69-25

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 69-25

GEOLOGY OF THE UPPER CRETACEOUS NANAIMO GROUP, VANCOUVER ISLAND AND GULF ISLANDS, BRITISH COLUMBIA

(Report, 3 tables and 11 figures)

J. E. Muller and J. A. Jeletzky

Price, $2.00

1970

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Price: $2.00 Catalogue No. M44-69-25

Price subject to change without notice

Queen's Printer for Canada
Ottawa
1970

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ABSTRACT

The Upper Cretaceous Nanaimo Group, for more than one hundred years subject of study of many geologists and paleontologists, is being restudied by Muller (geology and stratigraphy) and Jeletzky (biochronology).

The group is newly subdivided in four succeeding transgressive sedimentation cycles. Each contains most of the following successive facies:

(1) Fanglomerate (angular, unsorted) and greywacke: basal fluvial and coastal deposits.

(2) Conglomerate (well-rounded, sorted), grit, sandstone: deltaic and shoreline deposits.

(3) Sandstone, shale and coal (plant fossils): shore-bar and lagoonal deposits.

(4) Siltstone, shale minor sandstone, many thick-shelled fossils: nearshore marine deposits.

(5) Thin-bedded siltstone-shale turbidite sequences, few fossils are ammonites: offshore deposits.

Previous workers recognized the alternation of conglomerate-sandstone and siltstone-shale formations and established a double formational succession, one for the Nanaimo Basin and one for the Comox Basin. With some changes in correlation two formational names have been retained for each cycle, giving a succession of eight alternating mainly nonmarine and marine formations. A ninth and youngest formation is nonmarine.

Economic coal deposits were formed in the Nanaimo Group in the Comox Basin during the first cycle and in the Nanaimo Basin during the second cycle.

Six faunal zones and subzones are established on the basis of ammonites and inocerami and integrated with the depositional cycles.

The lower two faunal subzones correspond to McGugan's (1962) *Rugoglobigerina* zone; the middle three to his *Cibicides voltziana* zone and the upper subzone to his *Bolivina incrassata* zone.

The sedimentary basin occupied in the earlier cycles the southwestern part of the Strait of Georgia and adjacent areas of Vancouver Island with a southward oceanic connection. In the later cycles parts of northern Vancouver Island and the mainland were also submerged but the basin was probably closed off to the south and open to the north.

The structure features mainly northwestwardly tilted blocks, separated by northwesterly longitudinal normal faults and by northeasterly cross-faults. Near the fault zones beds are flexured steeply and closely folded; otherwise strata are flat or gently inclined.

<table>
<tr><th>STAGE</th><th colspan="2">ZONE AND SUBZONE</th><th>FORMATION</th><th>CYCLE</th></tr>
<tr><td rowspan="2">Maestrichtian</td><td colspan="2"></td><td>GABRIOLA
600' – 3000'</td><td>nonmarine</td></tr>
<tr><td rowspan="4">Suciaensis zone</td><td>Hornbyense subzone</td><td rowspan="2">SPRAY
950' – 1770'</td><td rowspan="3">fourth cycle</td></tr>
<tr><td rowspan="9">Campanian</td><td rowspan="3">cf. Pacificum subzone</td></tr>
<tr><td>GEOFFREY
400' – 1500'</td></tr>
<tr><td>NORTHUMBERLAND
500'</td><td rowspan="2">third cycle</td></tr>
<tr><td colspan="2" rowspan="3">Vancouverense zone</td><td>DE COURCY
900' – 1400'</td></tr>
<tr><td>CEDAR DISTRICT
1000'</td><td rowspan="3">second cycle</td></tr>
<tr><td rowspan="2">EXTENSION
PROTECTION
200' – 1900'</td></tr>
<tr><td colspan="2" rowspan="2">Schmidti zone</td></tr>
<tr><td rowspan="3">HASLAM
200' – 500'</td><td rowspan="4">first cycle</td></tr>
<tr><td rowspan="3">Elongatum zone</td><td>Haradai subzone</td></tr>
<tr><td rowspan="2">Santonian</td><td rowspan="2">Naumanni subzone</td></tr>
<tr><td>COMOX
150' – 2000'</td></tr>
</table>

GEOLOGY OF THE UPPER CRETACEOUS NANAIMO GROUP, VANCOUVER ISLAND AND GULF ISLANDS, BRITISH COLUMBIA

INTRODUCTION

The Nanaimo Group of western British Columbia embraces a late Upper Cretaceous sequence of sandstone, conglomerate, shale and coal. It is exposed along parts of the east coast of Vancouver Island and on the adjacent smaller islands in the Strait of Georgia and Queen Charlotte Strait, mainly in British Columbia but with small areas in the San Juan Islands group in the State of Washington.

Since about 1850 the economic value of its coal deposits has drawn the attention of geologists and the locally abundant fossil fauna and flora have been studied by several paleontologists. Regional mapping of Vancouver Island, undertaken by Muller in 1963 and still continuing, entailed a review of Nanaimo Group stratigraphy. This necessitated substantial biochronological field and office work by Jeletzky. The present paper is a progress report on these joint studies of the Nanaimo Group.

Special thanks are due to those who contributed in many ways to the investigation. K.J. Roy, M.E. Atchison and J.R. McLean aided materially by describing and sampling many stratigraphic sections and making fossil collections and valuable support of the work was received from many undergraduate field assistants. M.E. Atchison also aided substantially in the preparation of text figures. Messrs. S.B.W. Isachsen, W.W. Johnstone and W. Frew of Canadian Collieries Resources Ltd. and Mr. R. Bonar with other officials of the British Columbia Department of Mines and Petroleum Resources were most helpful by supplying information on the coal mines.

The following American and Canadian paleontologists facilitated Jeletzky's research by permitting him to study the relevant Upper Cretaceous collections and types in their care or by providing him with original specimens or plaster casts of the same: Dr. David L. Jones of United States Geological Survey, Washington, D.C.; Dr. Leo Hertlein of the California Academy of Science, San Francisco, California; Dr. Joseph H. Peck, Jr. of the Paleontology Department, University of California, Berkeley; Dr. W.P. Popenoe of the Geology Department, University of California, Los Angeles; Dr. R.V. Best of the Geology Department, University of British Columbia, Vancouver.

Project 630014
Ms. received 24 February, 1969
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TABLE 1. PRESENT AND EARLIER CORRELATIONS OF NANAIMO GROUP SUCCESSION IN COMOX AND NANAIMO BASINS

Richardson 1873	Clapp 1912-1917	McKenzie Williams 1924	Buckham, 1947 Usher, 1952			Crickmay and Pocock, 1963			McGugan, 1962 Williams-Burk, 1964			Muller-Jeletzky (this paper)		
COMOX BASIN	NANAIMO BASIN	COMOX BASIN		NANAIMO BASIN	COMOX BASIN		NANAIMO BASIN	COMOX BASIN		NANAIMO BASIN	COMOX BASIN		NANAIMO BASIN COMOX BASIN	
upper conglomerate	GABRIOLA	ST JOHN	MAESTRICHTIAN	GABRIOLA	HORNBY	MAESTRICHTIAN	GABRIOLA	TRIBUNE	MAESTRICHTIAN	GABRIOLA	HORNBY	MAESTR	GABRIOLA	NON-MAR.
upper shales		TRIBUNE		NORTH-UMBERLAND	SPRAY						SPRAY	CAMPANIAN	SPRAY	FOURTH CYCLE
middle conglomerate		HORNBY			GEOFFREY		NORTH-UMBERLAND	HORNBY			GEOFFREY		GEOFFREY	
											U. LAMBERT			
middle shales	NORTH-UMBERLAND	LAMBERT			LAMBERT			LAMBERT	upper CAMPANIAN	NORTH-UMBERLAND	L. LAMBERT		NORTH-UMBERLAND	THIRD CYCLE
lower conglomerate	DE COURCY	DENMAN	CAMPANIAN	DE COURCY	DENMAN	upper CAMPANIAN	DE COURCY	upper DENMAN		DE COURCY	DENMAN		DE COURCY	
lower shales	CEDAR DISTRICT	TRENT RIVER		CEDAR DISTRICT	TRENT RIVER		CEDAR DISTRICT	not present		CEDAR DISTRICT	U. TRENT RIVER		CEDAR DISTRICT	SECOND CYCLE
coal-measures	PROTECTION	COMOX		PROTECTION	COMOX		PROTECTION			PROTECTION			EXTENSION-PROTECTION	
	NEWCASTLE			NEWCASTLE	QUALICUM		NEWCASTLE	DENMAN	SANTONIAN to CAMPANIAN	NEWCASTLE				
	CRANBERRY			CRANBERRY			CRANBERRY			CRANBERRY				
	EXTENSION			EXTENSION			EXTENSION			EXTENSION				
	EAST-WELLINGTON			EAST-WELLINGTON		lower CAMPANIAN	EAST-WELLINGTON	not present		U. HASLAM			E. WELLINGTON MEMBER	
	HASLAM		? SANTONIAN	HASLAM			HASLAM	TRENT RIVER		L. HASLAM	L. TRENT RIVER	SANTONIAN	HASLAM	FIRST CYCLE
	BENSON			BENSON			BENSON	COMOX		BENSON	COMOX QUALICUM		COMOX BENSON MBR	

STRATIGRAPHY

(J.E. Muller)

Previous Work

The earliest geological reports, dealing briefly with Nanaimo Group sediments, are those of Newberry (1857) and Hector (1861), both made in the course of exploratory survey expeditions.

Richardson (1872, 1873) was the first to record detailed stratigraphic sections of the Cretaceous beds in the Comox region and to establish the general succession (Table I). He found the coal measures directly overlying the "crystalline rocks" (mainly Triassic basaltic lavas). Above these he distinguished three succeeding conglomeratic units, separated by marine shales. In the Nanaimo region, where his work was less detailed, he considered the productive coal measures and overlying marine shales to be correlative to the lower two divisions of the Comox area but did not subdivide the overlying formations.

Dawson (1887) reported on the Upper Cretaceous rocks of the northern 'Suquash' area and (1890) first proposed the name Nanaimo Group for the entire Upper Cretaceous succession.

Clapp (1912a to 1914b) and Clapp and Cooke (1917) carried out geological mapping in south Vancouver Island and established and named the succession of formations in the Nanaimo area. This work has become a standard reference on the Nanaimo Group. The subdivision into successive conglomerate-sandstone formations and shale formations appears generally valid and comparable to that of Richardson in the Comox Basin (Table I). The stratigraphy was entirely based on lithology as Clapp believed that identical Upper Cretaceous marine faunas occurred throughout the Nanaimo Group.

MacKenzie (1922, 1923) continued Clapp's and Clapp and Cooke's work and left two papers on the Alberni and Comox areas before his untimely death. Williams (1924) carried on in the Comox area and in an unpublished thesis changed Richardson's informal subdivisions into formation names.

Only part of the work of Buckham (1947a and b) on the Nanaimo Group has been published but some of his accumulated information is contained in Usher's publication. Usher (1949, 1952) concerned himself mainly with the ammonite fauna of the Nanaimo Group which he collected, described, and illustrated in detail but he also gave detailed descriptions of the formations and established several biochronological zones of Santonian to Maestrichtian age, thereby refuting Clapp's assumption of paleontological uniformity throughout the sequence.

Bell (1957) made a study of the available fossil plant collections and drew general conclusions on age and correlation.

McGugan (1962, 1964) made a study of the foraminifera of the marine shales. By his biochronologic correlation he showed indirectly that the productive coal measures of the Comox and Nanaimo basins, until then considered to be of equal age by all previous workers, were indeed not correlative. McGugan's stratigraphic correlations were adopted by Williams and Burk (1964) and a similar conclusion was drawn by Crickmay and Pocock (1963) on the basis of fossil pollen and spores.

Geographic Distribution

Nanaimo Group sediments are present along the east coast of Vancouver Island, in outliers farther inland to the west, and on islands in the Strait of Georgia to the east. Buckham (1947a, p. 460) distinguishes five basins of deposition: the Nanaimo, Comox, Cowichan, Alberni, and Suquash basins. Present 'basins' probably do not correspond to original areas of deposition but are largely determined by post-Cretaceous block-faulting and tilting and preservation of the sediments in structurally depressed areas. Outcrop areas of the Nanaimo Group may be designated as follows:

The Port McNeill ('Suquash') area, a coastal strip about 20 miles long, probably contains a thickness of less than 1,000 feet of Nanaimo sediments. The earliest discovery of coal was made there (1835) but despite several attempts at mining very little coal was ever produced due to uneconomical seam thickness. Small related occurrences of Nanaimo beds are now known on the west coast of Hope Island in Queen Charlotte Strait and east of Neroutsos Inlet.

Comox Basin or area is the name for the coastal strip of Upper Cretaceous rocks between Campbell River and Bowser. The name originated with Richardson (1872) who found Comox Harbour, now the city of Courtenay, to be the nearest settlement to the coal deposits of that area. The present village of Comox is on a drift-covered peninsula but as the name Comox Basin is well established in geological literature it is best retained. This region contains the Cumberland and Tsable River coal deposits in the Comox Formation with many abandoned mines. Coal has also been drilled but not mined in the Quinsam and Oyster River areas. Younger formations are exposed on Denman, Hornby and Texada islands.

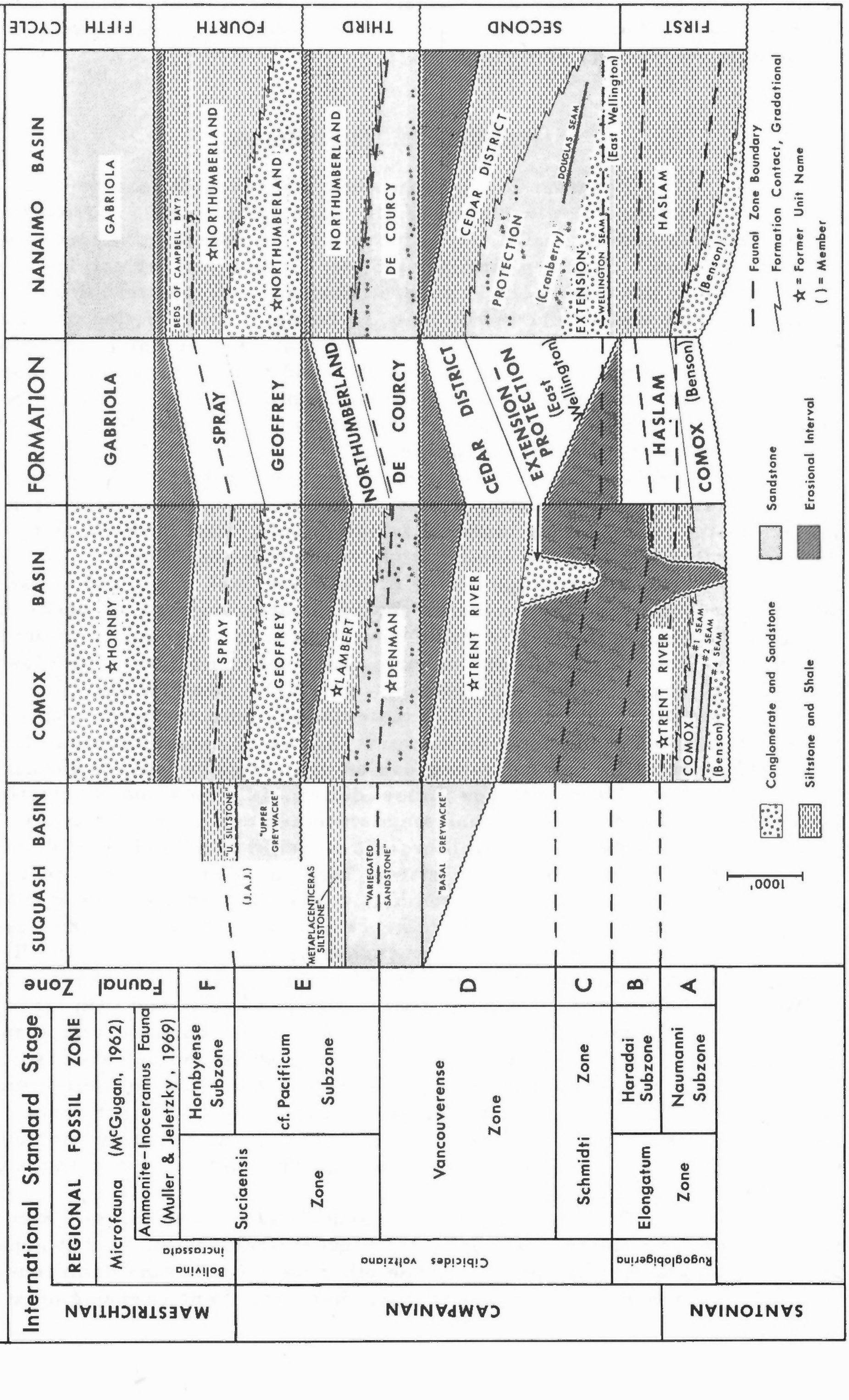
Cretaceous outcrops along the Upper Quinsam and Oyster rivers, and on Mount Washington and Forbidden Plateau are outliers of the Comox Basin occurring at elevations of 4,000 feet and over. They are noted for thick sills of dacite and the Mount Washington quartz diorite stock with associated breccias that intrude Cretaceous beds.

In the Alberni Basin, Cretaceous rocks have been preserved in the Alberni Valley graben. No coal has been discovered here and as the rocks are poorly exposed and only one drillhole has ever been recorded, relatively little is known about the geology. Outliers to the west are on Thunder Mountain and on Patlicant Mountain, the latter contains a thick dacite sill.

The term Nanaimo Basin or area is used here to designate the Cretaceous rocks in the vicinity of Nanaimo, and those of the Gulf Islands. Most of the coal from Vancouver Island was produced from this region between 1853 and 1953 from Wellington and Douglas seams. Here too the youngest formations are exposed only on the Gulf Islands east and southeast of the productive area. Between Comox and Nanaimo Basin there are outliers of Nanaimo beds, also with dacite sills, at the head of Englishman and Nanaimo rivers.

The Cowichan Basin or area is, like the Alberni Basin, preserved in a complex graben structure, though only narrowly separated by pre-Cretaceous rocks from the Nanaimo Basin. Its geology is also less well known due to absence of coal seams but exposures are better than near Alberni. Fossils found to date have substantiated the presence of the lower part of the Nanaimo Group.

Figure 1. BIOCHRONOLOGICAL AND LITHOLOGICAL DIVISIONS OF NANAIMO GROUP



Finally, equivalents of the Nanaimo Group are known in the Mount Garibaldi area (Mathews, 1958), the Fraser Lowlands and in northwestern Washington State (Miller and Misch, 1963) but these areas are not included in the present summary.

Conditions of Sedimentation

The Nanaimo Group sedimentary succession may be viewed as a series of transgressive cycles (Fig. 1), each exhibiting a progression from (a) fluvial to (b) deltaic and/or (c) lagoonal, to (d) nearshore marine and (e) offshore marine. They are similar to Upper Cretaceous formations on the eastern side of the Cordillera in general lithology and intertonguing relationships of marine and nonmarine beds (e.g. Young, 1955). Young defines the megacyclothems of the Upper Cretaceous of Utah as developing from marine shale at the bottom through littoral marine sandstone to lagoonal deposits with coal at the top indicating a regressive hemicycle. So far as can be judged from available information the Nanaimo Group shows such cycles in reverse, indicating gradual transgression.

The various sedimentary facies are named here after the formation that displays them prominently or exclusively. Most are present in each cycle, but the coal-bearing lagoonal facies is only found in the first cycle in the Comox Basin and in the second cycle in the Nanaimo Basin.

The Benson-type facies (fluvial) 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 (deltaic) is also a 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 (lagoonal) 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, separated from the sea by shore bars (Buckham, 1947a). The 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 (nearshore marine), 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 thick-shelled fossils indicating nearshore deposition. These beds were laid down at shallow depths subject to disturbance by wave action.

The Cedar District-type facies (offshore marine) 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 'diminutive overthrusts' ranges from a few inches for thin units to as much as 10 feet for sandstone beds of about one foot thickness. Similar structures in the coal seams were described by Clapp (1914a), 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 in thickness. 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.

This Cedar District-type facies was deposited in deeper water than the Haslam facies, 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 interrupted by rapid re-emergence, generally not accompanied by sedimentation, whereafter a new cycle followed. The lithological succession is schematically represented in Figure 1. 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.

The following shows the succeeding sedimentary cycles and their component formations, facies, and main lithology (discontinued formational names in brackets).

Fifth cycle (incomplete)

Deltaic: Gabriola; sandstone, conglomerate, shale

Fourth cycle

Marine: Spray; shale

Deltaic: Geoffrey; sandstone, conglomerate

Third cycle

Marine: Northumberland (Lambert); shale, siltstone, fine-grained sandstone

Deltaic: De Courcy (Denman); conglomerate, sandstone

Second cycle

Marine: Cedar District; shale, siltstone, fine-grained sandstone

Deltaic: Extension; conglomerate, sandstone

Lagoonal: Protection; sandstone, shale, coal: Douglas seam at base

Lagoonal and littoral marine (regressive phase): Wellington Member; sandstone, shale, coal: Wellington Seam

First cycle

Marine: Haslam (Trent River); shale, siltstone, fine-grained sandstone

Lagoonal: Comox; sandstone, shale, coal

Fluvial: Benson; conglomerate, greywacke

Comox Formation

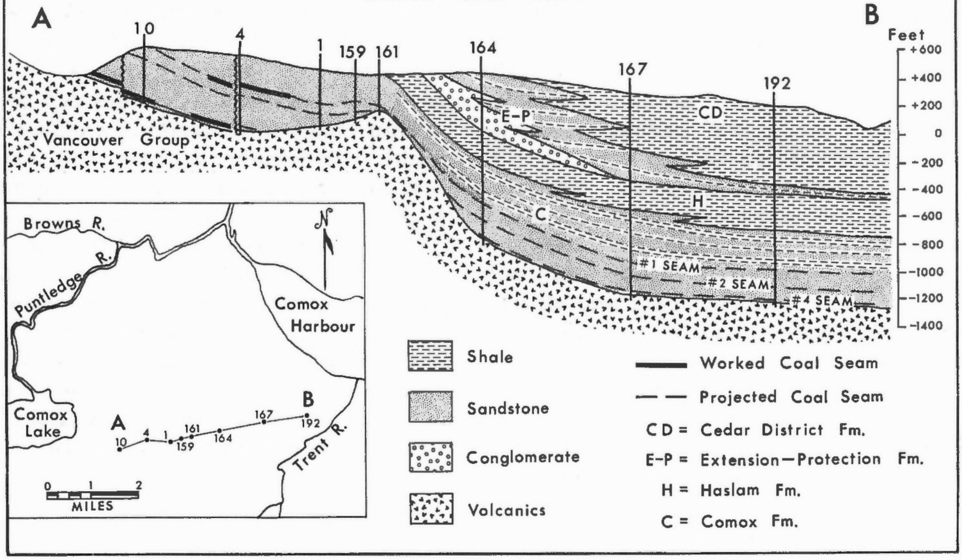
Names

The Comox Formation with Benson basal 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. It is now established that both Comox and Benson underlie marine beds with the Santonian Naumanni fauna. The Benson conglomerate is therefore to be considered as the basal conglomerate member of the Comox Formation.

Distribution and thickness

The Comox is exposed in all the Nanaimo Group areas on Vancouver Island and on Saltspring Island but is best developed in Comox

Figure 2. Structural Section Through Cumberland Area of Comox Coal Basin



Basin. There the beds have been laid down in three subbasins (see sec. A-B, Fig. 11): the Quinsam area in the north, the Cumberland area in the middle, and the Tsable River area in the south.

In the first area named both Benson conglomerate and Comox sandstone are well exposed on Oyster River. Here borehole 13, just south of the river, penetrated 1,345 feet of strata, consisting of conglomerate, overlain by sandstone, shale and coal (Fig. 4, sec. 1B). Another 400 feet of conglomerate, underlying this sequence, outcrops upstream in the river (Fig. 4, sec. 1A) and yet another 400 feet of partly marine sandstone, overlying the beds, are partly exposed farther downstream.

In the Cumberland area, site of all but one of the former coal mines of the Comox Basin (sec. A-B and Fig. 2) the Comox is exposed on Browns, Puntledge, and Trent rivers and has been drilled in many boreholes. There the basal conglomerate is thin or absent and the complete thickness of sandstone, shale and coal is about 600 feet.

In the Tsable River area, where one coal mine was worked until recently, the formation is similarly developed to a thickness of about 700 feet and only a few of the boreholes revealed up to 20 feet of conglomerate at the base.

On Mount Washington and Forbidden Plateau outliers of the Nanaimo Group consist partly of Comox sandstone and Benson conglomerate, intruded by several sills of dacite porphyry.

In the Alberni Valley Comox sandstone and some conglomerate, probably less than 300 feet thick (Fig. 4, sec. 3), overlain by marine Haslam shale are present in the northeast and within and south of the city of Alberni. Benson conglomerate is exposed on the edge of Beaufort Range. Between these areas, in Stamp Falls Provincial Park, the Comox is apparently absent between marine shale and underlying Karmutsen volcanic rocks.

The area between Comox and Nanaimo basins contains several outliers of Nanaimo beds in the Englishman River and upper Nanaimo River areas. In the latter there is 800 feet of conglomerate and sandstone (Fig. 4, sec. 4), and on Englishman River an estimated 400 feet, but on Qualicum River Haslam shale directly overlies granitic rocks and the Comox is absent.

