River (Bancroft, 1937; Dolmage, 1921), China Creek (Stevenson, 1945a) and Forbidden Plateau (Carson, 1960, 1968). However, the richest veins, many of which were mined, are at Zeballos (Stevenson, 1950) which is north of the map-area. Gold-quartz veins and fissure zones also occur on Texada and Lasqueti Islands.

Small amounts of gold and silver were produced at Musketeer, Buccaneer, Fandora (Tofino Gold), and Havilah, and many of the deposits have been explored by adits. None is presently in production.

The gold-quartz veins and fissure zones of the various areas of Vancouver Island are remarkably alike in most aspects. They occur in belts of known Tertiary intrusive activity (Carson, 1968) and those at Zeballos, Faith Lake, and Mount Washington are within or adjacent to quartz diorite-dacite porphyry intrusive complexes yielding K-Ar ages of 38, 39, and 35 million years respectively (Wanless et al., 1967, 1968). Most of the Vancouver Island deposits are therefore Tertiary. The age of the Texada-Lasqueti deposits is unknown.

Because of their spatial relationship to Tertiary quartz diorite and dacite porphyry, many gold-quartz veins and fissures of Vancouver Island are in close proximity to arsenic veins, arsenic-copper veins, and porphyry copper deposits. Thus the original discoveries at Mount Washington were the No. 1 (Domineer) and No. 2 gold-quartz veins. The Mount Washington Copper orebody, found later, is a copper-arsenic vein, and scattered zones of disseminated sulphides in the vicinity of the Mount Washington stock are low grade porphyry copper deposits. Gold-quartz veins and porphyry copper deposits also occur in close proximity to one another at Faith Lake and Big Interior Mountain.

Pyrite, sphalerite, arsenopyrite, galena, and minor chalcopyrite, pyrrhotite, and marcasite are found in most veins of all areas. High content of galena and sphalerite appear to be related to high gold values (Bancroft, 1937). Under the microscope, native gold was observed in samples from all the main areas. Exsolution chalcopyrite in sphalerite is a ubiquitous texture.

Despite their overall uniformity, the veins occur in extremely varied host rocks including those of the Sicker Group, Karmutsen Formation, Bonanza Formation,

Table 5

Main Coal Mines (all abandoned)

Index Number	Company	Mine
Nanaimo Basin		
Wellington Seam		
1	C.C.	No. 8 Mine Extension Mines
2	C.C.	White Rapids Mine
3	C.C.	No. 2 Slope, Extension Mines
4	C.C.	No. 3 Slope, Extension Mines
5	C.C.	Tunnel to Nos. 1, 2, 3 Extension Mines
6	C.C.	No. 1 Slope, Extension Mines
7	C.C.	Old No. 1 Slope, Extension Mines
8	C.C.	No. 4 Extension Mines
9	W.F.C.	Harewood Mine
10	W.F.C.	Wakesiah Mine
11	V.N.C.M.C.	Jingle Pot Mine
12	E.W.C.C.	East Wellington Mine
13	E.W.C.C.	Chandler Mine, No. 1 Shaft
14	W.F.C.	Northfield Mine
15	C.C.	No. 1 Shaft, Wellington Mine
16	C.C.	No. 5 Shaft, Wellington Mine
17	C.C.	No. 2 and 3 Shafts, Wellington Mine
18	C.C.	No. 9 Wellington Mine
19	N.W.C.	Lantzville Mine
20	L.C.	No. 1 Mine
Douglas Seam		
21	C.C.	Bright Mine
22	G.C.M.S.	Granby Mine
23	C.C.	No. 10 Mine
24	C.C.	No. 5 Mine
25	P.C.C.M.	Morden Mine
26	C.C.	Alexandra Mine
27	P.C.C.M.	South Wellington Colliery
28	W.F.C.	Southfield No. 1 and No. 2 Slopes
29	W.F.C.	Southfield No. 5 Mine
30	W.F.C.	Reserve Mine
31	W.F.C.	Southfield No. 4 Slope
32	W.F.C.	Southfield No. 3 Mine
33	W.F.C.	New Douglas Mine
34	W.F.C.	No. 1 Mine
35	W.F.C.	Old Douglas Shaft
36	W.F.C.	Earliest Hudson Bay pits
37	W.F.C.	Protection Shaft, No. 1 Mine
38	W.F.C.	Newcastle Shaft
39	W.F.C.	Fitzwilliams Slope

Table 5 (continued)