In the Nanaimo Basin Brannan Creek exhibits less than 200 feet of Comox sandstone, perhaps underlain by thin conglomerate (only exposed on a sidehill) but nearby, in a small ravine south of Boomerang Lake, 150 feet of conglomerate is exposed. Haslam Creek cuts through a gorge of conglomerate and sandstone about 1,000 feet thick (Fig. 4, sec. 7a). In the Cowichan area the bluffs of Mount Tzuhalem east of Duncan reveal some 700 feet of Benson conglomerate (Clapp and Cooke, 1917, p. 223) but on Koksilah River a few feet of conglomerate and about 100 feet of sandstone overlie Karmutsen volcanic rocks. Lastly, conglomerate is present on Mount Maxwell on Saltspring Island, but near Yeo Point, southeast of Ganges (Fig. 4, sec. 8) 140 feet of sandstone, in part pebbly, overlie Sicker schists. Thus the thickness and relative proportions of sandstone, conglomerate, shale and coal exhibit considerable local variation, reflecting succeeding fluvial, deltaic, lagoonal or littoral environment.

Lithology (see Fig. 4)

Individual lithologies are rather uniform throughout the entire region. The Benson conglomerate consists mainly of poorly sorted, subangular clasts commonly to more than one foot in size in dark green, rusty weathering greywacke matrix. Atchison (1968) found in a count of randomly picked pebbles and cobbles from Wilfred Creek in Tsable River area 80 per cent volcanic clasts (mainly Karmutsen, possibly some Sicker); 15 per cent granitic rocks, and 5 per cent quartzitic metasedimentary rocks (Sicker and Bonanza). The matrix was found to be angular to subangular quartz, 50 per cent; feldspar (mainly altered plagioclase) 20 per cent; biotite 10 per cent; and volcanic rock-fragments 10 per cent. The predominance of Karmutsen basic volcanic rocks is typical for most Benson exposures, even where the underlying rocks are granitic as for instance on Nanaimo River. But in places, for instance Cottam Point north of Nanoose, boulders several feet in size are derived mainly from underlying Sicker greywacke. No general study of conglomerates and their matrices has yet been made, but the Wilfred Creek example suggests that although the boulders were largely derived from nearby volcanic rock, the finer sand originated mainly from more distant granitic rocks.

The Comox is best exposed in steep bluffs of massive sandstone. These rocks are well cemented but generally not quartzitic, except near intrusive contacts such as found on Mount Washington. They are evenly medium grained, light to dark grey, and weather to light rusty or dull brown colours. The components are subrounded, well-sorted quartz and feldspar and minor biotite and hornblende. Other parts of the formation consist of alternations of sandstone, commonly crossbedded or festoon-bedded, greenish grey shale and coal. These less resistant to weathering parts are only exposed in river beds but are well documented in the drillhole records. They contain much carbonaceous material and in some places beds with fossil plants. The shale-coal-sandstone units, separated by barren sandstone units can generally be traced from borehole to borehole. Within the units, generally 10 to 30 feet thick, there are commonly three to five individual seams, separated by shale, shaly coal and minor sandstone. The seams split and merge from place to place and the possibility of economic recovery varies accordingly. Three seams, named Number One, Number Two and Number Four seams have been mined from eight slope or shaft mines in the Cumberland area (Fig. 2). They vary in thickness from about 30 inches to 8 feet and are of high volatile A bituminous grade.

Basal unconformity

The basal unconformity below the Nanaimo Group is well known from exposures and drillholes. It represents a considerable erosional interval where the underlying rocks are mainly Karmutsen volcanic rocks. In the Quinsam area they include also Jurassic volcanic rocks and in the Nanaimo and Cowichan region the underlying formations are in large part Sicker Group and granitic rocks. Generally formations of the first cycle of deposition are at the base of the Nanaimo Group but in areas marginal to the basin of deposition, basal beds belong to the second cycle. Either Benson conglomerate, Comox sandstone, or Haslam shale may directly overlie the pre-Cretaceous 'basement', depending on the local depth of the basin and rapidity of transgression.

The unconformity surface exhibits considerable relief. In outcrops 5- to 10-foot vertical rock faces, buried by basal Cretaceous sediments, were observed. The uneven unconformity surface has been noted by many earlier workers. MacKenzie (1922) described an occurrence on Tsable River where "an old knob of pillow lava is overlain at one place by about five feet of fine pearl grey shale, capped by a coal seam seven feet thick. Five hundred feet distant there is at least 100 feet of strata between this coal and the pre-Cretaceous rocks. The intervening strata .... wedge out as they approach the original knob. This filling of the .... depressions in the old surface is a characteristic feature of the basal Upper Cretaceous unconformity and has been previously noted by Richardson, Dawson, and Clapp." A rock-island that locally cuts out Number Four Seam has been delineated by the surrounding mineworks and borings (Fig. 2). Apparently it stood above the coal swamp of the older seams but was barely buried at the time Number One seam was formed.

Age

The age of the Comox is determined by fossil plants and marine fauna. Bell (1957) studied Comox plant material in existing Geological Survey of Canada collections. On the basis of the number of species, conspecific or related to species from formations of known age elsewhere, he could define the age to within the range Santonian to Maestrichtian. Pollen and spores from the Comox were described and discussed by Rouse (1957) and Crickmay and Pocock (1963). The latter authors inferred a probable Santonian age for the Comox. Marine fossils occur locally in the Comox and Jeletzky (this paper) places these in the Naumanni zone of upper Santonian age.

Haslam Formation

The Haslam Formation comprises the upper marine part of the first cycle of deposition of the Nanaimo Group and consists of marine shale, siltstone and minor sandstone with upper Santonian to lower Campanian fauna.

Name

The name was introduced by C.H. Clapp (1912a, p. 97) for the lower shales of the Nanaimo Basin. Shales overlying the Comox Formation in the Comox Basin were named Trent River by the same author (1912b, p. 105). In his report Clapp mentioned the similarity of the Trent River to Cedar District shales of the Nanaimo area. Later the correlation of 'Trent River' and Cedar District (see Table I) was adopted by Williams (1924, p. 93) and Usher (1952, p. 38). Usher admitted there were paleontological arguments in favour of a Haslam-Trent River correlation and the latter interpretation is now firmly established on the basis of the molluscan fauna (Jeletzky, this report). It was earlier proposed by McGugan (1962) and Crickmay and Pocock (1963) on the basis of microforaminifera. However, shales outcropping on the lower part of Trent River and on the west side of Denman Island, included in the 'Trent River' by Usher, are correlated with the Cedar District Formation by the present writers too. Reasons for this interpretation will be given in the section on Extension-Protection Formation and Jeletzky's discussion of equivalents of the Vancouverense Zone in Comox Basin. It is here proposed to abandon the name 'Trent River' (not yet recorded in the Index to Geologic Names of North America) in favour of Haslam Formation.

Usher (1952, p. 22) also introduced the Qualicum Formation, said to be exposed on Little Qualicum River, Englishman River and near Northwest Bay and believed to be overlain by the Comox Formation. The stratigraphic position of this formation has been questioned earlier (Jones, 1963, p. 14). These beds overlie Karmutsen volcanic rocks on Englishman River and granitic rocks on Little Qualicum River, and contain in both instances a Naumanni subzone (Fig. 1) fauna. The present writer has not discovered any outcrops of Comox sandstone, overlying 'Qualicum' shale and includes these beds in the Haslam Formation. The name Qualicum Formation should also be discontinued. The stratigraphic position of the beds near Northwest Bay is discussed in the section on the Extension-Protection Formation.

Distribution and thickness

Haslam shale is generally only exposed in rivers and coastal cutbanks, but is also known from many drillholes. In the Oyster River area there is no Haslam shale and the upper part of the Comox sandstone, carrying the Naumanni fauna, may be coeval with it. The Haslam ('Trent River shale') is well developed in Cumberland and Tsable River areas with a thickness of 200 to 400 feet (Figs. 2 and 4). The much greater thicknesses quoted by previous authors are a result of not separating Haslam and Cedar District shales in drillhole logs.

On Forbidden Plateau about 100 feet of marine, locally fossil-bearing shale, hardened by the porphyry intrusions into argillite, is present above 5,000 feet elevation on Strata Mountain. An equal thickness of shale is exposed on Mount Washington. In Alberni Valley, on the headwaters of Englishman and Nanaimo rivers and on Little Qualicum River, Haslam shale, generally less than 200 feet thick, overlie Comox sandstone, conglomerate, Karmutsen volcanics, or granitic rocks.

Haslam shale is present throughout Nanaimo Basin. As it underlies the coal-measures it has therefore been drilled less extensively than in the Cumberland area. According to the writers' interpretation of boreholes and sections on Brannan and Haslam creeks the thickness varies from 200 to 500 feet (Fig. 4).

Finally the Haslam is present in undetermined thickness in the Cowichan area and with about 500 feet thickness in the middle part of Saltspring Island (Fig. 4, sec. 8).

Lithology (see Fig. 4)

The Haslam consists mainly of poorly bedded, blocky to 'rubbly' dark grey shale, silty shale and siltstone, here and there containing sandy beds of a few feet thickness and layers of calcareous concretions. The shales may be divided into bedded units, 6 inches to two feet thick, separated by thin silty laminae. In weathered outcrops the shale layers commonly disintegrate into rows upon rows of dark rusty brown ellipsoidal shapes, that are about one foot in horizontal diameter. The ellipsoids are layered in onion-skin fashion and peel off in a manner not unlike the exfoliation of some granitic rocks. This type of weathering has been observed in all shale-units of the Nanaimo Group as well as in some of Lower Cretaceous age.

Sandstone dykes, cutting the shales at high angles to the bedding, from a few inches to several feet wide, are common in the Haslam and the younger shale-formations and have been described in the unpublished theses of Williams (1924) and Usher (1949, pp. 55-61). They are very fine grained to coarse grained quartz-feldspar-mica sandstones with, in places, abundant shale fragments. Some dykes are composite and platy to fissile, with feldspar and mica oriented parallel to the walls. They were intruded as sand-suspensions into cracks of semiconsolidated shale-sequences and forced upward by the weight of overlying shales on subjacent bodies of water-saturated sand ('quicksand').

The facies of the Haslam appears to be mainly the nearshore fossiliferous 'Haslam type' facies of shale, sandy shale, and sandstone. Layered turbidite offshore sediments of Cedar District type have not definitely been recognized in the available sections.

Basal contact

The contact between Comox and Haslam formations may be sharp, as on Trent River, where shales with marine fossils directly overlie coal-bearing sandstone (Fig. 4, sec. 2) or gradational as on Brannan Creek, where the lower part of the Haslam is marine sandy shale and shaly sandstone (Fig. 4, sec. 5) or on Oyster River and Haslam Creek, where Comox-type sandstone contains marine fossils (Fig. 4, sec. 1 and 7). In such cases the contact is arbitrarily drawn where the rocks change from predominant sandstone to predominant shale. In some places, such as Stamp River and Little

Qualicum River, the Haslam directly overlies the pre-Cretaceous basement, with only a thin veneer of conglomerate.

Age

According to Jeletzky the Haslam contains the upper Santonian Naumanni subzone and the lower Campanian Haradai subzone in all areas. The succeeding Schmidti zone is only represented in the Nanaimo Basin. The Haslam is further distinguished by the microfaunal Rugoglobigerina zone (McGugan, 1962).

Extension-Protection Formation

Names

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 (shown on Figs. 1 and 3) cannot be distinguished outside 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.

Distribution

The formation is best exposed in the area around Nanaimo and on Newcastle and Protection islands. There its maximum thickness is estimated to be 1,900 feet. Outside the mining area the thickness decreases sharply and the formation is represented by conglomerate and pebbly sandstone without coal seams. To the south, small areas of the formation overlie Haslam shale in the Cowichan area with an estimated maximum thickness of 500 feet. In the middle part of Saltspring Island the thickness is 200 feet near Yeo Point. Extension conglomerate is also exposed along the south shore of North and South Pender islands where thickness may exceed 1,000 feet. North of Nanaimo some isolated areas of conglomerate and sandstone near Parksville and the coal-bearing beds of Lantzville are included in the formation.

In the Comox Basin the Comox Formation has traditionally been correlated with the coal measures of the Nanaimo Basin, but it is now known to be older. However, a highly lenticular conglomerate-sandstone formation, overlying Haslam shale, Comox coal measures, or Karmutsen volcanics is known from many drillholes and a few outcrop areas. MacKenzie (1922, p. 394)

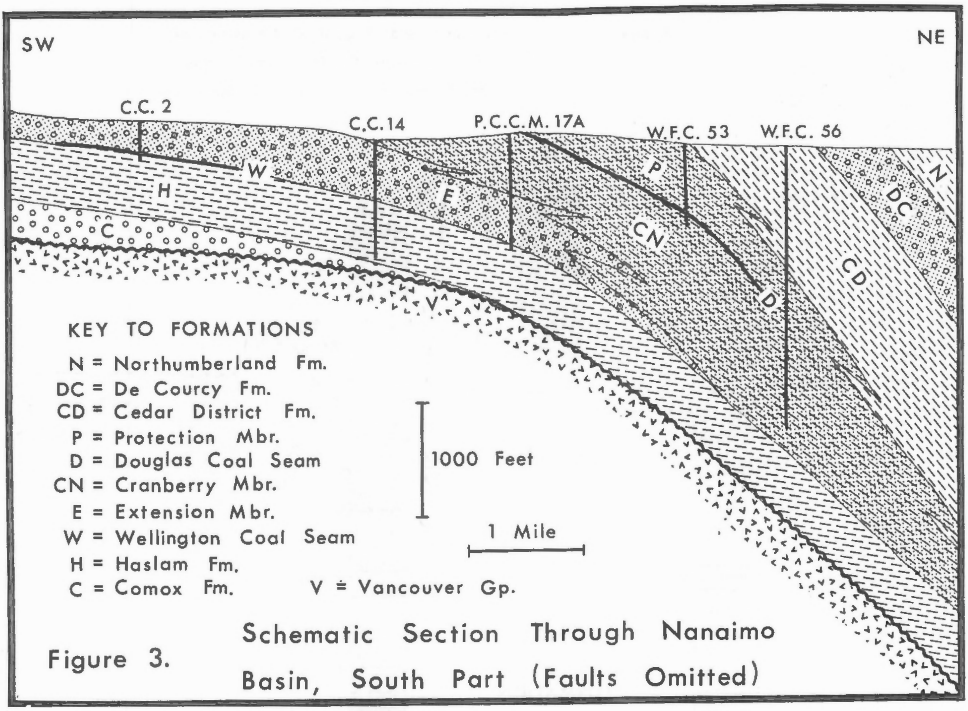


Figure 3. Schematic Section Through Nanaimo Basin, South Part (Faults Omitted)

already reported that an 'intraformational' conglomerate "locally fills hollows cut by contemporaneous erosion and in one part of the area has cut out nearly the whole thickness of the Comox Formation, including the contained coal seams". The writer believes that this conglomerate formation represents the Extension-Protection Formation (Figs. 1, 2; sec. A-B on Fig. 11).

The formation is exposed north of Trent River, on Bloedel Creek and north of Tsable River. Two other areas may be outlined in the subsurface from boring data. One is north of Trent River; the other larger one separates the Cumberland and Tsable River coal fields and is more than 1,000 feet thick in boring 40 at Langley Lake. However, on Trent River the formation is inferred to wedge out to a thin sandy layer that separates Haslam and Cedar District shales.[1] The failure of Trent River to intersect the conglomerate may be because the river follows a topographic depression, possibly due to differential compaction of the Nanaimo sediments that caused areas with the conglomerate in the subsurface to be higher than those where it is absent.

In the Alberni Valley Extension-Protection sandstone overlies Haslam shales in the northern part. Isolated conglomerate on Thunder Mountain directly overlies granitic rocks but 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 carries the Schmidti fauna and therefore also represents the Extension conglomerate.

[1] See Addendum 1, page 70

Figure 4a. Lithological and Faunal Correlation of First Depositional Cycle (Comox and Haslam Formations) in Comox Basin

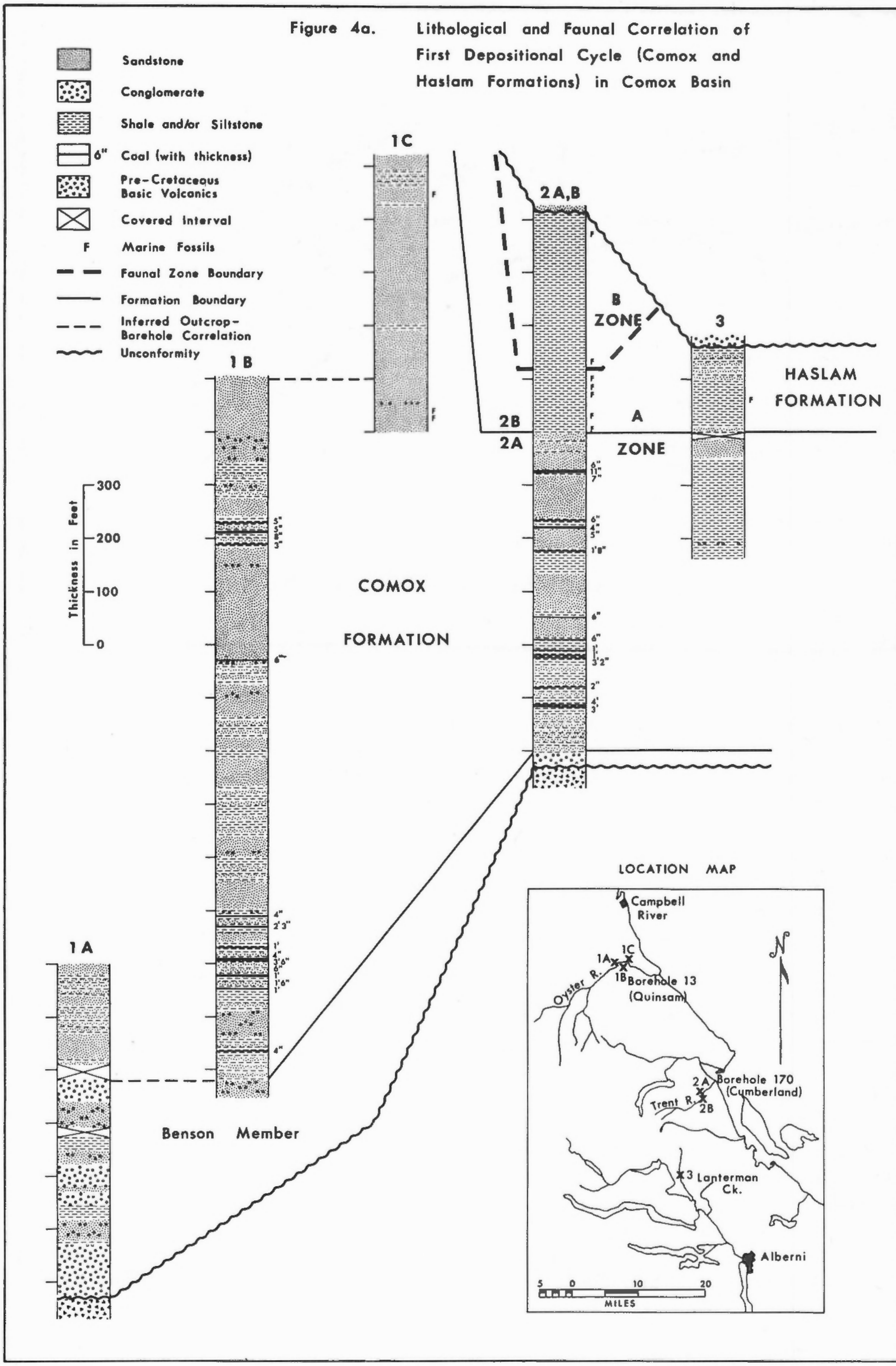


Figure 4b. Lithological and Faunal Correlation of First Depositional Cycle (Comox and Haslam Formations) in Nanaimo Basin

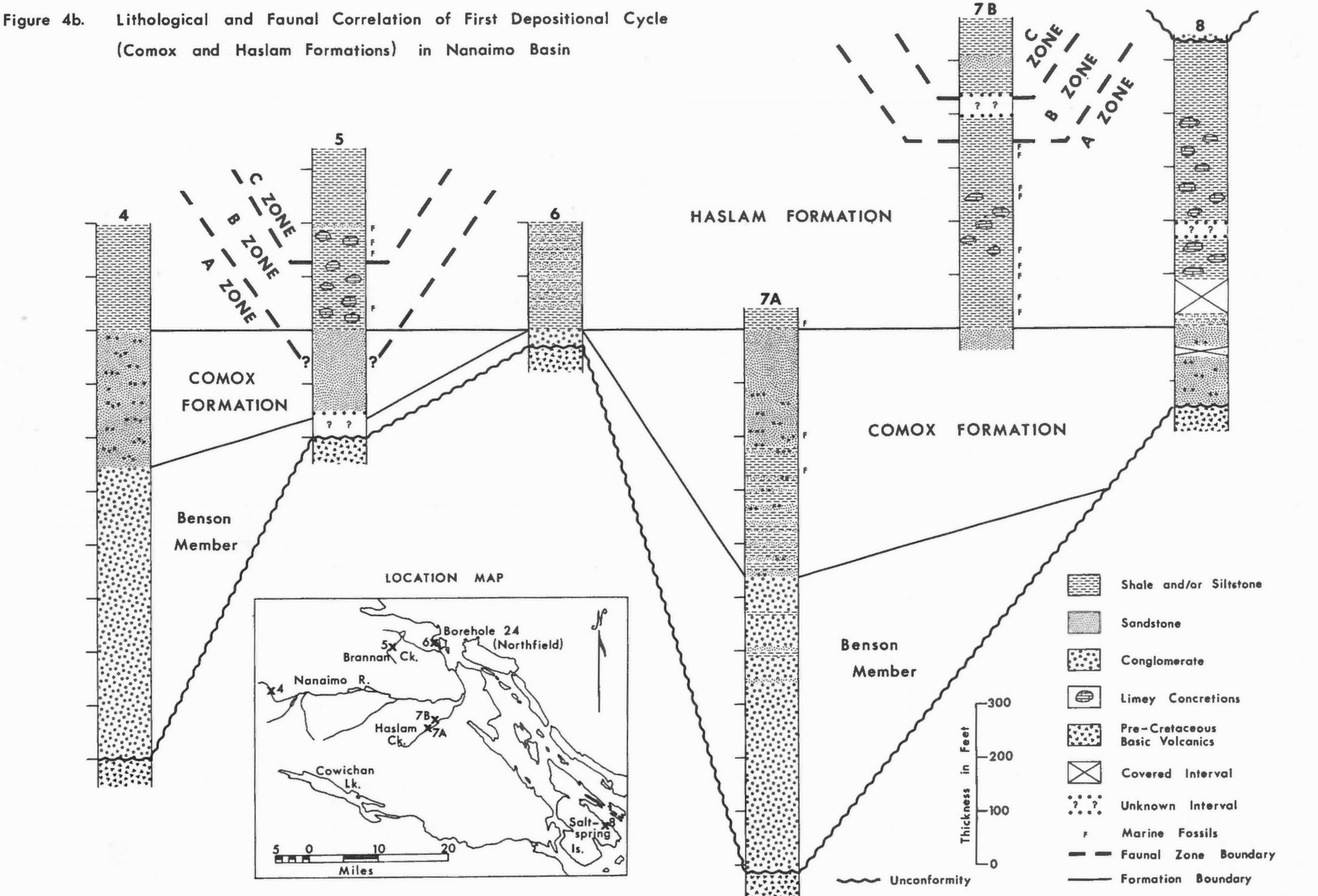
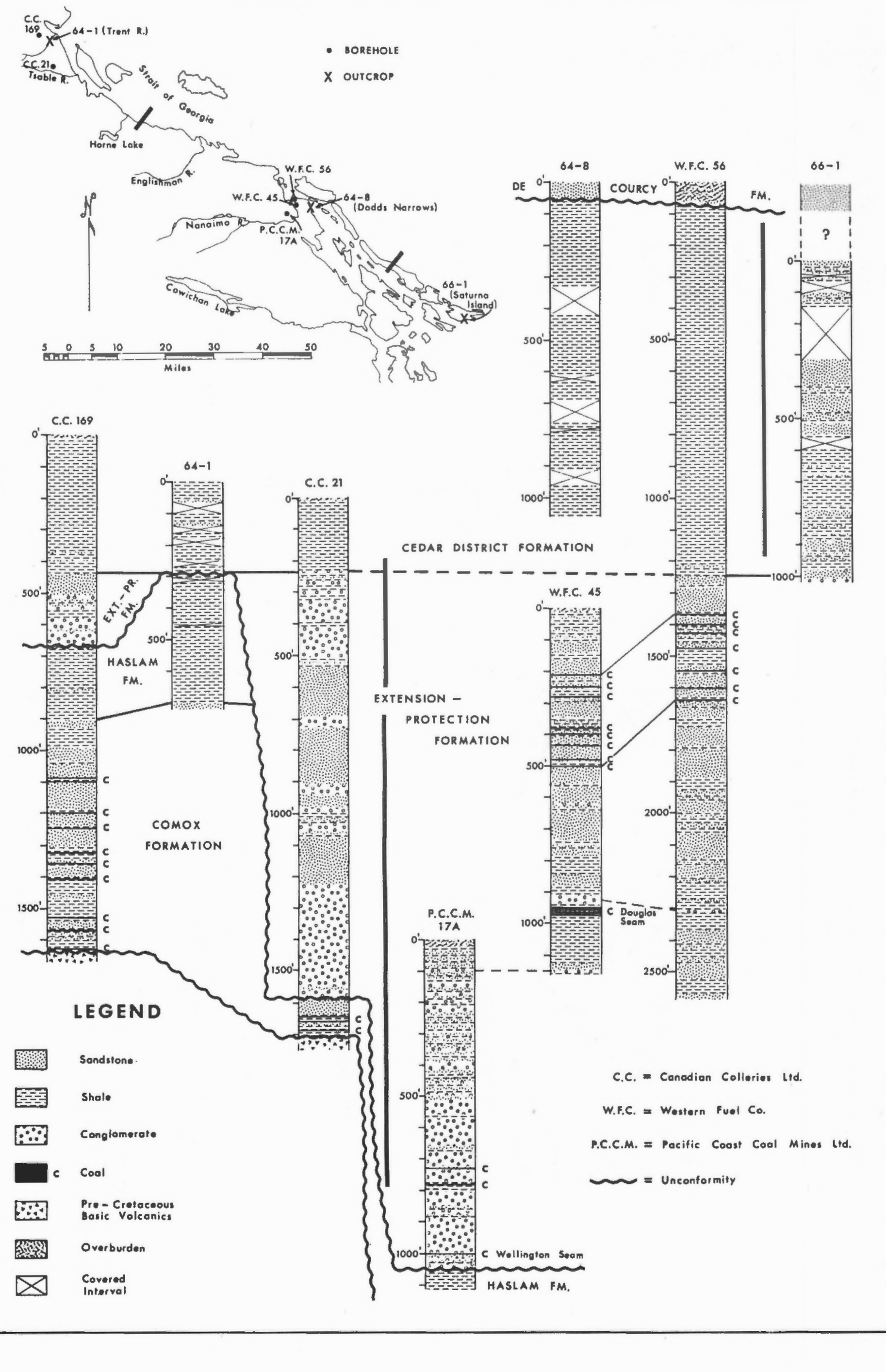


Figure 5. LITHOLOGICAL CORRELATION OF SECOND DEPOSITIONAL CYCLE
Extension – Protection and Cedar District Formations



Lithology and thickness (see Fig. 5)

The lithological succession of the Nanaimo Basin coal-bearing sequence induced Clapp to subdivide them into the five formations listed above (now regarded as members of the Extension-Protection Formation). Their probable relationships are illustrated in Figures 3 and 4 which show that the full thickness of the formation containing all members is not represented at any one locality. The writer believes that the relationship between Extension and Protection is similar to that between Benson and Comox. The Extension is a marginal coarse conglomeratic phase of the second depositional cycle and grades northeastward into the conglomeratic to shaly sandstone of the Cranberry and overlying Protection.

Figures 3 and 4 also show the position of the two main coal seams of the Nanaimo Basin, the Wellington and the Douglas. They occur and have been mined in two separate, roughly parallel belts, each less than a mile wide. Clapp (1914a, p. 103) states that the Wellington "doubtless extends with a variable thickness beyond the outcrop of the Newcastle and Douglas seams, at a depth of 800 to 1,200 feet". However, the scanty evidence of drill records, some of which were not available to Clapp, rather suggests little or no overlap of areal extent of the two seams.

Clapp called the beds overlying the Haslam shale the East Wellington sandstone. He mentions exposures in a few places in the Wellington district below the level of the Wellington seam, and the writers believe that the sandy beds of Northwest Bay and Blunden Point represent the same stratigraphic level. They are sandstone and sandy shale, mainly quartzofeldspathic, but with admixture of volcanic material, containing scattered pebbles, and with numerous concretions of calcareous sandstone. Clapp gives a thickness of 25 to 50 feet, but a boring in the Nanoose District penetrated 156 feet of predominantly sandstone above Haslam sandy shale with minor sandstone and the contact is gradational. Thus the East Wellington would appear to be a regressional phase of the Haslam and is taken as the beginning of the second depositional cycle of the Nanaimo Group.

The overlying Wellington coal seam is present and has been mined in two principal areas, northwest of Nanaimo in the Wellington District and to the south in the Extension District. They are separated by faults and by the pre-Cretaceous rocks of Mount Benson. The first mines of the coal mining empire, built by Robert Dunsmuir, were in this seam in the Wellington area, most later ones in the (therefore so named) Extension area.

Clapp (1914a, p. 103) quotes average seam-thicknesses of 4 to 7 feet in the Wellington seams and the rank is high volatile A bituminous. The floor is commonly sandstone and the roof may be sandy shale, sandstone, or conglomerate.

In the Wellington District the main Wellington No. 1 seam has several companion seams, the Little Wellington or No. 2, No. 3 and No. 4 seams, respectively 35, 60 and 75 feet above the main seam (Buckham, 1947b).

Of particular interest are the 'rolls' described by Clapp (1914a, p. 105) where a seam "pinches gradually to virtually nothing and then thickens to 10 feet. Although the floor may be nearly smooth, the roof in passing from the thin to the thick portion of the seam rolls sharply, and often irregularly upward. In some places the roof is even overturned, at least 25 feet in one place. These sharp rolls are locally called 'faults'. Invariably at the thin places or 'pinches' the coal is dirty or slickensided, while in the thick places, or 'swells' it is clean, black in colour, with a sub-brilliant lustre, and broken only by a few irregular joints. ....In some places the coal is clean and unfractured against the upturned roof, but more commonly it is somewhat slickensided and even contorted. The roof at the rolls is always contorted and slickensided. The strike of the rolls corresponds with the strike of the measures, that is northwest to west, and the pinches occur on the northeast or north side of the rolls, with the corresponding swells on the opposite side. Where the seam is overlapped, the overlap is to the northeast or north." There can be no doubt that these 'rolls' are similar in origin and structure to the slump-folds observed in many places in sandstone-shale sequences and mentioned earlier in this report. The apparent north to northeastward slumping is in accordance with field observations and indicates a north to northeastward tilted paleoslope.

The petrography of the coal of the Wellington seam was studied in detail by Hacquebard et al. (1967) and the general characteristics observed were described as follows: "The Wellington seam .... consists of a very finely striated humic coal that has a uniform semi-bright appearance. The coal may be classed as a dull clarain, which is practically devoid of associated vitrain bands or stringers. Somewhat duller layers occur occasionally, but do not stand out as distinct durain bands. Small lenses of fusain can be detected upon close observation. Due to its uniformity the coal is fairly hard and strong. It breaks with a hackly fracture into large lumps. Where the seam is contorted in the 'swells' the coal looks uniform and is fairly dull in appearance, except on slickensided faces which are brilliantly polished. Bedding cannot be detected in the disturbed coal."

The beds between Wellington and Douglas seams are conglomerate, sandstone and coal. Clapp named the lower part with predominant conglomerate, Extension, and the upper part with predominant shale, Cranberry. They form a belt several miles wide from Wellington south to Nanaimo River and there they are well exposed. They apparently thin out a short distance north and south of the Nanaimo area.

The conglomerates have commonly subrounded pebbles, fairly well sorted, one to two inches in size, mainly of green, red, light grey and black cherty rocks. Grit and sandstone, forming the matrix and interbeds of the conglomerate, have an average composition of 40 per cent rock fragments, 30 per cent quartz, 20 per cent feldspar and 10 per cent calcareous-argillaceous cement. Sandstones are massive to platy and commonly cross-bedded. They are greenish grey to brown, fine to medium grained and contain scattered pebbles. Coaly shale, coal and siltstone are minor components. The thickness of the interval between Wellington and Douglas seams is about 650 feet at Departure Bay (boring W. F. C. 27) and about 1,000 feet in the South Wellington district (boring P. C. C. M. 17A). No drillhole has intersected both the Douglas and Wellington seams. The inter-seam thickness apparently decreases again towards Ladysmith and the seams pinch out within a few miles.

The Douglas seam was the first to be mined in 1852 in the downtown Nanaimo area and was worked by the largest and longest-operating Number One Mine (1883-1938, 18,000,000 long tons). It has been mined in a nearly straight north-northwest trending belt, up to two miles wide, from Nanaimo River to Newcastle Island. Like the Comox area coal seams and the Wellington seam the coal is of high volatile A bituminous rank. Clapp states that the thickness is 5 feet in the South Wellington area but varies from virtually nothing to over 30 feet. The excessive thicknesses presumably occur in 'rolls' also described for this seam (Clapp, 1914a, p. 111) but here apparently mainly affecting the floor of the seam. The fact that the floor of the Douglas is shale rather than sandstone probably explains this different mode of intraformational slumping.

The Newcastle seam occurs in the northern part of the Nanaimo Basin. According to Buckham (1947a and b) it is about 60 feet below the Douglas seam and averages between 3 and 4 feet in thickness. It was mined around 1850 beneath downtown Nanaimo and under Newcastle Island but later mining apparently occurred only in the latter place.

The sequence overlying the Douglas seam was named Protection Formation by Clapp. It consists mainly of sandstone, shaly sandstone, and siltstone with minor carbonaceous shale, commonly thinly laminated and with fine crossbedding. The sandstones are a conspicuously light yellow and consist of medium, evenly grained quartz and feldspar with minor biotite, locally with carbonaceous material. In places they contain scattered pebbles; shaly sandstone and shale are the main lithology in the transition zone to the Cedar District Formation.

Intraformational slumping is a common feature and on Newcastle Island it was found to be in a general northward direction. A north to northeastward current direction is also indicated by crossbedding.

A thickness of 678 feet of Protection sandstone was measured by Clapp (1914a, p. 49) on Protection and Newcastle islands. The Reserve Mine shaft near the mouth of Nanaimo River reached the base of Cedar District shale at 122 feet and the Douglas seam at 1,043 feet. Allowing for a reported 22 degree dip of the seam and the overlying strata the thickness is 850 feet. Thus, the maximum thickness of the Extension-Protection Formation in the coal-mining area is the aggregate thickness of the Wellington Member (50 feet), the Extension and Cranberry members (maximum 1,000 feet), and the Protection Member (maximum 850 feet), or a total of 1,900 feet in the Nanaimo Coal Basin.

Conglomerate and sandstone along the south border of Cowichan Valley, Mount Benson and north of Chemainus River, representing the Extension-Protection Formation, contains subrounded poorly sorted pebbles, in places to 6 inches in size, of quartz, argillite, chert and light coloured siliceous volcanic rocks, probably derived from the Sicker Group, set in a gritty matrix. It is commonly interbedded with pebbly, coarse-grained sandstone of the same composition. Conglomerate representing the formation is also well-exposed on the southwest shores of North and South Pender Islands, and on the south shore of Saturna Island. There it exhibits a much more diverse assemblage of well-rounded to subrounded pebbles and cobbles of gneissic and granitic rocks (mainly hornblende granodiorite), together with quartzite, chert, and Sicker-type volcanic rocks. An abundance of jasperoid chert gives a distinctly reddish colour to many outcrops and adjacent shingle beaches.

In the Comox Basin inferred representatives of the formation are lenticular bodies of conglomerate and sandstone, over 1,000 feet thick in a few places (boring T.R. 40 near Langley Lake) but pinching out within a few miles. On Bloedel Creek the conglomerate can be seen to be in vertical stratigraphic contact, striking N 115° E, with flat-lying Comox sandstone. The contact is in part washed out by the creek and is apparently not a fault. The conglomerate is obviously a channel-fill and exhibits well-rounded boulders, up to 6 inches in size, of chert, quartzite, hornfels and granitic rock, but also much larger angular blocks, up to two feet in size, of Comox-type sandstone as well as shale and calcareous concretions that could have been derived only from the underlying Haslam Formation. The large angular shale and sandstone blocks show that the Comox and Haslam were well-indurated when the conglomerate was formed, indicating a considerable time-interval between deposition of the formations. The conglomerate is exposed for some distance upstream and in one place a channel was found containing a carbonized log; both channel and log strike about N 100° E and dip east, suggesting eastward flow of the ancient stream.

The conglomerate apparently pinches out toward Trent River. There a four-inch band of clay, in places with woody material, is exposed near where a small stream enters from the north, upstream from the power-line crossing. It could be traced for a distance of 150 feet and is believed to represent the Extension-Protection or the erosional gap between Haslam and Cedar District formations.

In Alberni Valley and on Thunder Mountain the beds are similar to those of the Comox area. The conglomerate on Thunder Mountain contains poorly sorted cobbles, up to 12 inches in diameter, mainly of black argillite and chert, and minor granitic rocks. It also contains large fragments of shale, concretions, and sandstone fragments, as much as 18 inches in size, apparently derived from older Nanaimo beds.

On Texada Island the formation occurs on Cook Creek as very poorly sorted conglomerate with subangular boulders to one foot in size and pebbly greywacke containing a layer of coquina comprising the fauna of the Schmidti zone.

Age

The age of the Extension-Protection Formation is determined on the one hand by that of its oldest member, the Wellington, which contains the Schmidti fauna of early Campanian age (Fig. 1). On the other hand the next-younger Vancouverense zone fauna, of younger Campanian age, is found in the succeeding Cedar District Formation. Thus the age of the Extension-Protection is well defined as lower Campanian. Bell (1957) described the available plant collections of the Extension, Newcastle and Protection members. He arrived at a less specific but compatible conclusion that the Nanaimo Group as a whole is Campanian to Maestrichtian in age. Crickmay and Pocock (1963), reporting on the microflora, did not clearly define the apparent age of the coal-bearing beds, but concluded that the Comox is older than the Protection.

Cedar District Formation

Name and distribution

The name Cedar District Formation was chosen by Clapp and Cooke (1917, p. 63) for the marine shales overlying the Nanaimo Basin coal measures. The formation is exposed along the coast south of Dodds Narrows, where a section of 1,010 feet measured by the writer's party may be considered as a type section. In the Nanaimo Basin it is also exposed on the lower part of Nanaimo River, on Chemainus River and along the coast of Saltspring, Pender, Mayne and Saturna islands. In Comox Basin the beds on lower Trent River and on the west side of Denman Island and those on the west side of Texada Island are included.

Lithology

The lithology of the Cedar District in the section on Dodds Narrows (Fig. 5) shows little variation over the full thickness of 1,000 feet. It consists of slightly silty dark grey shale, in places massive and poorly bedded, but commonly separated at intervals of a few inches to several feet by laminated siltstone and sandstone bands up to one inch thick. Concretionary layers and flat lenses of micritic limestone, up to 3 inches thick and 5 feet wide, are common near the top of the section and in the lowest part. Many exposures along the coastlines of Saltspring, Pender and Mayne islands exhibit graded bedded turbidite sequences with conspicuously ribbed layers 1 inch to 6 inches in thickness. On Saturna Island the measured section (Fig. 5) consists for its lower 440 feet of silty shale, interbedded with a few fine-grained sandstone units, 10 to 30 feet thick and a few layers with chert, quartz and argillite pebbles. This part also yielded several fossil collections. These beds are overlain by 210 feet of fine- to medium-grained sandstone with mainly subangular quartz and contain some shale-interbeds. Intraformational slumps indicate an eastward dipping paleoslope. The sandstone is in turn succeeded by an estimated 400 feet of alternating shale, silty shale and sandstone beds, forming the transition to the massive De Courcy sandstone. A sequence similar to that of Saturna Island was described by McLellan (1927, p. 121) on Sucia Island, 5 miles east of Saturna, in the San Juan Islands in the State of Washington. The underlying conglomerate is described as containing mainly Leech River Schist (presumably similar to Sicker Group rocks) and quartz in both boulders and matrix. The preservation and angularity of these rocks indicates a nearby source. The conglomerate is estimated to be more than 100 feet thick and is overlain by 700 feet of fossiliferous sandy shale (called Haslam by McLellan). Usher (1952) obtained most of his Cedar District fossils from Sucia Island exposures. The shale is overlain by 655 feet of coarse- to medium-grained sandstone and a concealed interval of 290 feet, probably shale. These are probably equivalent to the higher part of the measured section on Saturna Island.

In Comox Basin the beds are exposed in the lower part of Trent River (Figs. 2 and 5), probably on Puntledge River below Browns River, on Ship Point, and on the west side of Denman Island. The general lithology is similar to that described above: a rather uniform sequence of shale with varying amounts of interbedded siltstone and sandstone.

Basal contact

The contact with underlying Extension-Protection Formation is well defined in the recorded section of the Reserve Mine shaft near the Nanaimo River mouth, where 90 feet of shale overlies sandstone with minor shale bands. In the measured section on the south coast of Saturna Island the contact of the two formations is also distinct. There the lower part of the Cedar District is in transitional near-shore sandy facies. As mentioned earlier the section exposed on Trent River is inferred to represent Cedar

District shales and Haslam shales in direct superposition, separated only by a thin clay layer representing the Extension-Protection.

Age

The ammonite fauna of the Cedar District has been collected from few localities, mainly Sucia Island in the State of Washington and North Pender Island (see Usher, 1952). Jeletzky (see section on biochronology) groups them in the Vancouverense (D) zone of middle Campanian age. *Inoceramus* is far more common than ammonites and *I. vancouverense* and *I. subundatus* in large quantity are typical of the zone in the sandy nearshore facies. The straight ammonite *Baculites chicoensis* appears to be the more common fossil in the offshore siltstone-shale facies.

The paleontological arguments for correlating the beds exposed in the Comox Basin on the lower part of Trent River and on the west side of Denman Island with the Cedar District of the Nanaimo Basin are discussed by Jeletzky in the following chapter. That correlation was previously adopted by Usher (1952) for somewhat different reasons. The correlation of the shales of Texada Island with Cedar District, preferred by this writer, is not firmly established but strongly suggested by the presence of *Inoceramus schmidti* of the Schmidti zone in the basal conglomerate and abundant *I. vancouverense* in the shale. However, the presence of *Baculites* cf. *occidentalis* Meek is according to Jeletzky rather indicative of the Suciensis (E and F) zone and would place the beds alternatively in the Northumberland Formation.

De Courcy Formation

Name

Sandstone and conglomerate of the De Courcy Formation are the basal continental to littoral clastic deposits of the third cycle of deposition of the Nanaimo Group.

The name De Courcy was introduced by Clapp (1912a) after the De Courcy Islands that are underlain by this resistant sandstone formation. The name 'Denman Formation' was substituted by Williams (1924) for the 'Lower Conglomerate' of Richardson (1873) in the Comox Basin. As the Denman is equivalent to De Courcy it is proposed to drop the name in favour of the latter.

Distribution and thickness

In Nanaimo Basin De Courcy sandstone forms much of the shoreline of Vancouver Island from Harmac to Yellow Point, underlies De Courcy and Secretary Island groups, and forms many prominent cuestas and ridges on Saltspring, Prevost, Mayne, North and South Pender, and Saturna islands. The thickness is about 450 feet at Dock Point on Saltspring Island and 1,400 feet on the point south of Village Bay on Mayne Island. A maximum thickness of 1,400 feet was calculated by Clapp (1914, p. 64) for Woodley Range east of Ladysmith Harbour.

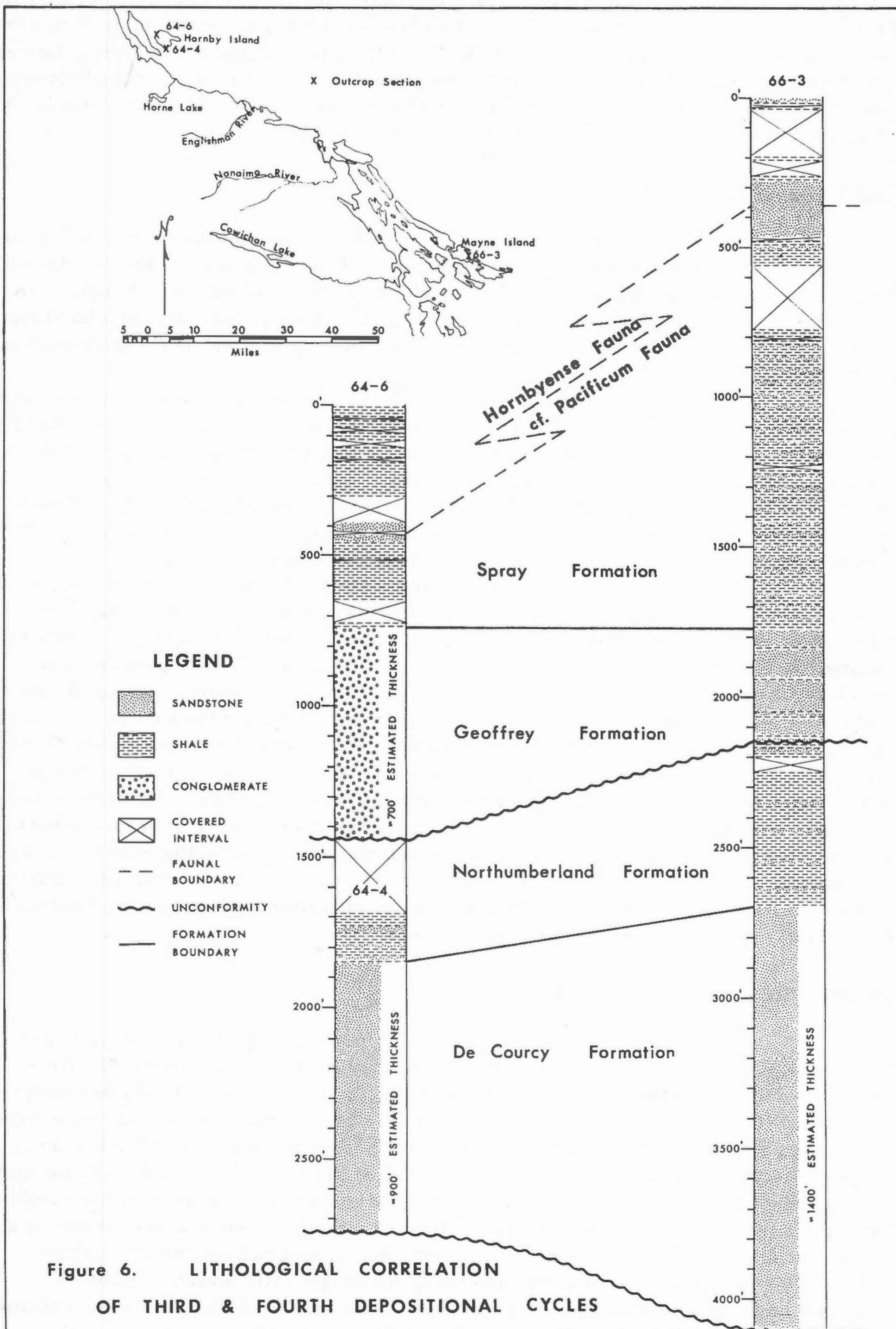


Figure 6. LITHOLOGICAL CORRELATION OF THIRD & FOURTH DEPOSITIONAL CYCLES

In the Comox Basin the 'Denman' forms the backbone of Denman Island in a broad central zone flanked to the west by a narrow strip of underlying Cedar District and to the east by a yet smaller strip of overlying Lower Northumberland. It occurs again at Norman Point on the south tip of Hornby Island and on Norris rocks southeast of that point. Here the formation is 900 to 1,000 feet thick, as estimated by previous writers.

Lithology (see Fig. 6)

No continuous section of De Courcy beds has been studied at any one point. In Nanaimo Basin the formation consists mainly of sandstone and pebbly sandstone, grading upward into the shaly beds of the Northumberland. In Comox Basin the 'Denman' is according to Usher (1952, p. 25) characterized by sandstone and shale in the lower half and sandstone and conglomerate in the upper half.

De Courcy is typically a brown grey massive sandstone, in beds two to 10 feet thick, separated by shaly layers. It consists of subrounded fine- to medium-grained quartz sand with minor feldspar, mica and rock fragments and in places carbonaceous material. Small, well-worn quartz and chert pebbles occur throughout in more or less well-defined bands. Finer grit, disseminated throughout, is commonly noted by the rough texture of the weathered surface, similar to very coarse sandpaper.

On the seashore, where most exposures occur, concretions, up to several feet across, are commonly more resistant to erosion than the otherwise identical surrounding rock by virtue of carbonate content. Honeycombed weathering surfaces are also due to carbonate-filled networks of cracks weathering out in relief. 'Galleries' formed by undercutting of sandstone at the high-tide mark, though most typical in Gabriola sandstone, also occur in De Courcy. Convolute bedding and intraformational slumping already noted in older formations is a general feature of De Courcy, especially in interfingering transition zones with Northumberland shales. Sandstone beds have moved along shaly partings as much as ten feet and have been contorted and overturned without any effects on overlying and underlying strata. Careful examination of these miniature overthrusts reveals their entirely sedimentary, nontectonic nature. The direction of slumping generally indicates a northeast to northwest dipping paleoslope.