Index Number	Company	Mine	
Newcastle Seam			
40	W. F. C.	Brechin Mine	
Comox Basin			
41	C. C.	Tsable River Mine	
42	C. C.	No. 1 Mine	No. 1 Seam
43	C. C.	No. 2 Mine	No. 4 Seam
44	C. C.	No. 3 Mine	No. 1 Seam
45	C. C.	No. 4 Mine	No. 4 Seam
46	C. C.	No. 5 Mine	Nos. 1, 2, and 4 Seams
47	C. C.	No. 6 Mine	Nos. 1, and 4 Seams
48	C. C.	No. 7 Mine	No. 4 Seam
49	C. C.	No. 8 Mine	No. 2 Seam

Companies:

W. F. C.	Western Fuel Corporation of Canada Limited
C. C.	Canadian Collieries (Dunsmuir) Limited
V. N. C. M. C.	Vancouver-Nanaimo Coal Mining Company Limited
E. W. C. C.	East Wellington Coal Company Limited
G. C. M. S.	Granby Consolidated Mining, Smelting and Power Company Limited
P. C. C. M.	Pacific Coast Coal Mines Limited
N. W. C.	North Wellington Collieries Limited
L. C.	Lantzville Collieries Limited

Nanaimo Group, skarn, gneisses, and Tertiary and older granitic intrusions. Hence they probably were deposited by solutions originating outside the host rocks, possibly at great depths.

Porphyry copper deposits (H)

Porphyry copper deposits of the Alberni map-area are Catface, Big I, Faith Lake, Gem Lake, Mount Washington - Murex, and Corrigan Creek. They consist of large scattered zones of low grade disseminated and fracture-filling chalcopyrite with minor to negligible gold and molybdenum. Their main characteristics are given in Table 3.

All known deposits are within and adjacent to intrusive complexes of quartz diorite, dacite porphyry and breccia. Quartz monzonite is also present at Catface. Three of these complexes are known and the others, excepting possibly the Corrigan Creek quartz diorite, are inferred to be of Tertiary age. All but the Corrigan Creek deposit are in a northeast-trending zone which crosses the regional structure and may be the locus of a major Tertiary fundamental fracture zone.

Fracturing of the outer parts of the complexes, and doming, fracturing, and brecciation of host rocks due to forcible intrusion and/or faulting have provided favourable zones for mineral deposition at Mount Washington - Murex, Catface, Faith Lake, and probably at Gem Lake and Big I.

To date, no production has occurred from the porphyry copper deposits.

Gold placers

Limited gold placer mining occurred, especially during the depression, on Oyster River, Bedwell River, China Creek, and at Wreck Bay.

COAL DEPOSITS

by J. E. Muller

The area contains both major coal fields of Vancouver Island in Nanaimo Basin and Comox Basin. The geology of the upper Cretaceous Nanaimo Group containing the seams has been outlined in a preceding section. Coal has been mined for over one hundred years, starting in 1853 with the small pits of the Hudson's Bay Company in present downtown Nanaimo. The major seams are now largely exhausted at mineable levels after a total production of about 72 million tons. Locations of erstwhile larger coal mines are shown on Figure 3 and they are listed in Table 5.

Mining was chiefly carried out by two successive lines of companies. The first one started with the original diggings by the Hudson's Bay Company in Nanaimo and developed, through several reorganizations, into the Western Fuel Corporation of Canada. Among several mines, operated by the company in the Nanaimo field, was the large and long-lasting Number One mine which produced a total of 18,000,000 tons from 1883 to 1938. Its workings were under Nanaimo Harbour to a depth of 1,700 feet with shafts on the Esplanade, near the foot of Dixon Street in Nanaimo, and on Protection Island. The mine was in the Douglas Seam in the upper part of the Extension - Protection Formation. Other mines of the company, listed in Table 5 were all in the Nanaimo field, mainly in Douglas, but also in Wellington and Newcastle seams. The company was amalgamated with Canadian Collieries Ltd. in 1928.

The other line of companies was started by Robert Dunsmuir who came from Scotland in 1851 to work for the Hudson's Bay Company coal mine. He located first the Harewood Mine and sold the lease to the then operating mining company. Later he found and acquired the Wellington coal field for himself. The line of companies owned by several generations of Dunsmuirs and ultimately known as Canadian Collieries (Dunsmuir) Limited, operated coal mines from 1869 to 1953.

To the original Wellington Mines in the Wellington seam, at the base of the Extension-Protection Formation, the company added in 1895 the Extension Mines on the same seam. The Alexandra Mine, and later Number Five and Number Ten Mines were in the Douglas seam. A few smaller companies listed in Table 5, also operated one or two mines in the Nanaimo field.