Basal contact

The base of the De Courcy Formation is generally a massive sandstone, commonly gritty or pebbly, that overlies Cedar District shales. In the Vancouver Island coastal section (Fig. 6, sec. 64-4) the Cedar District consists entirely of shale and the contact is sharp. Sandstone and conglomerate also overlie Cedar District shales with sharp contact on Pender and Mayne islands, but in several instances the shales are recessed in bays and not exposed at the contact. On Saltspring Island the upper part of the Cedar District contains beds up to one foot thick of fine-grained marine sandstone. Basal De Courcy is a different, massive, medium-grained locally gritty, light-coloured sandstone and the contact, although still sharp, could be inferred to be gradational. Large slump-folds and 'overthrusts' are common near the contact in the Cedar District sandstone interbeds and are well exposed at Vesuvius Bay near the ferry dock.

Age

No fossils are known from De Courcy beds. The formation, bracketed by the Cedar District with Vancouverense (D), fauna and Northumberland with cf. Pacificum fauna is considered to be in the Vancouverense zone, of middle Campanian age.

Northumberland Formation

Name

The Northumberland Formation is the shaly upper part of the third depositional cycle, starting with the De Courcy sandstone. Clapp (1912a, p. 100) introduced Northumberland for the shale formation overlying De Courcy and exposed northeast of Northumberland Channel on the south coast of Gabriola Island. He also mentions (1914a, p. 67) that the 'lower shales' of the Northumberland, about 500 feet thick, are 'replaced' by sandstone and coarse conglomerate, about 400 feet thick on Gabriola but up to nearly 1,000 feet thick on Galiano Island. Usher (1952, p. 19) similarly treats the conglomerate and sandstone as a middle member of the Northumberland. The writer considers this member to reflect an uplift of at least equal significance to that of the preceding De Courcy. It marks the base of another cycle of deposition and should be treated as a separate formational unit. It is therefore proposed to restrict the Northumberland to the shales below the conglomerate.

The apparent equivalent of the Northumberland in the Comox Basin is the 'Lambert', exposed on the east shore of Denman Island and near the south end of Hornby Island at Ford Cove, between underlying De Courcy (-"Denman") sandstone and overlying Geoffrey conglomerate. It is proposed here to abandon the name Lambert in favour of Northumberland.

Distribution and thickness

Thus defined the Northumberland occurs in narrow belts on all of the Gulf Islands. Tracing the Northumberland is in many places difficult as a result of scarcity of fossils and the similarity in lithology of Cedar District and Spray formations. In the Nanaimo Basin the thickness at False Narrows between Mudge and Gabriola islands, is estimated at 1,000 feet, at Village Bay on Mayne Island about 600 feet, and at Horton Bay on the east side of that island as more than 500 feet. In Comox Basin the formation outcrops on the northeast coast of Denman and the southwest coast of Hornby Island. Contrary to the interpretation of Richardson (1873, map) followed by all other workers, the writer prefers to consider the shale of Ford Cove not to be continuous with that of the west coast of Hornby Island, from Shingle Spit to Collishaw Point. The latter, well known for the rich ammonite fauna it has yielded in the past, is now included in the Spray Formation, which is younger rather than older than the Geoffrey. The Geoffrey and Spray are inferred to be in fault contact along the west-facing scarp of Mount Geoffrey. Thus less than 300 feet of Northumberland Formation is exposed on Denman Island and less than 200 feet on Hornby Island. The total thickness probably does not exceed 500 feet.

Lithology (see Fig. 6)

The lithology of Northumberland shale is similar to and indistinguishable from that of Cedar District and Spray formations. Again the basal part consists of a transitional sequence of interfingering sandstone and shale beds, and the higher beds are graded sandstone-siltstone-shale units, ranging in thickness from less than one inch to about six inches. Differential erosion gives these beds a strongly 'ribbed' appearance on beach exposures. Reddish weathering calcareous ironstone concretions are fairly common. The beds are apparently suitable for the production of lightweight aggregate by heat expansion. A quarry with adjacent oil-fired rotary kiln of British Columbia Lightweights Aggregates Ltd. is located on Lyall Harbour, Saturna Island, and another similar quarry was formerly operated at Wellbury Bay, Saltspring Island.

Age

Fossils are scarce in the Northumberland and the writer's party found few diagnostic specimens to add to those collected by Usher (1952). Jeletzky places them in the Suciensis (E and F) zone of upper Campanian age. In some instances the dating may be narrowed down to the cf. Pacificum (E) subzone. The only Northumberland ("lower Lambert Formation") localities investigated by McGugan (1962), on the west side of Denman Island contained only agglutinated forms of microforaminifera, which he did not consider suitable for biochronological zonation.

Geoffrey Formation

Name

It has already been mentioned in the foregoing section that a middle sandstone-conglomerate member of the Northumberland, in the unrestricted definition of Clapp (1914a) and Usher (1952), marks renewed uplift and the beginning of a new cycle of deposition. It therefore deserves formation status like the sandstone-conglomerate sequences of preceding cycles. The conglomerate is considered to be coeval to the Geoffrey Formation of Hornby Island and that formational name is therefore now extended to include these beds in the Nanaimo Basin.

Distribution and thickness

The greatest thickness, about 1,500 feet, is present on Mount Galiano and Sutil Mountain on Galiano Island and conglomerate occurs in a half-circle south of these points on Saltspring, Prevost, North Pender and Mayne islands. The thickness on the west side of Mayne Island at Helen Point is 750 feet and eastward on Mayne Island the conglomerate grades into 400 feet of sandstone, exposed at the south end of Bennett Bay. In the Comox Basin, in the revised interpretation of Hornby Island geology mentioned in the foregoing section, the Northumberland (as redefined) is overlain by the Geoffrey. The thickness of this formation, roughly estimated from outcrop area and general dip (Usher, 1952, p. 28), varies between 700 and 1,300 feet.

Lithology

The Geoffrey is mainly composed of coarse conglomerate with minor sandstone, but changes along strike southeastward on Mayne and northwestward on Saltspring Island into sandstone. The conglomerates contain typically two diverse types of clasts. The major part is composed of well-worn, subrounded pebbles and cobbles, in well-sorted layers but varying in size from 1/8 inch to one foot. They are mainly white quartz, black chert and argillite with minor dark, fine-grained volcanic rocks and in places granitic rocks. Between these one finds occasional blocks, commonly of greenschist derived from the Sicker Group, that stand out clearly by their much larger size and angularity. One such block is visible on the Mayne Island coast one half mile east of Helen Point towards Village Bay. The largest visible dimension is 6 feet, but it is indented to a depth of 2 feet along a softer layer that was later filled with fine conglomerate. Presumably such blocks were moved by torrential streams entering the delta. The indented block was apparently gouged by running water between the time of emplacement on the flood plain and burial by succeeding floods. Thus the conglomerate is composed of well-worn gravel of more distant source, mixed with large blocks from nearby-exposed Sicker Group rocks. The sandstones of the formation are light brownish grey, and are mainly developed in 3- to 10-foot beds and more rarely in thin platy to laminated units. The components are mainly quartz and minor chert; grit-size rock fragments, and small chert pebbles are commonly scattered through the beds. The Geoffrey Formation of Hornby Island was not examined in detail by the writer's party but Usher's description (1952, p. 28) tallies closely with that of the Galiano and Mayne Island conglomerate. It occurs in massive beds up to 300 feet thick, separated by beds and lenses of sandstone. It is unsorted and consists of boulders of quartz, schist, granitic and volcanic rocks together with clasts of sandstone, argillite and calcareous concretions presumably derived from older Nanaimo beds. The sandstones are rich in quartz and contain minor feldspar, mica and rock fragments. The Geoffrey sediments also exhibit crossbedding, shale breccias and slump structures and have cavernous to honeycomb weathering textures along the seashore.

Base and top

The basal contact is commonly sharp, but contains in several places slump folds to 10 feet in size with steep to overturned beds within generally undisturbed only slightly inclined beds. The contact with overlying shales is transitional from conglomerate through sandstone to shale. In places this change occurs within a thickness of 50 feet. The sharply limited areal extent of the conglomerate is indicative of local deltas in the Hornby and south Galiano Island areas.

Age

Rare fossils found by Usher (1952, p. 28) in Geoffrey conglomerate were obviously derived from older formations. The age is considered to be roughly equal to that of the overlying lower part of the Spray Formation (Upper Campanian).

Spray Formation

Name and definition

The Spray Formation overlies the Geoffrey and forms the marine shaly upper part of the fourth depositional cycle. Usher (1952) applied the name to shales partly outcropping on and underlying Tribune Bay, southeast Hornby Island. The name is derived from Spray Point, a resistant sandstone ledge projecting into the middle of the bay[1].

Distribution and thickness

The section at Tribune Bay, measured by the writer's party, is 950 feet thick, including 400 feet of covered interval in the upper part of the section. In the revised interpretation of the geology of Hornby Island the Spray also outcrops north of Shingle Spit on the west coast of that island. There the thickness of the incomplete section, without base or top, is 650 feet (Fig. 6). These beds were included in the Lambert Formation by Usher (1952). In the Nanaimo Basin the formation is exposed in Bennett and Miners bays on Mayne Island, in the former with 1,770 feet measured thickness (Fig. 6) and at Montague Bay on Galiano Island, and Degnen and Leboeuf bays on Gabriola Island, where the thickness is only a few hundred feet.

Lithology

The lithology of the lower part of the Spray Formation, as exposed on Mayne and Hornby islands, is similar to that of Northumberland and Cedar District formations. It consists mainly of siltstone-shale sequences with graded beds, one inch to six inches thick, and with a few ironstone and marcasite concretions. In the upper part shale is more predominant and individual shale beds are several feet thick and separated by thin bottom layers of siltstone. Outcrops of shale in unweathered condition are massive with smooth vertical joint faces and barely detectable silty laminae. Weathered outcrops exhibit the spheroidal structure described for the Haslam shale. The intermediate 60 feet of sandstone exposed at Manning Point (old ferry dock) (Fig. 6, sec. 64-6) is massive and contains mainly fine- to medium-grained subangular quartz, minor biotite, and calcareous cement. Towards the top interbedded shale becomes predominant and the overlying shale contains generally no more than 10 per cent siltstone, again as paper-thin bottom layers of shale beds up to about two feet thick. There are minor calcareous concretions and the shale weathers to rusty brown and yellowish colours.

Age and subdivision

The Spray Formation, as defined in this report is divided into lower and upper parts by the sandstone of Spray Point, Hornby Island. This sandstone is considered to be identical to the one outcropping on the west side

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1 The name does not appear on existing topographic maps but is mentioned in Usher's field notes. It was on the writers' suggestion adopted in 1968 by the Canadian Permanent Committee on Geographical Names.

of that island at Manning Point, between Phipps and Collishaw points, and may be also roughly equal to the sandstone on the point between Bennett and Campbell Bay on Mayne Island (see Fig. 6). As described in the following chapter in more detail, the Manning Point sandstone marks a break in the microfauna studied by McGugan (1962) and also in the ammonite-fauna collected by Usher (1952), allowing subdivision of the Suciensis zone into cf. Pacificum and Hornbyense subzones (E and F; see Figs. 1 and 6). The break is also considered to be the Campanian-Maestrichtian stage-boundary. The writers have made this interpretation mainly on the basis of the work of McGugan and Usher. If this view is confirmed by more detailed work it may justify the separation of the lower and upper shales into two formations. In that event it is recommended that the existing name Lambert, not used in the here proposed terminology, be retained for the lower shale, exposed between Shingle and Manning points and the name Spray be applied to the upper shale between Manning and Collishaw points. In sum, the lower part of the Spray Formation is considered to be upper Campanian in age and the upper part, including only beds exposed northeast of Manning and Spray points, on Hornby Island and perhaps in Campbell Bay on Mayne Island, is held to be Maestrichtian.

Gabriola Formation

Name and definition

The Gabriola is the highest formation of the Nanaimo Group, named by Clapp (1912a) after exposures on Gabriola Island. Unlike preceding depositional cycles it is not overlain by a marine shaly sequence. Conglomerate and sandstone, exposed at St. John Point, Hornby Island are correlated with the Gabriola. They were called (see Table I) 'Upper Conglomerate' by Richardson (1873), 'St. John' by Williams (1924) and were again renamed 'Hornby' by Usher (1952) because 'St. John' was preoccupied. However, Williams had used 'Hornby' for Richardson's 'Middle Conglomerate' that was renamed 'Geoffrey' by Usher. Furthermore Crickmay and Pocock (1963) appear to have used the name Hornby again for the 'Middle Conglomerate'. In view of this ambiguity there is good reason to drop the name Hornby in favour of Gabriola, even though there is only indirect paleontological correlation.

Distribution and thickness

In Nanaimo Basin the formation is exposed in a southeastward-narrowing belt in the outer island group of Gabriola, Valdez, Galiano, Mayne Saturna and Tumbo islands. Usher (1952, p. 20) reports a thickness of 1,400 feet on Gabriola Island and 3,000 feet on the south end of Galiano. For the beds of St. John Point, Hornby Island, he gave a thickness of 600 to 800 feet. Beds exposed at the north end of Lasqueti Island are according to G.E. Rouse (pers. comm.) somewhat younger than the Gabriola and have provisionally been mapped as a separate unit.

Lithology

The Gabriola is commonly a medium- to coarse-grained massive sandstone with about 50 per cent quartz, 30 per cent feldspar and 20 per cent dark minerals and rock fragments. Conglomeratic lenses and scattered pebbles occur in places in the sandstone but, as Usher observed, the lack of extensive conglomerates is a distinctive feature of the Gabriola in the Nanaimo Basin. Shaly layers commonly show small-scale intraformational slumping and sandy beds crowded with angular shale fragments are not uncommon. Coaly lenses have been observed in many places and large calcareous concretions weathering out in large ellipsoids or more irregular shapes occur everywhere. The so-called 'galleries' of Gabriola Island are large wave-cut benches with overhanging sandstone roof, cut into the friable Gabriola sandstone. The rapid progress of the weathering is witnessed by names with dates painted on the sandstone and due to the protection of the paint standing out in bold 1/4 inch relief after 5 to 10 years.

Crossbedding is not common but large-scale crossbeds were seen on Tumbo Island. The foreset beds are as much as 5 feet thick, thinly laminated and cut off at 30 degrees by the topsets. The sandstone is coarse grained to gritty with fragments only a few millimetres in size of quartz, black chert, and jasper. Perhaps these beds are of eolian origin.

The colours of the Gabriola beds, yellow-orange and pink, are generally brighter than those of older sandstones, where brown and grey predominate. This indication of somewhat different climatic conditions and the lack of marine shales are suggestive of terrigenous deposition of part of the Gabriola.

The 'Hornby' conglomerate of Comox Basin contains sandstone, pebbly sandstone, and massive conglomerate. Most clasts are pebbles and cobbles of quartz, chert, volcanic and granitic rocks and sandstone, shale and conglomerate from older Nanaimo beds. Some large blocks, one of limestone with a diameter of 8 feet, have been observed.

Base

The basal contact of the Gabriola is generally distinctly unconformable where observed on Hornby, Gabriola and Mayne islands.

Age

No paleontological dating is available for the Gabriola. Richardson (1873, p. 51) reported belemnites from the 'Upper Conglomerate' of Hornby Island in a unit of sandstone, conglomerate and coal. Usher (1952, p. 30) did not find these specimens in the Geological Survey collections nor did he find any additional belemnites in the field. He therefore was forced to base the age on the stratigraphic position of the 'Hornby' which he considered equivalent to that of the Gabriola. Regarding the latter he reported poorly preserved, large ammonites, probably *Pachydiscus suciaensis* found in Campbell Bay, Mayne Island. However, this locality, included in the Gabriola by Usher, is in this report tentatively correlated with the upper part of the Spray Formation. Thus the age of the Gabriola, placed at the top of the Nanaimo Group is only indirectly known to be Maestrichtian or Tertiary.

The sandstones of Lasqueti Island have yielded pollen that according to G.E. Rouse (pers. comm.) are broadly similar to those found in the Chuckanut Formation of northern Washington. But apparently the age is younger than that of the Gabriola. Provisionally these beds have been mapped as a separate unit but they may be the younger part of the Gabriola Formation.

Northern Vancouver Island

Introduction

No mention has been made in the foregoing discussion of the Nanaimo Group deposits of Suquash Basin and other related occurrences in northern Vancouver Island. The area was the scene of the earliest coal mining activities in about 1850 but was soon abandoned for the much better coal seams of Nanaimo. It was first visited and described by G.M. Dawson (1887).

Work done in the area by the present writers has as yet been of a cursory nature. The lithostratigraphic and paleontological data are at this time interpreted slightly differently in this section and in the related section of the succeeding chapter.

The principal area of Nanaimo beds is the coast and adjacent lowlands between Beaver Harbour (old Fort Rupert) and Port McNeill. The Suquash coal mine was about halfway between these points, near the mouth of Suquash Creek. Other exposures of Nanaimo sediments are west of Hardy Bay on the east side of Hope Island, and north of Jeune Landing on the east side of Neroutsos Inlet.

So far as this writer could establish the Suquash sequence is one depositional cycle, similar in development to the Comox-Haslam cycle. It contains a basal formation of greywacke, sandstone and some lagoonal plant- and coal-bearing beds and also marine sandstone. These beds are overlain by marine shale. The thickness of the presently unnamed sandstone sequence is estimated at 400 feet, the overlying shale sequence is perhaps 250 feet.

Greywacke-sandstone sequence, lithology

The following description is based on examination of partial sections along the shore for about 3 miles southwest of Thomas Point and for 2 miles up Keogh River by Muller in 1966 and in more detail by Jeletzky in 1968.

A basal greywacke and sandstone formation discordantly overlaps the volcanic rocks of Karmutsen Group about 3/5 mile southwest of Thomas Point. It consists predominantly of buff to rust coloured, coarse- to medium-grained, commonly gritty, intensively crossbedded and locally calcareous greywacke with some lenticular interbeds and lenses of fine to coarse grit and fine pebble conglomerate. Some poorly exposed interbeds of friable, fine-grained, locally carbonaceous to coaly greywacke and sandy siltstone occur in this unit.

In the upper part of the formation, outcropping west of the mouth of Keogh River, the greywacke is interbedded with light- to pinkish-greybuff to light grey weathering well sorted and rounded, fine- to medium-grained sandstone. The sandstone is crossbedded, ripple-marked, or thinly laminated. Locally it is carbonaceous to coaly and contains a 2-foot interbed of shale and coaly shale with some plant remains. The present writer believes that these beds are equivalent to those exposed on Keogh River and along the shore near Suquash Creek at the site of the former coal mine. There two 4-inch coal seams, separated by one foot of shale, are interbedded in feldspathic fine-grained sandstone with scattered coaly laminae. Dawson (1887, pp. 66B to 68B) quotes three ancient borings from this locality, apparently penetrating a sequence of sandstone and shale, but no coal was found below the outcropping seam. It is probable that boring No. 2 ended at 329-foot-depth in Karmutsen volcanic rock.

Greywacke-sandstone sequence: age and correlation

The formation contains a Campanian to Maestrichtian flora and a Vancouverense zone marine fauna (Fig. 1). As the overlying marine shale is probably Northumberland-equivalent the sandstone formation is most likely coeval with the De Courcy that forms the basal part of the third depositional cycle of the Nanaimo-Comox region.

Siltstone-shale sequence: lithology

The sandstone formation is gradationally overlain by a thinly bedded to laminated fine sandstone, siltstone and shale sequence, estimated to be about 250 feet thick. It is exposed on the coast east of the mouth of Keogh River and on that river, about 1 3/4 mile above the mouth. It is similar to the thinly bedded marine sequences of the Nanaimo region and contains also calcareous concretions that have yielded some fossils.

Siltstone-shale sequence: age and correlation

Metaplacenticeras occidentale, found previously by Dawson's party on Keogh River, and recently again by Jeletzky in the coastal outcrops, places the shale in the cf. Pacificum faunal zone. As the underlying sandstone is probably equivalent to De Courcy the shale is apparently coeval to Northumberland beds.

BIOCHRONOLOGY

(J.A. Jeletzky)

Previous Work

Previous work on various aspects of geology of the Nanaimo Group was discussed by J.E. Muller in the preceding part of this report. This section is, therefore, restricted to comments on the earlier investigations of the marine macroinvertebrate faunas and biochronology of Nanaimo Group and some correlative units of the North Pacific faunal realm.

The study of marine macroinvertebrate paleontology of the Nanaimo Group began with the description of several molluscan fossils from its sections in Nanaimo area and on Sucia Island by F.B. Meek in 1857.

In 1859 B.F. Shumard described three more invertebrates from Nanaimo River. This publication was soon followed by description of additional fossils from Nanaimo and Sucia Island areas by Meek (1861, 1864) and Gabb (1864). This early work established a Cretaceous age for the bulk of Nanaimo Group.

J.F. Whiteaves (1879) made the next important contribution to the invertebrate marine paleontology of the Nanaimo Group. His publication, "Mesozoic Fossils, Part II", was the first comprehensive work on the subject. Additional Upper Cretaceous fossils from Vancouver Island were described in several later publications of Whiteaves (1892, 1893, 1895a, 1895b, 1895c, 1901). His research of macroinvertebrate paleontology of the Nanaimo Group was concluded in a final report "Mesozoic Fossils, Part V" (Whiteaves, 1903), which also contained a brief and generalized account of the correlation of the group with the Upper Cretaceous rocks of California (Chico Group), the Senonian stage of Europe, and the Upper Chalk of England. It must be pointed out that no attempt at paleontological zoning of Nanaimo Group or its correlation with the more refined European Upper Cretaceous stages and zones was undertaken by Whiteaves (1879-1903) and his predecessors. The subdivision of the group proceeded on a purely lithostratigraphical basis until publication of Usher's (1952) work.

No publications dealing with the invertebrate marine macrofaunas and biochronology of Nanaimo Group appeared between 1903 and 1952 in Canada. However, McLellan (1927) published an account of the stratigraphy of the Upper Cretaceous rocks of San Juan Islands of northwestern Washington, which he correlated with those of the Nanaimo Group of Vancouver Island and the Gulf Islands. McLellan (1927) also described three new species of pelecypods and gastropods from the richly fossiliferous section of the Nanaimo Group of southern Sucia Island and gave lists of fossils from this and other Upper Cretaceous sections of San Juan Islands.

The publication of Usher's (1952) detailed study of the "Ammonite Faunas of the Upper Cretaceous Rocks of Vancouver Island" was an important milestone in the research of paleontology and biochronology of Nanaimo Group. This work provided a thorough description and good photographs of all ammonite genera and species then known from the Nanaimo Group of the Nanaimo and Comox basins and brought up to date their nomenclature and taxonomy. Even more important is the fact that this work included the first attempt to define the time ranges and age significance of all ammonite species studied within the succession of the Nanaimo Group and to subdivide the latter into ammonite faunizones. Four ammonite faunizones were recognized by Usher (1952) but only two of these were believed to be common to the Nanaimo and Comox basins. As will be shown below, some of Usher's (1952) biochronological conclusions were in error and have been revised by the writer. However, this does not detract from the fundamental value of his pioneering studies in paleontological zoning of the Nanaimo Group and in correlation of the regional ammonite faunizones with the international standard stages. Usher (1952, pp. 35-37) apparently attempted to reconcile the faunal evidence with already existing ideas about the formational sequences of the Nanaimo Group in Nanaimo and Comox basins and their correlation, based on lithostratigraphy. Usher (1952, pp. 37-39) was aware of the contradictions between biochronology and lithostratigraphy but elected (Usher, 1952, pp. 37-39) to subordinate the biochronology to the lithostratigraphy where the two were in conflict.

McGugan (1962, 1964) was the first to describe the foraminiferal faunas of all shale formations of Nanaimo and Comox basins and to attempt the time-correlation of sequences of the Nanaimo Group of these two basins using the standard foraminiferal zones of intercontinental value. This research has shown that some formational boundaries within the Nanaimo Group are diachronic and that the previous ideas about correlation of the shale and sandstone units in Nanaimo and Comox basins were partly in error.

According to McGugan (1962, 1964), the Cedar District, upper 'Trent River', all of Northumberland, all of the lower and the lower part of upper 'Lambert' Formation contains the upper Campanian <u>Cibicides voltziana</u> fauna and hence are correlative. Only the upper part of the upper 'Lambert' Formation and the Spray Formation of Comox basin were found to contain the early Maestrichtian <u>Bolivina incrassata</u> fauna.

Lower Trent River, Haslam, and Qualicum formations were found to contain the Campanian and? Santonian <u>Rugoglobigerina</u> fauna, which was interpreted as older than the <u>Cibicides voltziana</u> fauna. Furthermore, their basal beds contain a peculiar, possibly still older <u>Gaudrina</u> and <u>Lenticulina</u> fauna. Lower Trent River, Haslam, and Qualicum formations were accordingly treated as geologically contemporary rock units.

As will be shown below, the above-mentioned conclusions of McGugan (1962, 1964) are compatible with the biochronological results of the writer's research based on the study of ammonite and inocerami faunas of the same formations.

The paper by Crickmay and Pocock (1963) largely devoted to the allegedly Cretaceous nonmarine rocks of Vancouver area on the mainland of British Columbia, contains some interesting comments on stratigraphic succession and time-correlation of various formations of Nanaimo Group. These workers list, furthermore, most important invertebrate and plant fossils from these formations. Usher's (1952) correlations of the individual Nanaimo formations were questioned by Crickmay and Pocock (1963, pp. 1931-1932). They concluded in particular that the Cedar District Formation is younger than the Trent River Formation and that the latter is time equivalent of the Haslam Formation. They also found that the Cedar District Formation and the underlying coarse clastics of the Extension-Protection Formation are absent in the Comox Basin. Many of these conclusions have been confirmed in the present work.