In 1910 Canadian Collieries also took over the holdings of Union Colliery Company, operating in the Comox field, east and southeast of Comox Lake. There three seams, called Number One, Number Two and Number Four seams were worked in mines (numbered one to eight) starting in 1875. The Tsable River Mine, in a distinct and separate small coal field began operating in 1947 and continued as the last of the larger mines of Vancouver Island until 1966. All seams of the Comox field are in the Comox Formation.

A total of about 72,000,000 metric tons of coal has been mined from the area. In 1946 the Royal Commission on Coal, in their report estimated a probable recoverable reserve of coal of 26 million metric tons for the Nanaimo and Comox fields. More than four million tons have been mined since this estimate and a prediction that production at current (1946) level could not continue for more than 15 years has proved correct. The reserves of mineable seams were calculated to 2,000 feet depth although mining at depths over 1,000 feet has not been extensive due to the greater cost and the danger of bumps below that level. Thus the reserves may be actually smaller and it appears that under present conditions coal mining on Vancouver Island is no longer economic. However, considerable acreages of seams might become economic again with newer extraction methods. Most of these are in the Comox field, especially in undeveloped portion of Tsable River and Quinsam areas.

Analyses of Nanaimo and Comox coals, published by the Mines Branch, Department of Energy, Mines and Resources give the following ranges of values.

Moisture	%	2.5-6.0		
Ash	%	11.6 (in lump)	–	15.6 (fines)
Volatile matter	%	30.2 (fines)	–	36.5 (nut)
Fixed Carbon	%	45.6 (nut)	–	53.7 (cobble)
Calorific value		11.840 B. T. U. /lb.		

Ash softening temperature 2115 – 2305 F°

Coaking properties are fair to good and the classification by A. S. T. M. rank is High volatile A bituminous.

LIMESTONE

by J. E. Muller

Limestone deposits of the area have been described in detail by Mathews and McCammon (1957). Quatsino (Marble Bay) limestone, underlying large areas of Texada Island, is a pure limestone with less than one per cent magnesium and low phosphorous content. So far as known the Buttle Lake limestone of the Sicker Group does not have the same qualities.

Texada Island, with a production valued at more than 2 million dollars per year is the main source of limestone in British Columbia. Large reserves, mainly under lease to several cement companies, are present on this island. The geological map of the area shows other areas of Quatsino Limestone and some of these, outcropping near tidewater may be economic. They are probably more densely riddled with porphyry dykes than the Texada Island deposits and may be less pure.

BIBLIOGRAPHY

Bacon, W. R.
1957: Iron deposits in coastal and southwestern British Columbia; B. C. Minister of Mines, Ann. Rept. 1956, p. 125.

Bancroft, J. A.
1913: Geology of the coast and island between Strait of Georgia and Queen Charlotte Sound, British Columbia; Geol. Surv. Can., Mem. 23.

Bancroft, M. F.
1937: Gold-bearing deposits on the west coast of Vancouver Island between Esperanza Inlet and Alberni Canal; Geol. Surv. Can., Mem. 204.

Bell, W. A.
1957: Flora of the Upper Cretaceous Nanaimo Group of Vancouver Island, British Columbia; Geol. Surv. Can., Mem. 293.

British Columbia
Annual Report of Minister of Mines, 1900-1967.

Buckham, A. F.

1947a: The Nanaimo Coal Field; Trans. Can. Inst. Mining Met., vol. 50, pp. 460-472.

1947b: Preliminary map, Nanaimo coal field; Geol. Surv. Can., Paper 47-22.

Carlisle, D.

1963: Pillow breccias and their aquagene tuffs, Quadra Island, British Columbia; J. Geol., vol. 71, pp. 48-71.

Carlisle, D., and Suzuki, T.

1965: Structure, stratigraphy, and palaeontology of an Upper Triassic section on the west coast of British Columbia; Can. J. Earth Sci., vol. 2, pp. 442-484.

Carson, D. J. T.

1960: Geology of Mount Washington, Vancouver Island, B. C.; Univ. British Columbia, unpubl. M. Sc. thesis.

1968: Metallogenic study of Vancouver Island with emphasis on the relationship between plutonic rocks and metallic mineral deposits; Carleton Univ., Ottawa, unpubl. Ph. D. thesis.

Clapp, C. H.

1909: Southeastern portion of Vancouver Island; Geol. Surv. Can., Sum. Rept. 1908, pp. 52-60.

1912a: Geology of Nanaimo Sheet, Nanaimo Coal Field, Vancouver Island, British Columbia; Geol. Surv. Can., Sum. Rept. 1911, pp. 91-105.

1912b: Note on the geology of the Comox and Suquash Coal Fields; Geol. Surv. Can., Sum. Rept. 1911, pp. 105-107.

1912c: Southern Vancouver Island; Geol. Surv. Can., Mem. 13.

1913: Geology of the Victoria and Saanich map-areas, Vancouver Island; Geol. Surv. Can., Mem. 36.

1914: Geology of the Nanaimo map-area; Geol. Surv. Can., Mem. 51.

Clapp, C. H., and Cooke, H. C.

1917: Sooke and Duncan map-areas, Vancouver Island; Geol. Surv. Can., Mem. 96.

Dawson, G. M.

1887: Report on a geological examination of the northern part of Vancouver Island and adjacent coasts; Geol. Surv. Can., Ann. Rept. 1886, vol. 2, Pt. B, pp. 1-107.

1890: Notes on the Cretaceous of the British Columbian region. The Nanaimo group; Am. J. Sci., vol. 39, pp. 180-183.

Dolmage, V.

1919: Quatsino Sound and certain mineral deposits of the west coast of Vancouver Island, British Columbia; Geol. Surv. Can., Sum. Rept. 1918, pp. 30-38.

1921: West coast of Vancouver Island between Barkley and Quatsino Sounds; Geol. Surv. Can., Sum. Rept. 1920, Pt. A, pp. 12-22.

Eastwood, G. E. P.

1963: Geology of the Kennedy Lake area; B. C. Minister Mines and Petrol. Resources; Ann. Rept. 1962, pp. 111-122.

1964: Tofino Inlet; B. C. Minister Mines and Petrol. Resources; Ann. Rept. 1963, pp. 111-121.

1965: Replacement magnetite on Vancouver Island, British Columbia; Ec. Geol., vol. 60, pp. 124-148.

Fyles, J. T.

1955: Geology of the Cowichan Lake Area, Vancouver Island, B. C.; B. C. Dept. Mines, Bull. 37.

Fyles, J. G.

1963: Surficial Geology of Horne Lake and Parksville Map-Areas, Vancouver Island, British Columbia; Geol. Surv. Can., Mem. 318.

Givens, C. R., and Suzuki, T.

1964: Late triassic fauna from interlava sediments of east central Vancouver Island (abstract), Geol. Soc. Am., Spec. Paper 76, p. 203.

Gunning, H. C.

1930: Geology and mineral deposits of the Quatsino-Nimpkish area, Vancouver Island; Geol. Surv. Can., Sum. Rept. 1929, Pt. A, pp. 94-143.

1931: Buttle Lake map-area, Vancouver Island, British Columbia; Geol. Surv. Can., Sum. Rept. 1930, Pt. A, pp. 56-78.

1932: Preliminary report on the Nimpkish Lake Quadrangle, Vancouver Island, B. C.; Geol. Surv. Can., Sum. Rept. 1931A, pp. 22-35.

Hoadley, J. W.

1953: Geology and mineral deposits of the Zeballos-Nimpkish area, Vancouver Island, British Columbia; Geol. Surv. Can., Mem. 272.

Holland, S. S.

1964: Landforms of British Columbia; B. C. Dept. Mines Petrol. Resources, Bull. 48.

Hurst, M. E.

1927: Arsenic-bearing deposits in Canada; Geol. Surv. Can., Ec. Geol. ser. no. 4, pp. 36-38.

Jeffery, W. G.

1963: Buttle Lake area, Vancouver Island; B. C. Dept. Mines and Petrol. Resources, Prelim. Geol. Map.

1965: Lynx Paramount, Price (Western Mines Limited); B. C. Minister Mines and Petrol Resources, Ann. Rept. 1964, pp. 157-166.

Jeletzky, J. A.

1950: Stratigraphy of the west coast of Vancouver Island between Kyuquot Sound and Esperanza Inlet, British Columbia; Geol. Surv. Can., Paper 50-37.

1954a: Tertiary rocks of the Hesquiat-Nootka area, west coast of Vancouver Island, British Columbia; Geol. Surv. Can., Paper 53-17.

1954b: Geological history of the west coast of Vancouver Island (Abstract); Bull. Geol. Soc. Am., vol. 65, p. 1269.

1967: Biochronology of the lower part of Nanaimo Group (mid-Upper Cretaceous), eastern Vancouver Island (92F, 92G); Geol. Surv. Can., Paper 67-1, Pt. A, pp. 69-70.