The recent mapping of the Nanaimo Group by J.E. Muller began in 1963, and the study of various fossil collections from this group to aid this mapping project was started in 1965 by the writer. Some of the results of the author's and Muller's research have already been published in preliminary form (Jeletzky, 1967; Muller, 1966, 1967; Muller and Jeletzky, 1967). This report attempts to summarize the new information on the biochronology and paleontology that became available through office research and through the writer's own stratigraphic field work in the Nanaimo Group in 1966 and 1968. As already stressed in the introduction, this report is only a progress report. Some conclusions reached, although apparently reasonable in the light of the information available, may have to be revised later when the field work and office studies are completed.

The scarcity of information about true time ranges of most of the important zonal macrofossils of the Nanaimo Group, which are restricted to ammonites and inocerami, has often forced the writer to rely heavily on the relevant data available in the foreign literature. This task was greatly facilitated by the circumstance that most of the ammonites and inocerami occurring in the Nanaimo Group are either conspecific with or closely allied to those occurring in the Upper Santonian and Campanian rocks of the Pacific Slope of the United States (including southern Alaska), Japan, Indian Peninsula, Soviet Far East, and Madagascar. Of the more recent foreign publications dealing with paleontology and biochronology of these faunas, those of Matsumoto (1959a, 1959b, 1960), Nagao and Matsumoto (1939-1940), Popenoe _et al._ (1960), Jones (1963), Anderson (1958), Sokolov (1914), Collignon (1948, 1955a, 1955b, 1961), and Besarie and Collignon (1956) have been found to be particularly useful. The use of this valuable information considerably speeded up the writer's research. It enabled him to restrict own field work to an absolute minimum and to work out the tentative zonal scheme proposed in this report largely using fossil collections made by Richardson, Usher, J.E. Muller and party, and various others in much shorter time than would have been possible otherwise.

A number of ammonite and inocerami species from the Nanaimo Group have been discussed in the above-mentioned foreign publications. Some of them have been renamed in works of Matsumoto (1959a, 1959b, 1960) and Jones (1963). In the writer's opinion the validity of these nomenclatorial changes is in several instances uncertain. Therefore, and because of the preliminary nature of this report intended principally for use of the Canadian mapping geologists and stratigraphers, they are omitted for the time being. The familiar specific ammonite names are used instead in the sense of Whiteaves (1879-1903) and Usher (1952). The writer intends to publish a paleontological report bringing the nomenclature of the index fossils of Nanaimo Group up to date as soon as possible.

Paleontological Zones

Usher's (1952, pp. 36-41) proposal to name paleontological zones after geological formations in which they were found (or believed to be found) is not followed in this report for reasons already indicated and discussed in the section on previous work. Nor is the use of faunizones favoured by the writer who prefers to use the biozones (= range zones) or partial zones (= teilzones) based on known or inferred life spans of one or several

TABLE II AMMONITE AND INOCERAMUS FAUNAS OF NANAIMO GROUP

INDEX SPECIES	ZONES					
	A	B	C	D	E	F
Didymoceras? cooperi Gabb	-	-	-	-	X	X
Baculites chicoensis Trask sensu Usher	x?	x	x	X	x	-
Baculites occidentalis Meek sensu Usher	-	-	-	x?	X	X
cf. Baculites aff. B. teres Forbes	x	x	-	-	-	-
Bostrychoceras elongatum (Whiteaves)	X	X	-	-	-	-
Bostrychoceras sp. aff. B. otsukai (Yabe)	x	-	-	-	-	-
Damesites damesi var. intermedius Matsumoto	X	X	X	-	-	-
Diplomoceras notabile Whiteaves	-	-	-	-	x	-
Diplomoceras? subcompressum (Forbes)	X	X	-	-	-	-
Diplomoceras? sp.	-	-	-	x	-	-
Epigoniceras epigonum (Kossmat)	X	X	X	x?	-	-
Gaudryceras denmanense Whiteaves	-	x	x	X	x	-
Gaudryceras sp.	x	-	-	-	x	-
Hauericeras gardeni (Baily)	X	X	x	-	-	-
Hoplitoplacenticeras cf. plasticum Paulke	-	-	-	x	-	-
Hoplitoplacenticeras vancouverense (Meek)	-	-	-	x	-	-
Metaplacenticeras cf. pacificum (Smith)	-	-	-	-	x	-
Metaplacenticeras occidentale (Whiteaves)	-	-	-	-	X	-
Neophylloceras ramosum (Meek)	-	-	-	-	X	X
Neophylloceras sp.	x	x	x	x	-	-
Nostoceras hornbyense (Whiteaves)	-	-	-	-	-	x
Pachydiscus binodatus (Whiteaves)	x?	-	-	-	-	-
Pachydiscus buckhami Usher	x	-	-	-	-	-
Pachydiscus elkhornensis Usher	x	x	x?	-	-	-
Pachydiscus (Anapachydiscus) aff. wittekindi (Schluter)	-	-	-	x	-	-
Pachydiscus (Eupachydiscus?) haradai sensu Usher	-	X	-	-	-	-
Pachydiscus cf. jacquoti Seynes	-	-	-	x?	-	-
Pachydiscus (Canadoceras) multisulcatus (Whiteaves)	-	-	X	-	-	-
Pachydiscus neevesi (Whiteaves)	-	-	-	x	-	-
Pachydiscus (Canadoceras) newberryanus (Meek)	-	-	x	X	-	-
Pachydiscus ootacodensis (Stoliczka) sensu Usher	-	-	-	-	X	X
Pachydiscus (Eupachydiscus) perplicatus (Whiteaves)	X	-	-	-	-	-
Pachydiscus suciaensis (Meek)	-	-	-	-	X	X
Pachydiscus (Canadoceras) yokoyamai (Jimbo)	-	-	X	x?	-	-
Patagiosites aff. arbucklensis (Anderson)	-	-	-	x	-	-

TABLE II (Continued)

INDEX SPECIES	ZONES					
	A	B	C	D	E	F
Puzosia (Parapuzosia) sp.	x	-	-	-	-	-
Phyllopachyceras forbesianum (d'Orbigny)	-	-	-	-	-	x
Pseudoxybeloceras cf. lineatum (Gabb)	x	x	x?	x?	-	-
Pseudophyllites indra (Forbes)	-	-	-	-	X	X
Pseudoschloenbachia brannani Usher	-	x	-	-	-	-
Pseudoschloenbachia cf. umbulazi Bayle	-	-	-	x ?	-	-
Polyptychoceras vancouverense Whiteaves	X	-	-	-	-	-
Ryugasella ryugasensis Wright and Matsumoto	x	x	-	x?	-	-
Schluteria selwyniana (Whiteaves)	x	x	x	x	-	
Inoceramus ex gr. chicoensis Anderson	X	X	X	x	-	-
Inoceramus ex aff. cordiformis Sowerby	x	-	-	-	-	-
Inoceramus elegans Sokolov	-	-	X	-	-	-
Inoceramus ex aff. lobatus Goldfuss	X	-	-	-	-	-
Inoceramus naumanni Yokoyama	X	x	-	-	-	-
Inoceramus orientalis Sokolov emend. Nagao and Matsumoto	x	X	x	-	-	-
Inoceramus orientalis var. ambiguus Nagao and Matsumoto	x	X	x	-	-	-
Inoceramus n. sp. aff. orientalis Sokolov	X	x	-	-	-	-
Inoceramus sachalinensis Sokolov	-	-	X	-	-	-
Inoceramus schmidti Michael s. str.	-	-	X	-	-	-
Inoceramus ex gr. subundatus Meek	x?	x	x	X	x	x?
Inoceramus ex gr. vancouverensis Shumard	x?	x	x	X	x	X?

LEGEND

- \- = Absent
- x = Rare
- X = Common to abundant
- x? = Occurrence in this zone uncertain

A = Naumanni Subzone)
) Elongatum Zone
B = Haradai Subzone)
C = Schmidti Zone
D = Vancouverense Zone
E = cf. Pacificum Subzone)
) Suciensis Zone
F = Hornbyense Subzone)

essentially coeval ammonite and inocerami species, which have been found to have relatively short stratigraphic ranges and to be more or less facies breaking. As stressed elsewhere (Jeletzky, 1965a), every biochronologically used fossil must be evaluated individually as to the relative degree of its usefulness. No reliance was necessarily placed on the number of fossil ammonite or inocerami species common to any of the formations of the Nanaimo Group when attempting to correlate them, unless these forms happened to be approximately equally valuable biochronologically.

So far, only the majority of richly ornamented ammonites and some divergently ribbed inocerami of the Inoceramus naumanni-orientalis-schmidti species group were found to be useful for refined zoning of the Nanaimo Group. None of the other, in places much more numerous, molluscan and other invertebrate species, seems to be useful in this respect. In the present state of our knowledge at least all these marine macrofossils can only be used for the recognition of the Nanaimo Group as a whole. All ammonites and inocerami hitherto determined from the Nanaimo Group are listed in Table II. This table also summarizes the data available about the time ranges of these species within the Nanaimo Group.

A proposal was made recently by some British stratigraphers Dean, Donovan, and Howarth, 1961) to refer to the names of Mesozoic ammonite zones only by the trivial names of their index species once they have been introduced under their full names. This proposal is followed here for the ammonite and inocerami zones of the Nanaimo Group in view of the obvious advantages of convenience and economy of words offered by this style. For example, the name Bostrychoceras elongatum zone (or fauna) is abbreviated to 'Elongatum zone', and Inoceramus schmidti zone is shortened to 'Schmidti zone'.

Bostrychoceras elongatum zone

The oldest known marine macrofauna of the Nanaimo Group is characterized by the widespread and mostly common occurrence of two uncoiled ammonites Bostrychoceras elongatum (Whiteaves) and Diplomoceras? subcompressum (Forbes) the first of which is designated as the zonal index. So far as known, these two species range throughout the Elongatum zone, which comprises the upper marine beds of Comox (= Benson) Formation as well as the lower part of Haslam Formation (= 'Qualicum' and lower 'Trent River' formations) but are unknown in the overlying beds.

Usher's (1952, p. 106) record of B. elongatum from the Cedar District (= upper 'Trent River') Formation on the southwestern shore of Denman Island is discounted by the writer. The specimen concerned is believed to have been collected from the 6-inch to 3-foot-thick conglomerate layer which appears to be the only fossiliferous bed at Usher's locality 107 where the specimen of B. elongatum was stated to have been collected. This pebble-conglomerate is very rich in pebbles of limestone concretions lithologically identical with those which abound in the Haslam (= lower 'Trent River') Formation of Comox Basin and presumably derived therefrom. Some of these pebbles of concretions are fossiliferous. It is, therefore, most likely that the specimen of B. elongatum concerned was originally derived from the underlying Haslam Formation where it is known to occur.

The top of the time range of B. elongatum and D.? subcompressum in the Nanaimo Group apparently corresponds to the time of their extinction elsewhere. The same is, however, not necessarily true of the base of their time range in the Comox Formation. The latter may be younger than the base of their zone elsewhere and may merely reflect the moment of geological time when they were brought into the Nanaimo sea by its earliest known transgression. Both species could thus conceivably range considerably lower in section in adjacent areas where the marine regime began earlier.

A number of other species such as Inoceramus naumanni Yokoyama, emend. Nagao and Matsumoto, Inoceramus orientalis Sokolov emend. Nagao and Matsumoto, cf. Baculites aff. teres Forbes (in Jones, 1963), Pachydiscus (Eupachydiscus) perplicatus Whiteaves, P. (E.?) haradai Jimbo sensu Usher, 1952, Polyptychoceras vancouverense Whiteaves, Puzosia (Parapuzosia) sp. indet. etc. are not known to range above the top of the Elongatum zone. However, unlike its zonal index, these species appear to be either largely or completely restricted to certain parts of the zone, or restricted to certain depositional basins or even individual sections of the Nanaimo Group.

The Elongatum zone is, finally, characterized by an apparently complete absence of such index fossils of the overlying Schmidti zone as: P. (C.) multisulcatus, Pachydiscus (Canadoceras) yokoyamai, P. (C.) newberryanus, Pseudoschloenbachia brannani, Inoceramus schmidti Michael s. str., Inoceramus elegans Sokolov, and I. sachalinensis Sokolov, except in a relatively thin topmost part of the zone, here designated as the overlap beds.

A number of other ammonites and inocerami occurring more or less commonly in the Elongatum Zone are known to range up into one or more of the younger paleontological zones of the Nanaimo Group (Table II). Some of these fossils are more common in these younger beds than they are in the Elongatum zone (see below). They are accordingly either entirely nondiagnostic of the latter zone or have but a limited biochronological value. These forms include: Hauericeras gardeni Baily, Ryugasella ryugasensis Wright and Matsumoto, Pseudoxybeloceras cf. lineatum (Gabb), Gaudriceras denmanense Whiteaves, Epigoniceras epigonum (Kossmat), Baculites chicoensis Trask sensu Usher 1952, Neophylloceras sp. indet., Schluteria selwyniana Whiteaves, Damesites damesi var. intermedius Matsumoto, Inoceramus ex gr. chicoensis Anderson, Inoceramus vancouverensis Shumard.

Subzones

The following common and widespread species appear to be useful for subdivision of the Elongatum zone into more refined biochronological units treated as subzones in this report:

1. Inoceramus naumanni below; and
2. Pachydiscus (Eupachydiscus?) haradai sensu Usher, 1952, above.

It was previously suggested (Jeletzky, 1967, p. 70, Table I) that beds characterized by Pachydiscus (Eupachydiscus) perplicatus Whiteaves, which occur between subzones 1 and 2, deserve to be recognized as a third

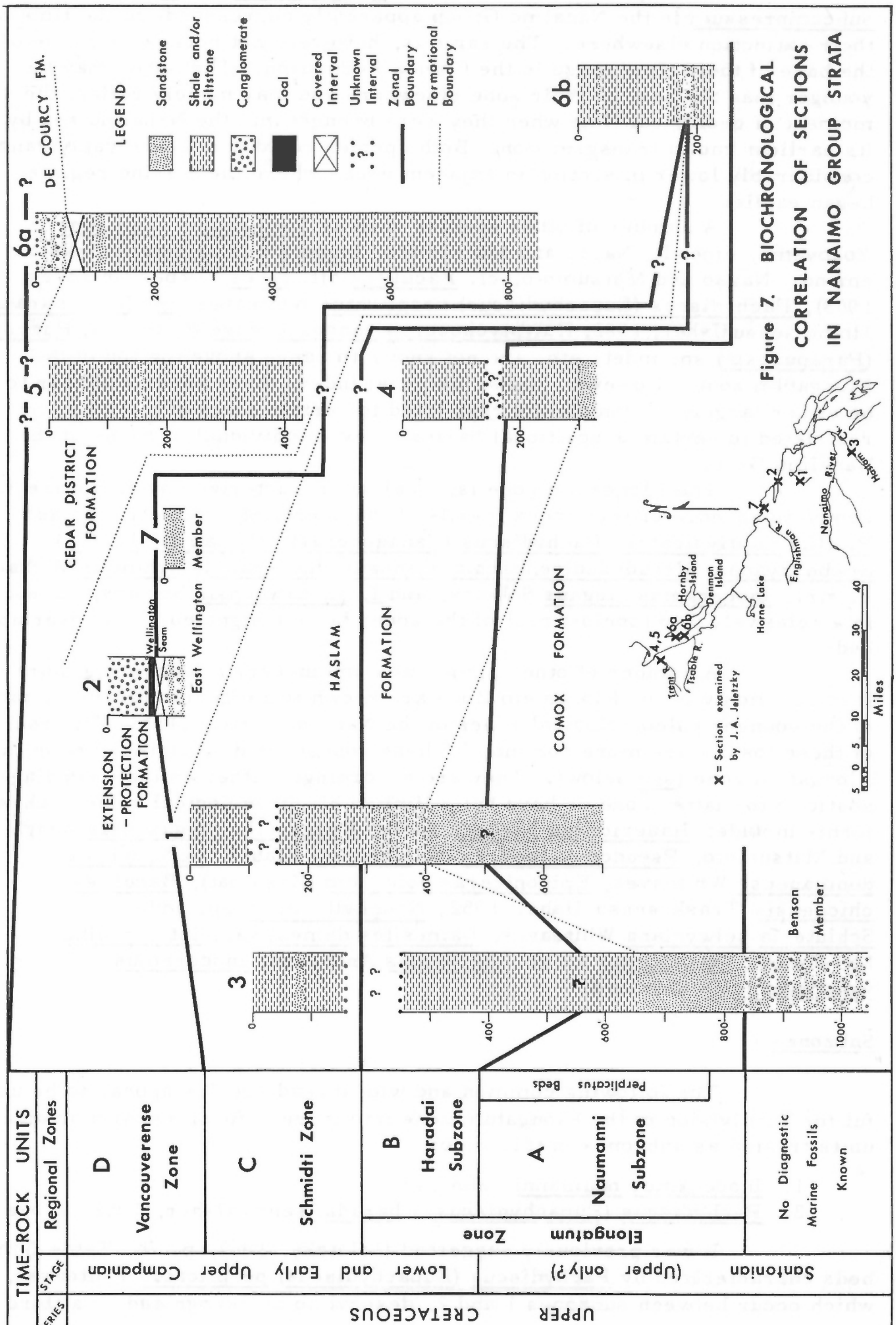


Figure 7. BIOCHRONOLOGICAL CORRELATION OF SECTIONS IN NANAIMO GROUP STRATA

subzone. These beds appear, however, to be largely restricted to the Comox Basin and to be but a faunal facies of the upper part of the Naumanni subzone. They are, therefore, not used as a subzone in this report (Table III, Fig. 7).

Inoceramus naumanni subzone

The lower coal- and plant-bearing part of Comox Formation did not yield any diagnostic marine fossils. Its upper part, largely represented by fine- to medium-grained sandstone with some grit and fine pebble conglomerate is, however, largely or entirely marine in most sections of Nanaimo and Comox basins. These marine beds, which locally are over 150 feet thick (Fig. 7), have yielded a fairly rich and diagnostic invertebrate fauna belonging to Elongatum zone. The best fossil localities are: Haslam Creek canyon (Fig. 7, sec. 3) and Oyster River (GSC loc. 69454 and fossil collections preserved at Geology Department, University of British Columbia).

In addition to a great number of apparently long-ranging and facies-bound pelecypods, gastropods, scaphopods, crustaceans, etc. the fauna of the upper part of Comox Formation includes: Bostrychoceras elongatum (Whiteaves), Bostrychoceras sp. aff. B. otsukai (Yabe), Diplomoceras? subcompressum (Forbes), Puzosia (Parapuzosia) sp. indet., very common Inoceramus naumanni Yokoyama and less common radially and divergently ribbed Inoceramus superficially similar to I. japonicus Nagao and Matsumoto and previously designated as I. aff. japonicus (Jeletzky, 1967, p. 70, Table I). This form is, however, believed to be more closely allied to I. orientalis Sokolov and shall be designated I. n. sp. aff. I. orientalis Sokolov in this report (Tables II-III, Fig. 7). Other relatively rare and insufficiently understood Inoceramus species of this fauna include I. ex aff. cordiformis Sowerby and I. ex aff. lobatus Goldfuss.

Except for extremely rare Bostrychoceras sp. aff. B. otsukai (Yabe), which was found once at the Oyster River locality of Comox Formation (University of British Columbia collections), and Puzosia (Parapuzosia) sp. indet., which was found once in Haslam Creek canyon (GSC loc. 77464), all above mentioned forms range up into the basal 70 to 130 feet of Haslam Formation (Fig. 7). The latter beds are, therefore, assigned to the same Naumanni subzone as the upper part of the Comox Formation (Table III).

The name-fossil of the subzone – I. naumanni – is equally common in sandstone and shale facies throughout the studied sections of Comox and Nanaimo basins. It ranges up into the next younger Pachydiscus (Eupachydiscus?) haradai subzone in some sections. However, it is much less common in this subzone than in the underlying beds. This makes it the most valuable fossil available of the Naumanni subzone. The same appears to be true of I. n. sp. aff. orientalis, which becomes replaced by typical I. orientalis Sokolov already in the basal part of the Haradai subzone (Table II). The last two Inoceramus species appear to be connected by numerous transitions and beds containing both forms occur locally in the topmost beds of the Naumanni subzone. The earliest representatives of I. orientalis f. typ. and its var. ambiguus Nagao and Matsumoto appear rarely in the interval from 50 to 70 feet above the base of the Haslam Formation (e.g. GSC loc. 60839) in Comox Basin and about 60 feet above the base in Nanaimo Basin (GSC loc. 77385). Because of this intermingling of species, sizable samples

TABLE III. CORRELATION OF REGIONAL FOSSIL ZONES OF NANAIMO GROUP WITH THOSE OF EUROPE AND THE PACIFIC SLOPE OF THE UNITED STATES.

Stage	INTERNATIONAL STANDARD STAGES AND EUROPEAN FOSSIL ZONES		NANAIMO GROUP FOSSIL ZONES (as suggested in this report)			CALIFORNIA, OREGON AND WASHINGTON FOSSIL ZONES (as suggested in this report)
EARLY LOWER MAESTR.	Hoploscaphites constrictus	Acanthoscaphites tridens Belemnella lanceolata f. typ.	Suciaense Zone	Hornbyense Subzone	F	Pachydiscus catarinae
UPPER CAMPANIAN	Bostrychoceras polyplocum, Belemnitella langei			cf. Pacificum Subzone	E	Metaplacenticeras pacificum
	Hoplitoplacenticeras coespheldiense, Hamites phaleratus, Belemnitella mucronata senior		Vancouverense Zone		D	Hoplitoplacenticeras vancouverense (only known on Sucia Island, northwestern Washington)
LOWER CAMP.	Pachydiscus oldhami Gonioteuthis quadrata		Schmidti Zone		C	Patagiosites and Anapachydiscus
	Diplacmoceras bidorsatum, Gonioteuthis granulatoquadrata, G. granulata f. typ.		Elongatum Zone	Haradai Subzone	B	Submortoniceras chicoense
SANTONIAN	Placenticeras surtale			Pachydiscus (Eupachydiscus) perplicatus beds ? ?	A	Unknown or devoid of diagnostic fossils
	Placenticeras cf. guadalupae, Placenticeras clypeale			Naumanni Subzone		
	Texanites texanum, Inoceramus cordiformis		Lower, mostly non-marine part of Comox (=Benson) formation apparently devoid of marine index fossils			Baculites capensis, Inoceramus naumanni, I. cordiformis, I. cf. undulatoplicatus (not zoned)

of Inoceramus ex gr. naumanni-orientalis, including at least 5 to 6 reasonably complete and well-preserved specimens, are needed for definitive differentiation of the Naumanni subzone from the Haradai subzone.

The data now available are insufficient to uphold the subdivision of the Naumanni subzone suggested recently by Jeletzky (1967, p. 70, Table I). Pachydiscus (Eupachydiscus) perplicatus is common in the basal 120 to 130 feet of the Haslam Formation in Comox Basin, but was not found in the overlying Haradai subzone. It is associated throughout with the abundant and typical fauna of Inoceramus naumanni identical with that from the Comox Formation. P. (E.) perplicatus is, however, almost unknown outside the Comox Basin. It has been found but once in the Haslem Formation of Nanaimo Basin on Haslam Creek (GSC loc. 69482). A subzone based on this fossil would therefore be of restricted use only and beds containing it are better treated as a faunal facies of the middle and upper parts of the Naumanni subzone (Table III, Fig. 7). Polyptychoceras vancouverense appears to be another common component of this biofacies. This species is common to abundant in the interval between 55 and 100 feet above the base of the Haslam Formation on Trent River and apparently is restricted to the same interval in Brown's and Puntledge rivers sections. It is however unknown elsewhere in the Nanaimo Group.

No biochronological significance can be ascribed to the apparent absence of Bostrychoceras sp. aff. B. otsukai (Yabe) and Puzosia (Parapuzosia) sp. indet. in the basal beds of Haslam (including lower Trent River) Formation representing the upper part of the Naumanni subzone because of extreme rarity of these index fossils.

It seems likely that all other Pachydiscus species occurring in the basal beds of Haslam Formation representing the upper part of the Naumanni subzone, such as P. buckhami, P. elkhornensis and P. binodatus, do not range either above or below these beds. In Comox Basin they are only found in Pachydiscus (Eupachydiscus) perplicatus beds, judging by their association with the latter species on Puntledge River (e.g. GSC loc. 508; Usher, 1952) and elsewhere.

Of the long-ranging ammonite species, Epigoniceras epigonum, Ryugasella cf. ryugasensis, Schluteria selwyniana, Gaudryceras denmanense and Baculites chicoensis sensu Usher have not been found below the base of Haslam shales. The faunal differences between the upper and lower parts of the Naumanni subzone seem, however, to reflect facies changes rather than true biochronological differences. All these species are, indeed, unknown also in the upper part of the Comox Formation in Benson (= Brannan) Creek-Boomerang Lake area which is definitely contemporary with the basal part of Haslam shales (see below and Fig. 7).

In Benson Creek-Boomerang Lake area situated northeast of Nanoose Ridge between Nanaimo and Comox depositional basins (Figs. 6, 7 and McGugan, 1962, p. 586) all of the Naumanni subzone and the basal beds of Haradai subzone occur within the abnormally thick succession of medium to coarse clastics of the Comox Formation. This is indicated by the occurrence of P. (E.?) haradai and typical representatives of Inoceramus orientalis closely below the Comox-Haslam contact in the upper course of Benson Creek (see Fig. 7). There seems to be little doubt that in these sections at least the topmost 200 feet or so of the Comox Formation are geologically contemporary to at least 200 to 250 feet of the Haslam shales of other studied sections.

The presence of Puzosia (Parapuzosia) sp. indet. and Bostrychoceras sp. aff. B. otsukai, as well as the strong predominance of Inoceramus naumanni over all other Inoceramus forms, strongly suggests the Santonian (probably upper Santonian only) age for most or all of the Naumanni subzone. This subzone is believed to be largely or completely equivalent to the Baculites capensis beds of California (Popenoe et al., 1960, p. 1513; Table III). The presence of Inoceramus ex aff. cordiformis and I. ex aff. lobatus supports this conclusion.

The appearance of rare representatives of I. orientalis f. typ. and its var. ambiguus combined with the apparent absence of Puzosia (Parapuzosia) sp. indet and Bostrychoceras sp. aff. B. otsukai in the upper part of the Naumanni subzone, opens the possibility of an earliest Campanian age of these beds (basal parts of Haslam and lower Trent River shales). However, for the time being all of the Naumanni subzone is referred tentatively to the Santonian stage of the international standard (Table III).

Pachydiscus (Eupachydiscus?) haradai subzone

This subzone is characterized by rare to fairly common occurrence of Pachydiscus (Eupachydiscus?) haradai sensu Usher, 1952. According to Matsumoto (1959a, pp. 33-38) this form is only doubtfully distinct subspecifically from the typical representatives of P. (E.) haradai Jimbo, which are in turn identical with P. (E.) perplicatus Whiteaves. The writer was unable to form a definite opinion about the exact relationships of the Japanese and Canadian representatives of P. (E.) haradai species group at this stage of his research. There seems to be little doubt, however, that P. (E.) perplicatus Whiteaves is clearly morphologically distinguishable from P. (E.?) haradai sensu Usher, 1952 and that these two forms occur in beds of a different age in all sections studied. Their time relationships suggested by Matsumoto (1959a, p. 38) were confirmed by the writer's research. These two forms are accordingly treated as specifically distinct in this report. It seems likely that P. (E.?) haradai sensu Usher, 1952 is an immediate descendent of P. (E.) perplicatus Whiteaves and an immediate ancestor of P. (C.) yokoyamai Jimbo.

P. (E.?) haradai sensu Usher, 1952 is equally common in the higher beds of the Haslam Formation of Comox Basin and in the middle part of the Haslam Formation of Nanaimo Basin. Furthermore, it is known to occur in the Duncan area. This makes it an entirely appropriate subzonal fossil. The presence of P. (E.?) haradai in the geologically contemporary beds of the Comox Formation in Benson Creek-Boomerang Lake area (see pp. 45 and 47) indicates its considerable facies tolerance.

Except for P. (E.?) haradai sensu Usher 1952, the writer does not know of any ammonite forms diagnostic of the Haradai subzone. However, the strong predominance of Inoceramus orientalis f. typ. and its var. ambiguus Nagao and Matsumoto over all other inocerami of Inoceramus naumanni-schmidti-orientalis species group is rather diagnostic of this subzone. As noted, these inocerami occur sparsely in the upper part of the underlying Naumanni subzone. This fact and the scattered occurrence of I. naumanni in the Haradai subzone decreases somewhat the value of I. orientalis et var. ambiguus as an index fossil of the latter zone. As with I. naumanni and I. n. sp. aff. I. (see p. 43), one has to have a representative sample of I. orientalis including five to six fairly complete and well-preserved specimens to definitively recognize the Haradai subzone on its inocerami fauna alone.

Inoceramus orientalis f. typ. and its var. ambiguus Nagao and Matsumoto were found to range up into the basal beds of the next younger Schmidti zone (i.e. its Inoceramus elegans subzone). A mixed fauna of these two units including I. schmidti s. str. and related forms in addition to both P. (E?) haradai and I. orientalis f. typ. was found to range through 20 to 30 feet of beds at the zonal boundary on Benson (= Brannan) Creek. These 'overlap beds' were arbitrarily assigned to the Schmidti zone. Similarly mixed faunas also seem to be present at this boundary on Haslam Creek, on Chemainus River and elsewhere in Nanaimo Basin. Unfortunately, none of these sections was studied in any detail.

The Haradai subzone is in excess of 200 feet thick in the Benson (= Brannan) Creek section. In Haslam Creek canyon it appears to be about 180 feet thick with its top cut off by a major fault zone. Finally, some 120 to 130 feet of the Haradai subzone are exposed on Trent River; there both its contacts are faulted out and the subzone is probably repeated several times by faulting and folding. The best partial section of the subzone in Trent River section is estimated to be about 120 feet thick (Fig. 7).

The common presence of I. orientalis f. typ. and its var. ambiguus combined with the apparently complete absence of Inoceramus ex gr. schmidti-sachalinensis-elegans indicates the early Lower Campanian age of the Haradai subzone. This subzone is directly and gradationally overlain by the Schmidti zone. The latter zone appears to correspond to the Patagiosites and Anapachydiscus zone of California (Popenoe et al., 1960, pp. 1513-1514) as Inoceramus schmidti and I. sachalinensis are common in both zones and are unknown either above or below them in both regions. Haradai subzone must, therefore, correspond to part or all of Submortoniceras chicoense zone of California in spite of an apparently complete absence of representatives of subgenus Canadoceras in the Canadian subzone.

Unless the Naumanni subzone includes some earliest Campanian rocks in its upper part (see p. 46), the lower part of the Haradai subzone could also include the equivalents of the upper part of Member VI of the Redding area, in addition to those of Submortoniceras chicoense zone of California (Matsumoto, 1959a, 1959b, 1960; Popenoe et al., 1960, p. 1513). Popenoe et al. (1960, p. 1513) rightly point out the possibility of the earliest Campanian age for the upper part of Member VI and the recorded occurrence of I. orientalis var. ambiguus Nagao and Matsumoto agrees well with this suggestion. As already mentioned, however, the Santonian-Campanian boundary within the Nanaimo Group is placed tentatively at the base of the Haradai subzone in this report (Table III).

Thickness and facies of the Elongatum zone

The intermittent outcrops and the commonly severe faulting make it difficult to estimate, let alone measure exactly, the thickness of the Elongatum zone in any of the sections personally studied (Fig. 7).

In the measured type section of Haslam Formation in Haslam Creek canyon (Fig. 7, sec. 3) Elongatum zone is about 401 feet thick with its top cut off by a major fault zone. This thickness is believed to be only 50 to

100 feet short of the complete thickness of the zone in this area as the early forms of Inoceramus schmidti Michael s. str., I. orientalis Sokolov f. typ. and Pachydiscus (Canadoceras) cf. yokoyamai Jimbo occur close by in the downfaulted block of Haslam Formation (e.g. GSC loc. 77405).

Scattered pebble-conglomerate and greywacke sandstones, locally containing I. naumanni outcrop on the northwest side of Benson Creek near the concealed contact with the Karmutsen Formation. These rocks are believed to represent the lower and middle parts of the Elongatum zone and to underlie more than 200 feet of unfossiliferous greywacke sandstone, outcropping farther downstream in Benson Creek. These in turn underlie some 80 to 100 feet of the Haradai subzone, which form the basal part of a reduced Haslam Formation (Fig. 7, sec. 1). The entire Elongatum zone in Benson Creek may therefore be in the order of 400 feet thick, with its base concealed.

In the section of the Haslam (= lower Trent River) Formation on Trent River (Fig. 7, sec. 4, 5) the Elongatum zone has a total exposed thickness in order of 250 feet. Unfortunately its top is cut off by a major fault and several other major faults cut through the upper part of the Naumanni subzone. Still other faults cut through the lower and upper part of the Haradai subzone. This makes the above estimate rather tentative. No diagnostic fossils were found beneath the Haslam (= lower Trent River)-Comox contact in the Trent River section. It is, therefore, unknown what part of the Comox Formation of that section forms part of the Naumanni subzone.

Inoceramus schmidti zone

In the Nanaimo Basin, and apparently in the Cowichan area as well, the Elongatum zone is immediately followed by a 250- to 300-foot-thick succession of mostly sandy shale and siltstone or calcareous sandstone of the Haslam Formation with numerous nodules containing a variegated and rich invertebrate fauna. This fauna has several ammonite and Inoceramus species in common with those of the underlying Elongatum zone. However, it is sharply distinguished by the abundance of divergently ribbed inocerami of Inoceramus schmidti species group, including I. elegans Sokolov, Inoceramus schmidti s. str. and I. sachalinensis Sokolov. Inoceramus schmidti was selected as the index fossil of the zone. Among ammonites, Pachydiscus (Eupachydiscus) ex gr. perplicatus-haradai are apparently completely replaced by the probably descendant Pachydiscus (Canadoceras) ex gr. multisulcatus-yokoyamai-newberryanus. Other rare but apparently diagnostic species of the zone is Pseudoschloenbachia brannani Usher.

Among Canadoceras forms of the zone, P. (C.) newberryanus appears to be rare while P. (C.) yokoyamai and P. (C.) multisulcatus appear to predominate. At least some of the specimens from the Schmidti zone (i.e. from 'Qualicum' and upper Haslam Formations) identified as P. (C.) newberryanus by Usher (1952, p. 68) are referable to P. (C.) yokoyamai Jimbo in the writer's opinion. The latter species may itself be a senior synonym of P. (C.) multisulcatus according to Matsumoto (1959b, pp. 56-59).

Neither Inoceramus ex gr. schmidti nor P. (C.) multisulcatus and P. (C.) yokoyamai are known to range into the overlying or underlying zones of the Nanaimo Group, with the possible exception of the basal (?) part of the Vancouverense zone of southern Sucia Island and with the 20- to 30-foot-thick overlap beds with the Elongatum zone on Benson (Brannan) Creek.

The sandstone facies of the Schmidti zone in Northwest Bay area (Fig. 7, sec. 7) was believed by Usher (1952, pp. 7, 22) to be older than the Bostrychoceras elongatum and Diplomoceras? subcompressum carrying part of Trent River Formation and equivalent to the Newcastle Formation of Nanaimo area. There is little doubt, however, that these beds are younger than the lower and middle parts of the Haslam (= lower Trent River). Formation and equivalent to the sandy shales and siltstones of the upper part of Haslam Formation on Benson (= Brannan) Creek, on Nanaimo River and on Haslam Creek which carry Inoceramus schmidti s. str. fauna either with or without P. (C.) yokoyamai and P. (C.) multisulcatus (Fig. 7). The Qualicum Formation of Usher (1952, pp. 22-23) is obviously a misinterpreted north-westward extension of Haslam Formation, all the more so as the shales of its lower part exposed on Qualicum and Little Qualicum rivers contain the fauna of the Elongatum zone (GSC loc. 57584) apparently representing its Naumanni subzone. Rocks which appear to form the uppermost part of the Schmidti zone, are exposed at Blunden Point near Lantzville (Fig. 7, sec. 2). These predominantly arenaceous beds immediately underlie the Wellington coal seam; they were named East Wellington sandstone member by Clapp (1914a).

On Nanaimo River (GSC loc. 69481) and on Haslam Creek (GSC loc. 77401, 77404, 77408) sandy siltstones of the upper part of Haslam Formation contain diagnostic fossils of the Schmidti zone. It is believed that in this area this zone is at least 250 to 300 feet thick and is largely represented by sandy shale and siltstone. In the type section of the Haslam Formation in Haslam Creek canyon (Fig. 7, sec. 3) beds which appear to represent the basal part of the Schmidti zone contain early forms of I. schmidti s. str. associated with I. orientalis var. The same mixed fauna was also found in the Cowichan area (GSC loc. 75451, etc.). Except for Haslam Creek canyon section, none of these sections was studied in any detail either by the writer or by Muller.

The Schmidti zone is typically developed in the Cowichan area, south of Chemainus River (GSC loc. 75509) and farther southwest near Skutz Falls on Cowichan River (GSC loc. 75462). It is also present on Texada Island (GSC loc. 79760). None of these sections was studied in any detail either. Except for Texada Island, all occurrences of I. schmidti f. typ. in these areas are in sandy shale or siltstone comparable to that of the upper Haslam Formation of the Haslam Creek-Nanaimo River area.

So far there are no definite records of the Schmidti zone either from the Gulf Islands or from San Juan Islands in spite of the fact that both the Elongatum zone and the equivalents of the overlying Extension-Protection Formation are locally known there (e.g. on Saltspring Island and on Saturna Island). The record of Inoceramus elegans Sokolov and I. schmidti s. str. on southern Sucia Island could, however, possibly be not from the Vancouverense zone of Cedar District Formation but from unrecognized equivalents of East Wellington sandstone member or from the sandy facies of the upper part of Haslam Formation. It shall be discussed in greater detail in connection with the Vancouverense zone (see p.51).

The Schmidti zone is unknown in the Comox Basin north of Arbutus Point. The writers (see Fig. 1) explain this absence either by a widespread subsequent erosion or by a nondeposition of this zone throughout

Comox Basin in connection with its regional uplift during the time of deposition of the Extension-Protection Formation (and upper Haslam?) farther southeast in Nanaimo-Northwest Bay area. It is also possible that the strongly faulted, almost unfossiliferous upper part of Trent River shale exposed in Trent River canyon between the point some 1,600 feet above the mouth of Bloedell Creek and the power line crossing (Fig. 7, sec. 4, 5) is partly or entirely equivalent to the Schmidti zone rather than to the Vancouverense zone with which it is tentatively correlated in this report. The occurrence of Pseudoschloenbachia cf. umbulazi Bayle near the top of this unit (GSC loc. 60845) is in particular suggestive of this as Pseudoschloenbachia is largely restricted to upper Santonian and Lower Campanian beds and is known to occur in the Schmidti zone on Benson (= Brannan) Creek (Usher, 1952, pp. 92-93, pl. XXIV, Figs. 3-4; pl. XXXI, Fig. 25). The complete absence of Inoceramus ex gr. naumanni-orientalis-schmidti and the Vancouverense zone-like character of other forms of this fauna (see under the Vancouverense zone, p. 53) seem, however, to indicate the younger age of these beds.

The occurrence of Inoceramus schmidti-like forms on Puntledge River just below the power house (GSC loc. 15580, 15581; Usher's locality 120) does not seem to be indicative of the presence of any part of the Schmidti zone in this section. These morphologically peculiar forms are better referable to I. orientalis Sokolov s. lato, all the more so as they are associated with diagnostic ammonites of the Elongatum zone.

Subzones

Inoceramus elegans subzone: The lower 200 to 250 feet of the Schmidti zone on Benson (= Brannan) Creek (Fig. 7, sec. 1) are characterized by the predominance of small- to medium-sized but relatively thick and distinctly winged I. elegans Sokolov, apparently identical with the specimen from Sucia Island figured by Anderson (1958, pl. 22, Fig. 4) under the name I. undulatoplicatus, small representatives of I. schmidti Michael s. str. and rare representatives of I. sachalinensis Sokolov. Large, flat representatives of I. schmidti s. str. were not observed in these beds at all.

Inoceramus schmidti s. str. subzone: The medium-sized to large, flat representatives of Inoceramus schmidti s. str. appear to predominate over all other forms of I. schmidti species group in the topmost 70-80 feet of Benson (= Brannan) Creek section (Fig. 7, sec. 1) and in the presumably somewhat younger beds of Blunden Point (East Wellington sandstone member; Fig. 7, sec. 2). They were also found in the Extension Tunnel near Extension (GSC loc. 5832).

On this basis Jeletzky (1967, p. 70, Table I) has tentatively separated the older 200 to 250 feet of Benson (= Brannan) Creek section as the Elegans subzone. Its topmost 70-80 feet and the beds of Blunden Point were tentatively designated as Schmidti s. str. subzone. Additional field work and bed by bed collecting is needed to confirm or reject the regional validity of these subzones.

The early forms of Inoceramus schmidti found in the faulted upper part of Haslam Formation in the Haslam Canyon section (Fig. 7, sec. 3) and elsewhere, locally in association with Inoceramus orientalis Sokolov var., seem to be morphologically distinguishable from those of the Elegans subzone.

as well as from those of the Schmidti s. str. subzone. Further study of these forms is needed to confirm this observation and to justify the regional validity of this third subzone of the Schmidti zone.

Age and correlation of the Schmidti zone was already discussed in connection with that of the Haradai subzone (see p. 47).

Hoplitoplacenticeras vancouverense zone

Until last year the index fossil of Hoplitoplacenticeras vancouverense zone was known from a single locality of the Cedar District Formation on southern part of Sucia Island (Usher, 1952, p. 16). All other distinctive ammonites of this zone (e.g. Patagiosites aff. P. arbucklensis (Anderson), Pachydiscus cf. jacquoti Seynes, Pachydiscus (Anapachydiscus) aff. wittekindi (Schlüter), Diplomoceras? sp. indet., and Pachydiscus neevesi (Whiteaves) are restricted to the same locality with exception of Pachydiscus neevesi, which was recorded also from James Island north of Victoria (Usher, 1952, p. 88). The recognition of the so-called Cedar District-Trent River Faunizone of Usher (1952, pp. 38-39) elsewhere in Nanaimo Basin had, therefore, to depend on the lateral tracing of the Cedar District shale unit and the immediately underlying (Extension-Protection Formation) and overlying (De Courcy Formation) sandstone-conglomerate units. The assumed presence of time equivalents of the Vancouverense zone in the Trent River Formation of Comox Basin was likewise based on lithostratigraphy alone (Usher, 1952, pp. 35-36, 38-39) until the publication of results of foraminiferal studies of McGugan (1962, 1964).

The recent find of Hoplitoplacenticeras cf. plasticum Paulke on the south shore of North Pender Island (GSC loc. 75515) near the base of the Cedar District Formation confirms the essential contemporaneity of the Canadian sections of this formation with its richly fossiliferous Sucia Island section. Another biochronologically useful criterion is provided by accumulation of small to large specimens of Baculites chicoensis Trask sensu Usher on the bedding planes of Cedar District Formation of the Gulf Islands. B. chicoensis sensu Usher appears to range down into the Schmidti zone and even into the upper and middle parts of the Elongatum zone; however, it appears to be invariably rare there and is not known to form accumulations of specimens on the bedding planes such as are locally common in the Cedar District Formation.

Other, apparently biochronologically useful, paleontological distinctions of the Vancouverense zone are:

1. Prevalence of more or less typical forms of Pachydiscus (Canadoceras) newberryanus in the Cedar District Formation already noted by Usher (1952, p. 66) over P. (C.) multisulcatus and P. (C.) yokoyamai in contrast to the relationships observed in the upper part of Haslam Formation (i.e. in the Schmidti zone);

2. An apparently complete absence of Inoceramus of I. elegans-schmidti-sachalinensis species group in all Canadian sections of the Cedar District Formation. If the previously mentioned specimens of Inoceramus elegans and I. schmidti (pp. 49, 55) are indeed from the Vancouverense zone rather than from the underlying equivalents of Extension-Protection Formation or upper part of the Haslam Formation, this would represent an

upward extension of time-range of this species group apparently unique for the Pacific slope of North America.

3. A mass occurrence of Inoceramus ex gr. vancouverensis Shumard and Inoceramus ex gr. subundatus Meek. Representatives of these two species groups appear to be present also in the underlying zones of Nanaimo Group, including upper and middle parts of the Elongatum zone. They are, much less common there than the large, flattish and more or less regularly rounded Inoceramus ex gr. chicoensis Anderson (? = I. ezoensis Nagao and Matsumoto, 1940). The latter are, in turn, much less common (or absent) in the Vancouverense zone than they are in the underlying paleontological zones of Nanaimo Group. A number of occurrences of Inoceramus ex gr. vancouverensis-subundatus ascribed to paleontological zones older than the Vancouverense zone may actually be the latter zone. The type locality of Inoceramus vancouverensis Shumand 2 1/4 miles up Nanaimo River, from which all specimens of the species figured by Whiteaves (1879, p. 170, pl. 20, Figs. 4, 4a, 4b) have been collected, is, for example, in the Cedar District Formation according to Muller.

All above described elements of the Vancouverense fauna were only found in the Cedar District Formation. However, the Extension-Protection Formation is believed to be a largely nonmarine, coarse clastic facies of the basal part of Vancouverense zone. This conclusion agrees well with the eastward wedging out of this formation observed by Muller (see previous chapter of this report p. 19-21 and Fig. 1) and with the apparent absence of Inoceramus ex gr. schmidti-sachalinensis-elegans in the marine phase of Protection Member in the Nanaimo area (Usher, 1952, pp. 14-15).

The De Courcy Formation is also treated as part of the Vancouverense zone for the purpose of this report (Fig. 1). This suggestion is supported only by the complete absence of any faunal elements of Pachydiscus (Pachydiscus) suciaensis zone either in the uppermost Cedar District or in De Courcy formations. So far as known, these first appear in the overlying lower part of the Northumberland Formation.

Vancouverense zone in Comox Basin

The amalgamation of the fauna of the Cedar District and Trent River formations by Usher (1952, pp. 35-39), his time correlation of Cedar District Formation with the whole of Trent River Formation, and his conclusion that the entire Haslam Formation is older than any part of the Trent River Formation are believed by the writer to be erroneous. However, the correlation of the whole of Haslam Formation with the whole of Trent River Formation proposed by Crickmay and Pocock (1963, p. 1931) is also in disagreement with the writer's conclusion. It was already demonstrated in the previous sections of this report (p. 40) that the lower part of the Trent River Formation is an approximate biochronological equivalent of the Elongatum zone of the Haslam Formation. Likewise the Comox Formation is an approximate biochronological equivalent of the Benson Formation, except for the already described, marked diachronism of the upper contacts of these two formations from one area to another (see Figs. 1, 7). The lower Trent River and Benson formations are accordingly suppressed as superfluous by the writers (Table I).

As already mentioned, the upper part of the Haslam Formation, namely its Schmidti zone, is unknown and presumed to be absent in the Comox Basin (Fig. 1). It may be locally represented in an unnamed conglomeratic unit separating the lower part of the Trent River shale from the upper part of the Trent River shale and believed by Muller to be the equivalent of the Extension-Protection Formation of the Nanaimo Basin (see previous part of this report and Fig. 1).

The possibility that the upper part of Trent River shale, as exposed on Trent River between a point about 1,600 feet above the mouth of Bloedel Creek and the powerline crossing, is equivalent of the Schmidti zone of Nanaimo Basin has already been considered (see p. 50). The following features of its fauna are, however, believed to outweigh the previously mentioned (p. 50) presence of Pseudoschloenbachia cf. umbulazi Baily in it:

1. No diagnostic elements of the Schmidti zone were found in several hundred feet of that section (Fig. 7, sec. 4-5).

2. This, for the most part unfossiliferous, succession has yielded local accumulations of Inoceramus ex gr. vancouverensis-subundatus either in pods or in the bedding planes, similar accumulations of Baculites cf. chicoensis Trask sensu Usher 1952 (especially near the top), rare specimens of Endocostea sp. indet., some poor Pachydiscus (Canadoceras) comparable with P. (C.) newberryanus Meek, Gaudryceras denmanense Whiteaves, Pseudoxybeloceras cf. lineatum Gabb and Ryugasella cf. ryugasensis Wright and Matsumoto.

In spite of the absence of all diagnostic ammonites of the Vancouverense zone, the above listed fauna of the upper Trent River shale seems to the author to be more closely allied to that fauna than to that of any older zones of the Nanaimo Group. For this reason this shale unit is tentatively correlated with the Cedar District Formation in spite of the previously discussed contrary evidence of Pseudoschloenbachia cf. umbulazi (see p. 50 of this report), which was preferred in the earlier report of the writer (Jeletzky, 1967, p. 70, Table I)[1]. It may be noted in this connection that the Trent River Pseudoschloenbachia form is not conspecific with the Haslam Formation form.

Unfortunately no part of the shale unit concerned was tested for its foraminiferal fauna by McGugan (1952, p. 587, Fig. 1) judging by the location of his micropaleontological probes.

The extensive sections of the upper Trent River shale on the western side of Denman Island did not yield any faunal elements of the Elongatum and Schmidti zones apart from the one recorded, but here discounted occurrence of Bostrychoceras elongatum (see p. 40 of this report). Furthermore, these beds are locally rich in Baculites chicoensis Trask sensu Usher and Inoceramus ex gr. vancouverensis-subundatus occurring in blue-grey limestone concretions or as accumulations on the bedding planes. Finally, they have yielded diagnostic Upper Campanian Cibicides voltziana fauna (McGugan, 1952, p. 589, Fig. 3). This part of the upper Trent River shale may accordingly be confidently correlated with the Vancouverense zone of the Nanaimo Basin. The previously mentioned 6-inch to 3-foot-thick pebble conglomerate accompanied by a sharp erosional boundary (see p. 40 and Fig. 7, sec. 6b), is tentatively considered to represent the lower boundary of the upper part of the Trent River shale correlative with the Cedar District Formation in the Denman Island sections. The underlying beds, did not yield

[1] See Addendum 2, page 70.

any macrofauna and the writer does not know anything about their foraminiferal fauna either.