Mathews and McCammon

1957: Calcareous deposits of southwestern British Columbia; B. C. Dept. Mines, Bull. 40 (essentially a revision of B. C. Dept. Mines, Bull. 23 by Mathews 1947).

McConnell, R. G.

1914: Texada Island, British Columbia; Geol. Surv. Can., Mem. 58.

McGugan, A.

1962: Upper Cretaceous Foraminifera Zones, Vancouver Island, British Columbia; J. Alta. Soc. Petrol. Geol., vol. 10, pp. 585-592.

MacKenzie, J. D.

1922: The coal measures of Cumberland and vicinity, Vancouver Island; Trans. Can. Inst. Mining Met., vol. 25, pp. 382-411.

1923: Alberni area, Vancouver Island; Geol. Surv. Can., Sum. Rept. 1922A, pp. 51a-67a.

Muller, J. E.

1964: Alberni area; Geol. Surv. Can., Map 49-1963.

1965: Comox Lake area; Geol. Surv. Can., Map 2-1965.

Muller, J. E., and Jeletzky, J. A.

1967: Stratigraphy and biochronology of the Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia; Geol. Surv. Can., Paper 67-1B, pp. 38-47 (summary of larger paper, in preparation).

Richardson, J.

1872: Coal fields of the east coast of Vancouver Island; Geol. Surv. Can., Rept. of Prog. 1871-1872, Pt. 3, pp. 73-100.

1873: Coal fields of Vancouver Island; Geol. Surv. Can., Rept. of Prog. 1872-1873, Pt. 4, pp. 32-65.

1878: Coal fields of Nanaimo, Comox, Cowichan, Burrard Inlet and Sooke, B. C.; Geol. Surv. Can., Rept. of Prog. 1876-1877, Pt. 7, pp. 160-192.

Sargent, H.

1940: Preliminary report on the Bedwell River area, Vancouver Island, British Columbia; B. C. Dept. Mines, Bull. 8.

1941: Supplementary report on Bedwell River area, Vancouver Island, British Columbia; B. C. Dept. Mines, Bull. 13.

Stevenson, J. S.

1945a: Geology and ore deposits of the China Creek area, Vancouver Island, British Columbia; B. C. Minister of Mines, Ann. Rept. 1944, pp. 142-161.

1945b: Geology of the "Twin J" Mine; Western Miner, vol. 18, pp. 38-44.

1950: Geology and mineral deposits of the Zeballos Mining Camp, British Columbia; B. C. Dept. Mines, Bull. 27.

Surdam, R. C., Suzuki, T., and Carlisle, D.

1963: Upper Triassic Section on Iron River, Vancouver Island (abstract); Geol. Soc. Am., Special Paper 76, p. 203.

Sutherland Brown, A.

1966: Tectonic history of the insular belt of British Columbia; Can. Inst. Mining Met., Spec. vol. 8, pp. 83-100.

in press: Geology of the Queen Charlotte Islands; B. C. Dept. Mines, Bull. 54.

Tozer, E. T.

1967: A standard for Triassic time; Geol. Surv. Can., Bull. 156.

Usher, J. L.

1952: Ammonite faunas of the Upper Cretaceous rocks of Vancouver Island, British Columbia; Geol. Surv. Can., Bull. 21.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Rimsaite, J. Y. H.

1966: Age determinations and geological studies, K-Ar Isotopic ages, Report 6; Geol. Surv. Can., Paper 65-17.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Edmonds, C. M.

1967: Age determinations and geological studies; K-Ar Isotopic Ages, Report 7; Geol. Surv. Can., Paper 66-17.

Wanless, R. K., Stevens, R. D., Lachance, G. R., and Edmonds, C. M.
1968: Age determinations and geological studies; K-Ar Isotopic Ages, Report 8, Geol. Surv. Can., Paper 67-2A.

Webster, A.
1903: Geology of the west coast of Vancouver Island; Geol. Surv. Can., Sum. Rept. 1902, pp. 52-76.

Williams, T. B.
1924: The Comox Coal Basin, Univ. Wisconsin, unpubl. Ph.D. thesis.

Yole, R. W.
1963: An Early Permian fauna from Vancouver Island, British Columbia; Bull. Can. Petrol. Geol., vol. 11, pp. 138-149.

1965: A faunal and stratigraphic study of Upper Paleozoic rocks of Vancouver Island, British Columbia; Univ. British Columbia, unpubl. Ph.D. thesis.