Regardless of numerous details, which must be settled by further detailed field work and fossil collecting, it is obvious that the Trent River Formation as defined by Buckham (1947a, 1947b) and Usher (1952, pp. 24-25) is a heterogeneous assemblage of rocks which includes time equivalents of both the Haslam and the Cedar District formations of the Nanaimo Basin. The term Cedar District Formation is used by the writers (Table I) for the upper part of the Trent River shale of Comox Basin. The De Courcy Formation of Denman Island (i.e. the here suppressed Denman Formation) is tentatively placed in the Vancouverense zone because of the complete absence of any faunal elements of the Suciaensis zone in this formation. So far as known, these only appear in the overlying upper part of the Northumberland (= Lambert) Formation.[1]

Age and interregional correlation

Unlike Popenoe et al. (1960, pp. 1513-1515), the writer interprets the Vancouverense zone of the Cedar District Formation as of early Upper Campanian age and older than the Metaplacenticeras pacificum zone of California and Japan (Table III).

As pointed out by Matsumoto (1960, pp. 17-20) and Popenoe et al. (1960, pp. 1513-1514), such index ammonites of the Vancouverense zone as Pachydiscus (Canadoceras) newberryanus and Pachydiscus neevesi range down into the Patagiosites and Anapachydiscus zone and even into Submortoniceras chicoensis zone of California. The same is true of the Nanaimo Group of Nanaimo Basin where these species range down into the upper part of the Haslam Formation (e.g. on Brannan Creek and in Northwest Bay). At the same time none of these or other [Patagiosites aff. P. arbucklensis (Anderson), Pachydiscus (Anapachydiscus) aff. wittekindi (Schlüter)] diagnostic ammonites of the Vancouverense zone are known to range up into the Metaplacenticeras pacificum zone in California which contains instead such diagnostic elements of the Northumberland-Lambert Faunizone of Usher (1952) as Didymoceras? cooperi Gabb and Pseudophyllites indra Forbes. The record of Baculites occidentalis from the Vancouverense zone of Sucia Island (Usher, 1952, p. 99) has remained without confirmation for over 80 years and may well be due to either the mislabelling or misplacement of the specimen concerned.

In western Europe, Poland and southern USSR (Jeletzky, 1951, pp. 18-19, Table 1; Mikhailov, 1951, pp. 124-128, Table 32) the Hoplitoplacenticeras coesfeldiense zone is of early rather than late Upper Campanian age. It is invariably separated from the basal Maestrichtian beds in the now generally accepted sense by the Bostrychoceras polyplocum and Belemnitella langei zone (Table III).

The presence of a unique specimen of Pachydiscus cf. jacquoti (= Pachydiscus cf. egertoni according to Matsumoto, 1959b, pp. 42-46, Figs. 18-20) in the Vancouverense zone of southern Sucia Island is hardly indicative of the stratigraphic position of these beds in the immediate proximity of the Campanian-Maestrichtian boundary contrary to the opinion of Usher (1952, pp. 16, 38-39) and Matsumoto (1959b, p. 46). Pachydiscus of P. neubergicus-gollevillensis-egertoni species group have long been known from the late Upper Campanian Bostrychoceras polyplocum-Belemnitella

[1] See Addendum 3, page 70.

langei zone in western Europe and elsewhere (e.g. Pachydiscus hibernicus Spath, 1922; see G.W. Wright and E.V. Wright, 1951, p. 20; Pachydiscus preegertoni Collignon, 1955a, p. 61, pl. XX, Fig. 1; Pachydiscus colligatus; see Jeletzky, 1951, pp. 18-19, Table I, p. 133) and one should not be surprised to see the first representatives of this species group in the early Upper Campanian beds. Besides, this unique and old (collected by J. Richardson, in 1874) specimen may have been collected elsewhere and mislabelled.

Hoplitoplacenticeras vancouverense beds of southern Sucia Island occur near the base of the Cedar District Formation originally called Haslam shale) and are underlain by a coarse pebble conglomerate (McLellan, 1927, p. 122). The conglomerate is now inferred to be correlative to the Extension-Protection Formation of the Nanaimo Basin. Contrary to the statement of Popenoe et al. (1960, p. 1515) there are specimens of Inoceramus ex gr. schmidti Michael apparently identical with I. elegans Sokolov́ and I. schmidti s. str. recorded as collected in some part of the southern Sucia Island section (see Anderson, 1958, pl. 22, Fig. 4, confirmed by personal observations in the Stanford University fossil collections in the USGS Menlo Park office, November 1966). However, the extensive fossil collection from Sucia Island by Usher (locality 526) which has yielded all the Hoplitoplacenticeras vancouverense fauna described by Usher (1952) does not seem to contain any specimens or fragments of Inoceramus ex gr. schmidti Michael. This suggests that the above mentioned specimens of Inoceramus elegans and I. schmidti s. str. preserved in Stanford University collections either were not collected in the same beds as Hoplitoplacenticeras vancouverense fauna or are mislabelled specimens collected elsewhere. If these specimens are from Sucia Island, they were probably collected either from the still lower part of the about 700-foot-thick sandy shale unit that yielded Hoplitoplacenticeras vancouverense fauna or from the underlying pebble conglomerate unit. If so, the presence of Inoceramus schmidti fauna in close proximity to Hoplitoplacenticeras vancouverense beds would provide another important link with the Schmidti zone of the upper Haslam Formation and militate against inserting the Metaplacenticeras pacificum zone between the two.

In California I. schmidti and I. sachalinensis are so far only known from the Patagiosites and Anapachydiscus zone which appears to underlie Metaplacenticeras pacificum zone (Table III). Finally, Muller has found a readily identifiable specimen of Metaplacenticeras cf. pacificum (Smith) on South Pender Island (GSC loc. 75495) in 1966 in beds forming part of the Northumberland Formation.

In summary, it is virtually certain that the Vancouverense zone of the Cedar District Formation is not quite as young as was hitherto believed and represents the lower rather than uppermost part of the upper Campanian stage of the international standard. It is definitely older than the youngest Campanian zone of the Indo-Pacific faunal realm – the Metaplacenticeras pacificum zone.

Pachydiscus (Pachydiscus) suciaensis zone

Usher's (1952, p. 17, 27, 39) unreserved placement of the Northumberland-Lambert Faunizone in the Maestrichtian Stage and McGugan's (1962, 1964) equally positive placement of the bulk of this zone into the upper

Campanian are less contradictory than they seem to be. This contradiction is largely a matter of a nomenclatorial tangle concerning the Campanian-Maestrichtian boundary.

The problem of delimitation of Campanian and Maestrichtian stages was highly controversial for several decades. No less than four different positions of this boundary were advocated by competent specialists at one time or another. The subject matter was summarized by Mikhailov (1951, pp. 126-130, Tables 32-33), Jeletzky (1951, p. 13-25, Table I) and best of all by Voigt (1956) whose paper should be consulted by anyone concerned. At present most specialists have agreed to place the Maestrichtian-Campanian boundary at the base of Hoploscaphites constrictus zone and its equivalents (see Jeletzky, 1951, Table 1; this report Table III), leaving Bostrychoceras polyplocum-Belemnitella langei zone in the uppermost Campanian and placing the next younger European zones of Belemnella lanceolata f. typ. and Acanthoscaphites tridens in the basal Maestrichtian (Table III). It would appear that the Matsumoto's (1959a, 1959b, 1960) and Popenoe's et al. (1960) placement of the Campanian-Maestrichtian boundary above Metaplacenticeras pacificum zone and its Japanese equivalents agrees closely with this placement of the boundary in Europe. This definition of the Maestrichtian and Campanian stages was used by McGugan (1962, 1964) but apparently not by Usher (1952). Although he does not say so unequivocally, Usher's (1952, Fig. 2) placement of all of the Navarro Group in the Maestrichtian indicates that he has placed Bostrychoceras polyplocum-Belemnitella langei zone in the basal Maestrichtian following Spath (1926), Muller and Schenck (1942) and some other workers.

As already mentioned, the writer adheres to the same concept of the Maestrichtian stage as McGugan (1962, 1964) and the majority of other Cretaceous specialists. Therefore he places the bulk of the Northumberland-Lambert Faunizone of Usher (1952) in the late Upper Campanian and correlates it tentatively with most or all of the European Bostrychoceras polyplocum-Belemnitella langei zone. This assignment is in perfect agreement with the reference of the Vancouverense zone to the early upper Campanian proposed in the previous section of this report.

Metaplacenticeras cf. pacificum subzone

The already mentioned (p. 55) recent discovery of Metaplacenticeras cf. pacificum (Smith) at GSC loc. 75495 on South Pender Island provides the hitherto lacking link between the fauna of the Suciaensis zone of the Nanaimo Group and the latest Campanian beds of California where apparently most of these faunal elements are missing.

According to Muller the stratigraphic position of the Metaplacenticeras from South Pender Island, is most likely close above the De Courcy. The beds are steep and faulted but the gradational transition from De Courcy to Northumberland seems uninterrupted.

It is possible that this particular specimen of M. cf. pacificum hasbeen collected from an older part of Northumberland Formation than the rest of its ammonite fauna (Pachydiscus suciaensis, P. cotacodensis and Pseudophyllites indra) but, as already mentioned (p. 54 of this report), M. pacificum is known to be associated in California with some faunal elements of the Suciaensis zone. Furthermore, the same ammonite and foraminiferal fauna ranges up into the Spray Formation of Nanaimo Basin

(= upper shale member of the Northumberland Formation of Usher, 1952; see Fig. 1 of this report). McGugan (1962, p. 591) states that: "the presence of the Cibicides voltziana fauna and the absence of the abundant and diagnostic fauna including Bolivina incrassata, Bulimina petroleana, Globorotalites spina, Planulina nacatochensis and Allomorphina cf. cretacea, definitely dates the highest Northumberland as older than B. incrassata zone."

Ammonites previously collected in the lower shale member of the Northumberland Formation (= restricted Northumberland Formation of this report) of Nanaimo Basin (Usher, 1952, p. 19) include Pachydiscus suciaensis Meek, P. ootacodensis (Stoliczka) renamed P. usheri by Jones, 1963, and Pseudophyllites indra (Forbes). Of these only P. suciaensis has been definitely recognized in the upper member (Usher, 1952, p. 19) renamed the Spray Formation by the writers (Fig. 1).

The combined evidence of foraminifers and ammonites is sufficient to equate all of the Pachydiscus suciaensis-bearing beds of the Northumberland and Spray formations of Nanaimo Basin with the Metaplacenticeras pacificum zone of California and to place them into the late Upper Campanian Stage for the purpose of this report (Table III). However, Muller has tentatively suggested that beds of Campbell Bay on Mayne Island may be equivalent to the upper Spray Formation of Comox Basin (see Fig. 1 and following section).

Nostoceras hornbyense subzone

Pachydiscus (Pachydiscus) suciaensis fauna has, however, a longer time range in the Northumberland (formerly lower Lambert Formation) and the Spray (formerly upper Lambert) formations of Comox Basin (Fig. 1). P. suciaensis Meek, P. ootacodensis (Stoliczka) and Pseudophyllites indra (Forbes) have been collected among others in the Spray Formation (formerly the upper part of Lambert Formation) on Hornby Island (Usher, 1952, p. 19) and these two ammonite faunas apparently belong to the same paleontological zone which is named herewith the Suciaensis zone after P. (P.) suciaensis (Meek).

McGugan (1962, pp. 588-589, Fig. 3) has discovered a most striking microfaunal break in the middle part of the Spray ('Upper Lambert') Formation of Hornby Island. The upper part of the formation was found to contain the early Maestrichtian Bolivina incrassata fauna whereas its lower part was found to contain the late Campanian Cibicides voltziana fauna (Figs. 1 and 6).

With the aid of supplementary field information kindly supplied by Dr. A. McGugan and a stratigraphic section measured by his own party, Muller was able to tentatively equate McGugan's break as a 50-foot sandstone unit within the Spray (= upper Lambert) Formation, occurring at Manning Point, about halfway between Phipps and Colishaw points. It could also be established with the aid of Usher's field notes that his locations east of there (stratigraphically higher and more or less equivalent to Bolivina incrassata zone) would be from the highest location down: GSC 15566 (110); 15572 (115); and 15571 (114). This group contains Pachydiscus ootacodensis, P. suciaensis, Baculites occidentalis and Pseudophyllites indra, with the last named fossil occurring only in the lowermost locality. The next lower localities, probably within the Manning Point sandstone, are 15569 (112) and

15570 (113), containing the above-named ammonites and also Didymoceras? cooperi, Neophylloceras ramosum, Nostoceras hornbyense and Phyllopachyceras forbesianum. Lastly, locality 15565 (109) is below the Manning Point sandstone and probably below the Bolivina incrassata zone. It contains all previously named ammonites except N. hornbyense and P. forbesianum and in addition Diplomoceras notabile and Gaudryceras sp.

This stratigraphic information clearly indicates that the Pachydiscus suciaensis fauna is long ranging. Most of its species, including P. suciaensis, P. ootacodensis, B. occidentalis, P. indra and D. cooperi, range up into the early Maestrichtian part of the Hornby Island section. Only D. notabile and Gaudryceras sp. seem to be restricted to the late upper Campanian part of the section. Conversely, only N. hornbyense and P. forbesianum appear to be confined to the early Maestrichtian part of the section.

The data at hand are few and inconclusive. They suggest, nevertheless, the subdivision of the Suciaensis zone into two subzones. The lower subzone is characterized by the presence of Diplomoceras notabile and rare occurrence of Metaplacenticeras cf. pacificum and is named cf. Pacificum subzone. It can be correlated with the Metaplacenticeras zone of California and Japan and placed in the late Upper Campanian stage of the international standard (Table III). The upper, early Maestrichtian subzone seems to be characterized by the absence of M. cf. pacificum and the presence of Nostoceras hornbyense and Phyllopachyceras forbesianum. It is named the Hornbyense subzone. Further research may necessitate the assignment of full zonal rank to these two subzones, considering the circumstance that their boundary seems to coincide with an important micropaleontological break and with the Campanian-Maestrichtian boundary (Fig. 1; Table III).

STRATIGRAPHY AND BIOCHRONOLOGY OF NANAIMO GROUP IN SUQUASH BASIN

(J.A. Jeletzky)

In 1968 the writer (Jeletzky, 1969, p. 132-133) measured several discontinuous partial sections of the Nanaimo rocks within an about 3-mile-long stretch of the shoreline southwest of Thomas Point and along the lower 2 miles of Keogh (= Ki-Uk) River. This part of Suquash Basin appears to represent the northern limb of a gentle (prevalent dips of 5 to 15 degrees to southwest) synclinal structure, commonly complicated by supplementary equally gentle folds and strongly disrupted by a number of major faults of several directions. The inferred structural relationships of the individual fault blocks and marked lithological differences of the individual rock units suggest an upward succession of Nanaimo Group in this part of Suquash Basin consisting of two sandstone-siltstone cycles. The writer's interpretation differs from the interpretation of this succession by Muller, as it is stressed in the chapter on stratigraphy. pp. 33-34 and in Figure 1. The suggested upward succession of Nanaimo Group of Suquash Basin is as follows:

1. Basal coarse-grained greywacke unit discordantly overlapping the volcanic rocks of Karmatsen Group about three-fifths of a mile southwest of Thomas Point. This unit consists predominantly of buff- to rust-coloured, coarse- to medium-grained, commonly gritty, intensively crossbedded and

locally calcareous greywacke with some lenticular interbeds and lenses of fine to coarse grit and fine pebble conglomerate. Some poorly exposed interbeds of friable, fine-grained, locally carbonaceous to coaly greywacke and sandy siltstone occur in this unit. The Beaver Harbour florule described by G.M. Dawson and J.W. Dawson (1889, pp. 71-72) and J.W. Dawson (1894) was collected from equivalent carbonaceous to coaly interbeds in the small outliers of the Basal coarse-grained greywacke unit occurring within Beaver Harbour (G.M. Dawson, 1887, p. 62B). These outliers were not seen by the writer.

The Basal coarse-grained greywacke unit appears to be more than 1,000 feet thick, provided that it is not repeated several times by unrecognized major faults.

An about 13-foot-thick interbed of more or less calcareous, richly fossiliferous, coarse-grained greywacke occurring in the middle part of the Basal unit has yielded (GSC loc. 82952): Inoceramus subundatus Meek, I. aff. vancouverensis Shumard, Trigonia cf. tryonana Gabb, Pectunculus weatchii Whiteaves and other marine pelecypods and gastropods. Otherwise no identifiable fossils have been found in the unit which appears to consist largely of beach and deltaic deposits.

The Inoceramus subundatus fauna of GSC loc. 82952 cannot be any younger than the overlying late upper Campanian Metaplacenticeras occidentale fauna of the Suquash Basin. It is unlikely to be any older than the Vancouverense zone of Nanaimo and Comox basins because of the common occurrence of I. subundatus and I. aff. vancouverensis as well as the complete absence of I. ex gr. schmidti-orientalis-naummani and I. ex gr. chicoensis. This suggests the equivalence of the Basal coarse-grained greywacke unit of Suquash Basin with the Cedar District Formation of Nanaimo and Comox basins (Fig. 1).[1] This correlation is confirmed by the fact that an almost identical fauna consisting of Inoceramus vancouverensis Shumard and I. subundatus Meek (GSC loc. 82953) has been found only 20 to 25 feet above the base of a coarse-grained, often gritty and pebbly greywacke discovered by Dawson (1887, p. 72B) on the east side of Hope Island. This greywacke unit is lithologically and stratigraphically identical to the Basal coarse-grained greywacke unit of Suquash Basin and is herewith correlated with the latter.

The proposed correlation of the Basal coarse-grained greywacke unit with the Cedar District Formation of Nanaimo and Comox basins is compatible with the following recent (1966) dating of megaplants collected by J.E. Muller from the apparently equivalent beds (GSC loc. 7819) occurring low in Suquash Basin succession on the north shore of Port McNeill on Broughton Strait, at 50°36'10"N lat. and 127°5'19" long. provided by the late Dr. W.A. Bell: "Pseudocycas latipennis, Trochodendroides arctica and Rhamnites eminens are members of Nanaimo Group floras. Quereuxia angulata, formerly known as Trapa? microphyla, occurs in St. Mary River and Edmonton (both lower and upper parts) Formation, as well as in Wapiti Group, and Paleocene beds of Alberta and Saskatchewan, but was not until present, recorded from the Nanaimo Group. It is concluded that the above florule falls within the time limits Campanian-Maestrichtian and more probably within age limits of the Nanaimo Group."

The pollen and spores collected by J.E. Muller from the above locality have been dated as follows by W.S. Hopkins, Jr.:

[1] See Addendum 4, page 70.

"Preservation of pollen and spores from these rocks is very poor and the density is low. As a result, some of the determinations are questionable while other determinations are to a generalized level.

"The relative abundance of angiosperm pollen suggests a post-early Cretaceous age; furthermore there is nothing characteristic of an Eocene or younger age. Gleichenia is most abundant in Paleocene and Upper Cretaceous rocks, although it does occur farther down the column. Proteacidites seems, at present time, to be restricted to Upper Cretaceous rocks in western North America. Most of the other forms are found in Jurassic, Cretaceous and Tertiary rocks, but none are incompatible with an Upper Cretaceous age. It is the writer's opinion that this florule is Senonian in age, probably Maestrichtian."

The above cited paleontological data suggest that the oldest Nanaimo rocks of the Suquash Basin represent some part of the early Campanian Vancouverense zone and are correlative with the Cedar District Formation of Nanaimo and Comox basins (Fig. 1). It seems likely that the older beds of Nanaimo Group were not deposited in Suquash Basin as the Upper Cretaceous transgression has covered the northeast part of Vancouver Island considerably later (in Vancouverense time) than it did its southeastern part. The writer agrees with Sutherland-Brown (1966, Figs. 6-7) that the late upper Cretaceous sea of northeastern Vancouver Island was not directly connected with the Nanaimo-Comox sea and has reached Suquash Basin from northwest.

2. Variegated sandstone unit. At the point of shoreline situated about 3/4 mile west of the mouth of Keogh River the Basal coarse-grained greywacke unit is conformably and gradationally overlain by an at least 500-foot-thick sandstone unit consisting of an irregular interbedding of the usually 10- to 30-foot-thick members of:

1. Greywacke, dull grey weathering, rust to chocolate coloured, medium to coarse grained, hard and weathering-resistant, mostly massive-looking, commonly more or less calcareous and ferruginous. This greywacke is commonly similar to that of the Basal coarse-grained greywacke member; and

2. Subgreywacke and (?) arkose, light to pinkish grey, weathering buff to whitish grey, well sorted and rounded, mostly fine grained, predominantly thinly bedded to laminated, mostly strongly and intricately cross-bedded and ripple-marked. These sandstones are locally carbonaceous to coaly and include a 1- to 2-foot-thick interbed of dark brown, coaly siltstone rich in poorly preserved plant remains in the middle part of the unit. An apparently lenticular 5- to 6-inch-thick bed of impure coal occurs in this siltstone interbed.

No marine fossils have been found in this apparently deltaic sandstone unit which could correspond either to the Vancouverense zone or to the cf. Pacificum subzone of the Nanaimo and Comox basins because of its stratigraphic position.

3. Metaplacenticeras occidentale siltstone. The Variegated sandstone unit grades upward into an at least 35-foot-thick unit of ash to medium grey, sandy to very sandy siltstone rich in concretions and thin concretionary bands of impure limestone and calcarenite. At the point of shoreline situated about 2 1/2 miles southeast of Thomas Point this siltstone unit has yielded Metaplacenticeras occidentale (Whiteaves), Schluteria cf. selwyniana

(Whiteaves), juvenile ammonite probably belonging to Pseudophyllites indra Forbes, Trigonia (Pterotrigonia) cf. evansana Meek and various long-ranging, marine pelecypods and gastropods (GSC loc. 82962 and 82963).

Metaplacenticeras occidentale (Whiteaves, 1889) was known previously only from its holotype found by Dr. G.M. Dawson in 1885 on Ki-Uk (= Keogh) River and described by Whiteaves (1889, p. 155, pl. 21, Fig. 1) as Placenticeras occidentale. Dawson (1887, p. 63B) does not indicate the exact locality of this unique specimen but the writer believes that it was found somewhere in the stretch between 1/4 and 3/8 of a mile above the mouth of Keogh River. Poor outcrops of unfossiliferous siltstone lithologically similar to the previously described Metaplacenticeras occidentale siltstone occur locally within this interval.[1]

The holotype of Placenticeras occidentale Whiteaves 1889 (a complete, apparently adult living chamber with fragments of the last suture line) is a representative of the genus Metaplacenticeras Spath 1926 in terms of modern ammonite taxonomy.

M. occidentale Whiteaves 1889 appears to be more closely allied to M. californicum (Anderson) (Anderson, 1958, pl. 36, Fig. 1) than to any other representative of Metaplacenticeras. It differs, however, from this species in its considerably coarser and sparser umbilical nodes and ribs. The broadly rounded rib surfaces are, furthermore, covered by fine, longitudinal riblets and feebly developed bullae occur commonly at the points of their bifurcation slightly below mid-flank. The adapical part of the indifferently preserved venter seems to exhibit an ill-developed median keel while its adoral part is flat between ventro-lateral transverse bullae of a general Metaplacenticeras type.

According to Dawson (1887, p. 63B) the shaly beds which have yielded M. occidentale are closely related to the coal-bearing rocks of Port McNeill and Beaver Harbour which have yielded a meagre late Cretaceous flora collected by him and later by J.E. Muller (see discussion earlier in this section). This flora was tentatively compared with that of Protection Island (i.e. of Extension-Protection Formation of this report) by G.M. Dawson and J.W. Dawson (1889, pp. 71-72). Somewhat later J.W. Dawson (1894, pp. 53-73) suggested that the Port McNeill florule is a little younger than the Nanaimo flora. However, Bell (1957, p. 14) was inclined to treat it as of "about the same age as that of the Comox, or possibly somewhat older".

The Metaplacenticeras occidentale siltstone of Suquash Basin obviously represents some part of the cf. Pacificum subzone of Suciaensis zone of Nanaimo and Comox basins. It indicates the equivalence of this siltstone unit with the restricted Northumberland Formation (including lower Lambert Formation) of these basins (Fig. 1).

The upper contact of Metaplacenticeras occidentale siltstone is concealed and probably faulted in all sections studied. Its true thickness may therefore be considerably greater than its maximum measured thickness of about 35 feet.

4. Upper greywacke unit. The Metaplacenticeras occidentale siltstone appears to dip under and is believed to be overlain by an at least 400-foot-thick unit of bluish grey to light grey, coarse- to fine-grained, hard greywacke and (?) arkose with some interbeds of similarly coloured grit and locally with several feet long, rounded inclusions of calcareous, differentially weathered greywacke. These rocks are carbonaceous to coaly. They contain at least one 30-foot-thick member of grey siltstone rich in wood-bearing clay

[1] See Addendum 5, page 70.

ironstone concretions and bands. This siltstone member contains interbeds of black to dark brown coaly siltstone with 1- to 3-inch-thick layers and pods of impure coal. The complete thickness of the Upper greywacke unit is unknown.

The Upper Greywacke unit is believed to be younger than Metaplacenticeras occidentale siltstone because of its predominantly south-western dips and occurrence on the apparently downthrown southern side of an important east-west trending fault. This normal or strike-slip fault appears to cut off the top of Metaplacenticeras occidentale siltstone on the sea shore and in the lower course of Keogh River.

Because of its inferred superposition on the Metaplacenticeras occidentale siltstone the unfossiliferous Upper greywacke unit is believed to be only slightly younger than the latter unit and to correspond to the upper part of cf. Pacificum subzone of Nanaimo and Comox basins. It is correlated tentatively with the lithologically similar Geoffrey (= middle conglomeratic member of the Northumberland and the lower part of the upper Lambert Formation of previous workers; see Fig. 1).

5. Upper siltstone unit. At the point about 1 3/4 miles above the mouth of Keogh River the Upper greywacke unit is overlain conformably and gradationally by an at least 250-foot-thick unit of dull- to dark-grey sandy to very sandy, commonly thinly bedded to laminated, friable siltstone. This Upper siltstone unit contains considerable bands and lenses of similarly coloured, predominantly friable, fine grained, silty greywacke but appears to lack limestone concretions and bands.

Numerous 3- to 8-inch cannonball concretions of hard, very fine grained greywacke or sandy siltstone occur in uppermost exposed beds (20 to 25 feet) of the unit. These concretions have yielded some long-ranging, marine pelecypods and gastropods of the general Nanaimo Group affinities (GSC loc. 82964) and some poor leaves. The top of the Upper siltstone unit was not reached either in the bed of Keogh River or in that of its second left confluent.

The Upper siltstone unit cannot be dated closely from its rare, long-ranging fossils. However, it could possibly be younger than the cf. Pacificum subzone in part and to include equivalents of the Suciaense zone of Comox Basin (see pp. 57-58) and to include early Lower Maestrichtian beds because of its inferred stratigraphic position several hundred feet above the Metaplacenticeras occidentale siltstone. This correlation is favoured in this report (Fig. 1) pending additional field work in Suquash Basin.

PALEOGEOGRAPHY

(J.E. Muller)

Introduction

The paleogeography of the Nanaimo Group may now be summarized. The general distribution and probable basin limits were aptly shown by Sutherland-Brown (1966). He outlined one large basin, embracing Strait of Georgia, Nanaimo and Comox basins and adjacent outliers on Vancouver

Island and a portion of the mainland including the Garibaldi area. He regarded this as a downfaulted trough, the 'Georgia Seaway'. Another small embayment, not directly connected, was shown over Queen Charlotte Strait, the Suquash Basin and the Neroutsos Inlet outlier. The writer follows this concept in principle with some modification.

It must be borne in mind that much of the present topography is due to post-Cretaceous vertical crustal movement. Along the coast of Vancouver Island and the Gulf Islands the sediments of the Nanaimo Group are exposed at sea level, but inland on Vancouver Island and on the mainland they are now at 3,000- to 5,000-foot elevation. For example Forbidden Plateau and Beaufort Range were apparently uplifted after deposition of Nanaimo beds, now at more than 5,000 feet elevation. Thus a direct connection between Comox and Alberni areas probably existed in Late Cretaceous time (*see* Fig. 8). A direct connection from Alberni to the Pacific Ocean although possible is unsupported by field evidence and therefore not shown. However, according to Jeletzky the development of ammonite and *Inoceramus* faunas clearly indicates a good connection with California and Japan via the Pacific Ocean. As the extent and thickness of the oldest Nanaimo sediments is greatest in southern Vancouver Island, the seaway is inferred to have occupied that part of the island during first and second depositional cycles.

First cycle

At the beginning of the first cycle of deposition (Fig. 8) fluvial and beach-gravels accumulated in the northwestern part of the Comox Basin and on the Horne Lake and Nanoose ridges (Benson Member). At the same time thick layers of sand were laid down along the shorelines. The sands formed an ever-shifting shore-bar that closed off lagoons in the Comox Basin. There several layers of peat were formed, interbedded with clay and sand (Comox Formation). Away from the shore, but still in shallow water, sandy and silty clay enclosing shells of the Naumanni fauna came to rest, and near the shore, sand with the same fauna was deposited. Later the sea advanced and silty clays, also containing the Naumanni (A) and later the Haradai (B) fauna were laid down (Haslam Formation) over the lagoonal deposits, on the shoreline sands, or directly on pre-Cretaceous rocks, with a basal veneer of gravel and sand derived from the volcanic substratum (Fig. 8). The cycle ended with sandy deposits containing the early Campanian Schmidti fauna (Wellington Member). This fauna is only present in Nanaimo Basin and the sea had either retreated from Comox Basin or its deposits were removed by erosion before the beginning of the second cycle.

There are indications that no marine transgression of the northeast half of the Strait of Georgia or the mainland occurred during the first depositional cycle. For on Texada Island conglomerate and greywacke with (reworked ?) Schmidti fauna, considered to represent Extension conglomerate, directly overlies Karmutsen volcanic rocks. Conglomerate on Pender, Saturna, and Sucia islands underlying Cedar District Formation and rich in poorly sorted subangular clasts of pre-Cretaceous rocks, is also inferred to lie directly on these rocks, although the contact is nowhere exposed. The Cheakamus Formation on the mainland (Mathews, 1958) apparently also contains Schmidti and Vancouverense zone fossils suggesting that the sea of the second depositional cycle was the first to invade the mainland.

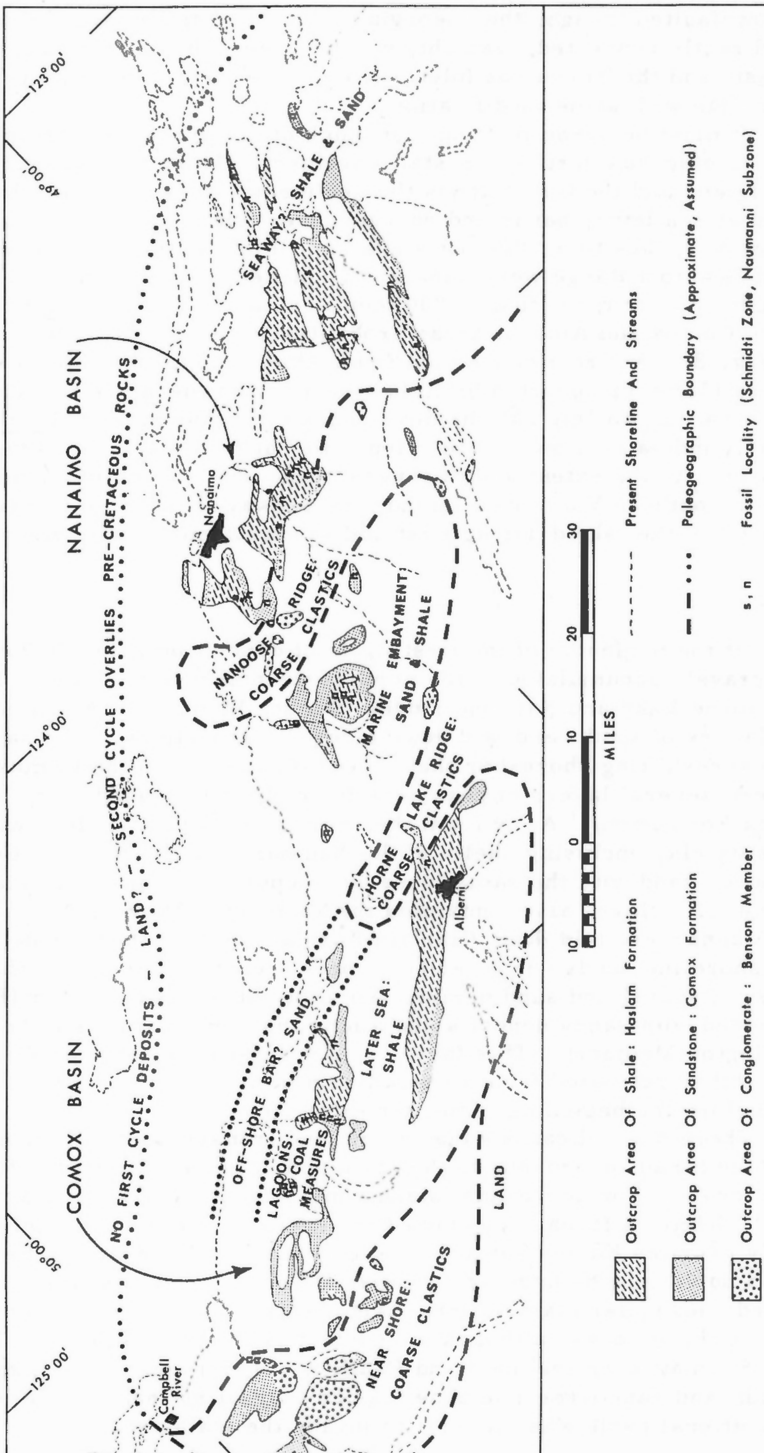


Figure 8. PALEOGEOGRAPHY OF FIRST SEDIMENTATION CYCLE OF NANAIMO GROUP (Naumanni Fauna)

Second cycle

The marine transgression of the second depositional cycle was probably more extensive than its predecessor. It started with peat moor conditions in the Nanaimo Basin, similar to those prevailing in the Comox Basin in the first depositional cycle. The Wellington seam, in places consisting of up to four closely spaced seams, was deposited on marine sands (Wellington Member) succeeding Haslam marine shales in the Wellington and Northwest Bay areas. The Douglas seam was formed later, after an interval of deposition of gravel and sand (Extension and Cranberry members). The Wellington peat moor probably did not extend eastward into the area later occupied by the Douglas moor. A study of the petrography of the Wellington coal (Hacquebard et al., 1967) has indicated that the peat swamps were alternatingly forest moors and open reed moors. More shoreline-sands followed the Douglas peat moor.

In the Comox Basin a few narrow wedges or 'shoestring'-lenses of sand and gravel, were deposited in river-channels excavated into first-cycle sediments. As they contain blocks of Comox sandstone and Haslam calcareous concretions a considerable time interval may have elapsed to permit consolidation of the older sediments. The conglomerate of Thunder Mountain, likewise containing debris of older Nanaimo beds, is another remnant of the early part of the second depositional cycle.

In the later part of the cycle the sea again invaded the lagoons and shores. The lower part of its deposits, perhaps coeval to the lagoonal deposits, were nearshore gravelly to sandy clays, enclosing shells of the Vancouverense fauna. The higher beds are thinly bedded graded sandstone-siltstone-shale sequences indicating deeper water where periodically turbid mudflows of sand, silt and clay were laid down. This sea is inferred to have extended at least from Great Central Lake in the west to Garibaldi Park in the east and from the Comox Basin in the north to Cowichan Valley and Sucia Island in the south. It may have extended much more widely over south Vancouver Island. In this section it is assumed that the north Vancouver Island area was not reached by the sea before the third depositional cycle. But alternatively the sandstones with Vancouverense fauna of Suquash Basin and Hope Island could represent the Cedar District Formation and indicate second cycle deposition (see Jeletzky's section on the Suquash Basin).

Third and fourth cycle

Sediments of the third and fourth depositional cycles (Fig. 9) are present on the islands in the Strait of Georgia and on northern Vancouver Island, but their former distribution is open to speculation. Both cycles have basal clastic sequences; De Courcy and Geoffrey formations. The outcrop-areas of these conglomerates are concentrated in three areas: Hornby and Denman islands; Gabriola Island, and Saltspring Island to Mayne Island. This may reflect an original condition: perhaps the conglomerates intertongue laterally with less resistant sandstone and shale that are now covered by the straits between the islands. In the case of the Geoffrey the wedging out of conglomerate from a maximum thickness on south Galiano Island to thinner conglomerate and sandstone on Saltspring and Mayne islands has been pointed out. One may surmise that these are deltaic fans issuing from separate streams onto a coastal plain. Furthermore several observations have been

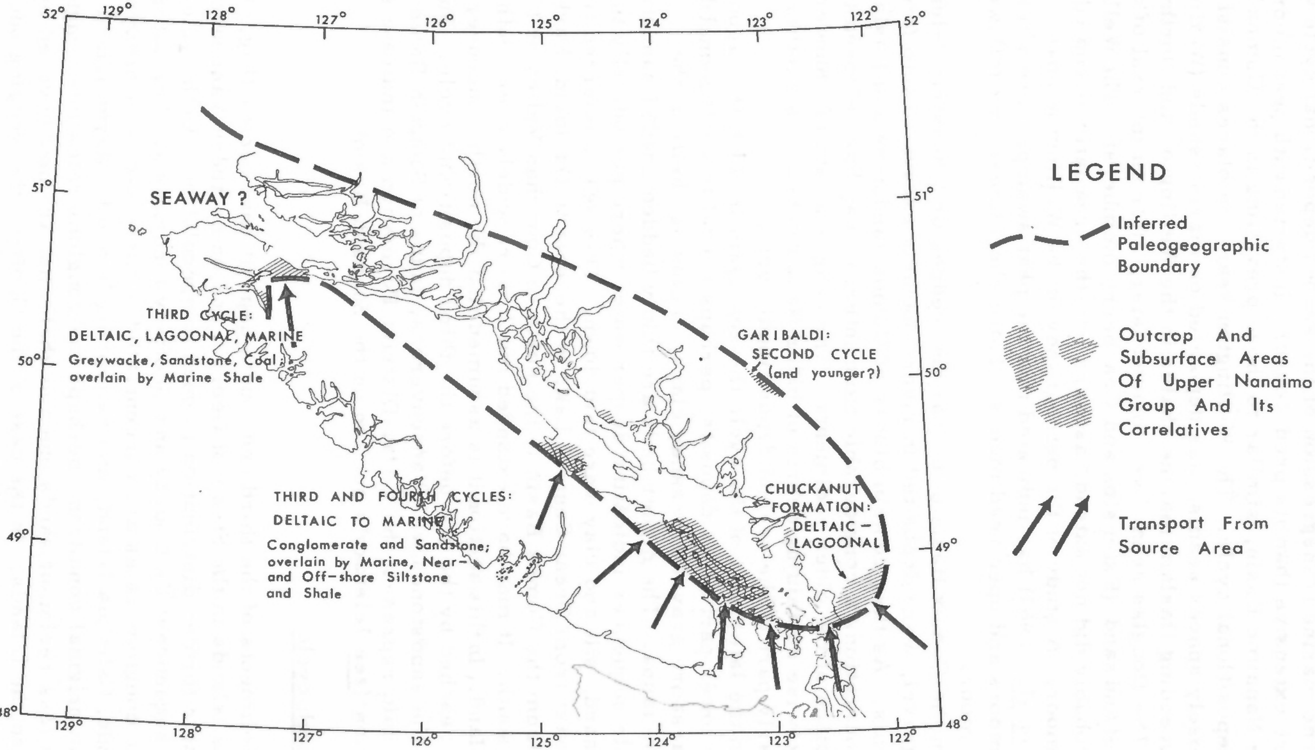


Figure 9. PALEOGEOGRAPHIC DATA FOR UPPER PART OF NANAIMO GROUP

made on the directions of movement in the many instances of intraformational slumping found in sandstones and sandstone-shale sequences of these younger depositional cycles. They generally indicate northerly, northeasterly, or northwesterly direction of slump and thus a similarly directed slope of the ancient sea-bottom. It seems therefore that the coast was in the south or southwest.

As the conglomerates indicate a nearby source of granitic, volcanic and metamorphic rocks, it is most likely that the pre-Cretaceous 'basement' of south Vancouver Island and the San Juan Islands formed a shoreline at that time and supplied debris to the delta-building streams. That shore may well have closed off the basin in the south. It is unlikely that the seaway passed through northwestern Washington State as the Chuckanut Formation, apparently coeval to the upper part of the Nanaimo Group, is entirely nonmarine (Miller and Misch, 1963).

On the other hand it has been indicated that the third cycle marine transgression was perhaps the first one to invade parts of northern Vancouver Island. This transgression could have extended southeastward, thus making a connection with the Comox and Nanaimo basins. One may also speculate that the transgression covered much of northern Vancouver Island and that the Nanaimo beds east of Neroutsos Inlet were laid down at this time.

Later in these depositional cycles full marine conditions prevailed with deposition of offshore turbidites similar to those of the second cycle. The full gamut of late Campanian and early Maestrichtian ammonites entered from the Pacific Ocean. Curiously most of the species are at present confined to the Hornby Island exposures in the northern part of the basin. Although this may be due to lack of preservation farther south one may also speculate that in early Maestrichtian time full marine conditions were mainly in the northern part of the Georgia seaway, with access to the Pacific Ocean from the north.

STRUCTURE

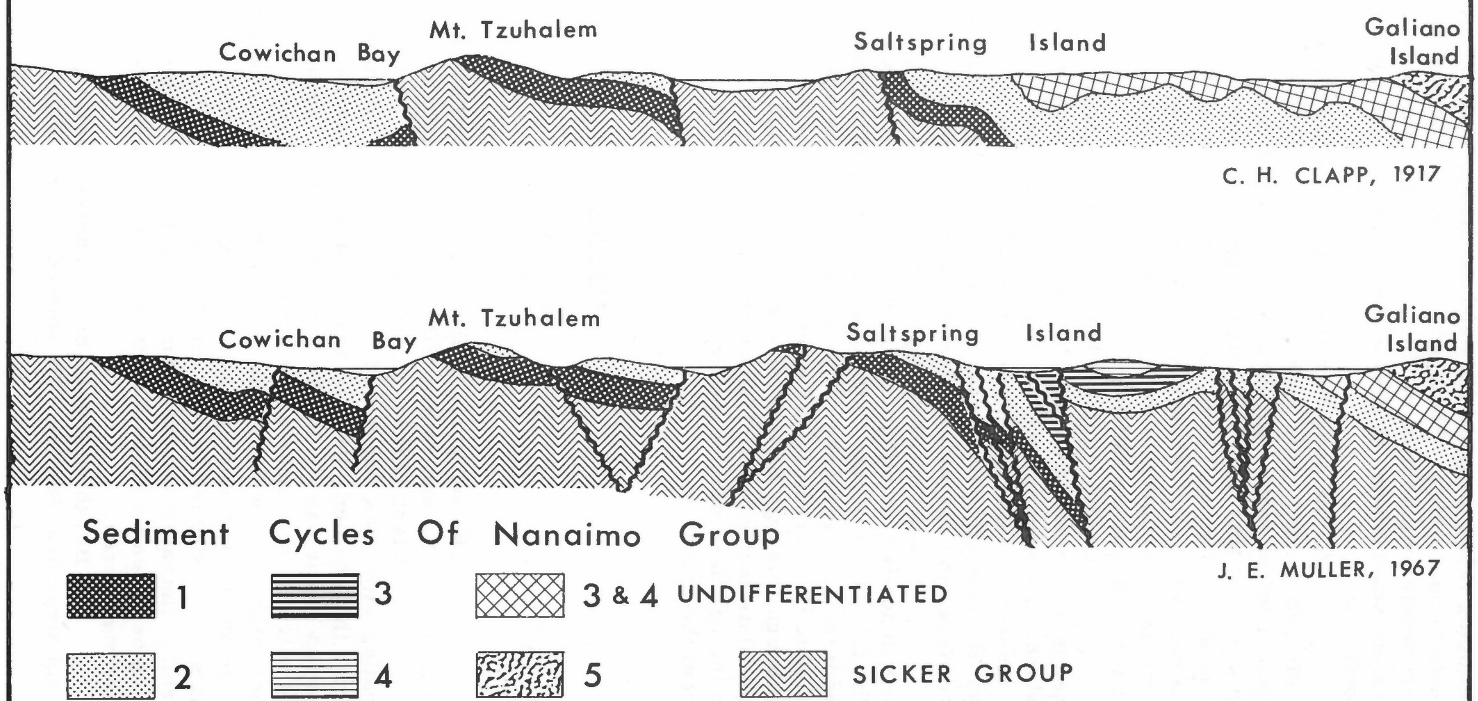
(J.E. Muller)

The structure of the Nanaimo Group has been described and generalized briefly and rather differently by various authors.

Clapp (1914a, p. 69) described the structure as one of mainly folding with a few "reversed or thrust faults" all striking northwesterly. He noted that the fault 3/4 mile southwest of the Extension anticline was nearly vertical as it was cut by the Extension tunnel "about 300 feet vertically below its outcrop, the rocks of the downthrown side turning abruptly up against the fault plane". Locally in the mineworkings the surface of the fault was found to be an overthrust dipping at low angle to the southwest. He mentioned and showed a few more faults, mainly longitudinal, but some transverse. The ' rolls ' (intraformational slumps) included by Clapp in structural features have been dealt with earlier in this report as penecontemporaneous sedimentary structures.

Buckham (1947a, b) emphasized faulting rather than folding as the main structural feature He showed in the Nanaimo area a series of

Figure 10. Structural Sections, Cowichan to Galiano Is: Faulting and Folding of Nanaimo Group



near-parallel northwesterly striking faults, many of them with northeastward downthrow at the south end and southwestward downthrown at the north end.

Sutherland-Brown (1966) held that sharp northwesterly trending folds in Late Cretaceous rocks were surface expressions of basement fault movement.

The writer also considers the nature of late Cretaceous to Tertiary structure essentially one of tilted fault blocks. Over large areas Cretaceous strata are gently inclined with rather uniform direction of dip (mainly northeast) and only in narrow faulted zones they have steep to vertical dips. Only a few well-defined synclines, anticlines and perhaps no flat-dipping thrust faults, so characteristic of the folded eastern foothills of the Rocky Mountains, are part of this structural pattern (Fig. 10).

One main system of faults strikes northwesterly. Subsidiary cross-faults strike north to northeasterly. The faults are rarely exposed but commonly they are indicated by zones of steeply dipping beds, concealed contacts between Cretaceous and older rocks, and by prominent lineaments.

Faults between Nanaimo beds and older rocks are most conspicuous by unmistakable contrast in topography and rock types. Some of these, like the fault between Beaufort Range and Alberni graben, the one along the north edge of Cowichan Lake and the fault south of Sicker Mountain, through Maple Bay and continuing through Saltspring Island, have a southwestward downthrow of one to several thousands of feet. Such faults separate northeastward tilted blocks, each exposing older formations along the southwest edge and containing wedges of Cretaceous strata in the asymmetrical grabens along the northeast edge. The thin, southwest edge of these wedges is either the basal unconformity or a fault of minor importance. Faulting generally increases northeastward in intensity and is most pronounced in the southern Gulf Islands. Here, a broad fault zone marked by steeply northeast-dipping to southwest-overturned beds transects Saltspring, Prevost, Mayne, Pender and Saturna islands. An asymmetrical syncline with steep southwest limb, offset by several cross faults, occurs on north Saltspring, Prevost, Mayne and Saturna islands.

The longitudinal faults are in several places offset by cross-faults, in varying northeasterly directions. Although the block faulting is thought to reflect essentially differential vertical crustal movement and horizontal tension, compression resulted locally at the near-vertical interfaces of differentially moving blocks. Small-scale tight to isoclinal folding thus developed locally in the fault zones.

More detailed structural work, aided by better stratigraphic control, is needed to determine more fully the nature of faulting. In general one may surmise that the faulting was connected with late Cretaceous to Tertiary differential uplift of Vancouver Island and simultaneous depression of the Georgia Basin.

ADDENDA

Addendum 1. Since this was written Jeletzky has discovered exposures of conglomerate on Trent River in the interval 850 to 950 yards upstream from the mouth of Bloedel Creek. These beds apparently represent the Extension-Protection Formation and consist of 18 to more than 40 feet of the pebble to boulder conglomerate rich in shaly matrix with considerable interbeds of pebbly shale. They rest unconformably on the Pachydiscus perplicatus-bearing beds of the Elongatum zone. The Haradai subzone apparently was eroded away prior to the deposition of conglomerate formation which grades upward into pure, fissile shale of the Cedar District Formation. The latter outcrops uninterruptedly from the conglomerate outcrops to the mouth of Bloedel Creek and thence to the exposures of the thin sandy layer previously favoured by Muller as the boundary between the Haslam and Cedar District shales. The discovery of the conglomerate formation on Trent River adds at least 500 feet to the thickness of the Cedar District shales there (see Fig. 5).

Addendum 2. Since this was written several readily identifiable specimens of typical Pachydiscus (Canadoceras) newberryanus, such as occur in the Sucia Island section of the Cedar District Formation, have been found by Jeletzky at this locality. This confirms the correlation of these beds with the lower part of the Cedar District shale of the Nanaimo Basin.

Addendum 3. Since this was written several specimens of Metaplacenticeras cf. pacificum have been found by Jeletzky in the lowermost beds of the upper Cedar District shale outcropping at the signal light north of the Government ferry landing on the southwestern side of Denman Island. The De Courcy Formation and all of the upper Cedar District shale exposed on Denman Island (i.e. Sections 6a and 6b of Fig. 7) form accordingly part of the Metaplacenticeras cf. pacificum zone. Only the lower part of the Cedar District shale exposed on Trent River (i.e. Section 5 of Fig. 7) and the lower part of the Cedar District shale of more southerly areas can now be placed in the Vancouverense zone.

Addendum 4. The correlation of the Basal coarse-grained greywacke unit with the Cedar District Formation was more recently confirmed by the discovery of well-preserved specimens of Baculites chicoensis Meek sensu Usher 1953 in beds immediately overlying those containing Inoceramus subundatus Meek, etc. fauna at the G.S.C. locality 82952.

Addendum 5. When studied in a greater detail in 1969 during an exceptionally low water level these siltstones have been found to be a blue Pleistocene clay. This observation invalidates Jeletzky's conclusion concerning the exact locality of the type specimen of Metaplacenticeras occidentale.

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